AN445

Si4431 RF Performance and ETSI Compliance Test Results

1. Introduction

The purpose of this application note is to provide measurement results and ETSI compliance results for the Si4431B when operated from 863 to 870 MHz. All tests are performed using an ISM-DK3 kit with a with a 4431-T-B1-B-868 (or DKDB1) TX/RX Split RF Test Card. The Wireless Development Suite (WDS) is used to control the test card. The results can be duplicated by using the same configuration and scripts available on the Silicon Labs website and referenced in the EZRadioPRO® Quick Start Guide. All settings were used directly from the Excel Register Calculator worksheet provided on the Silicon Labs web site. For measurement results with different RF parameters, contact customer support at: https://www.silabs.com/support/pages/contacttechnicalsupport.aspx and register to submit a technical support request.

2. Relevant Measurements to Comply with ETSI

In this report the rules of the 300220001v020301 ETSI document are applied.

ETSI compliance of the transmitter in the EU pertains to TX frequency error (subclause 7.1), output power (subclause 7.2 and 7.3), emissions and harmonics (subclause 7.8), and transient power (subclause 7.5). When operating under the sub-bands (g1, g2, g3, g4, alarm, etc.), the modulation bandwidth limit (subclause 7.7) is also applied. In narrowband channelized applications, the adjacent channel power (ACP, subclause 7.6) should also be measured.

In RX mode, the Si4431 is an ETSI Class 2 receiver. For Class 2 compliance, the following measurements must be checked: blocking (subclause 8.4), sensitivity (subclause 8.1), receiver spurious radiation (subclause 8.6). The Si4431 does not comply with ETSI Class 1 requirements.

The compliance with each of the above ETSI measurement points are summarized in Table 1.

Table 1. ETSI measurement Point Compliance

EN 300220 Spec Number	ETSI Limit	VDD=3.3 V, Si4431 complies:	VDD=3.3 V, Si4432 complies:	Notes
TX frequency error (sub-clause 7.1) See "4.2. TX Frequency Error (ETSI 300220001v020301, Subclause 7.1)" on page 11 for details.	For narrowband channelized systems: ±12 kHz for F≤500 MHz ±20 kHz for F>500 MHz For other systems: ±100 ppm	At all power levels	At all power levels	Depends on the crystal selection
Output power conducted (sub-clause 7.2) See "4.1. Output Power (Average Power, Conducted, ETSI 300220001v020301, Subclause 7.2)" on page 9 for details.	+14 dBm (max) in g1 sub-band +27 dBm (max) in g3 sub-band	At all power levels in g3 and g1 sub-bands	At all power levels in g3 sub-band Several steps below max power in g1 sub-band	

Table 1. ETSI measurement Point Compliance (Continued)

EN 300220 Spec Number	ETSI Limit	VDD=3.3 V, Si4431 complies:	VDD=3.3 V, Si4432 complies:	Notes
Effective radiated power (sub-clause 7.3) See "4.3. Effective Radiated Power (ETSI 300220001v020301, Subclause 7.3)" on page 11 for details.	+14 dBm ERP (max) in g1 sub-band +27 dBm ERP (max) in g3 sub-band	At all power levels in g3 sub-band At all power levels in g1 sub-band, but limited to <2.4 dB antenna gain	At all power levels in g3 sub-band Several steps below max power in g1 sub-band	
Transient power (sub-clause 7.5) See "4.4. Transient Power (ETSI 300220001v020301, Subclause 7.5)" on page 12 for details.	Spurious emission limits (sub-clause 7.8) or less than 3 dB difference compared to CW operation	At all power levels	At all power levels	The 3 dB difference between CW and switched operation is checked.
Adjacent channel power (sub-clause 7.6) See "4.5. Adjacent Channel Power (ACP) (ETSI 300220001v020301, subclause 7.6)" on page 14 for details.	200 nW with channel spacing ≥20 kHz 10 µW with channel spacing <20 kHz	With default settings the integrated output power (16 kHz bandwidth) limited to +5 dBm when 25 kHz channel spacing is used. Integrated output power (8.5 kHz bandwidth) limited to +15 dBm when 12.5 kHz channel spacing is used.	With default settings the integrated output power (16 kHz bandwidth) limited to +5 dBm when 25 kHz channel spacing is used. Integrated output power (8.5 kHz bandwidth) limited to +15 dBm when 12.5 kHz channel spacing is used.	Applicable to narrowband channelized systems only. The case of 25 and 12.5 kHz spacing is checked. With VCO current boost and PLL bandwith optimization some ACP performance improvement can be achieved (see section 4.5 for details)
Modulation bandwidth (sub-clause 7.7) See "4.6. Modulation Bandwidth (ETSI 300220001v020301, Subclause 7.7)" on page 22 for details.	Special spectrum mask (refer to Figure 22 in Section 4.6)	At all power levels	The Si4432 complies at reduced power levels (~14dBm) with default register settings. By setting the Ox58, 0x59 and 0x5A register values to 0x40, 0x80 and 0x81 respectively, compliance can be achieved with full power.	Applicable in the sub-bands

Table 1. ETSI measurement Point Compliance (Continued)

EN 300220 Spec Number	ETSI Limit	VDD=3.3 V, Si4431 complies:	VDD=3.3 V, Si4432 complies:	Notes
Unwanted emissions in the spurious domain (sub-clause 7.8) See sections 4.7, 4.8, and 4.9 for details.	Special spectrum mask (refer to Figure 26 in Section 4.7)	At all power levels	At all power levels	
Receiver sensitivity (sub-clause 8.1) See "3.1. Sensitivity (ETSI 300220001v020301, Subclause 8.1)" on page 4 for details.	Sp[dBm] = 10log(BW[kHz]/16)-107	Complies easily, with large margin	Complies easily, with large margin	
Receiver blocking (sub-clause 8.4) See "3.2. Blocking (ETSI 300220001v020301, Subclause 8.4)" on page 4 for details.	–69 dBm at ±2 MHz offset –44 dBm at ±10 MHz offset	Complies easily, with large margin	Complies easily, with large margin	Limits valid for Class 2 receivers. EZRadioPRO devices do not comply with Class 1 limits
Receiver spurious radiation (sub-clause 8.6) See "3.3. Receiver Spurious Radiation (ETSI 300220001v020301, Subclause 8.6)" on page 5 for details.	Spurious emission limits (subclause 7.8)	Complies easily, with large margin	Complies easily, with large margin	

3. RX Measurement Results

3.1. Sensitivity (ETSI 300220001v020301, Subclause 8.1)

The ETSI standard requires –107 dBm sensitivity with a 16 kHz RX bandwidth at 20% PER. If the RX bandwidth is not 16 kHz, the sensitivity limit is modified according to the following formula:

$$Sp[dBm] = 10\log\left(\frac{BW[kHz]}{16}\right) - 107$$

Equation 1.

For this test, a much more strict 1% PER requirement is used as this more closely reflects a link that may be considered usable for most applications. Figure 1 demonstrates the ETSI 20% PER sensitivity limit in red and the Si4431 1% PER sensitivity over temperature. The sensitivity limit changes for datarates higher than 8 kbps because the 16 kHz bandwidth can no longer be maintained. A modulation index of H = 1 is used for all cases with no additional allocation in the IF bandwidth for XTAL tolerance. Even with the more stringent 1% PER measurements, the Si4431 sensitivity complies with subclause 8.1 with a large margin over the –40 to 85 °C temperature range.

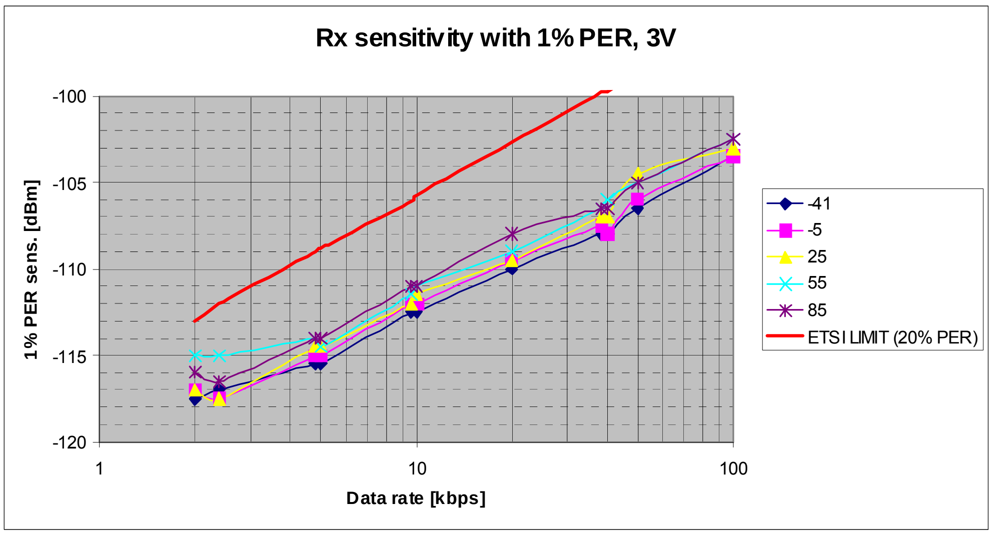


Figure 1. Sensitivity vs. Datarate, PER 1%

3.2. Blocking (ETSI 300220001v020301, Subclause 8.4)

Blocking is a measure of the capability to receive a desired modulated signal in the presence of a strong undesired blocking signal. The unwanted input signal may be present at any frequency other than the spurious responses. All selectivity results are measured by positioning the input power 3 dB above the ETSI sensitivity limit given in subclause 8.1.4 (see Equation 1 above) with the primary signal source generator. A second generator with an unmodulated signal is used as the interferer and combined with the primary signal using a power combiner such as Mini-Circuits ZFSC-2-4-S+. The second interferer generator is placed at the desired frequency offset and the power is increased until the PER degrades to 20%. For example, the +2 MHz point in Figure 2 shows –35.4 dBm spurious signal level. It means that if the spurious level is lower than this the PER will surely lower than 20%.

The utilized data rate and deviation in the measurements were respectively 100 kbps and 50 kHz (H=1). The appropriate Si4431 RX bandwidth to receive this signal is 208 kHz. The primary generator is set to –92.8 dBm, which is 3 dB above the ETSI RX sensitivity limit for this bandwidth.

ETSI specifies the blocking limits in absolute values at two points: ±2 and ±10 MHz. The limit for Class 2 receivers at ±2 MHz is –69 dBm, and at ±10 MHz it is –44 dBm.

The blocking performance of the Si4431 is shown in Figure 2 together with the ETSI limits for class 2 receivers (red lines). The Si4431 is fully compliant with the ETSI Class 2 receiver blocking requirements with large margin. The peak at ~ –1.8 MHz offset is the rejection at the receiver's image frequency. This spurious response is not part of the blocking measurements.

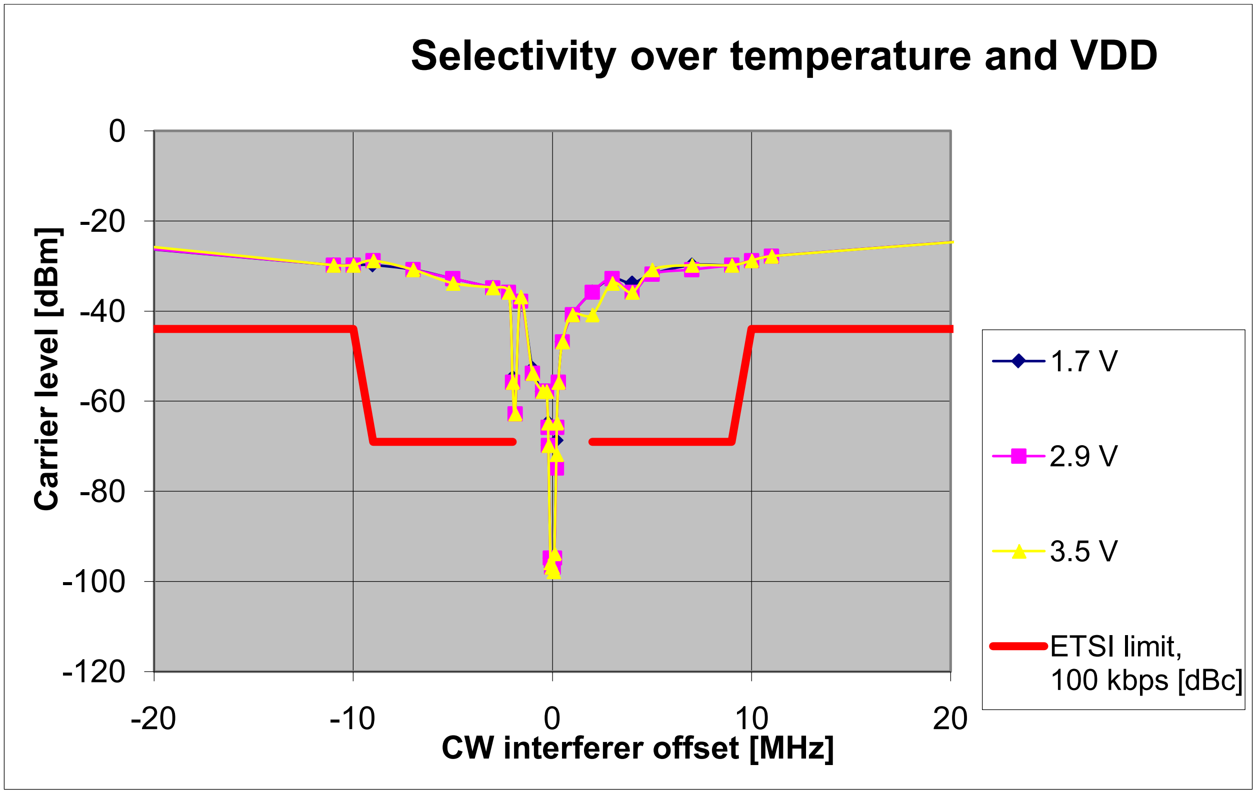


Figure 2. 100 kbps Blocking
(Datarate = 100 kpbs, Deviation = 50 kHz, No Allocation in BW for XTAL Tolerance)

3.3. Receiver Spurious Radiation (ETSI 300220001v020301, Subclause 8.6)

If the device under test (DUT) uses an RF connector, then the spurious power delivered to a 50 Ω termination in RX mode is measured. If the DUT does not use an RF connector and uses an integrated or dedicated antenna, then the spurious radiation in RX mode is measured.

The measurement frequency range in the first step is between 9 kHz and 4 GHz. If a spurious signal approaches the limit by less than 10 dB in the 1.5 to 4 GHz range, then the whole procedure needs to be repeated in the 4 to 12.75 GHz range as well.

Figure 3 shows the conducted leakage at the RX connector in RX mode up to 1 GHz. This complies with the ETSI limit of –57 dBm ERP up to 1 GHz (corresponding to 40.3 dBµV/m generated rms E field strength at 3 m distance).

Figure 4 shows the spurious leakage with a monopole antenna at the RX connector in RX mode from 1 GHz up to 7 GHz. The measurement is provided by Elliot Labs, a certified Electromagnetic Compatibility (EMC) test house.

The measurement of –47 dBm ERP above 1 GHz is ETSI compliant but with less than 10 dB margin therefore, measurements up to 12.75 GHz are required and shown in Figure 5.

According to Figures 3, 4, and 5, the leakage in RX mode is significantly lower than the ETSI limits.

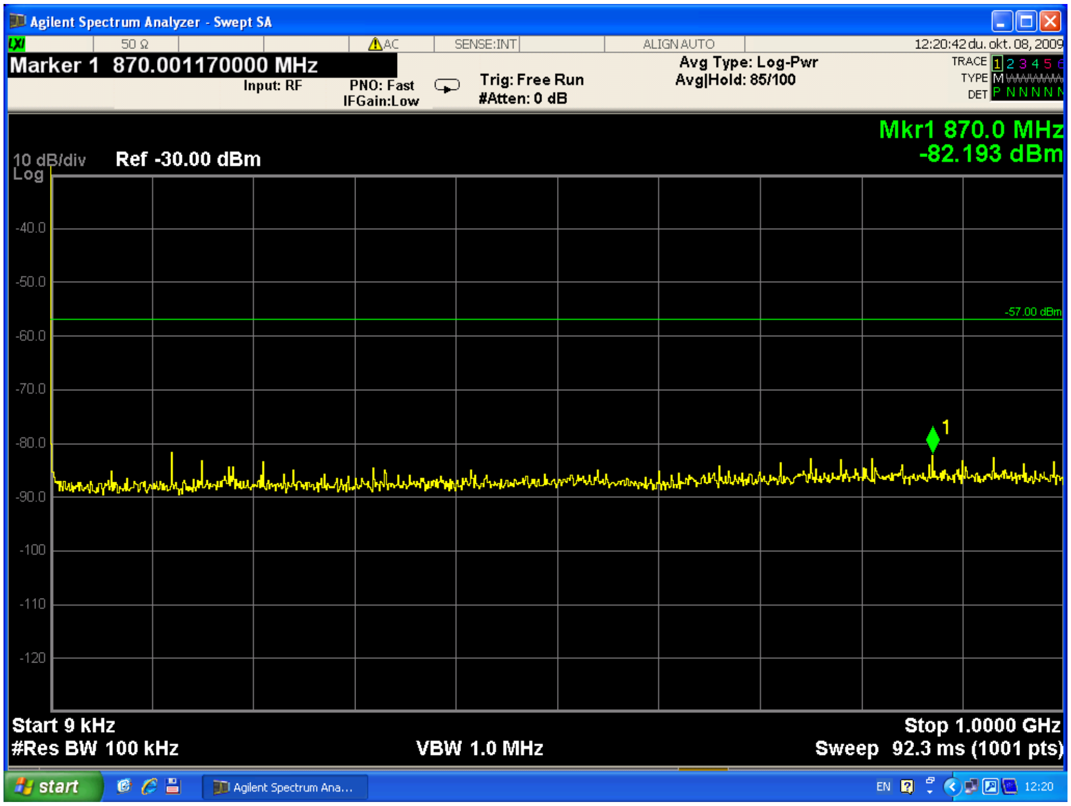


Figure 3. Receiver Leakage in RX Mode (Conducted up to 1 GHz)

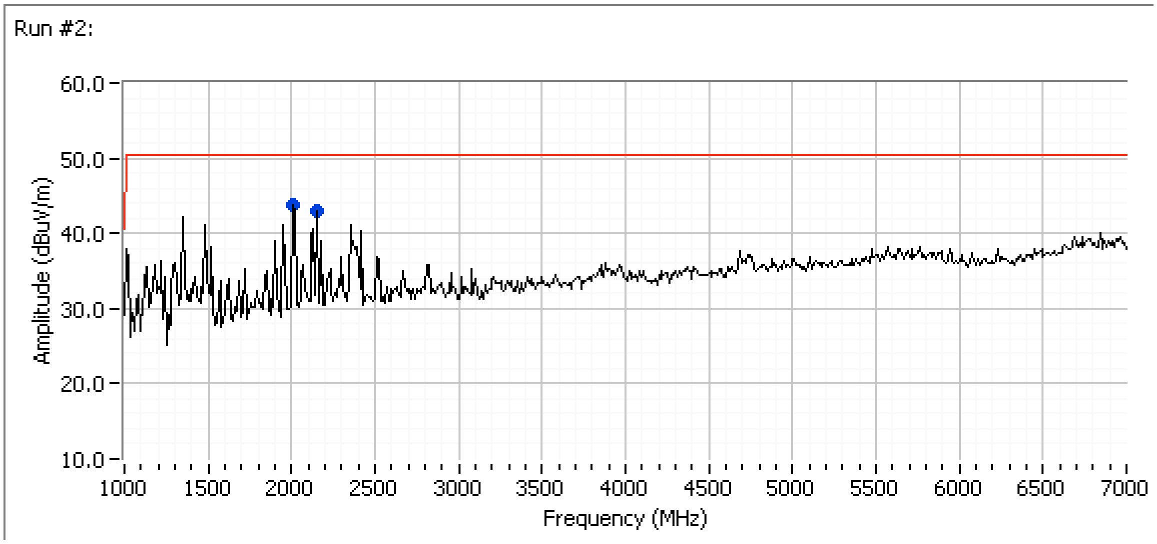


Figure 4. Receiver Leakage in RX Mode, Radiated with Monopole Antenna (Measured at Elliot Labs)

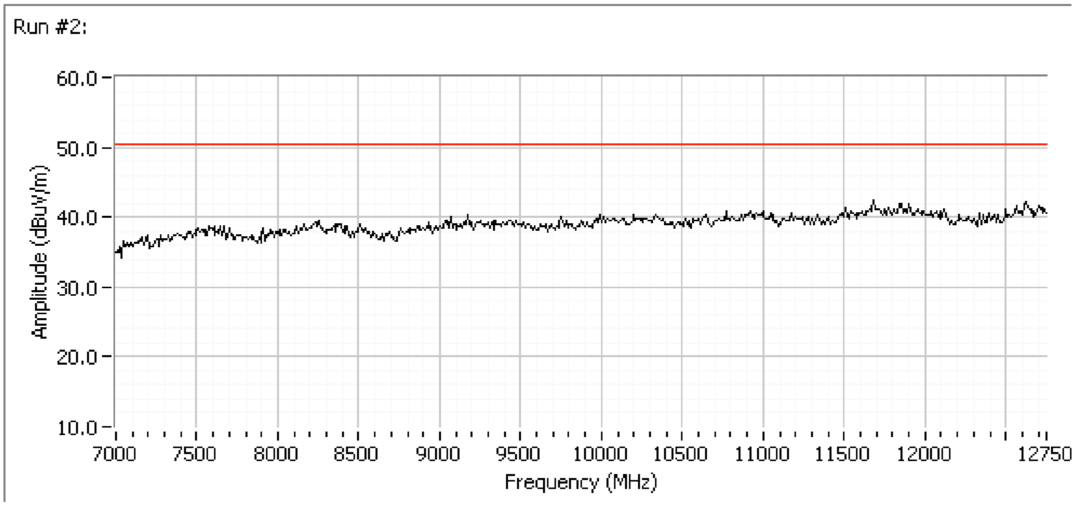


Figure 5. Receiver Leakage in RX Mode, Radiated with Monopole Antenna (Measured at Elliot Labs)

3.4. Sensitivity vs. Frequency Offset

The Sensitivity vs. Frequency Offset measurements are referred to as bucket curves due to their shape. This test is not required by ETSI, but it is of practical importance. The receiver and generator frequencies are calibrated for zero frequency offset. The signal generator is then offset and the sensitivity measurement is repeated. The performance for this parameter is directly linked to the programmed receive bandwidth. With AFC disabled, there is still internal modem compensation, which corrects for offsets up to 0.25 x RX BW, and, with AFC enabled, offsets can be corrected up to 0.35 x BW. The modem parameters and receiver bandwidths were set using the Excel Register Calculator worksheet assuming a 20 ppm crystal tolerance on both the transmitter and receiver as shown below.

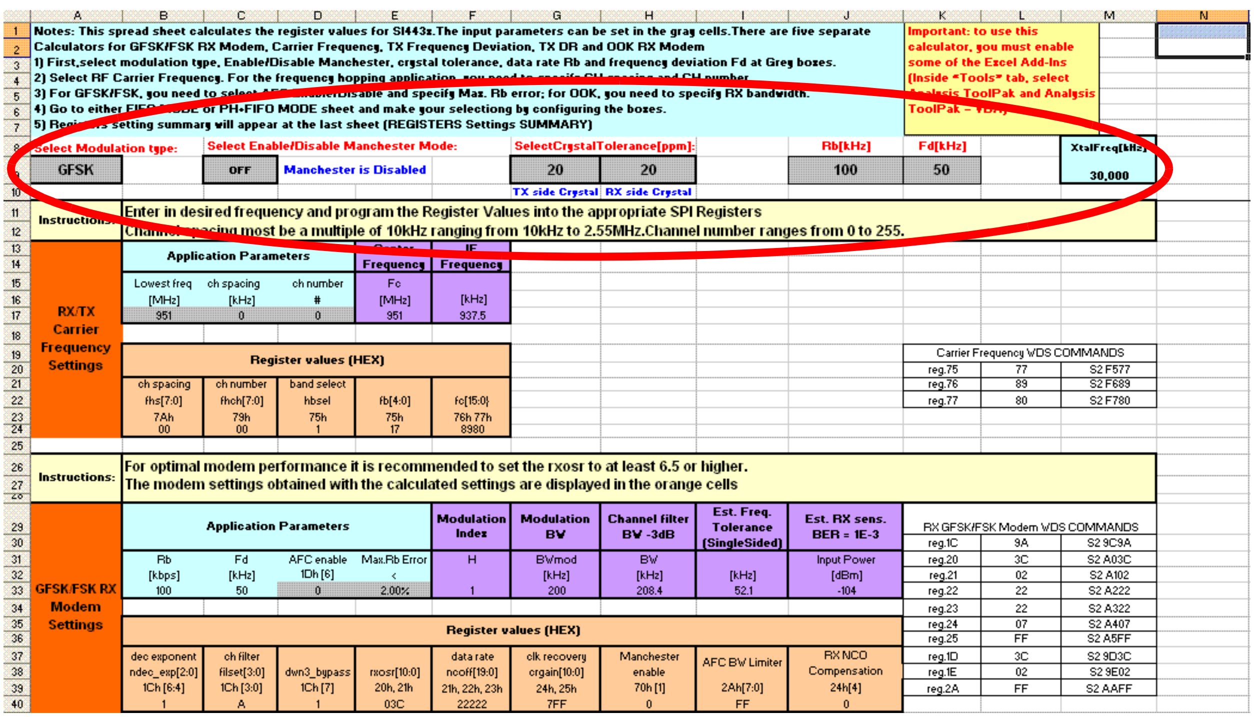


Figure 6. Modem Parameters and Receiver Bandwidths

Figure 7 demonstrates the performance for DR = 100 kbps, Dev = 50 kHz, and a BW of 208.4 kHz. For the AFC disabled (modem compensation only) case, the frequency offset compensation can be calculated as 0.25 x 208.4 = 52.1 kHz, which may be observed in Figure 7. For the AFC enabled case, the frequency offset compensation can be calculated as 0.35 x 208.4 = 73 kHz. If more frequency offset compensation is desired, the RX bandwidth should be increased to a value greater than that shown in the Excel Register Calculator worksheet. This may easily be done by artificially increasing the value used for XTAL Tolerance.

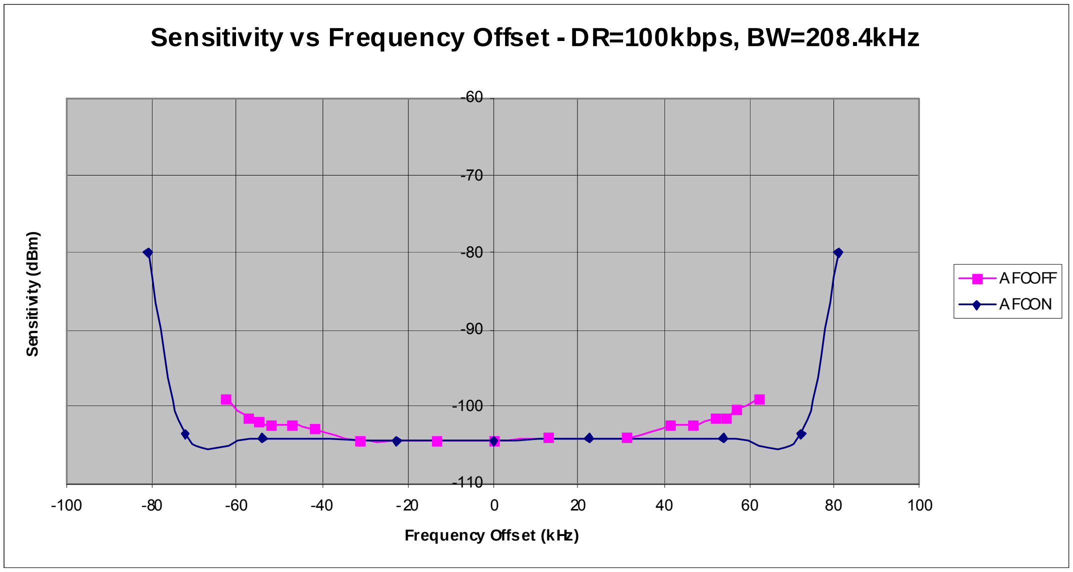


Figure 7. Selectivity vs. Frequency Offset (100 kbps)

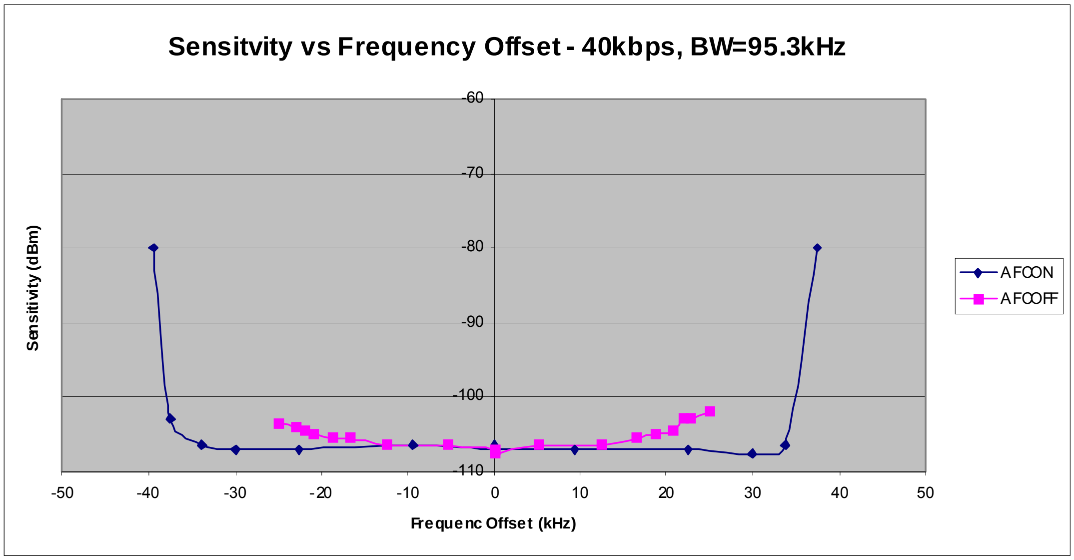


Figure 8. Selectivity vs. Frequency Offset (40 kbps)

4. TX Measurements

Unless otherwise specified, all TX measurements are measured with VDD = 3.3 V, txpow[2:0] = 111, frequency = 868 MHz using the scripts available on the Silicon Labs website and a TX/RX split test card. All measurements are done at the output of the low-pass filter at the TX SMA connector. The output power is ~1 dB higher at the TX pin of the chip before the low pass filter.

4.1. Output Power (Average Power, Conducted, ETSI 300220001v020301, Subclause 7.2)

The TX output spectrum in power state 0F with the proposed TX matching of the 4431-T-B1 B 868 testcard is shown in Figure 9 at 868 MHz. The power delivered to the antenna is 13.7 dBm in power state 0F.

The ETSI sub/bands and limits are shown in Figure 10. The limit in the g1 sub-band is +14 dBm effective radiated power (ERP) (corresponding to 16.1 dBm effective isotropic radiated power or EIRP), which allows for an antenna gain of 2.4 dB in power state 0F.

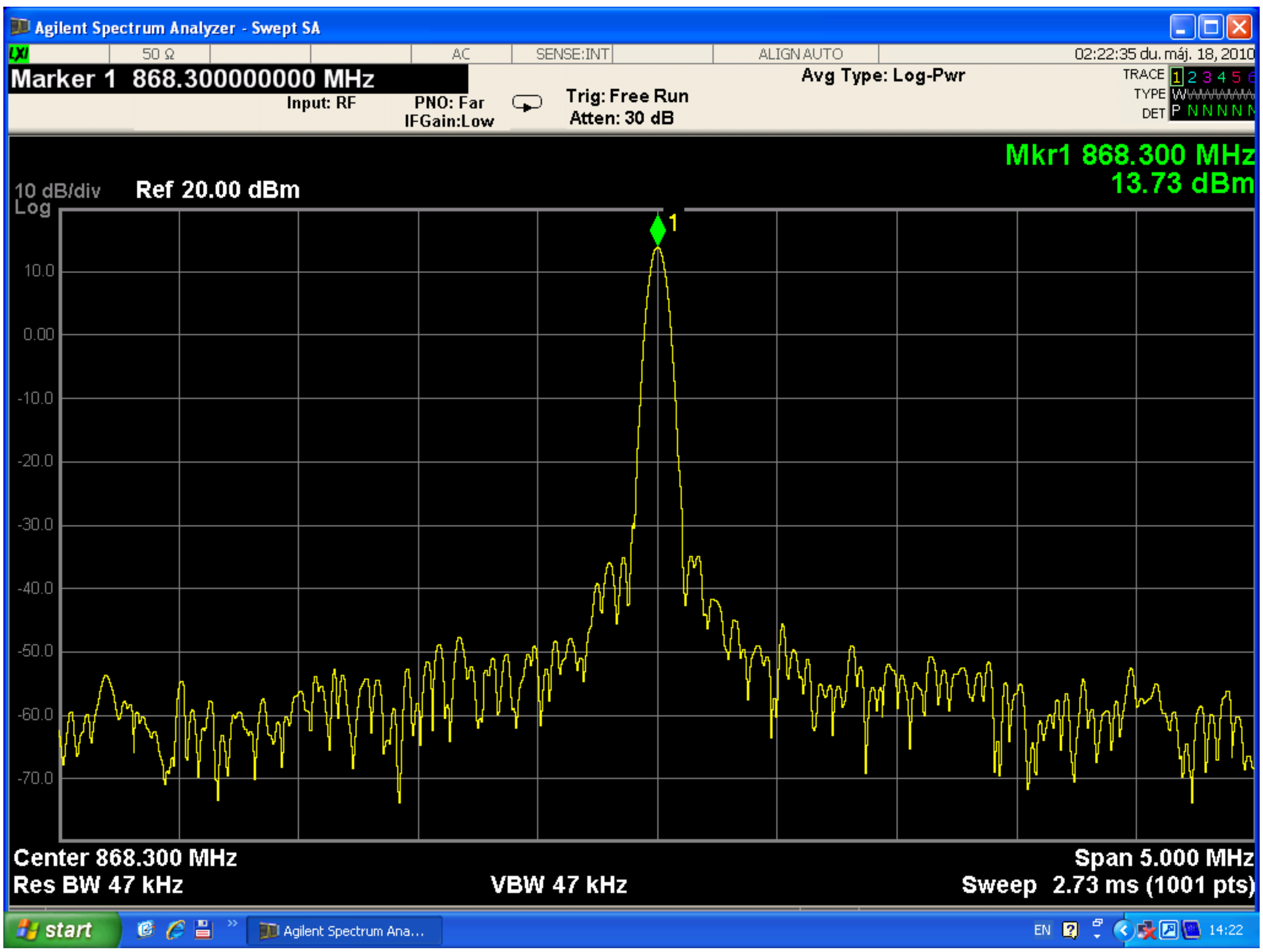


Figure 9. Output Power at Power State 0F at 3.3 V

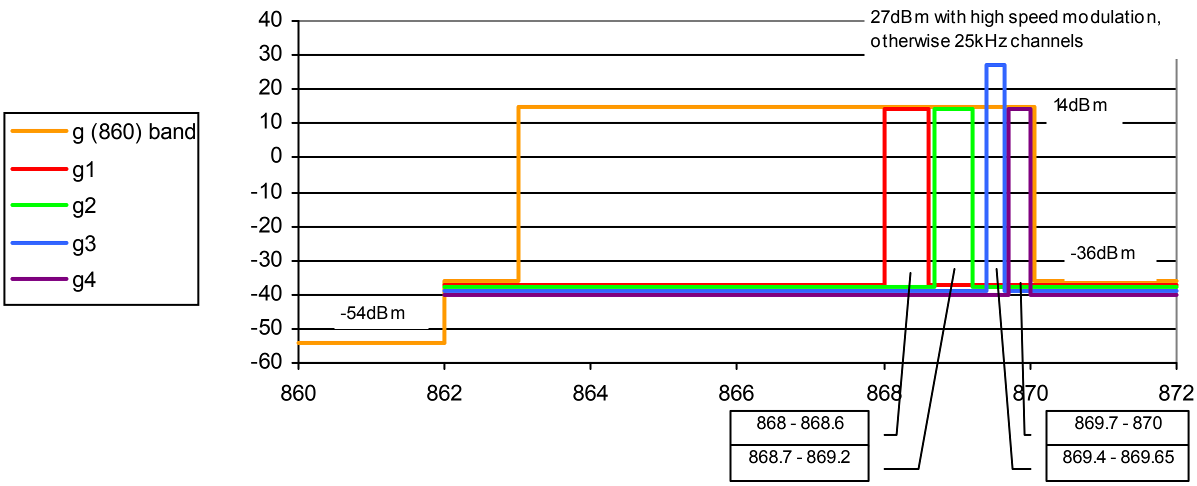


Figure 10. ETSI Sub-Bands and Limits at the 868 MHz Band

The conducted power and total current consumption at different power settings and supply powers are listed in Table 2.

Table 2. Conducted Power and Total Current Consumption at Different Power Settings and Supply Powers

Power Setting Register 6Dh	TX Output Fund Power [dBm], 3.6 V	Total Current Consumption [mA], 3.6 V	TX Output Fund Power [dBm], 3.3 V	Total Current Consumption [mA], 3.3 V	TX Output Fund Power [dBm], 1.8 V	Total Current Consumption [mA], 1.8 V
8	–4	14.4	–4.1	14.3	–4.7	13.9
9	–2	14.9	–2.1	14.8	–2.8	14.4
0A	2.6	17.1	2.5	17	1.7	16.4
0B	5.8	19.5	5.7	19.4	4.6	18.6
0C	8	21.8	7.9	21.7	6.2	20.3
0D	11	25.9	10.9	25.7	7.5	22.4
0E	13.2	30.6	12.8	29.8	8.2	24.4
0F	14.4	35.3	13.7	34.1	8.8	26.9

4.2. TX Frequency Error (ETSI 300220001v020301, Subclause 7.1)

The frequency error basically depends on the crystal spreading. A typical value is 20 ppm; so, the ±100 ppm ETSI limit for non-channelized devices is usually satisfied without any difficulty.

The internal capacitance bank of the Si4431 is used to tune the load capacitance of the applied crystal before measurement.

In the case of narrowband channelized applications, the required frequency accuracy is more strict and depends on the channel bandwidth. In this application, a more accurate crystal is necessary.

4.3. Effective Radiated Power (ETSI 300220001v020301, Subclause 7.3)

The effective radiated power at the fundamental frequency depends on the power delivered to the antenna and the antenna gain. The conducted power at power state 0F was already shown in "4.1. Output Power (Average Power, Conducted, ETSI 300220001v020301, Subclause 7.2)" on page 9. To comply with the g1 sub-band limit, the antenna gain should be less than 2.4 dB at 0F power state.

Using the configuration with a monopole (shown in Figure 11) the radiated power maximum at the fundamental frequency is +12.1 dBm EIRP at power state 0F and at 3.3 V. It is below the ETSI limit by 4 dB (14 dBm ERP or 16.1 dBm EIRP).

Figure 11. Test Card with Monopole Antenna for 868 MHz

4.4. Transient Power (ETSI 300220001v020301, Subclause 7.5)

Transient power is the power falling into adjacent spectrum due to switching the transmitter on and off during normal operation. The modulation bandwidth limits (see chapter 4.5 i.e. ETSI clause 7.7) shall be fulfilled irrespective of the transient power limit values.

4.4.1. Measurement Procedure According to ETSI

1. The measured receiver shall use a QUASI-PEAK DETECTOR defined in CISPR 16-1-1.
2. RBW should be 120 kHz.
3. Special narrowband and wideband settings:
   a. For narrowband equipment (channel spacing <25 kHz), the measurement shall be started at 60 kHz offset from the beginning of the upper adjacent channel.
   b. For wide-band devices, the initial offset shall be 100 kHz from the modulation bandwidth edge.
   c. The measurement shall be repeated in 120 kHz steps, up to 2 MHz offset.
   d. The measurement shall be done on both sides of the carrier.
4. The measurement shall be repeated in 120 kHz steps, up to 2 MHz offset.
5. The measurement shall be done on both sides of the carrier.
6. The measurement shall be done in ZERO-SPAN mode.
7. The transmitter shall be turned on and off at least 5 times
8. The power level should be recorded at least for a period of 60 seconds
9. If the resulting power level is above the spurious limit (see Section 4.5 or subclause 7.8 of the ETSI document), then the measurement shall be repeated with continuous transmission, and the transient level in Step 6 shall not exceed this power level by more than 3 dB. This is the so-called Step 2 of this measurement according to ETSI.

4.4.2. Modified Measurement Results

Slight modifications were done in the measurement method to address the worst-case scenario and to simplify the measurement.

1. The TX_state signal was multiplexed to GPIO2 of Si4431.
2. This signal was used for triggering the spectrum analyzer (to capture PA transient, which is so fast that it could not be captured by turning on and off the PA five times as requested in ETSI).
3. The sweep time in ZERO-SPAN mode was set to 5 ms, number of points 1001 (it does not make sense to measure 60 seconds as requested in ETSI due to the fast transient response).
4. The ZERO-SPAN measurement was repeated in 50 kHz frequency steps from –2 MHz to 2 MHz offset around the carrier.
5. The carrier was set to 868.3 MHz, Si4431 XTAL was tuned to 0 ppm offset.
6. The same measurement was repeated with the max peak detector as well.

4.4.3. Transient Power Results

1. The quasi-peak detector has 1 ms charge time by definition; therefore, it has a huge suppression (about 12 dB according to CISPR 16) for narrow pulses like a few microseconds in our case.
2. Because of its slow response, the quasi-peak detector cannot detect VCO pulling in our case. Effectively, there is no difference in the results between the transient signal and the continuous transmission, by using the quasi-peak detector for the measurement (the result was the phase noise curve in both cases (see the magenta curves in Figure 12), which means the 3 dB criteria of ETSI test Step 2 is always met. The difference between the continuous and on-off switched PA case can only be seen with the max peak detector (in continuous mode, the peak detector results are the same as the quasi peak detector, while, with switched PA, the pulling appears with the peak detector (blue curve)).
3. *There is no limitation in channel spacing* according to these results.

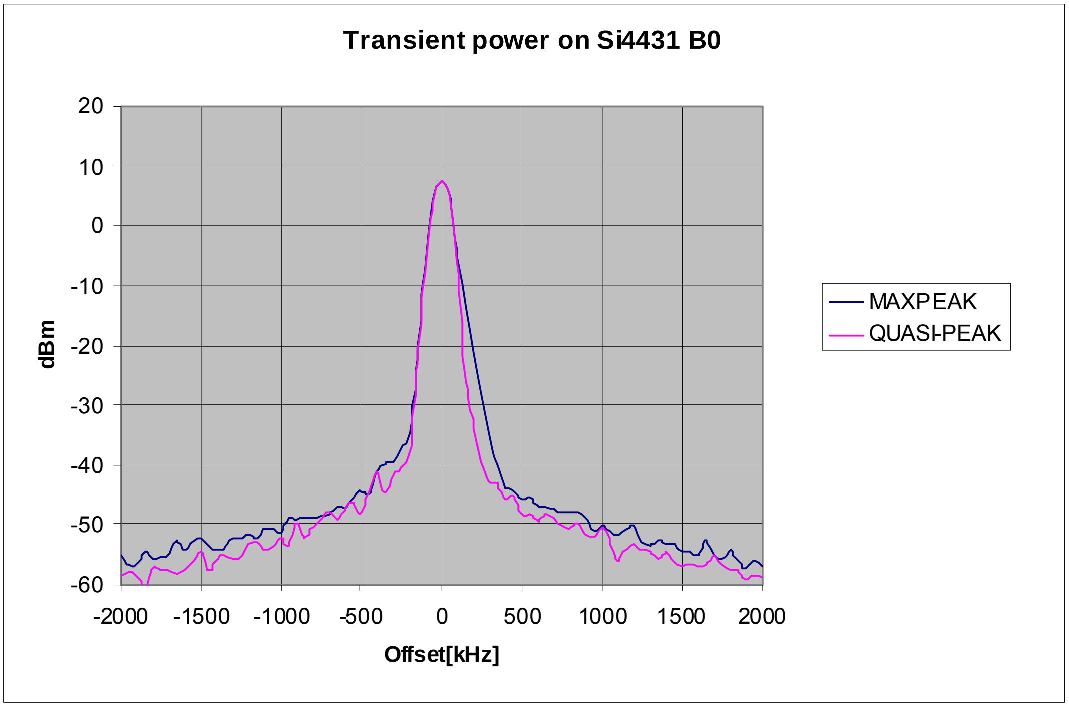


Figure 12. Transient Power Measurement

With the Quasi-peak detector, both the continuous and on-off measurement gives the same curve (magenta), while with the Maxpeak detector, the VCO pulling can be observed with PA on-off.

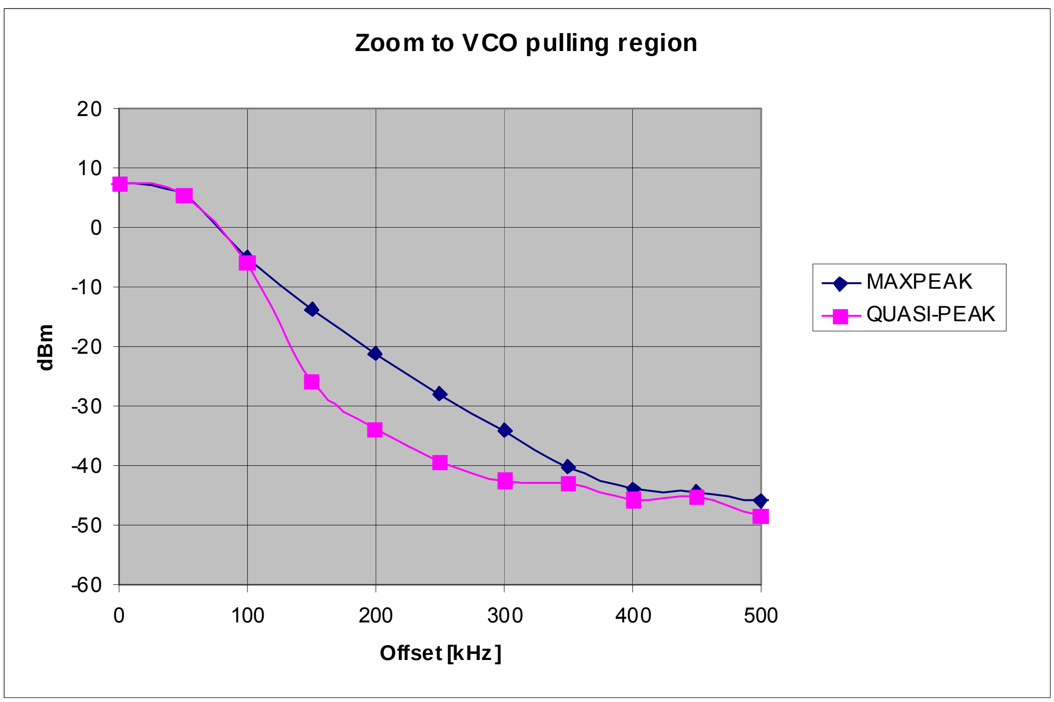


Figure 13. Zoomed VCO Pulling Region of Fig. 12

4.5. Adjacent Channel Power (ACP) (ETSI 300220001v020301, subclause 7.6)

The adjacent channel power (ACP) is defined as the amount of the modulated RF signal power which falls within a given adjacent channel. ACP measurements are applicable to narrowband systems. Narrowband systems are used in a non-channelized continuous frequency band with a channel bandwidth of less than or equal to 25 kHz or used in a channelized frequency band with a channel spacing of less than or equal to 25 kHz.

According to ETSI the narrowband systems are divided into two groups. In the first group, if the channel separation is smaller than 20 kHz, then the ACP limit is –20 dBm in an integrated bandwidth of 8.5 kHz. In the second group, if the channel separation is higher or equal to 20 kHz, then the limit is –37 dBm in an integrated bandwidth of 16 kHz. The script used for the ACP measurement is given in Annex A.

4.5.1. ACP Measurements with Channel Spacing Higher or Equal to 20 kHz

In this chapter the ACP measured with a 25 kHz channel spacing is investigated. For this measurement the integrated bandwidth of the adjacent channel is 16 kHz and the ETSI limit for the ACP is 200 nW (–37 dBm).

Figure 14 illustrates the measured ACP at the 869.65–869.7 MHz alarm band with default VCO current and PLL bandwidth settings (the corresponding lines are ignored in the script in Annex A) with a 1 kbps data rate and a 5 kHz deviation. In theory, the Si4431 can work with much lower deviation as well, but 5 kHz is a practical choice due to crystal selection considerations. The integrated power around the carrier is +3.8 dBm in 16 kHz bandwidth and with average detection. In CW mode and with peak detection the measured power is around +4.4 dBm. With this power the ACP is 0.6 dB lower than the ETSI limit (–37 dBm) therefore the Si4431 complies with the ETSI ACP limits with 25 kHz channel spacing up to +4.5–5 dBm fundamental output power with the default VCO and PLL register settings if no margin is left. With a 3 dB margin, the allowed power is +1.5–2 dBm.

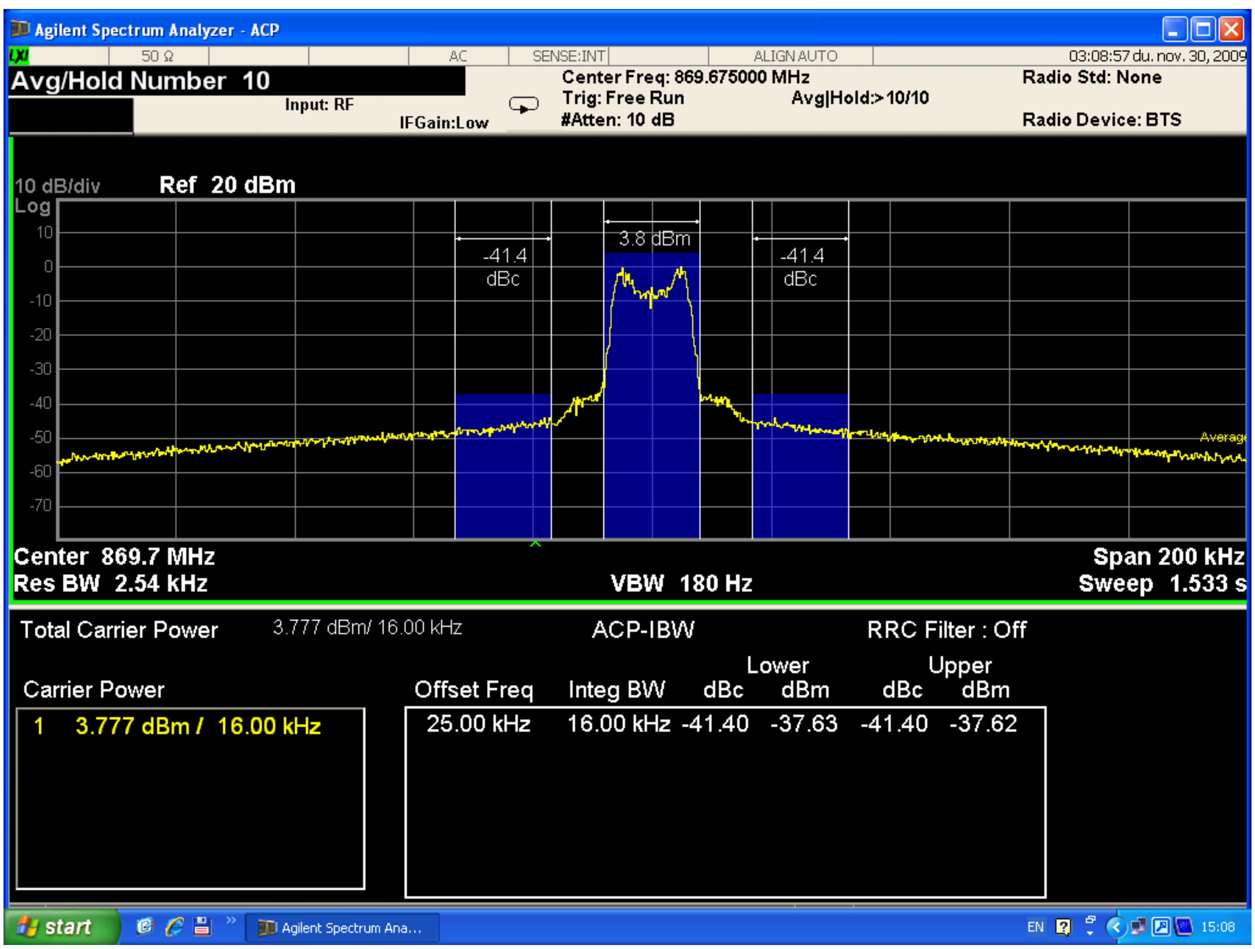


Figure 14. Adjacent Power Measurement, 25 kHz Narrowband Channel Spacing, Default Settings, 1 kbps, 5 kHz Deviation (+4.4 dBm CW Power Measured by Peak Detector)

Figure 15 shows the measured ACP at the 869.65…869.7 MHz alarm band with VCO current boost (7Fh is written into register 5A). The data rate and dev. are the same as the previous example (1 kbps, 5 kHz). The improvement on the ACP is approximately 1.7 dB due to the VCO current boost. The allowed fundamental power to comply with the ETSI ACP limits with 25 kHz channel spacing is approximately +6–6.5 dBm (CW, measured by peak detector) with VCO current boost if no margin is left. With a 3 dB margin, the allowed power is approximately 3–3.5 dBm.

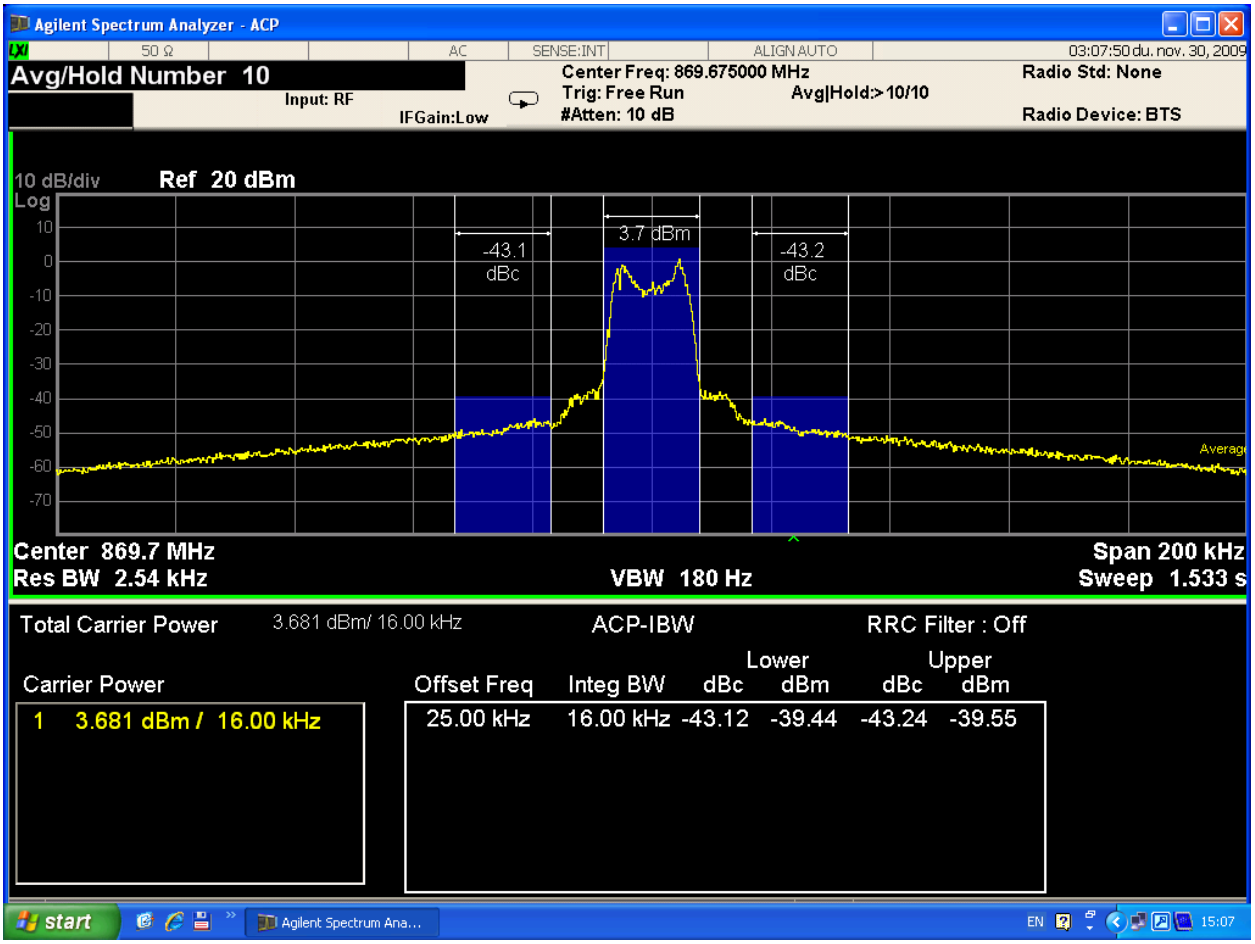


Figure 15. Adjacent Power Measurement with 25 kHz Narrowband Channel Spacing with VCO Current Boost (the value of register 5A is 7Fh), 1 kbps, 5 kHz Deviation (+4.4 dBm CW Power Measured by Peak Detector)

Figure 16 shows the measured ACP at the 869.65–869.7 MHz alarm band with VCO current boost (7Fh in register 5A) and with PLL BW increase (EFh in register 58). The data rate and dev. are the same as before (1 kbps, 5 kHz). The improvement on the ACP is approximately 3 dB due to PLL bandwidth increase. The VCO current boost and PLL BW result together in a 5 dB improvement and therefore the maximum fundamental output power which complies with the ETSI ACP limits with 25 kHz channel spacing is ~ +9–9.5 dBm (CW, measured by peak detector) in this case if no margin is left. With a 3 dB margin, the allowed power is approximately 6–6.5 dBm.

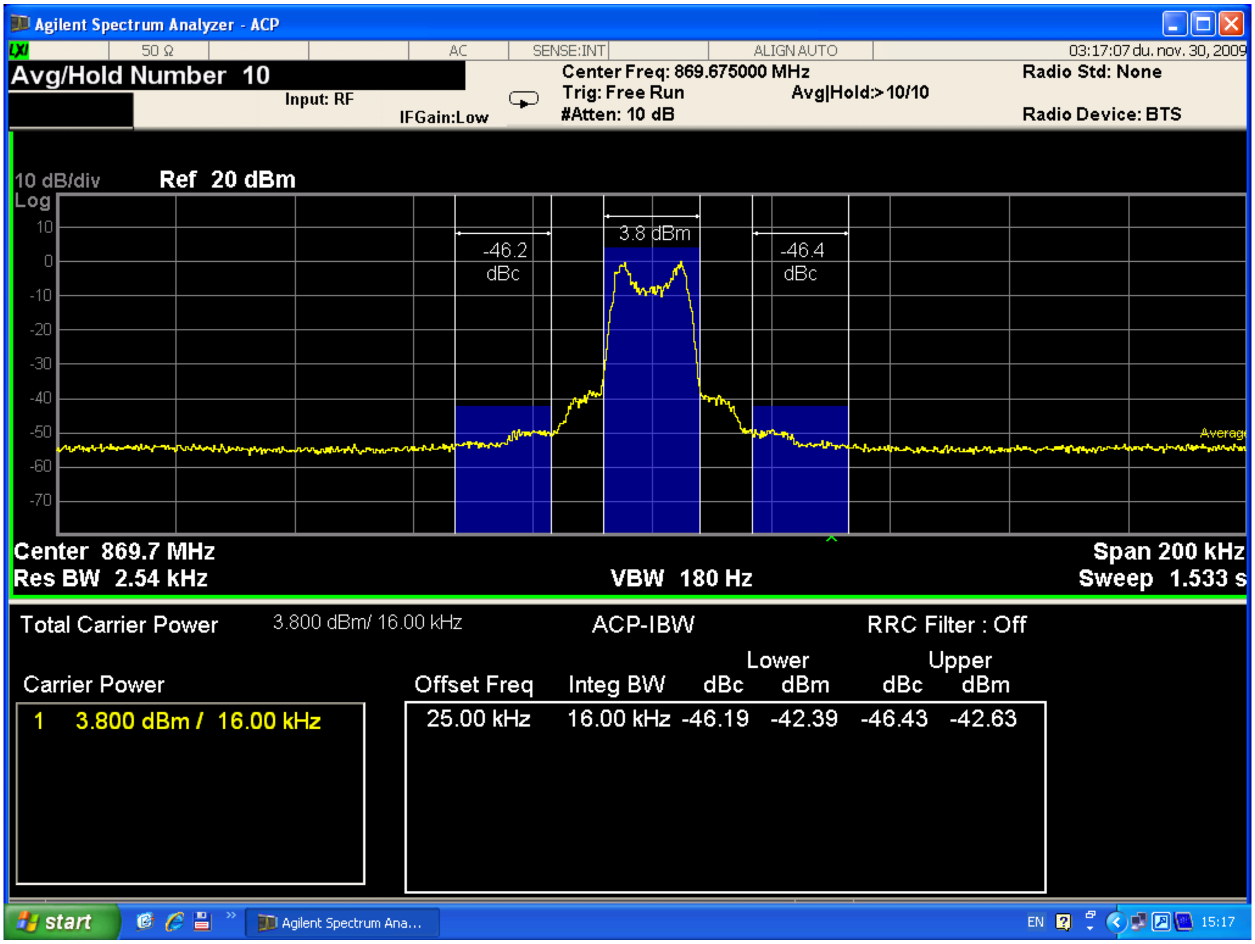


Figure 16. Adjacent Power Measurement with 25 kHz Narrowband Channel Spacing with VCO Current Boost (7Fh is in register 5A) and with PLL BW Increase (EFh in register 58), 1 kbps, 5 kHz Deviation (+4.4 dBm, CW Power Measured by Peak Detector)

4.5.2. Measurements with 12.5 kHz Channel Spacing

In this section, the ACP measured with a 12.5 kHz channel spacing is investigated. In this measurement the integrated bandwidth at the adjacent channel is 8.5 kHz and the ETSI limit for ACP is 10 µW (–20 dBm).

The measured ACP is shown in Figure 17. The Si4431 is modulated with 2.4 kbps and the applied deviation is 2.5 kHz. The power is set to maximum (0Fh in register 5A). The Si4431 is used in default mode (no VCO boost, no PLL BW increase). The integrated ACP power in the applied 8.5 kHz bandwidth is 6 dB below the ETSI limit, therefore with 12.5 kHz channel spacing the Si4431 can be used at maximum power level with high margin.

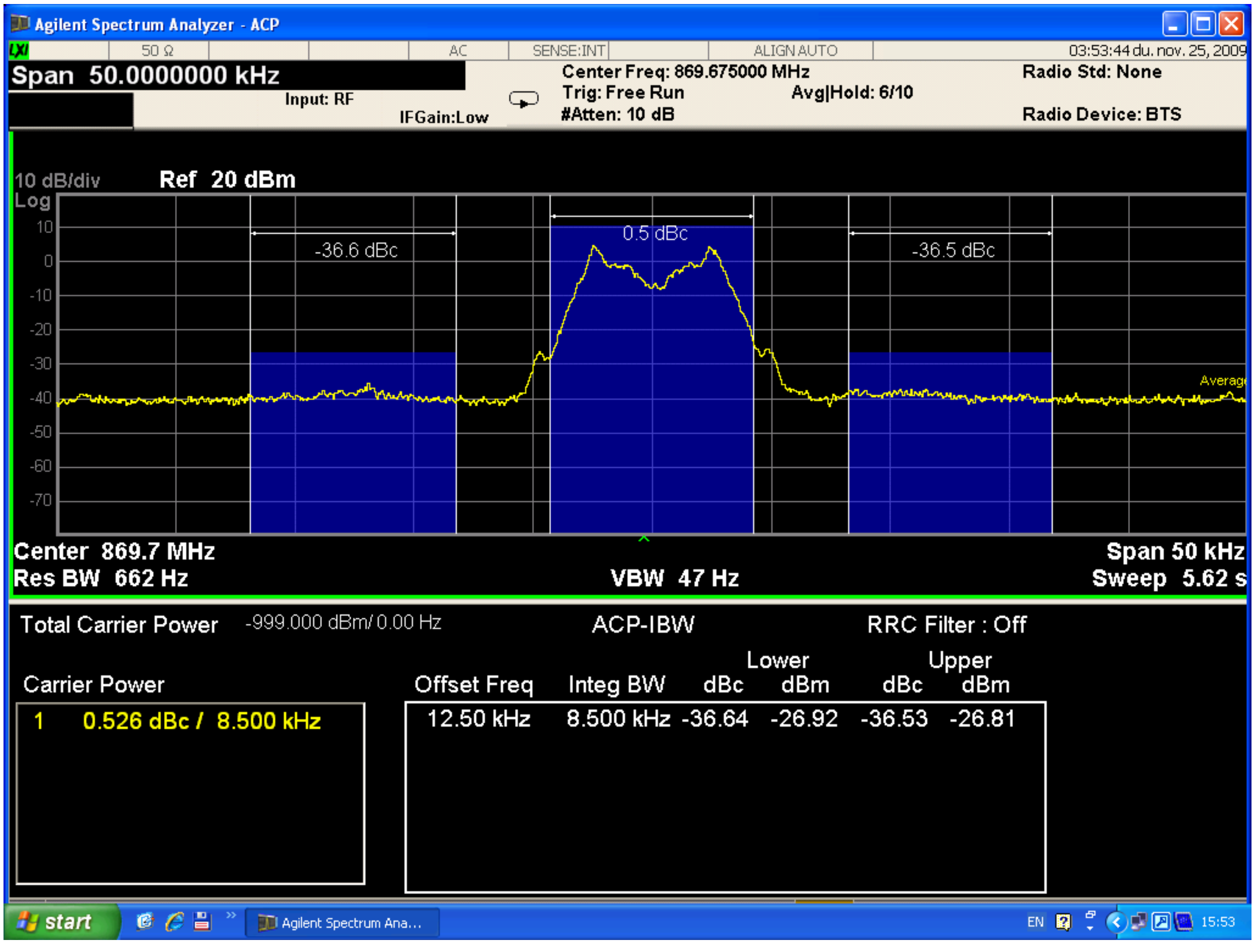


Figure 17. Adjacent Power Measurement with 12.5 kHz Narrowband Channel with Default Settings, Max Power State, 2.4 kbps, 2.5 kHz Deviation

4.5.3. Measurements with 12.5 kHz Channel Spacing with 9.6 kbps and 4.8 kHz Deviation

In this section, the ACP is measured with a 12.5 kHz channel spacing and 9.6 kbps is investigated. The deviation is 4.8 kHz. In this measurement, the integrated bandwidth at the adjacent channel is 8.5 kHz and the ETSI limit for ACP is 10 µW (–20 dBm). The operation frequency here is 868 MHz.

The measured ACP is shown in Figure 22 with default settings (no VCO boost, no PLL BW increase). The power is set to –1.5 dBm (09h in register 5A in case of the split testcard) to comply with the ACP standard with ~3 dB margin.

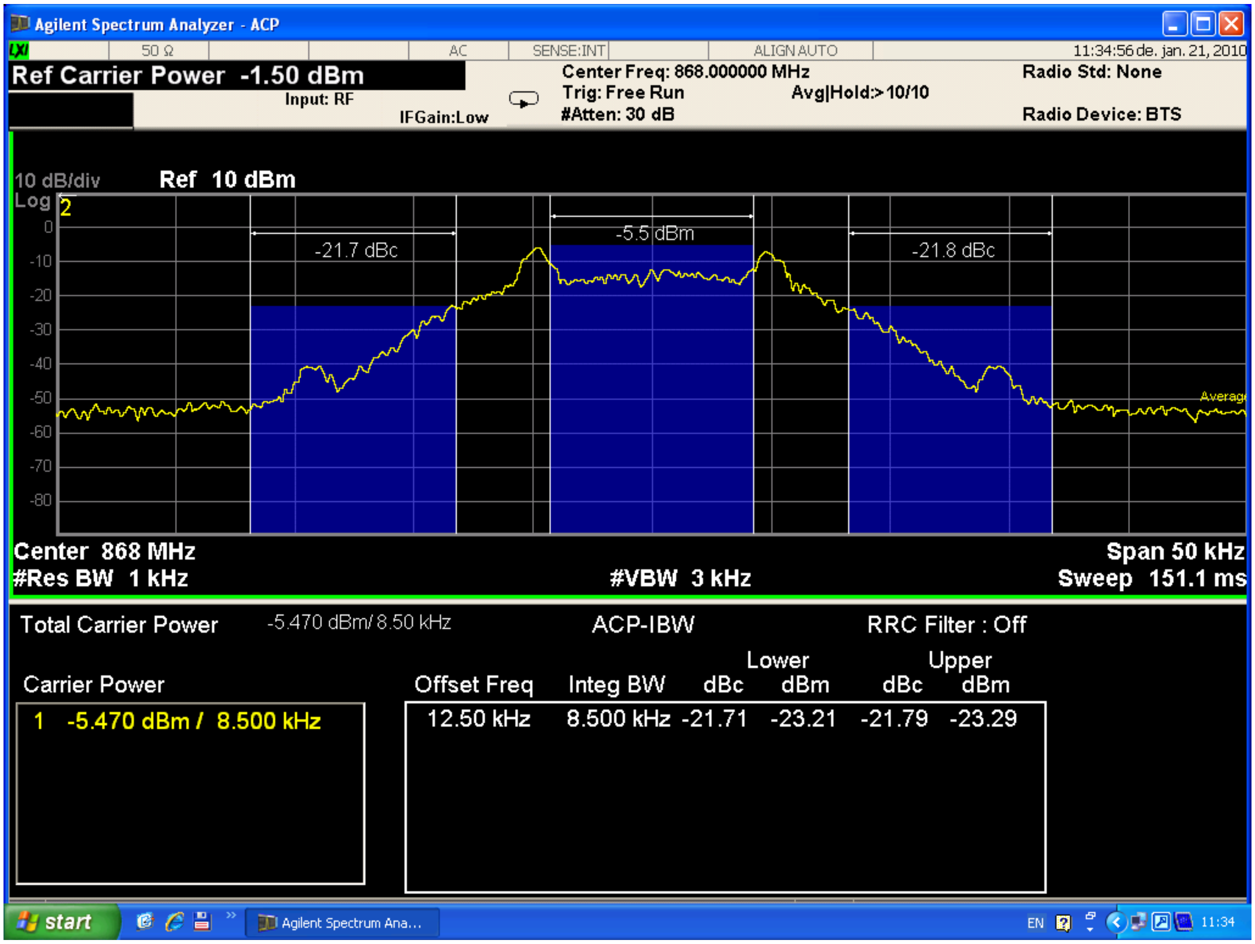


Figure 18. Adjacent Power Measurement with 12.5 kHz Narrowband Channel with Default Settings and with 9.6 kbps and 4.8 kHz Deviation, –1.5 dBm CW Power Measured by Peak Detector)

Figure 19 shows the measured ACP with VCO current boost (7Fh in register 5A) and with PLL BW increase (EFh in register 58) at a power of 3 dBm (state 0 A in case of split testcards). The data rate and deviation are the same as before (9.6 kbps, 4.8 kHz). With a 3 dB margin, the allowed power is ~0 dBm (CW, measured by peak detector), so the improvement due to the VCO current and PLL BW boost is ~1.5 dB.

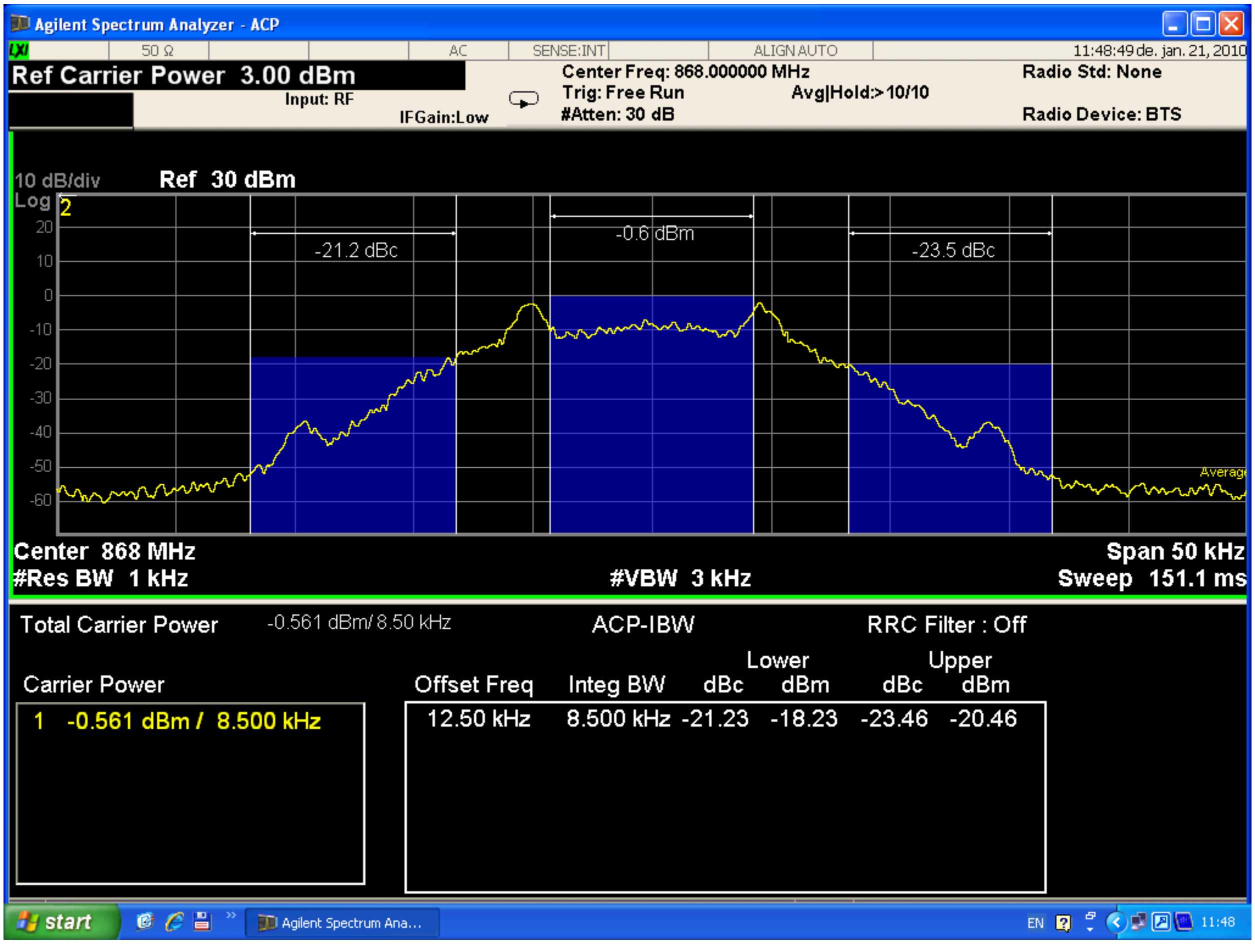


Figure 19. Adjacent Power Measurement with 12.5 kHz Narrowband Channel with VCO and PLL BW Boost and with 9.6 kbps and 4.8 kHz Deviation, CW Power is +3 dBm Measured by Peak Detector

4.5.4. Measurements with 12.5 kHz Channel Spacing with 9.6 kbps and 2.4 kHz Deviation

In this section, the ACP is measured with a 12.5 kHz channel spacing and 9.6 kbps is investigated. The deviation is 2.4 kHz. In this measurement, the integrated bandwidth at the adjacent channel is 8.5 kHz, and the ETSI limit for ACP is 10 µW (–20 dBm). The operation frequency here is 868 MHz.

The measured ACP is shown in Figure 20 with default settings. The power is set to 11.4 dBm (0Dh in register 5A in case of the split testcard) to comply with the ACP standard. The Si4431 is used in default mode (no VCO boost, no PLL BW increase). With a 3 dB margin, the allowed power (CW, measured by peak detector) is ~9.5 dBm.

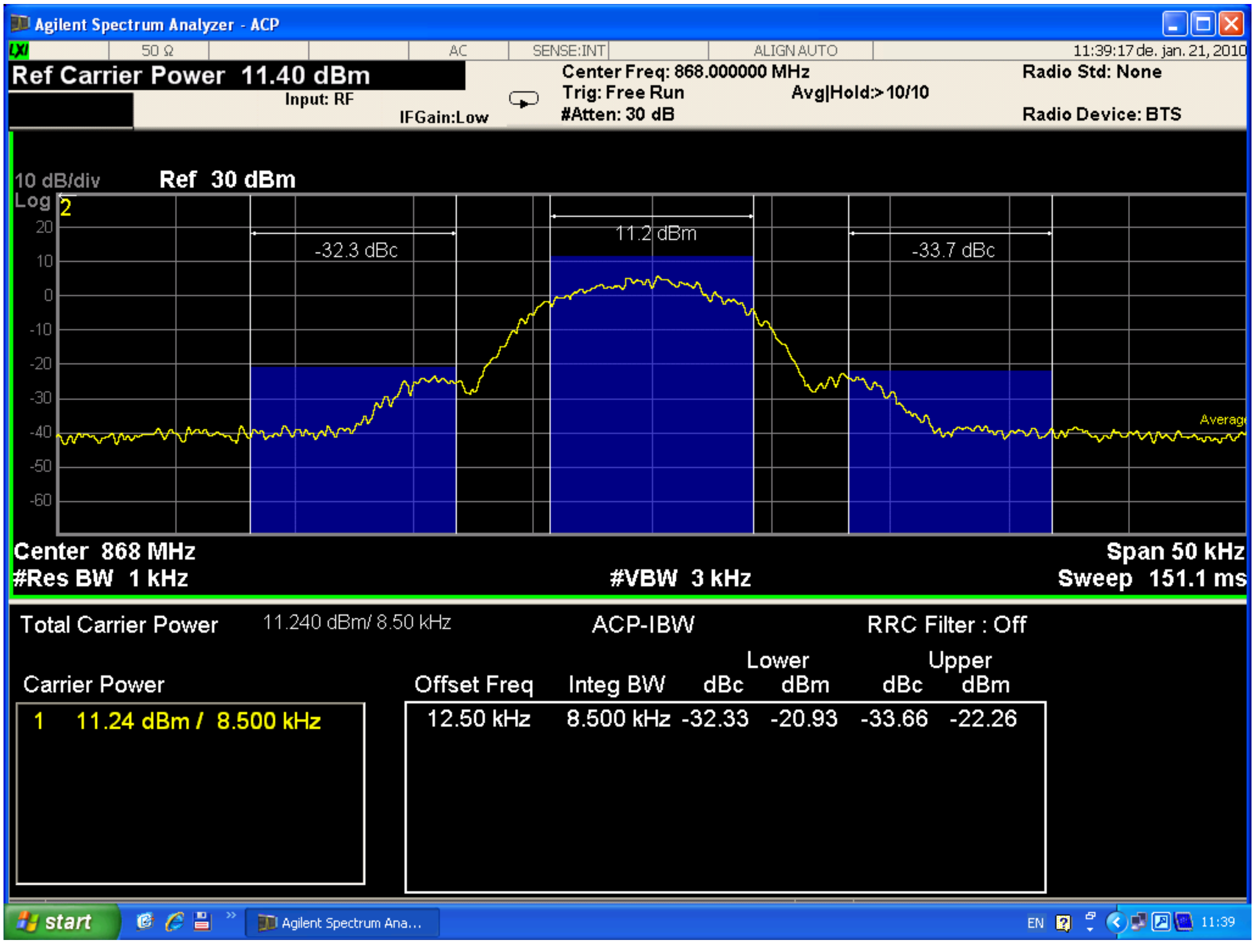


Figure 20. Adjacent Power Measurement with 12.5 kHz Narrowband Channel with Default Settings and with 9.6 kbps and 2.4 kHz Deviation, CW Power is +11.4 dBm Measured by Peak Detector

Figure 21 shows the measured ACP with VCO current boost (7Fh in register 5A) and with PLL BW increase (EFh in register 58) with a power of 13.5 dBm (power state 0E). The data rate and deviation are the same as before (9.6 kbps, 2.4 kHz). With a 3 dB margin, the allowed power (CW, measured by peak detector) is ~10.5 dBm, so the improvement due to VCO current and PLL BW boost is 1 dB.

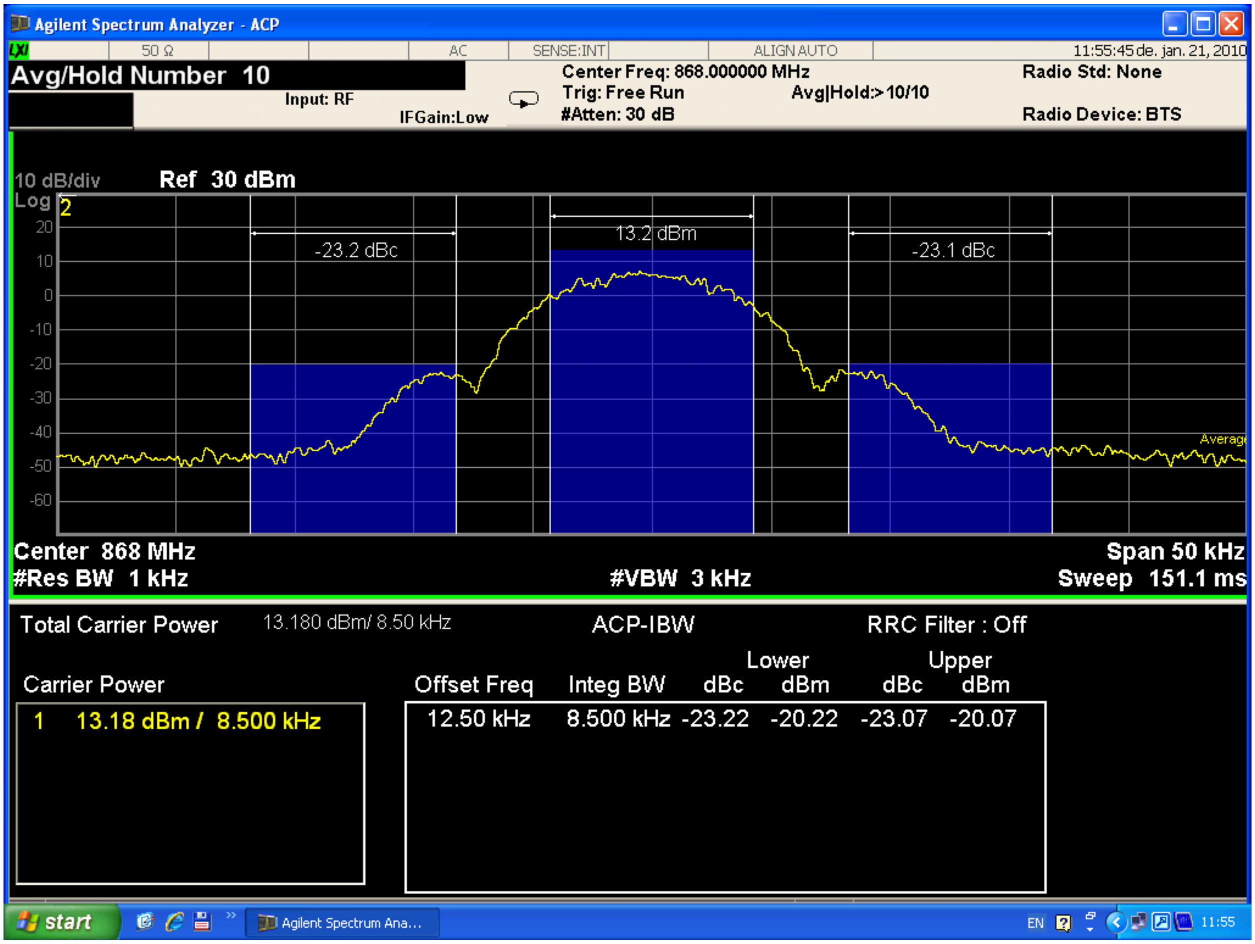


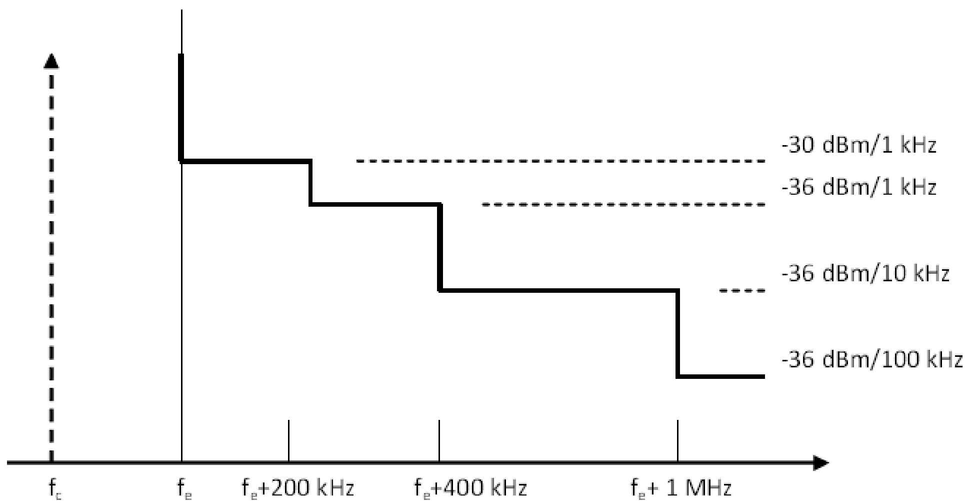
Figure 21. Adjacent Power Measurement with 12.5 kHz Narrowband Channel with VCO and PLL BW settings and with 9.6 kbps and 2.4 kHz Deviation, CW power is +13.5 dBm Measured by Peak Detector

4.6. Modulation Bandwidth (ETSI 300220001v020301, Subclause 7.7)

The range of modulation bandwidth includes all associated side bands above the appropriate emissions level (ETSI 300220001v020301, subclause 7.8) and the frequency error or drift under extreme test conditions. The frequency drift in extreme test conditions primarily depends on the crystal quality, which is not included in this report.

The ETSI spectral mask with which the radio must comply at the sub-band edges is demonstrated in Figure 22. Basically, there are only two limit thresholds, and the bandwidth of integration is varied at the different offset regions.

This can be observed in the spectral mask measurements as well (see Figures 23 and 25), where the limit lines mark the –30 and –36 dBm levels. As the RBW is changed according to the ETSI spectrum mask, the measured phase noise level is changing in the –36 dBm level region.



- f_c is the emission center frequency.
- f_e is the sub-band edge frequency.
- Only the upper half of the emission is shown. The lower half is a mirror image.

Figure 22. ETSI Spectral Mask Measurement Limits at the Sub-Band Edges

Figure 23 demonstrates the measured spectral mask in the g3 sub-band (869.4–869.65 MHz) with default register settings. Since the allowed output power in the g3 sub-band is 500 mW, the power level is set to maximum (power state 0Fh, where the power in CW mode is ~14 dBm). The applied bit rate is 50 kbps with H = 1. With these parameters, the spectral mask of 4431 complies with ETSI subclause 7.7 at the most critical G3 sub-band with minimal margin (~1 dB) due to modulated sidebands products. Unfortunately, due to this, the power cannot be higher at any other sub-bands as well with default register settings. It also means that with the Si4432 a significant (~6 dB) power reduction is required.

If higher output power is desired, the Si4432 can be used with a modified register setting. By setting the 0x58, 0x59 and 0x5A register values to 0x40, 0x80 and 0x81, respectively, the sideband spurs practically can be eliminated. This way the Si4432 is compliant with ETSI spectrum mask restrictions even with max power. Figure 24 shows the spectrum mask test result with a Si4432 having ~19.5 dBm CW power. The Si4432 complies with full power with the above described register settings.

Figure 25 shows the measured spectrum mask in the 868.6–868.7 MHz alarm band where the maximum allowed power is +10 dBm. To comply with this limit, the power is set to state 0Dh (Vcc = 3.3 V).

The applied bit rate for this test is 19.6 kbps, H = 1. With these parameters the Si4431 complies with the ETSI spectral mask limits up to the allowed maximum power limit (+10 dBm) in the 100 kHz wide alarm sub-band.

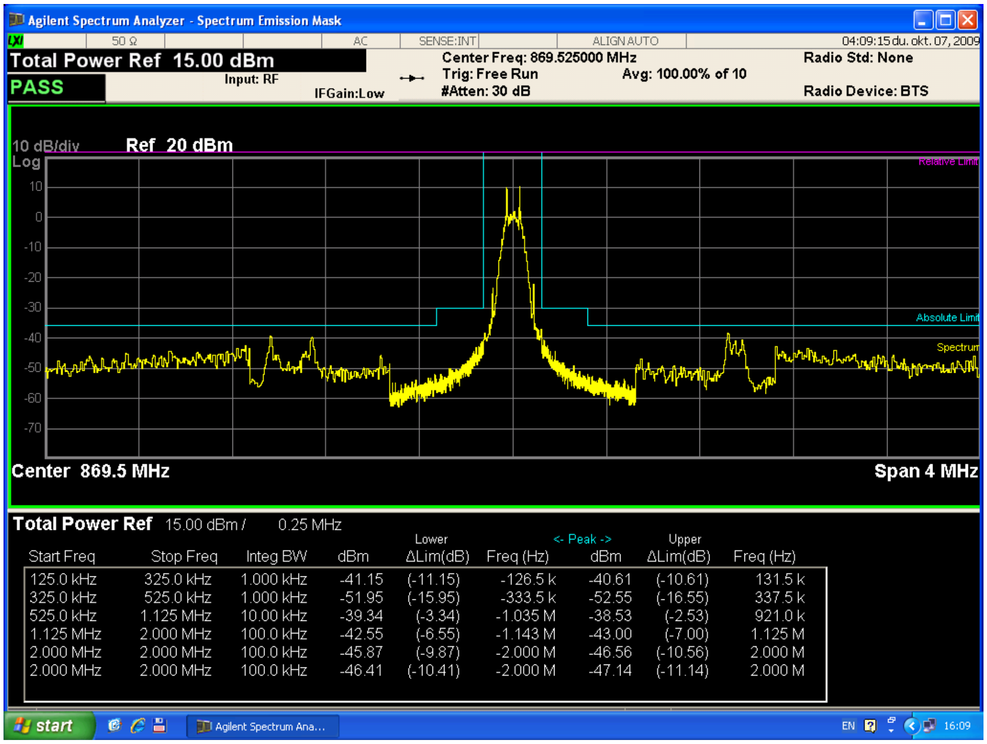


Figure 23. Spectral Mask Measurement in G3 Sub-Band (869.4–869.65 MHz), 3.3 V (Power State 0Fh (max), 50 kbps, H = 1)

s

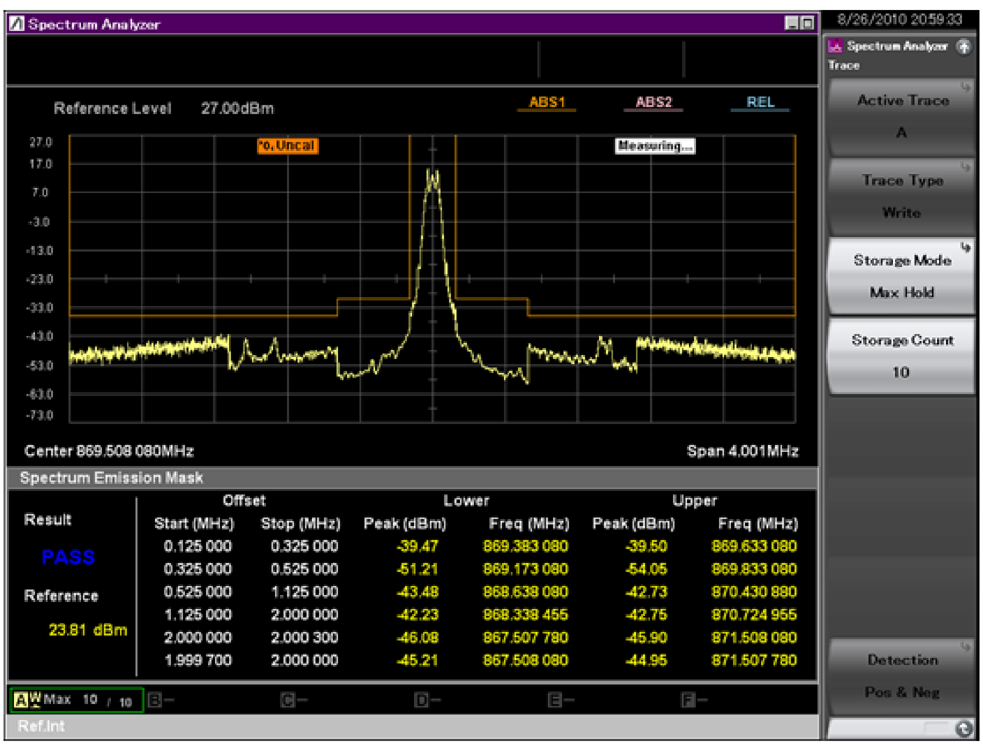


Figure 24. Si4432 Spectrum Mask Test at G3 Sub-Band; Full (19.5 dBm CW) Power, 25k Deviation, 50k Data Rate

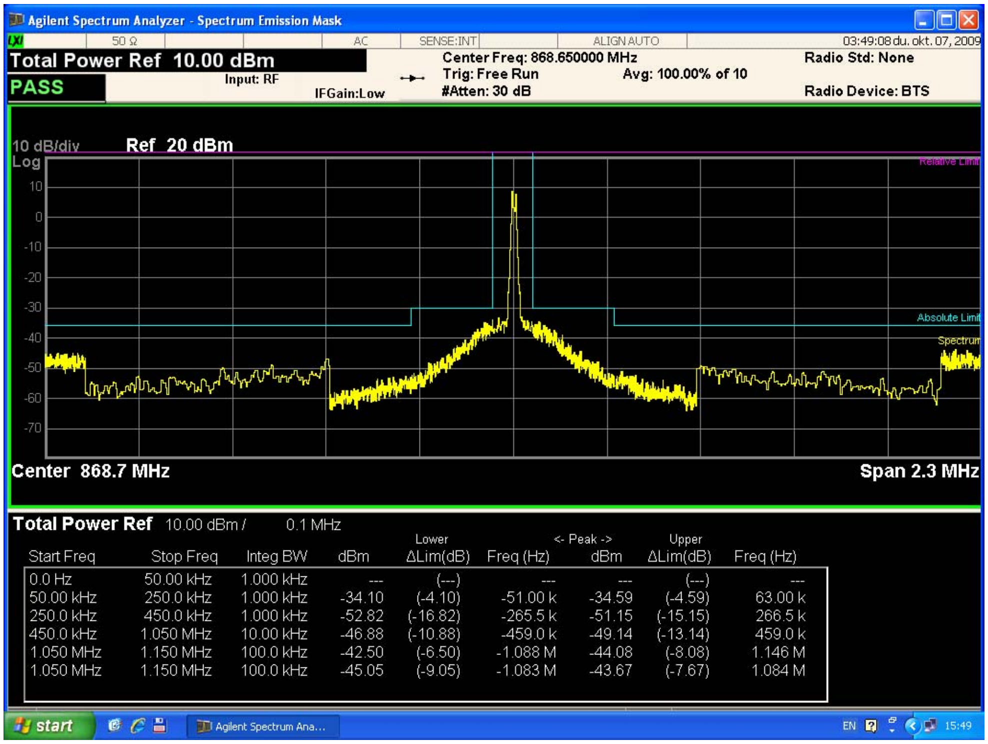


Figure 25. Spectral Mask Measurement in 100 kHz Alarm Sub-Band (868.6–868.7 MHz), 3.3 V, (Power State 0Dh to be below the 10 dBm Fundamental Limit, 19.6 kbps, H = 1)

SILICON LABS

4.7. Unwanted Emissions in Spurious Domain (ETSI 300220001v020301, Subclause 7.8)

The allowed emissions in ERP in the spurious domain are shown in Figure 26.

A critical restriction is the –54 dBm limit below 862 MHz.

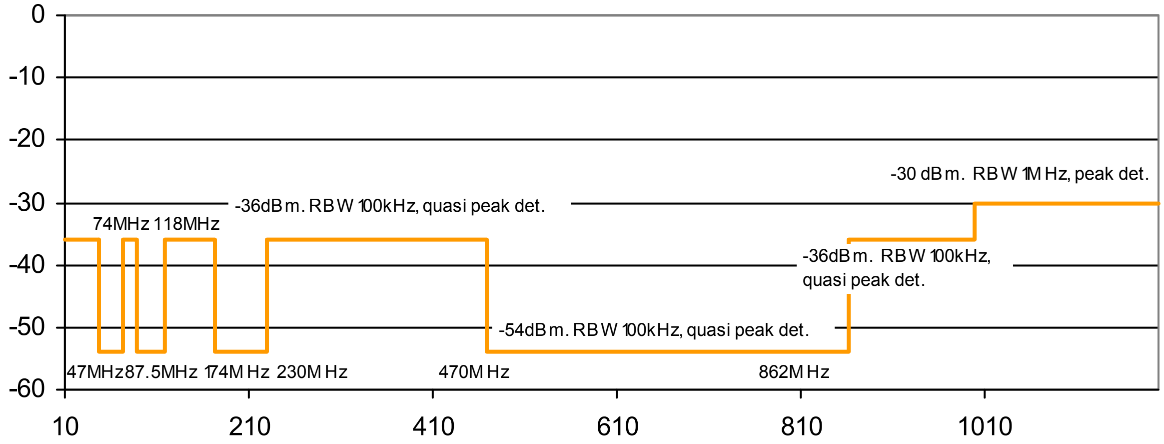


Figure 26. ETSI Spurious Radiation Limits in ERP

4.8. Conducted Harmonics

Figure 27 shows the conducted spectrum with a 100 MHz span around the 868 MHz carrier with full power at 3.6 V VDD. Below 862 MHz, all spurious emissions are lower than –60 dBm. Above 862 MHz the spurious emissions are below the ETSI –36 dBm limit.

Figure 28 demonstrates the conducted full spectrum below 1 GHz. There are no spurs above the ETSI –54 dBm limit.

Above 1 GHz, the main spur components are the harmonics. Figure 29 shows the conducted harmonics above 1 GHz up to 12.75 GHz. This measurement is done with 1 MHz RBW and max hold. No harmonics above the ETSI limit (–30 dBm) are observed.

Peak detectors were used in all the conducted measurements.

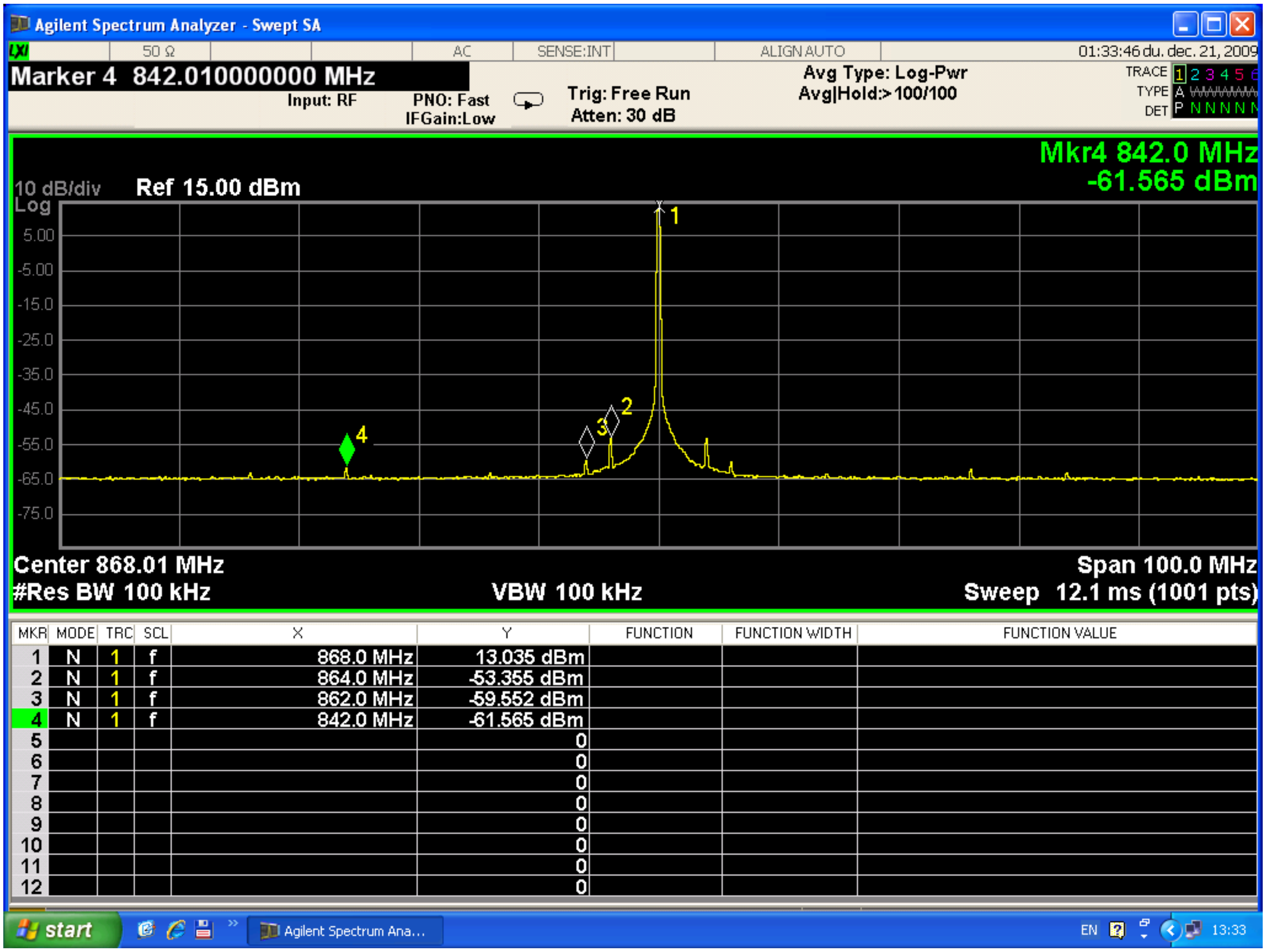


Figure 27. Si4431 Spectrum around the Carrier

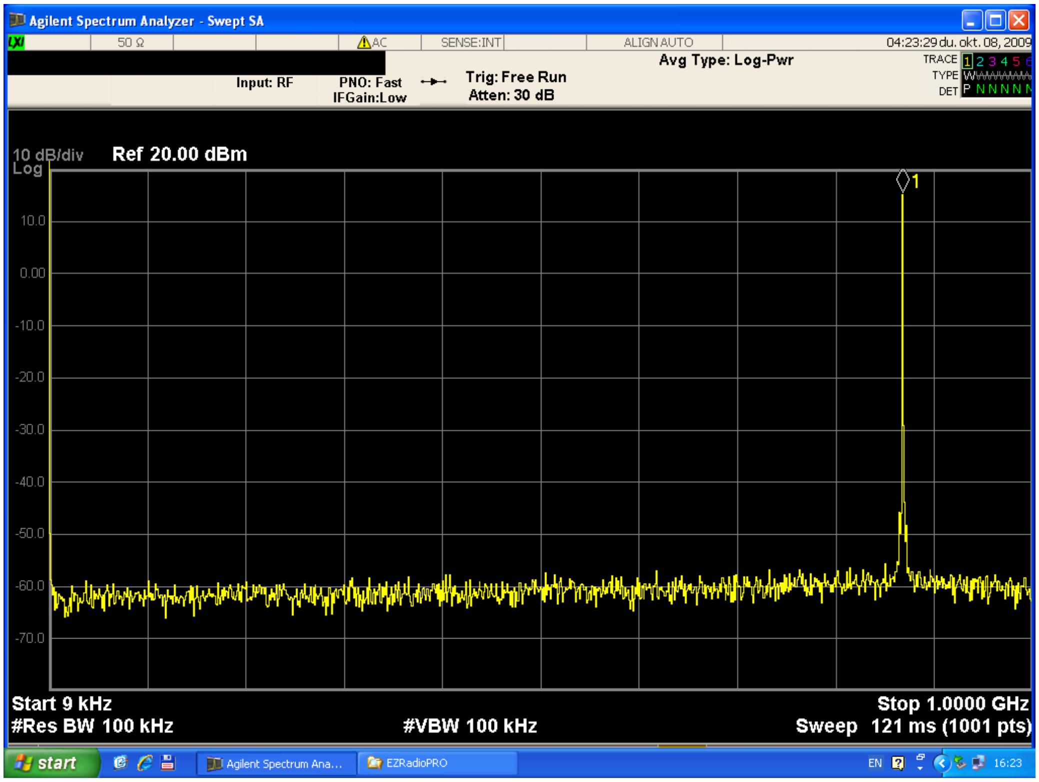


Figure 28. Si4431 Spectrum below 1 GHz

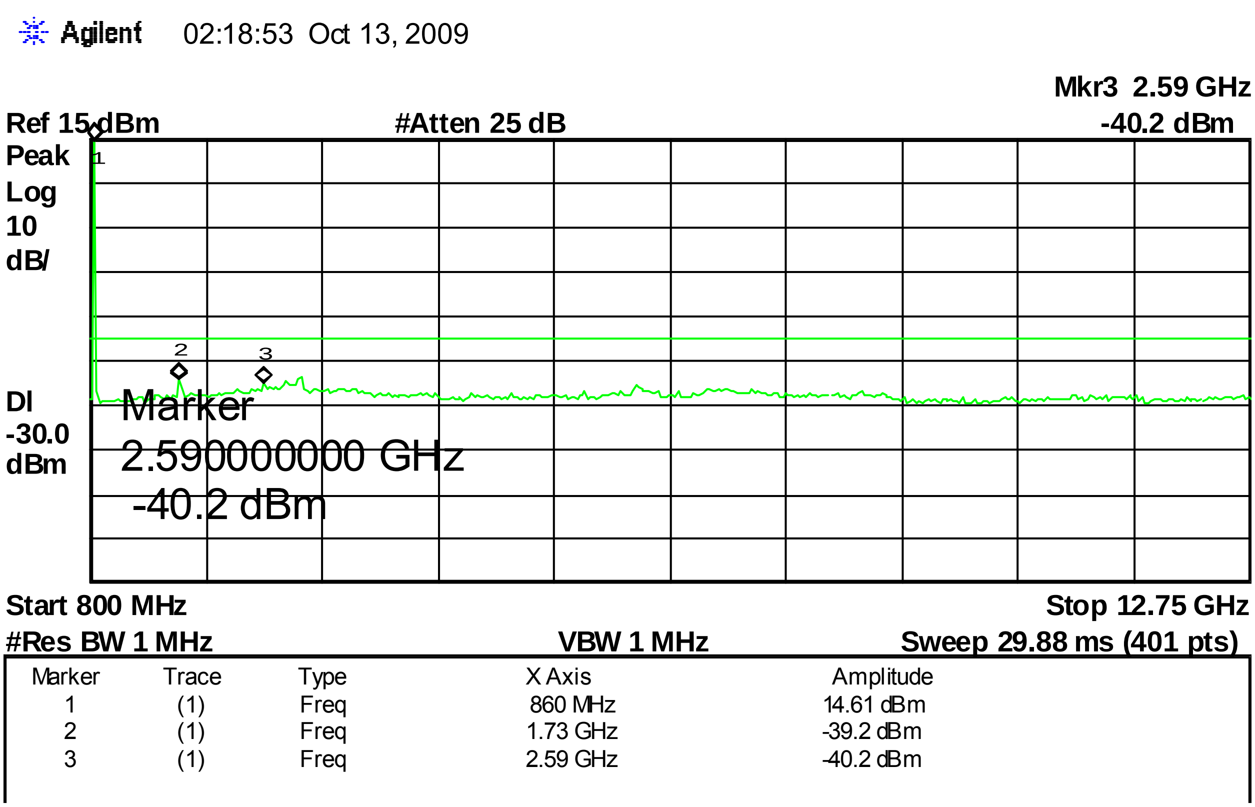


Figure 29. Conducted Harmonics above 1 GHz (State 0F, 3.6 V)

4.9. Radiated Harmonics

ETSI compliance for radiated harmonics is shown in Figures 30 through 36. These tests were performed by Elliott Labs an ETSI certified Electromagnetic Compatibility (EMC) test house. The test is performed with a Si4431-4431-T-B1_D_868 Test Card (2 layer design for direct-tie) at the 868 MHz frequency band at an output power level of +13 dBm (power state 07, 3.3 V). The measured harmonic levels up to the 10th harmonic in TX mode are shown below. According to this, the two-layer design direct-tie board is fully-compliant with ETSI radiated limits up to 12.75 GHz using the monopole antenna shown in Figure 11 on page 11.

EN 300 220-1 Radiated Spurious Emissions

Test Specific Details

Objective: The objective of this test session is to perform engineering evaluation testing of the EUT with respect to the specification listed above.

Date of Test: 9/11/2009 Config. Used: 1
Test Engineer: David Bare Config Change: None
Test Location: Fremont Chamber #4 EUT Voltage: 3.3V DC

General Test Configuration

The EUT and all local support equipment were located on the turntable for radiated spurious emissions testing.

For radiated emissions testing the measurement antenna was located 3 meters from the EUT.

Ambient Conditions: Temperature: 26 °C
Rel. Humidity: 44 %

Summary of Results

Run #	Mode	Channel	Power Setting	Measured Power	Test Performed	Limit	Result / Margin
1	CWTX	868.3 MHz	Max	-	Radiated Emissions, Transmitter Harmonics	EN 300 220-1	59.3dBμV/m @ 5209.8MHz (-8.2dB)

Modifications Made During Testing

No modifications were made to the EUT during testing

Deviations From The Standard

No deviations were made from the requirements of the standard.

Figure 30. EN300 220-1 Radiated Spurious Emissions Test Results (Page 1 of 7)

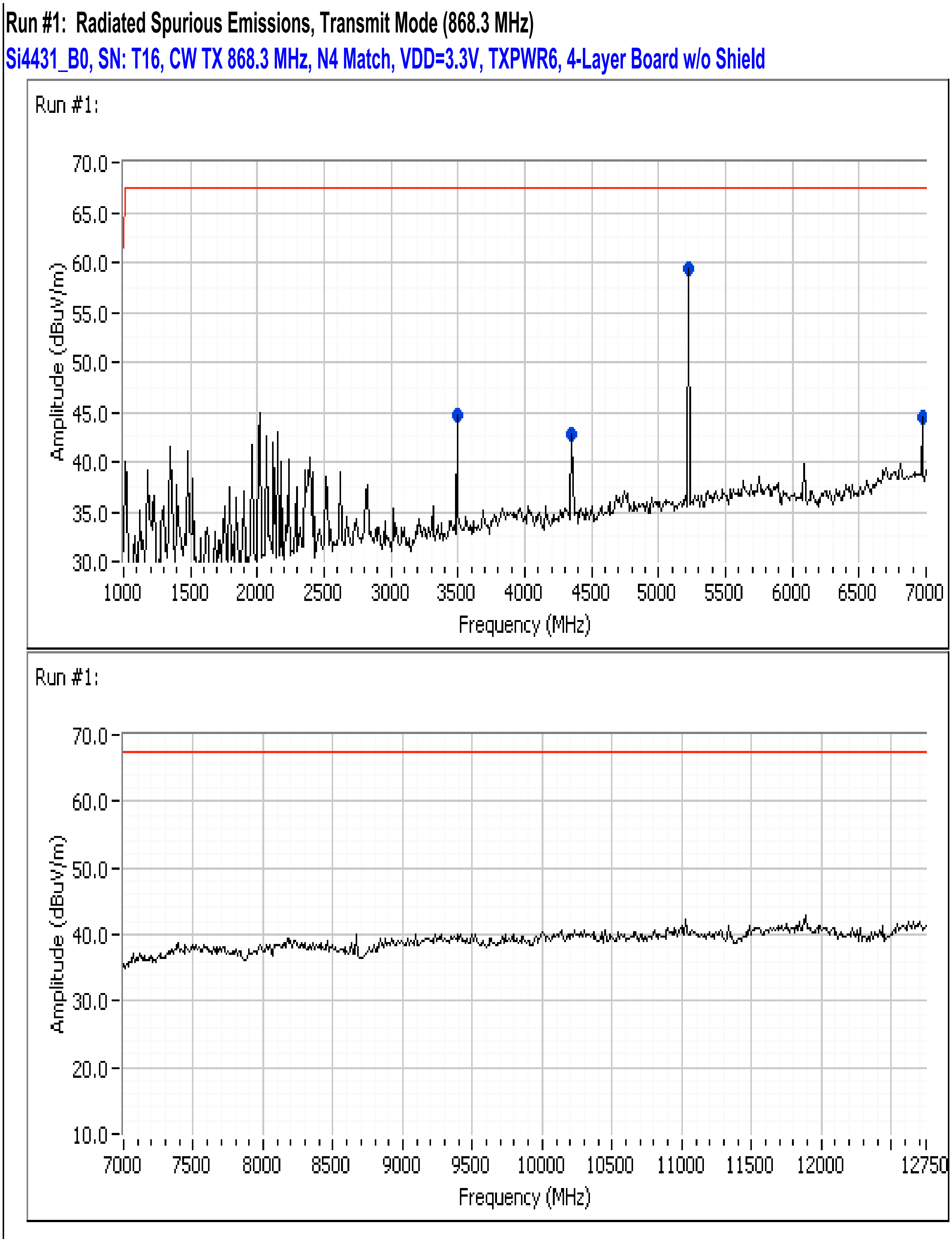


Figure 31. EN300 220-1 Radiated Spurious Emissions Test Results (Page 2 of 7)

Frequency	Level	Pol	EN 300 220-1[1]		Detector	Azimuth	Height	Comments
MHz	dBµV/m	v/h	Limit	Margin	Pk/QP/Avg	degrees	meters	
5209.820	59.3	H	67.5	-8.2	Peak	253	2.2	
3473.200	44.7	V	67.5	-22.8	Peak	215	1.3	
6946.470	44.4	V	67.5	-23.1	Peak	203	2.5	
4341.580	42.7	V	67.5	-24.8	Peak	340	1.0	
Note 1:	The field strength limit in the tables above was calculated from the erp/eirp limit detailed in the standard using the free space propagation equation: E=√(30PG)/d. This limit is conservative - it does not consider the presence of the ground plane and, for erp limits, the dipole gain (2.2dBi) has not been included. The erp or eirp for all signals with less than 10dB of margin relative to this field strength limit is determined using substitution measurements.							

Figure 32. EN300 220-1 Radiated Spurious Emissions Test Results (Page 3 of 7)

EN 300 220-1 Radiated Spurious Emissions

Test Specific Details

Objective: The objective of this test session is to perform engineering evaluation testing of the EUT with respect to the specification listed above.

Date of Test: 9/11/2009
Test Engineer: David Bare
Test Location: Fremont Chamber #4

Config. Used: 1
Config Change: None
EUT Voltage: 3.3V DC

General Test Configuration

The EUT and all local support equipment were located on the turntable for radiated spurious emissions testing.

For radiated emissions testing the measurement antenna was located 3 meters from the EUT.

Ambient Conditions:

Temperature: 26 °C
Rel. Humidity: 44 %

Summary of Results

Run #	Mode	Channel	Power Setting	Measured Power	Test Performed	Limit	Result / Margin
1	CWTX	868.3 MHz	Max	-	Radiated Emissions, Transmit Mode	EN 300 220-1	62.6dBµV/m @ 6078.2MHz (-4.9dB)
2	RX	868.3 MHz	Max	-	Radiated Emissions, Receive Mode	EN 300 220-1	43.7dBµV/m @ 1991.9MHz (-6.8dB)

Modifications Made During Testing

No modifications were made to the EUT during testing

Deviations From The Standard

No deviations were made from the requirements of the standard.

Figure 33. EN300 220-1 Radiated Spurious Emissions Test Results (Page 4 of 7)

Run #1: Radiated Spurious Emissions, Transmit Mode (868.3 MHz)

Si4431_B0, SN: T18, CW TX 868.3 MHz, N4 Match, VDD=3.3V, TXPWR6, 2-Layer Board w/o Shield

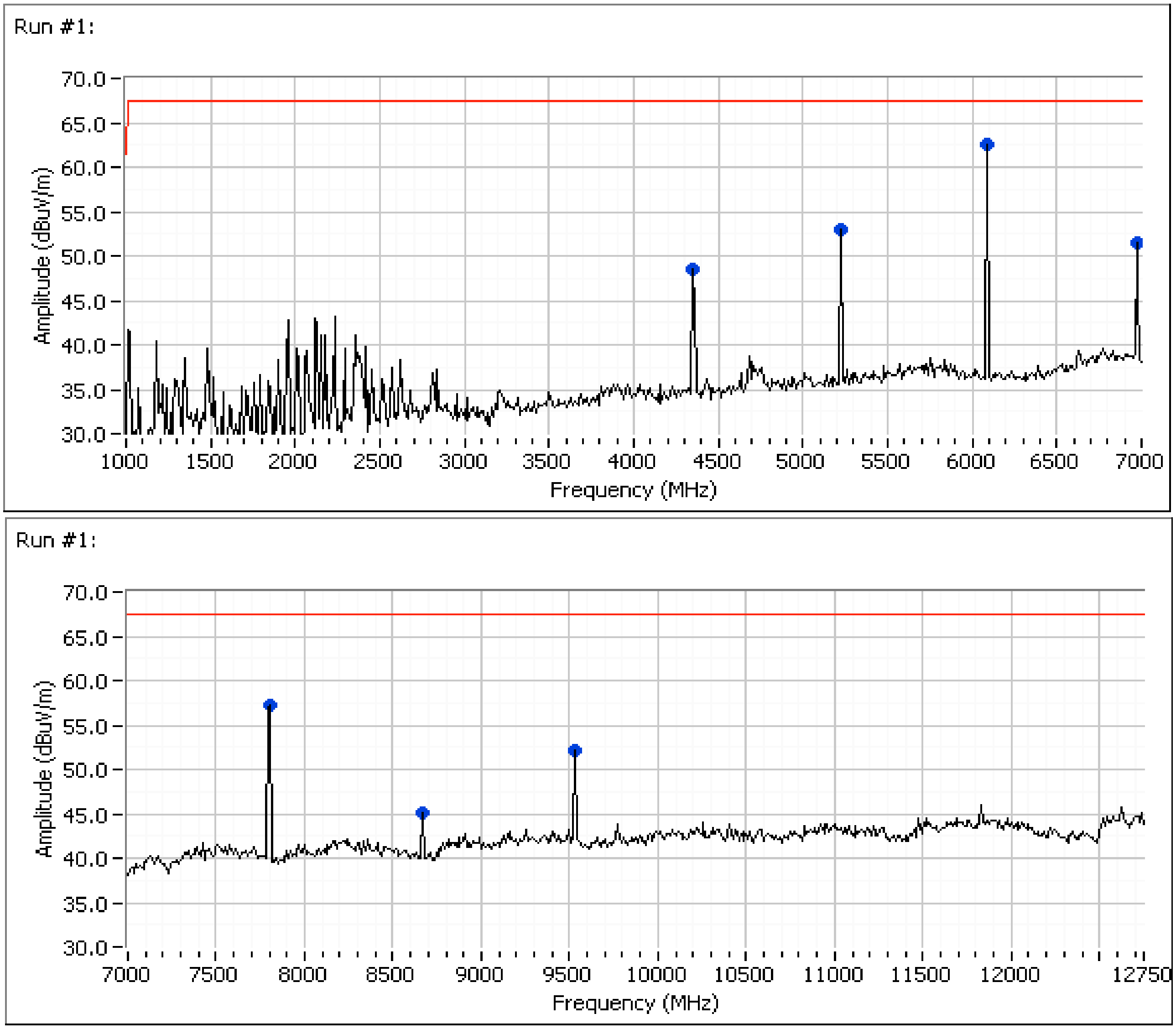


Figure 34. EN300 220-1 Radiated Spurious Emissions Test Results (Page 5 of 7)

Frequency	Level	Pol	EN 300 220-1[1]		Detector	Azimuth	Height	Comments
MHz	dBμV/m	v/h	Limit	Margin	Pk/QP/Avg	degrees	meters	
6078.220	62.6	V	67.5	-4.9	Peak	186	1.3	Maximized
7814.940	57.2	H	67.5	-10.3	Peak	180	2.2	
5209.820	53.0	V	67.5	-14.5	Peak	200	1.0	
9551.530	52.1	H	67.5	-15.4	Peak	184	1.6	
6946.470	51.4	V	67.5	-16.1	Peak	174	2.5	
4341.580	48.6	V	67.5	-18.9	Peak	204	1.6	
8683.160	45.1	H	67.5	-22.4	Peak	190	1.9	

Note 1:	The field strength limit in the tables above was calculated from the erp/eirp limit detailed in the standard using the free space propagation equation: E=√(30PG)/d. This limit is conservative - it does not consider the presence of the ground plane and, for erp limits, the dipole gain (2.2dBi) has not been included. The erp or eirp for all signals with less than 10dB of margin relative to this field strength limit is determined using substitution measurements.

Run #2: Radiated Spurious Emissions, Receive Mode, 1000 - 12750 MHz

Si4431_B0, SN: T18, CW TX 868.3 MHz, N4 Match, VDD=3.3V, TXPWR6, 2-Layer Board w/o Shield

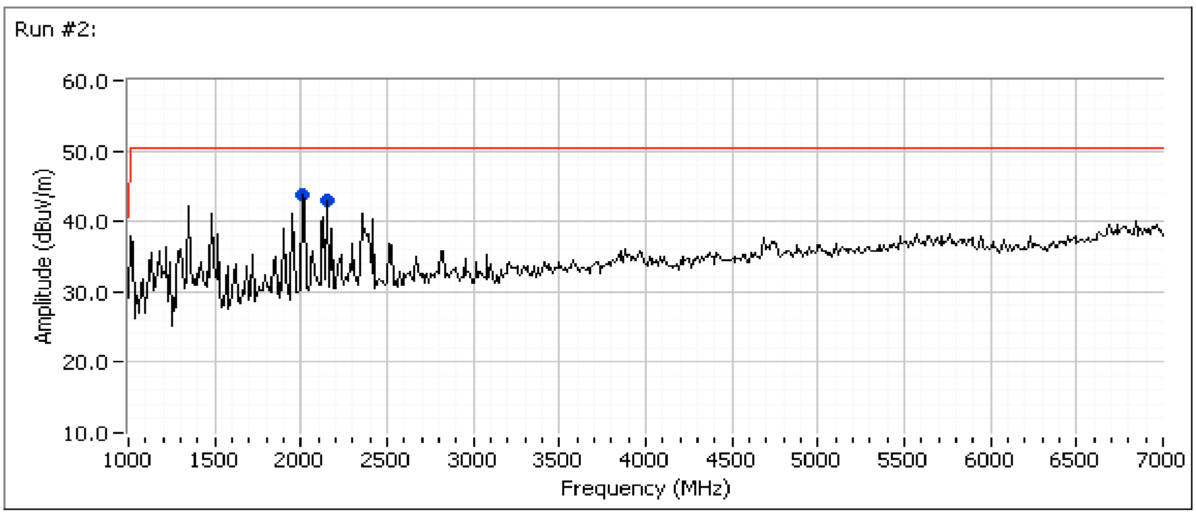
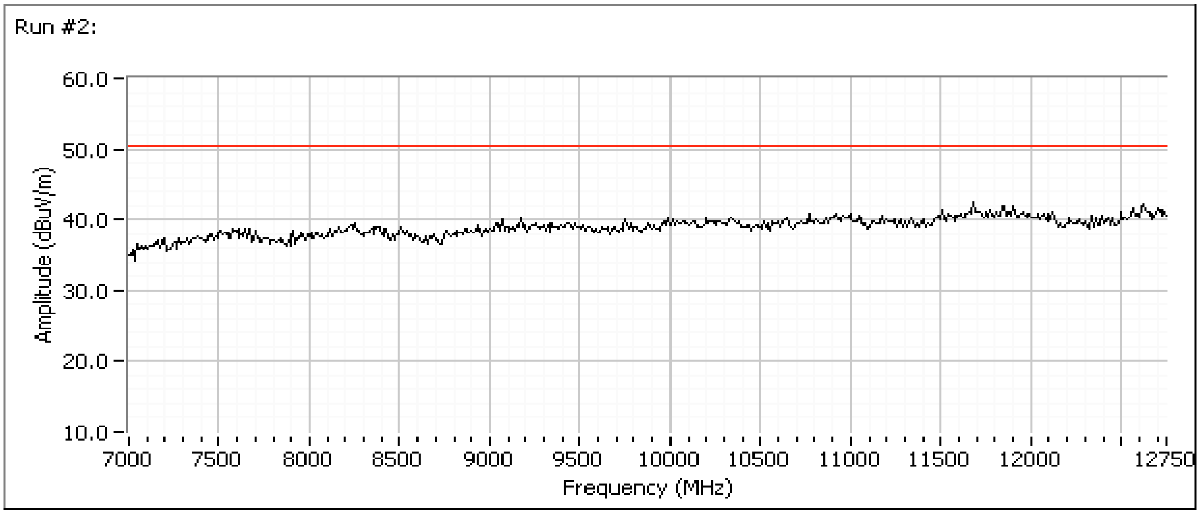


Figure 35. EN300 220-1 Radiated Spurious Emissions Test Results (Page 6 of 7)



Frequency	Level	Pol	EN 300 220-1[1]		Detector	Azimuth	Height	Comments
MHz	dBµV/m	v/h	Limit	Margin	Pk/QP/Avg	degrees	meters	
1991.900	43.7	V	50.5	-6.8	Peak	240	1.0	
2133.160	43.0	V	50.5	-7.5	Peak	290	1.0	

Note 1:	The field strength limit in the tables above was calculated from the erp/eirp limit detailed in the standard using the free space propagation equation: E=√(30PG)/d. This limit is conservative - it does not consider the presence of the ground plane and, for erp limits, the dipole gain (2.2dBi) has not been included. The erp or eirp for all signals with less than 10dB of margin relative to this field strength limit is determined using substitution measurements.

Figure 36. EN300 220-1 Radiated Spurious Emissions Test Results (Page 7 of 7)

Appendix

Si4431 B1 script used in the ACP measurements ("4.5. Adjacent Channel Power (ACP) (ETSI 300220001v020301, subclause 7.6)" on page 14).

```
#BATCHNAME 868M
s2 8780
# Crystal Oscillator Load capacitance
S2 896c
#VCO current boost
S2 da7f
#PLL BW boost
S2 D8EF
#TX freq set
S2 F573
S2 F678
S2 F7F0
# TX data rate: 1kbps
S2 EE08
S2 EF31
S2 F02C
#TXdeviation: 5KHz
S2 F208
S2 F100
# PN9 GFS
S2 F133
#TXon
s2 8708
#TXpower state
s2 ed0a
```

Document Change List

Revision 0.1 to Revision 0.2

- Updated "3.2. Blocking (ETSI 300220001v020301, Subclause 8.4)" on page 4.
- Added "4.5.3. Measurements with 12.5 kHz Channel Spacing with 9.6 kbps and 4.8 kHz Deviation" on page 18.
- Added "4.5.4. Measurements with 12.5 kHz Channel Spacing with 9.6 kbps and 2.4 kHz Deviation" on page 20.

Revision 0.2 to Revision 0.3

- Updated Table 1 on page 1.
- Updated Figure 9 on page 9.
- Added spectrum mask measurements with optimized register settings to "4.6. Modulation Bandwidth (ETSI 300220001v020301, Subclause 7.7)" on page 22.
- Added Figure 24 on page 23.

Simplicity Studio

One-click access to MCU tools, documentation, software, source code libraries & more. Available for Windows, Mac and Linux!

www.silabs.com/simplicity

MCU Portfolio
www.silabs.com/mcu

SW/HW
www.silabs.com/simplicity

Quality
www.silabs.com/quality

Support and Community
community.silabs.com

SILICON LABS

Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
USA

http://www.silabs.com