Revision Control

Date	Contributors	Revision	Comments
30/01/13	W. Bruchner	1.0	Created.
08/03/13	B. Johnson	1.1	Added to the hardware description in section: Hardware
26/10/15	W. Bruchner	1.2	Updated Vector Signal Generator to EXG Series
16/07/19	Aime Lian	1.3	Updated new logo

Table of Contents

1 Required Equipment

1.1 Hardware

- Signal Generator: Keysight EXG N5172B Vector Signal Generator

- Signal Analyser: Keysight N9020A MXA

Note that in theory any XSA (CXA,EXA,MXA or PXA) vector signal analyser could be used, provided it has enough bandwidth. This guide describes how to use the N9020A MXA for 802.15.4 specific measurements.

In order to be controllable by software the 2 test sets should be connected to a local network.

1.2 Software installed on System running Windows 7

- Keysight IO Libraries Suite (Version 16.3.16603.3 used here)

- Keysight 89600 VSA Software (Version 16.0 (64-bit)) used here) for controlling the MXA Signal Analyser.

2 Setting up the EXG Vector Signal Generator as 802.15.4 Signal Generator

The EXG is used as a transmit signal generator generating a close to ideal 802.15.4 reference signal to be used for receiver tests and measurement calibrations.

2.1 Waveform Samples

The EXG uses ideal baseband I/Q data from a file to generate the 802.15.4 RF Signal. Contact Cascoda to obtain these files.

3 waveform file groups are provided:

1. TM_P20: Framed 802.15.4 Packet with 20 bytes packet length (26 bytes including SHR and PHR, or 832 us), 10 ms packet interval. This is a packet of Nominal Packet Length as described in the specification, and should be used for Packet Error Rate (PER) test runs for receiver sensitivity tests. Random data for payload.

2. TM_P40: Framed 802.15.4 Packet with 40 bytes packet length (46 bytes including SHR and PHR, or 1472 us), 10 ms packet interval. This is a packet of twice the Nominal Packet Length and can be used for setup and calibration of EVM tests on the signal analyser, as the specification requires a EVM measurement time of 1000 chips, which is equivalent to at least 32 bytes. Random data for payload.

3. TM_CONT: Continuous (unframed) 802.15.4 signal. Not usually required, but can be used as a reference signal etc. 10 ms of Random Data.

2.2 EXG Setup

Here the EXG is controlled via front-panel input.

- Select Waveform File to use: **File** Button will bring up list of files on a USB Stick. For each group there are 3 file types with different extensions ([name].HEADER for header, [name].WAVEFORM for waveform and [name].MARKERS for marker). It is not relevant which file type gets selected. Choose file with cursor up/down and the press **Select**. The message 'Playing Waveform File' will appear on the bottom of the display.

- Select Frequency: Press the **FREQ** button and enter the frequency. This should be the 802.15.4 channel centre frequency (i.e. 2.440 GHz). Press the **Incr Set** and select a good increment to facilitate the specific test (for example 5 MHz if channels need to be changed, or 12.2 kHz if frequency tolerance is to be tested with an increment of 5 ppm from the channel centre frequency). The frequency can then easily be changed in increment steps when pressing the **FREQ** button and then using the cursor up/down).

- Select Signal Amplitude: Press the **AMPTD** button and enter the desired output signal amplitude (output power in dBm). Press the **Incr Set** and select a good increment to facilitate the specific test (for example 1 dB for a coarser range, or 0.1 dB for a finer range). The frequency can then easily be changed in increment steps when pressing the **AMPTD** button and then using the cursor up/down).

- Make sure the RF Output is enabled (**RF On/Off** button, and corresponding LED).

3 Setting up the Signal Analyser using the Keysight 89600 VSA Software

3.1 Basic Setup

The Keysight N9020A MXA Signal Analyser can be entirely controlled by the Keysight 89600 VSA software without any front-panel input required. However, the frequency span in this setup is limited to in-band frequencies (max. 40 MHz), therefore wideband measurements required for example for out-of band emission tests have to be conducted using direct analyser control with the analyser in *Spectrum Analyser* mode.

When using the VSA software is recommended to control the software using the pull-down menus, as some options are not accessible by other means such as right-hand mouse button for example.

- Start up the VSA software.

- Go to *Utilities->Hardware->Configurations...* and make sure the VSA software is connected to the correct signal analyser instrument. The front panel of the analyser should indicate that the instrument is in use by the Keysight VSA.

- For certain measurements some results are not visible in the corresponding trace window. To access all measured values the marker window should be opened by selecting *Window->Markers*.

- Always make sure that the *Play/Restart* button is on and that the *Single/Continuous Sweep* button is set to Continuous:

3.2 Triggering for Framed Signals (Packets)

For measurements on continuous (unframed) signals, the trigger can be set to free-run (*Input->Trigger...->Style: Free Run*). However, for packet-based measurements (framed data) the trigger has to be set up to trigger on the packet by using the menu *Input->Trigger...*

The following settings are recommended:

- *Style*:   *IF Mag*

- *Level*:   Depending on input signal power, see below.

- *Slope*:   *Positive*

- *Delay*:   *0 s*

- *Holdoff Style*:   *Conventional*

- *Holdoff*:   *20 ns*
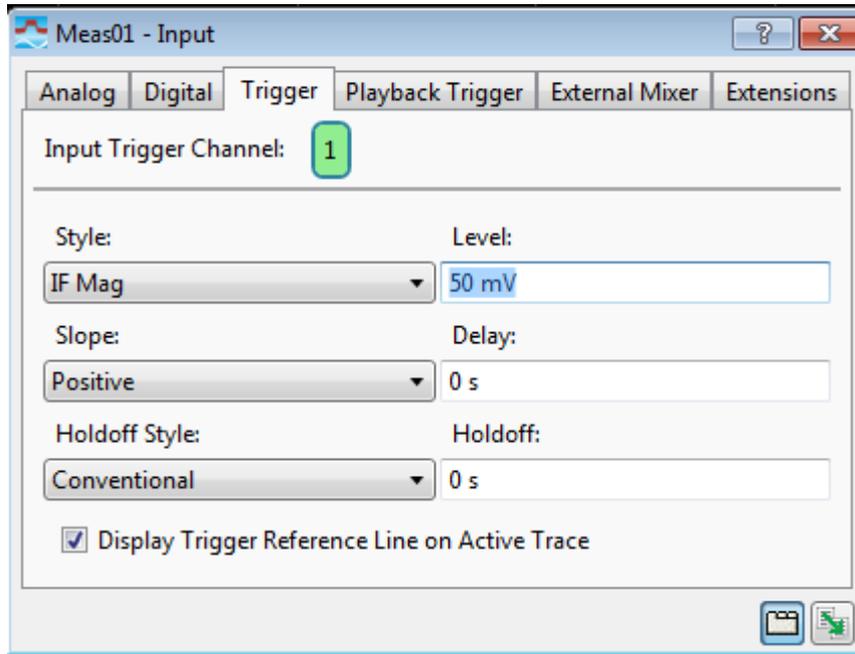
Figure 3.1: Keysight 89600 VSA Trigger for Packet based Signal

Trigger Level:

The trigger level is dependent on the Power of the input signal. It is set at roughly half the input amplitude and can be calculated as:

$$Level = \frac{\sqrt{2}}{2} * \sqrt{1\,mW * 10^{\frac{Pin\,[dBm]}{10}} * 50\,Ohms}\;[V] \;=\; 10^{\frac{Pin\,[dBm]}{20}} * 0.16\;[V]$$

The following table gives a rough setting of the trigger level for various useful input powers.

Input Power [dBm]	Trigger Level	Analyser Range Setting [dBm]
-10	50 mV	0
-20	15 mV	0
-30	5 mV	0
-40	1.5 mV	0
-50	600 uV	0
-60	160 uV	-40
-70	50 uV	-40

Table 3.1: Trigger Level for various Input Powers

At input signal levels below -50 dBm the range setting of the signal analyser has to be set close to minimum (-42 dBm) to provide enough SNR for a reliable trigger. At input signal levels below -70 dBm the time trace of the signal is too noisy to provide a reliable trigger for the signal analyser.

4 Measurement of Transmitter Output Power and other In-Band Parameters

For this type of measurements the Keysight N9020A MXA Signal Analyser can be entirely controlled by the Keysight 89600 VSA software without any front-panel input required.

- Start up VSA software and configure input trigger as described in 3 .

- Measurement type is *Vector* (default): *MeasSetup->Measurement Type: Vector.*

- Set *Range* to a reasonable level: 0 dBm (+10 dBm if input signal is expected to be larger):
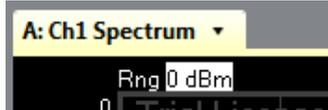
An OV1 indication in the trace windows indicates an input overload, and the range setting has to be increased.

- Set up measurement parameters in *MeasSetup->Frequency...* Note that any of the *MeasSetup* Parameter menus will give access to all 4 parameter sets (*Frequency*, *ResBW*, *Time* and *Average*) under different tabs.
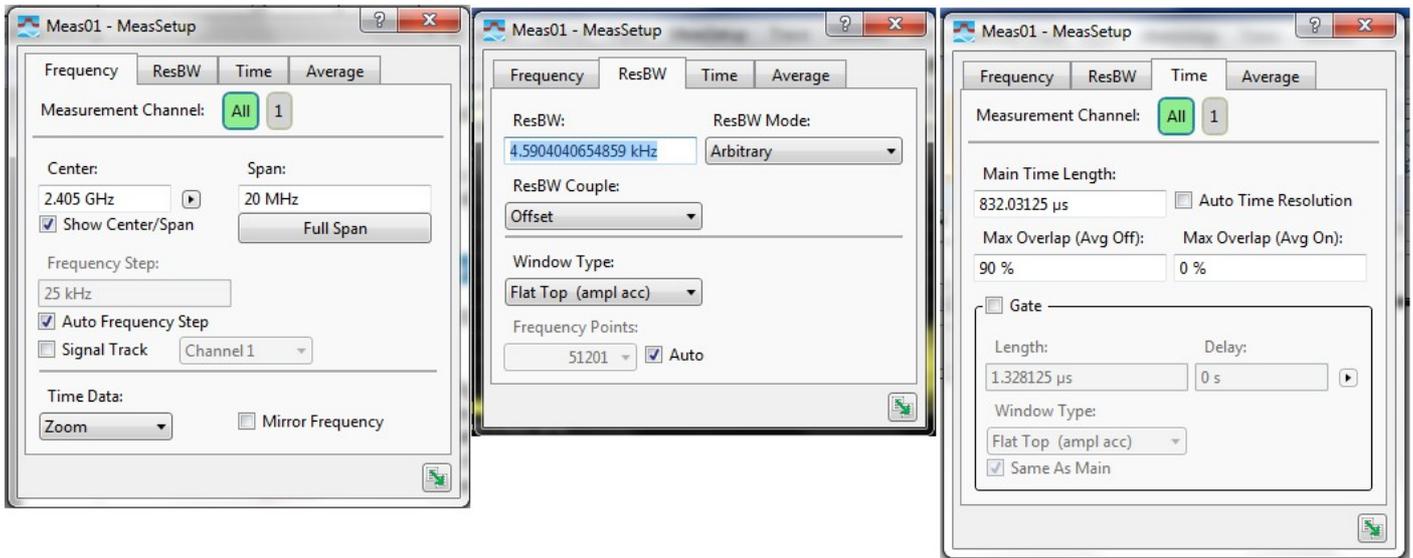
Figure 4.1: MeasSetup Parameter Setup for Power Measurement

- For the *Frequency* tab enter the following parameters:

  - *Center*:   The channel centre frequency (i.e 2.405 GHz).

  - *Span*:   20 MHz (also 10 MHz).

  - *Frequency Step*:   Select *Auto Frequency Step*.

- For the *ResBW* tab enter the following parameters:

  - *ResBW Couple*:   *Offset*.

  - *Window Type*:   *Flat Top*.

  - *Frequency Points*:   Select *Auto*.

- For the *Time* tab enter the following parameters:

  - *Main Time Length*:   This has to be consistent with the Packet Length (i.e. 832 us for a nominal 20-byte packet).

- Add Marker For Transmit Power Measurement: Select the Spectrum Trance Window. In *Markers* select Marker 1. In *Markers->Calculation...* enter the following parameters:

  - Select *Band Power*.

  - *Type*:   Power.

  - Calculate: Mean

  - Center: Channel centre frequency (i.e. 2.405 MHz).

  - Span: 5 MHz.

The transmit power can now be measured. Note that any losses in the measurement chain (connectors, cables, attenuators) have to be accounted for.
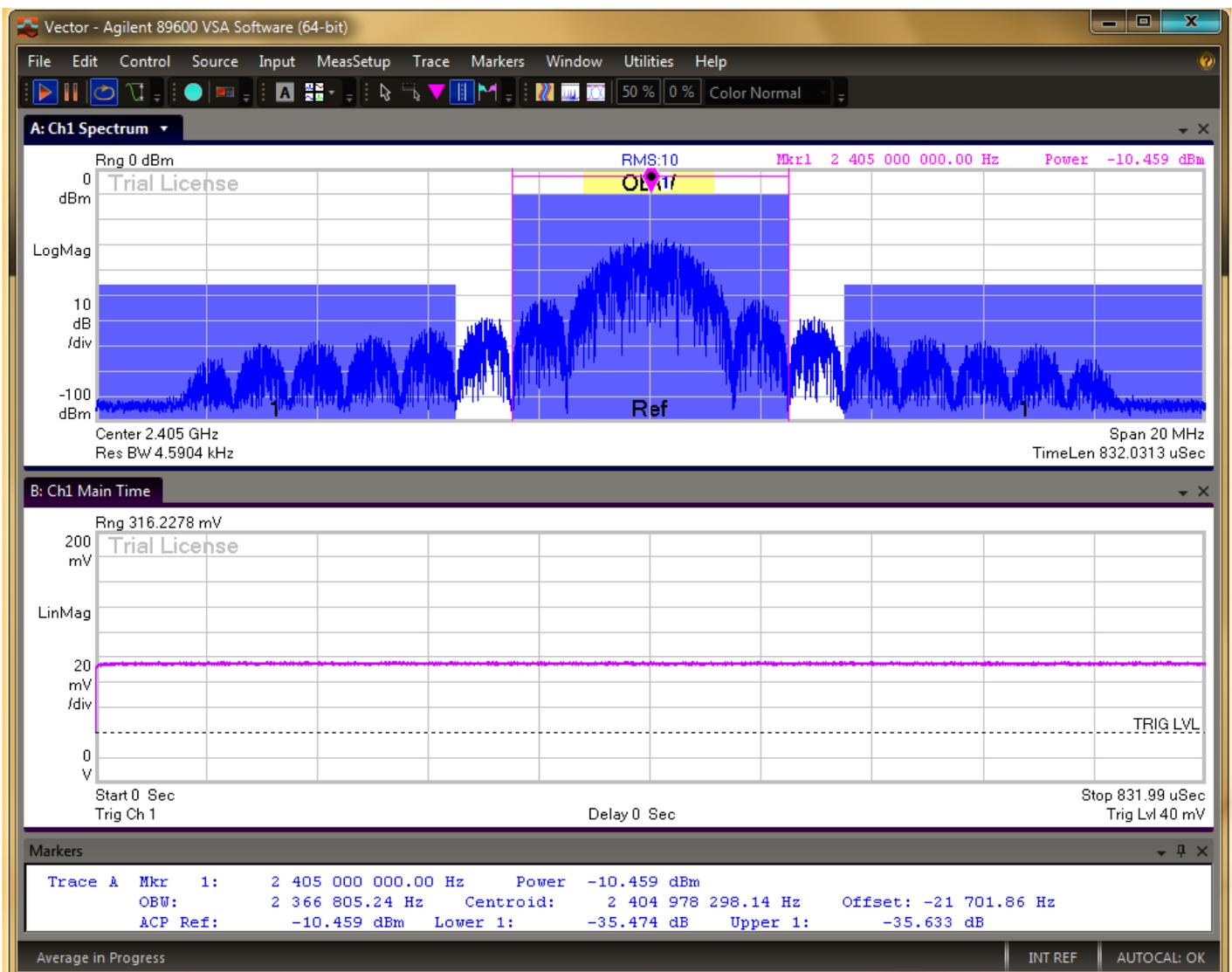
Figure 4.2: Transmit Power Measurement using the KeysightKeysight 89600 VSA Software

In case spectral averaging is required, this can be activated in the *MeasSetup->Average...* tab: *RMS (Video) Exponential* has to be selected as *Average Type* and the required *Count* has to be entered to achieve the desired averaging depth.

Other useful measurement additions are:

- Occupied Bandwidth measurement turned on (*Markers->OBW...*), *% Power* set to 99 %. the OBW gives an initial estimate for the quality of the EVM. Also, the channel centre frequency and the offset from the ideal frequency can be determined in this way. However, this can be done more accurately when measuring the transmitter EVM.

- Adjacent Channel Power measurement turned on (*Markers->ACP...*). This can be used to determine the leakage of transmit power into adjacent channel, and the close-in Power-Spectral Density Mask (PSD) in a surrounding of 40 MHz span (max.). 802.15.4 specifies both absolute and relative PSD limits for |f-f$_c$| > 3.5 MHz. So for example within a span of 40 MHz (f$_c$ ±20 MHz) the out-of-band PSD can be measured by setting the adjacent channel *Offset* to (3.5 MHz + 20 MHz)/2 = 11.75 MHz, and the *BW* to (20 MHz – 3.5 MHz) = 16.5 MHz. Note that the ACP measurement results are given in dB relative to the main channel power and not absolute (dBm).

5 Measurement of Transmitter Error Vector Magnitude (EVM)

For this measurement the Keysight N9020A MXA Signal Analyser can be entirely controlled by the Keysight 89600 VSA software without any front-panel input required. The VSA software has to create a new measurement for digital demodulation. Here the step-by-step instructions follow the creation from the default settings, but the new measurement could be saved and later simply be recalled.

Note that the transmitter packet length has to be greater or equal 32 bytes to ensure that the 1000 chips required by specification can be measured within one packet.

- Start up VSA software

- Change Measurement type to Digital Demodulation: *MeasSetup->Measurement Type: Digital Demod.*
  Make sure that the *Play/Restart* button is on.

- Configure input trigger as described in 3 .

- Set *Range* in the spectral trace window to a reasonable level: 0 dBm (+10 dBm if input signal is expected to be larger).
  An OV1 indication in the trace windows indicates an input overload, and the range setting has to be increased.

- Set the centre frequency of the channel: *MeasSetup->Frequency...->Center.*

- Recall the predefined settings for 802.15.4 demodulation:
  Go to *MeasSetup->Digital Demod Properties ...->Format->Preset to Standard...* and select
  Wireless Networking->Zigbee 2450 MHz.
  This predefined setting will preset the following parameters in the *MeasSetup->Digital Demod Properties ..* tabs:
  Format tab:
    - *Format*:   *Offset QPSK*
    - *Symbol Rate*:   1 MHz
    - *Points/Symbol*:   10
    - *Couple to Gain Imb.*:   selected
    - *Result Length*:   1001 Symbols
  Filter tab:
    - *Measurement Filter*:   *None*
    - *Reference Filter*:   *Half Sine*
  Search tab:
    - *Search Length*:   3 ms
    - *Pulse Search*:   selected
  Compensate tab:
    - *Normalise IQ Traces*:   selected

- Change the setting for *Search Length* in the *Search* tab to be longer than the packet length plus the packet interval, for example:
    - *Search Length*:   12 ms

The EVM can now be measured correctly. For debugging purposes here are some commonly displayed warning messages and their likely causes:

- PULSE NOT FOUND: The *Search Length* is less than the packet length plus the packet interval.

- DATA?:   Same as above.

- CARRIER LOCK?:   The packet is not large enough to accommodate all the chips defined in *Result Length*.

As 802.15.4 uses Offset-QPSK modulation, the result value given as OffsetEVM is the actual EVM value specified in 802.15.4.
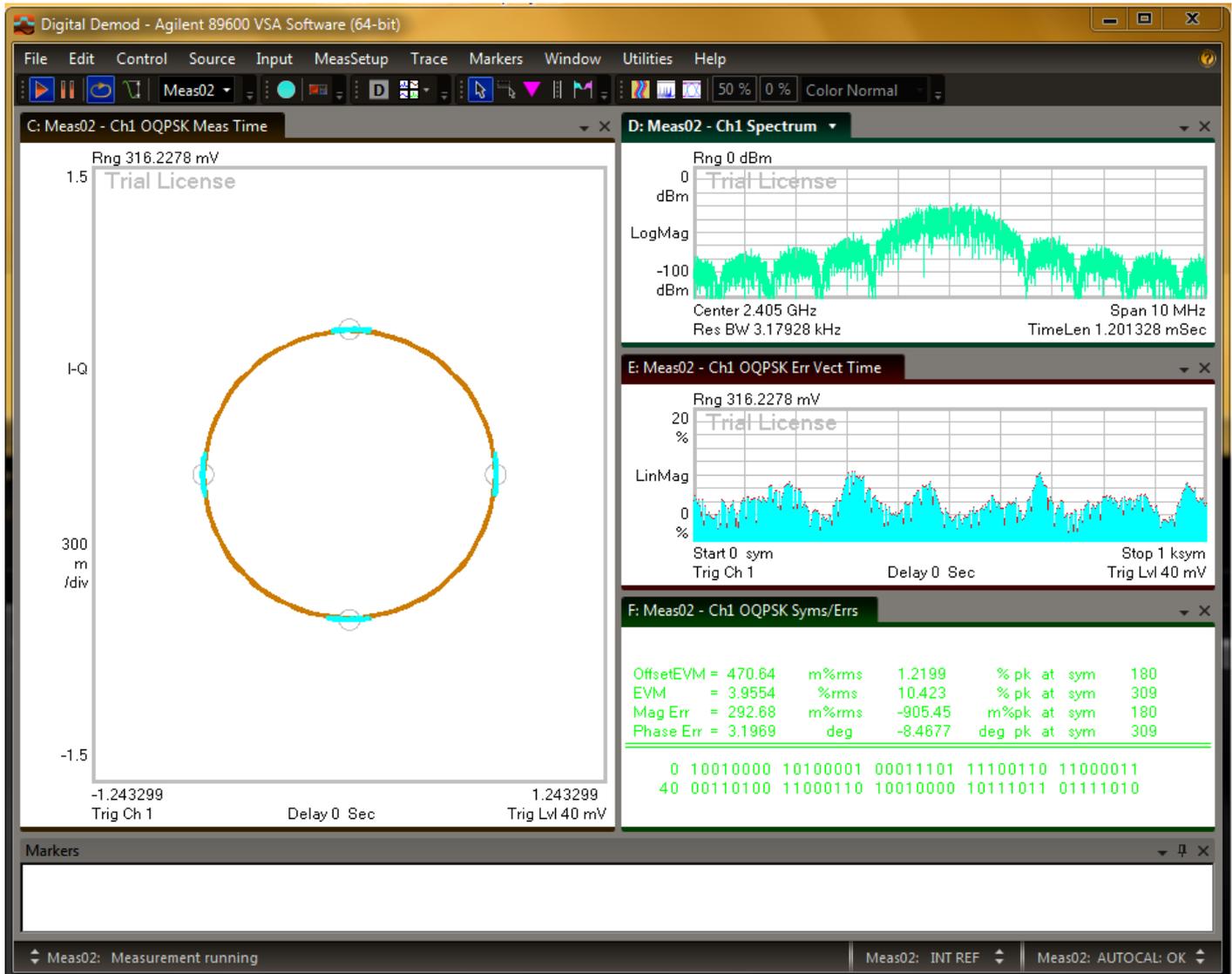
Figure 5.1: Transmit EVM Measurement using the Keysight 89600 VSA Software

6 Results for Direct EXG to MXA Test (Ideal Transmitter)

The following tables include results of direct test equipment testing using the EXG as ideal transmitter. Measurement chain:

- EXG, Tx

- 1 RF Cable (UTIFLEX FA210)

- 2 SMA to N-Type Adaptors

- MXA, Rx

The results of these tests can be used as reference points to calibrate real-life DUT tests such as transmit power of the EXG for receiver sensitivity test runs.

6.1 In-Band Spectral Tests

The following table gives a matrix of the EXG Output Power over 802.15.4 channel frequencies and output power variation in 10 dB. A nominal (20-byte) packet waveform has been used. The *Range* setting of the signal analyser has been optimised for the various power settings. The output power was measured in a frequency span of 5 MHz.

Output Power Setting [dBm]		-10	-20	-30	-40	-50	-60	-70
Channel	**GHz**							
11	2.405	-10.5	-20.6	-30.5	-40.4	-50.2	-60.1	-70.2
12	2.410	-10.6	-20.6	-30.5	-40.4	-50.3	-60.2	-70.1
13	2.415	-10.6	-20.6	-30.5	-40.4	-50.3	-60.2	-70.1
14	2.420	-10.5	-20.5	-30.4	-40.3	-50.2	-60.1	-70.1
15	2.425	-10.5	-20.5	-30.4	-40.3	-50.2	-60.1	-70.1
16	2.430	-10.5	-20.6	-30.5	-40.4	-50.3	-60.2	-70.1
17	2.435	-10.6	-20.7	-30.6	-40.5	-50.4	-60.3	-70.2
18	2.440	-10.6	-20.7	-30.7	-40.5	-50.4	-60.3	-70.2
19	2.445	-10.7	-20.7	-30.7	-40.5	-50.4	-60.3	-70.2
20	2.450	-10.7	-20.8	-30.7	-40.4	-50.4	-60.3	-70.2
21	2.455	-10.8	-20.9	-30.8	-40.5	-50.6	-60.4	-70.2
22	2.460	-11.0	-21.1	-30.9	-40.6	-50.7	-60.5	-70.3
23	2.465	-11.0	-21.1	-31.0	-40.7	-50.7	-60.6	-70.4
24	2.470	-11.0	-21.1	-31.0	-40.7	-50.7	-60.6	-70.4
25	2.475	-11.1	-21.1	-31.1	-40.7	-50.7	-60.7	-70.5
26	2.480	-11.1	-21.2	-31.1	-40.7	-50.8	-60.7	-70.5

Table 6.1: Keysight EXG Output Power for all 2.4 GHz Band 802.15.4 Channels

The following table shows measurements for the EXG occupied bandwidth, frequency offset and adjacent channel power for the 802.15.4 channels 11,18 and 26 (low, mid and high). Both EXG output power and MXA range are set to -20 dBm. The frequency span is set to 40 MHz. A nominal (20-byte) packet waveform has been used. Note that the resolution bandwidth has been set to Auto (4.6 kHz) to cover the whole packet (832 us time length). The resolution bandwidth of 100 kHz as specified in 802.15.4 for PSD measurements will result in a less accurate (lower) reading for ACP. Averaging has been enabled with a count of 10.

Parameter	Condition	Ch. 11	Ch.18	Ch.26	Unit
Occupied Bandwidth	99%	2.367	2.367	2.367	MHz
Frequency Offset	Given by OBW Measurement	-20	-21	-21	MHz
Lower ACP	Offset = 11.75 MHz, BW = 16.5 MHz	-35.3	-35.3	-35.3	dB
Upper ACP	Offset = 11.75 MHz, BW = 16.5 MHz	-35.3	-35.3	-35.3	dB

Table 6.2: Keysight EXG In-Band Results for 802.15.4 Channels 11,18 and 26

6.2 Digital Demodulation Tests (EVM)

The following table shows measurements for the EXG digital demodulation parameters for the 802.15.4 channels 11,18 and 26 (low, mid and high). Both EXG output power and MXA range are set to -20 dBm. A 40-byte packet waveform has been used. Averaging has been enabled with a count of 10.

Parameter	Ch. 11	Ch.18	Ch.26	Unit
Offset EVM	0.5	0.6	0.7	% RMS
EVM	4.3	4.5	4.6	% RMS
Magnitude Error	0.32	0.36	0.42	% RMS
Phase Error	3.4	3.5	3.7	Deg
Frequency Error	-12.4	-12.7	-12.9	kHz
IQ Offset	-52	-64	-47	dB
Rho	0.996	0.996	0.995	
Quadrature Error	0.25	0.33	0.50	Deg
Gain Imbalance	0.05	0.06	0.08	dB

Table 6.3: Keysight EXG Digital Demodulation Results for 802.15.4 Channels 11,18 and 26

Note: In the KeysightKeysight Documentation it states under "ZigBee Standard (IEEE 802.15.4)(Digital Demod)":

"The definition of EVM in the ZigBee standard corresponds to the Offset EVM displayed by the VSA. The standard says to measure EVM for 1000 chips, but to achieve this the VSA should be set to a Result Length of 1001. This is necessary because the VSA doesn't use the last half of the last OQPSK symbol, so it computes Offset EVM only on Result Length - 1 symbols."

7 Wideband PSD and Spurious Emissions

Wideband measurements for PSD or spurious emissions have to be performed by using the MXA Signal Analyser directly in Spectrum Analyser mode requiring front-panel input. In order to avoid complex triggering it is recommended to use a continuous (unframed) test signal for transmitter tests.

7.1 Wideband PSD

The following plot shows the EXG 802.15.4 continuous test signal in a wider-band around the carrier (± 100 MHz).

Figure 7.1: EXG Wideband PSD, Fc +- 100 MHz

Signal analyser setup:

- *Mode*:   *Spectrum Analyser.*
- *FREQ Channel*:   Channel centre frequency (i.e. 2.405GHz).
- Span: 200 MHz.
- *BW->Res BW*:   100 kHz.
- *Trace/Detector*:   *Trace Average*.

7.2 Spurious Emissions

Section F.8 of annex F of the IEEE 802.15.4 specification summarises the out-of-band spurious emission requirements regarding both FCC and ETSI regulations. Generally, a measurement bandwidth of 100 kHz has to be used for frequency bands up to 1 GHz, and 1 MHz above 1 GHz.

The following plot shows the EXG 802.15.4 continuous test signal spectrum for frequencies below 1 GHz.

Signal analyser setup:

- *Mode*:   *Spectrum Analyser.*
- *FREQ Channel*->Start Frequency: 100 kHz
- *FREQ Channel*->Stop Frequency: 1 GHz.
- *BW->Res BW*:   100 kHz.
- *Trace/Detector*:   *Max Hold*.
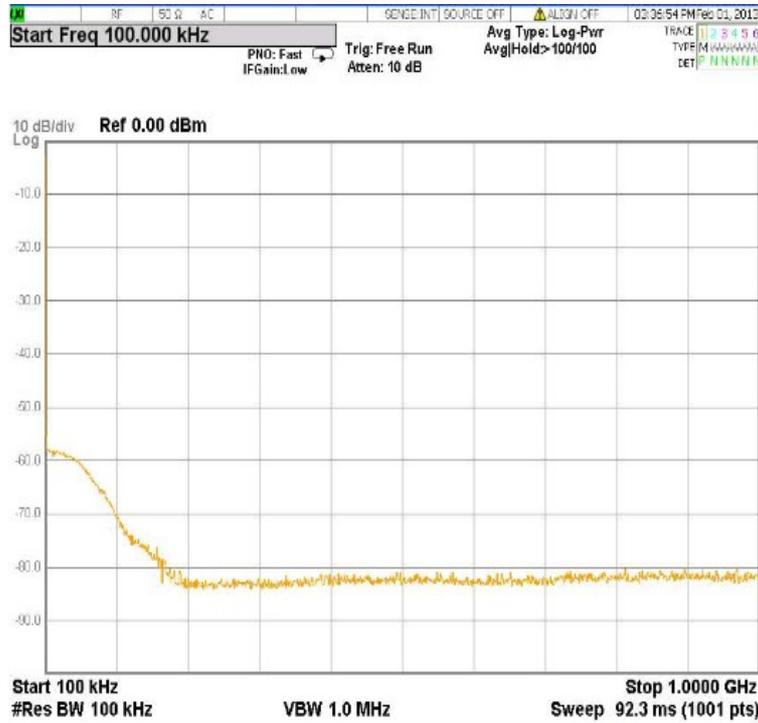
Figure 7.2: EXG Spectrum from 100 kHz to 1 GHz

Note that the AC coupling of the RF signal is influencing the results at frequencies below 10 MHz. Therefore the accuracy of the measurement in this area is unknown. However, the uplift at low frequencies shown above is likely to be due to internal clocking of the signal generator or limited DC rejection of the baseband signal into the RF path.

The following plot shows the MXA 802.15.4 continuous test signal spectrum for frequencies above 1 GHz.

Signal analyser setup:

- *Mode*:   *Spectrum Analyser.*

- *FREQ Channel*->Start Frequency: 1 GHz.

- *FREQ Channel*->Stop Frequency: 15 GHz.

- *BW->Res BW*:   1 MHz.

- *Trace/Detector*:   *Max Hold*.
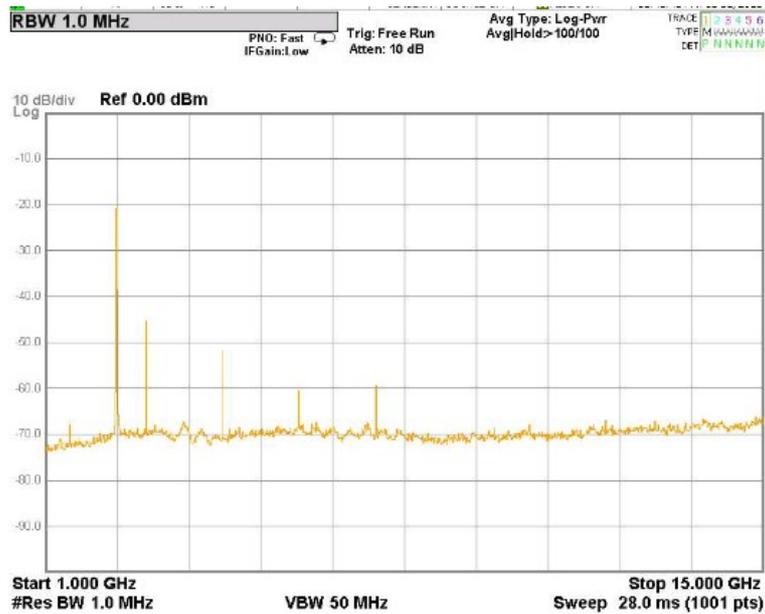
Figure 7.3: EXG Spectrum from 1 GHz to 15 GHz

8 Phase Noise Measurements

It is useful to have information for the phase noise of the LO (and also the XTAL oscillator). The measurements have to be performed by using the MXA Signal Analyser, which has a dedicated phase noise mode. For this purpose a continuous (unframed) sinusoidal (unmodulated) test signal has to be generated. Therefore for RF phase noise measurements any DUT requires a test mode with a continuous and unmodulated signal being transmitted. For XTAL Oscillator phase noise measurements the DUT requires a mode where the (system-) clock can be observed via a direct I/O.

The following plot shows the EXG 802.15.4 phase noise measurement result. The results are given in dBc/Hz from carrier.

Signal analyser setup for measuring phase noise:

- *Mode*:   *Phase Noise.*

- *Carrier Freq*:   Channel centre frequency (i.e. 2.405GHz).

- *Meas*:   *Log Plot.*

- Press *Auto Tune*

- Adjust *X Scale* and *Y Scale* as required.

- Go back to *Meas* and press *Auto Tune* again.

Figure 8.1: EXG Phase Noise Plot from 100 Hz to 10 MHz

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