WLAN 802.11p Measurements for Vehicle to Vehicle (V2V) DSRC

Application Note

Products:

- R&S®SMU200A
- R&S®SMATE200A
- R&S®SMJ100A
- R&S®SMBV100A
- R&S®AMU200A
- R&S®AFQ100A
- R&S®AFQ100B
- R&S®FSQ
- R&S®FSG
- R&S®FSV
- R&S®FSL
- R&S®PTW70

For automotive applications, the IEEE is creating the IEEE 802.11p™ amendment to the IEEE 802.11™-2007 standard. The IEEE 802.11p PHY layer uses the OFDM PHY, i.e. IEEE 802.11a™.
This Application Note explains the changes the 802.11p amendment makes to the 802.11-2007 standard and how to perform 802.11p measurements using Rohde & Schwarz 802.11-compliant test equipment.

Application Note

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ROHDE&SCHWARZ

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1 Introduction

V2V promoters focus on vehicle-to-vehicle and vehicle-to-infrastructure communication. Dedicated applications include toll collection, red light duration broadcast at traffic lights or hot spots for transferring maps, routing information or traffic jams. But also active accident warnings should be transferred from cars in a traffic jam to the oncoming cars.

The 802.11p amendment (currently in draft) modifies the 802.11 standard to add support for wireless local area networks (WLANs) in a vehicular environment.

The main application of 802.11p is car-to-car (C2C) or vehicle-to-vehicle (V2V) communication. V2V is also a synonym for dedicated short range communication (DSRC); both are based on RFID and 802.11p standards.
The main challenges for the 802.11p standard are frequency spectrum availability and fading.

A low failure rate can be ensured by high-quality tests, which is essential in 802.11p security-relevant applications.

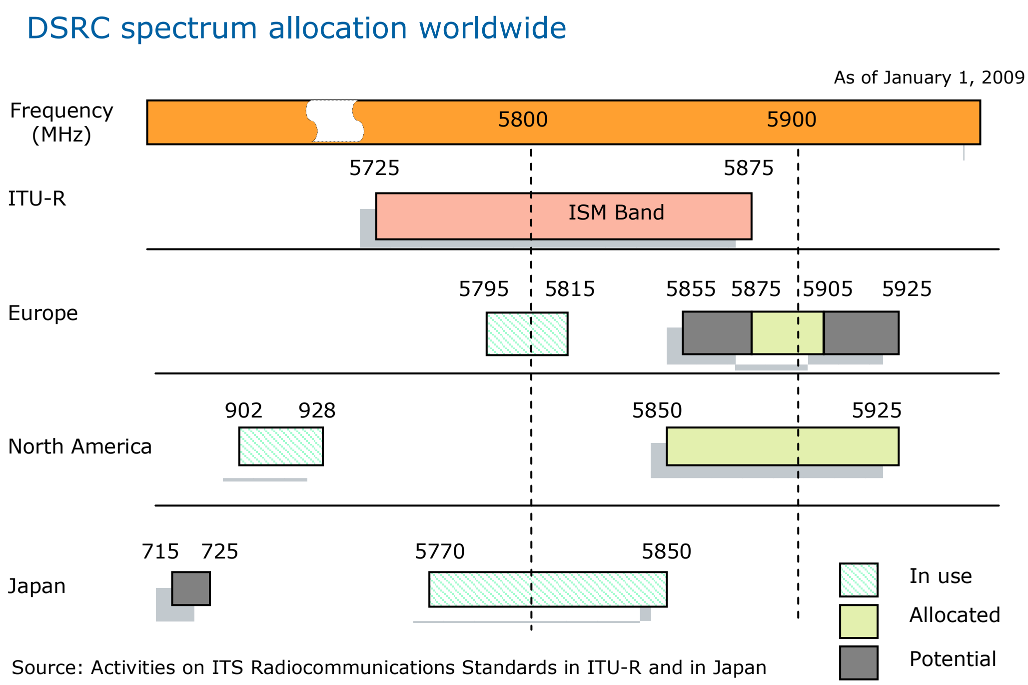

Figure 1: – Spectrum allocation for DSRC

2 Differences between IEEE 802.11p and IEEE 802.11(a, b, g, j, n)

802.11p is an amendment to the 802.11-2007. It's PHY is based on the OFDM section of that standard (section 17) which is the same PHY used by the well-known 802.11a devices.
The 802.11p amendment proposes small modifications to the PHY and MAC in order to achieve a robust connection and a fast setup for moving vehicles.

2.1 IEEE 802.11a, g Physical Layer

For detailed information, please refer to the Standard or / and to the WLAN IEEE 802.11 a, b, g Application Note from Rohde & Schwarz (1MA69).

802.11p and 802.11a,g use OFDM Modulation. 802.11b does not use OFDM and is therefore not listed here.

2.1.1 Overview

The following table gives an overview of the available 802.11a/g modulation schemes including mapping and coder rates.

Standard	Data Rate [Mbit/s]	Modulation per Carrier	Data Carriers	Pilot Carriers	Coding Rate	Mapping		
						from	to	Using
802.11 a / g	6	BPSK	48	4	½	48 Bits	1 OFDM Symbol	48 BPSK carriers
	9	BPSK	48	4	¾	48 Bits	1 OFDM Symbol	4 BPSK carriers
	12	QPSK	48	4	½	96 Bits	1 OFDM Symbol	48 QPSK carriers
	18	QPSK	48	4	¾	96 Bits	1 OFDM Symbol	48 QPSK carriers
	24	16QAM	48	4	½	192 Bits	1 OFDM Symbol	48 16QAM carriers
	36	16QAM	48	4	¾	192 Bits	1 OFDM Symbol	48 16QAM carriers
	48	64QAM	48	4	½	288 Bits	1 OFDM Symbol	48 64QAM carriers
	54	64QAM	48	4	¾	288 Bits	1 OFDM Symbol	48 64QAM carriers

Figure 2: – Overview over the 802.11 modulation schemes and mappings

2.1.2 802.11a

The Standard 802.11a uses an Orthogonal Frequency Division Multiplex (OFDM) transmission technique including 8 different data rates.
To design an easy-to-implement transmission system, 64 carriers are defined, but only the inner 52 carriers (-26 ... -1, 1 ... 26) are utilized. 4 pilot carriers (± 21 and ± 7) transmit a fixed pattern, while the other carriers contain the data. The carrier spacing of 312.5 kHz leads to a nominal signal bandwidth of 16.6 MHz.
The data content of the carriers change every 4 µs (the slot time), except for the preamble period, where the slot time is 8 µs.

- The burst begins with the preamble containing training sequence information used by the receiver for frequency correction and channel estimation.
- The following signal field (4 µs length) contains information on the modulation, the length of the transmission, and other additional information.
- The following PLCP Service Data Unit (PSDU) contains the Data.

The picture below shows a spectrogram representation of the 802.11a signal as described above.

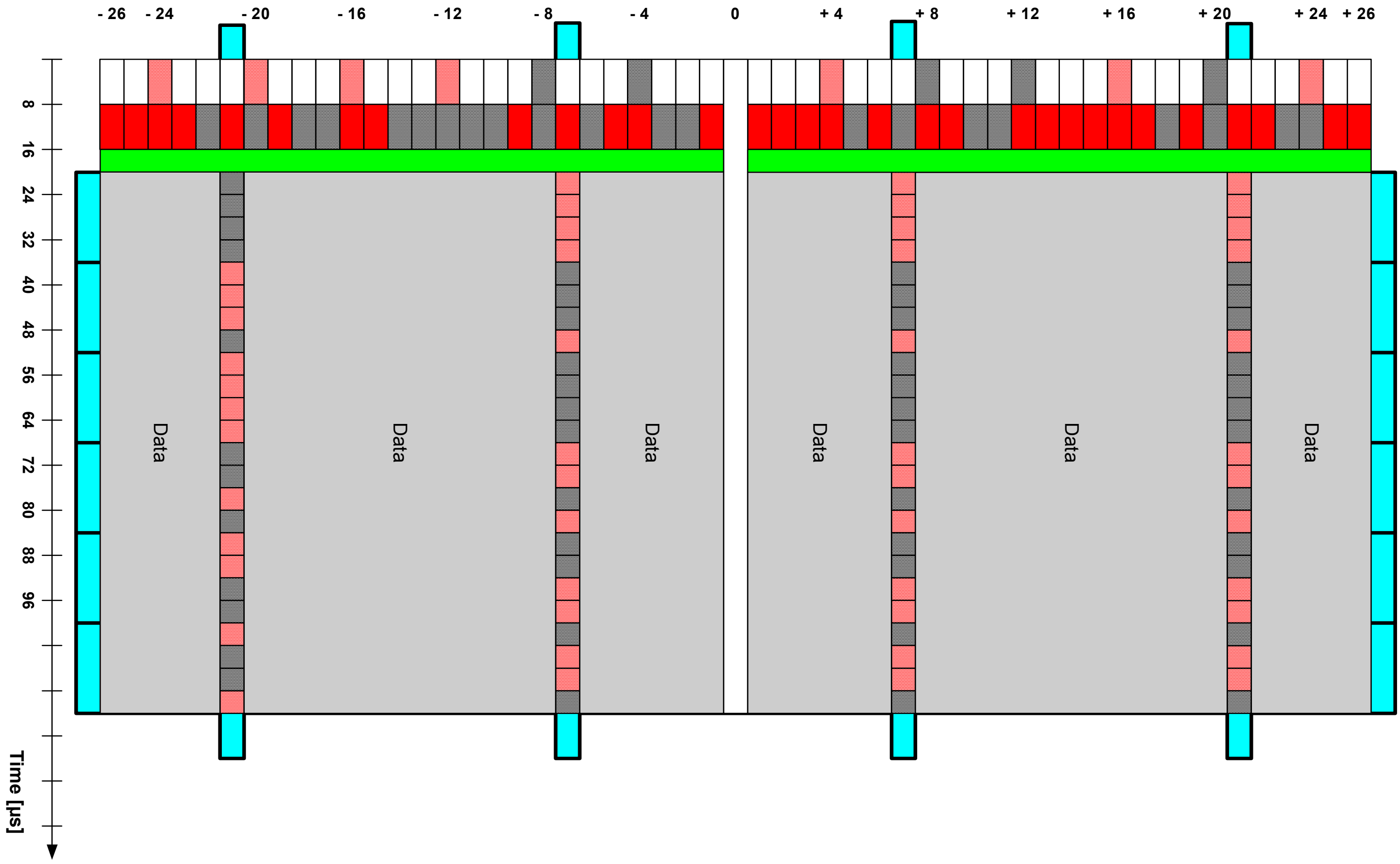

Figure 3: – 802.11a spectrogram representation (carriers vs. time)

Each of the 48 data carriers can be modulated with BPSK, QPSK, 16QAM or 64 QAM. In combination with different coding rates, this leads to a nominal data rate of 6 to 54 Mbit/s. The different constellations are shown in the figure below. The index of b represents the distribution of the bit stream on the constellation points.
(Green and red points are also occupied by blue ones, and green points by red ones)

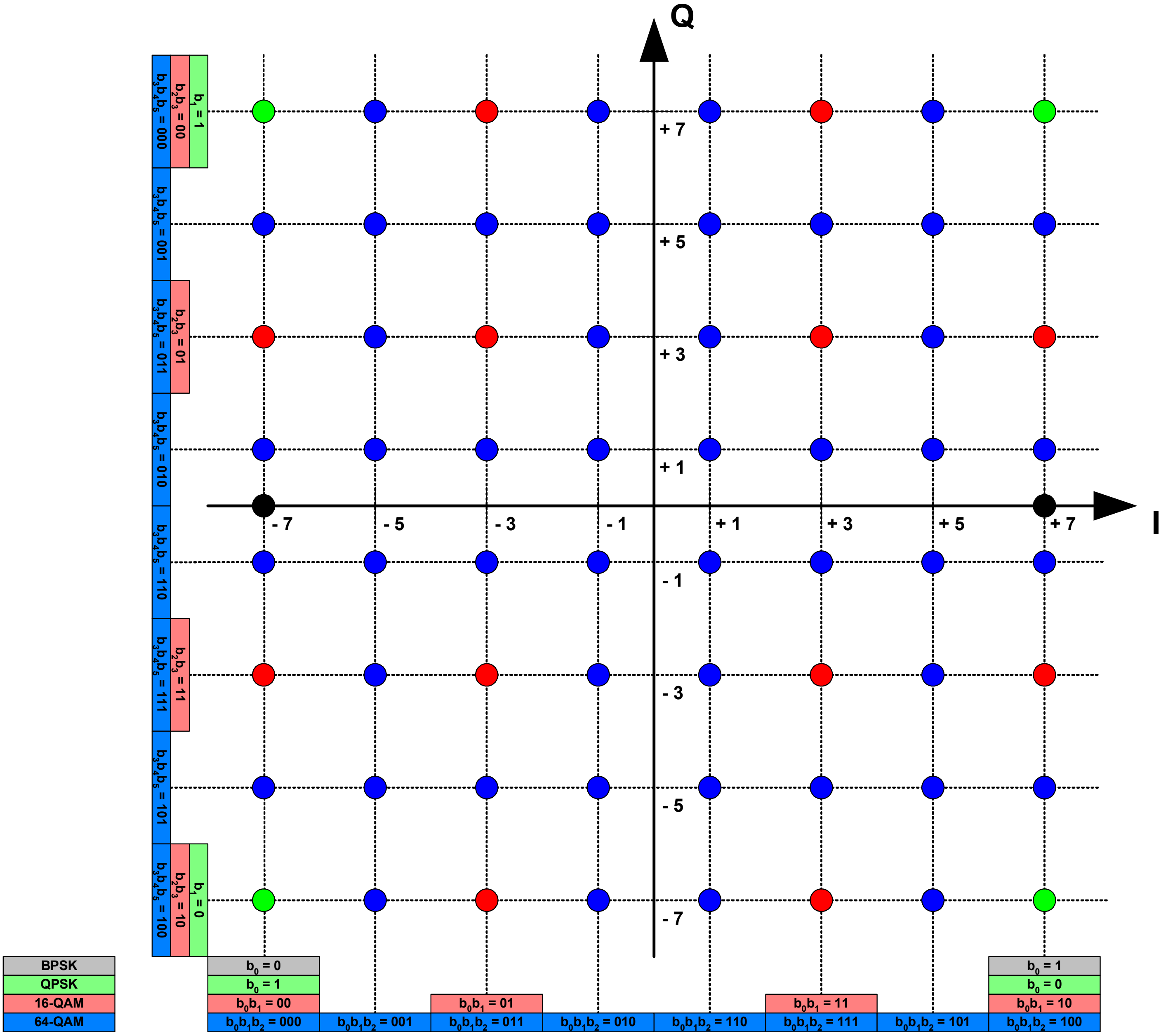

Figure 4: – 802.11a carrier constellations

2.2 IEEE 802.11p Physical Layer

The 802.11-2007 standard defined three different PHY Layer modes. The 20 MHz, 10 MHz and 5 MHz modes. The different modes can be achieved by using a reduced clock / sampling rates. 802.11a usually uses the full clocked mode with 20 MHz bandwidth. 802.11p usually uses the half clocked mode with 10 MHz bandwidth.
The 802.11j standard also uses the half clocked mode.
Please note: All modes with 5, 10 and 20MHz are defined in the 802.11 standards.

By using a 802.11a signal with reduced sampling rate / clock rate, a 802.11j/p signal can also be achieved in the PHY

The half clocked mode affects the following parameters:

- **Bandwidth**
  In 802.11p, the 10 MHz bandwidth is usually used, in order to make the signal more robust against fading. The 20 MHz bandwidth is optionally implemented.
- **Carrier spacing**
  The 802.11p signal uses a carrier spacing reduced by ½ compared to 802.11a.
- **Symbol length**
  The symbol length is doubled, making the signal more robust against fading.
- **Frequency**
  The 802.11p standard usually operates in the 5.8 GHz and 5.9 GHz frequency bands. Depending on regional regulatory authorities' regulations, 700 MHz and 900 MHz frequency bands are also used and in discussion. (See Fig. 1).

Beside the clock rate, the ACR (adjacent channel rejection) and the SEM (spectrum emission mask) for IEEE 802.11p also changed compared to 802.11-2007.
The ACR values in 802.11p are more stringent and are listed in figures 9 and 10.
The additional SEMs for 802.11p are shown in figures 7 and 8.

The following table compares the PHY Layer values of the 802.11a and 802.11p implementations.

Parameters	IEEE 802.11a	IEEE 802.11p half clocked mode	Changes
Bit rate (Mbit/s)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27	Half
Modulation mode	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	No change
Code rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4	No change
Number of subcarriers	52	52	No change
Symbol duration	4 µs	8 µs	Double
Guard time	0.8 µs	1.6 µs	Double
FFT period	3.2 µs	6.4 µs	Double
Preamble duration	16 µs	32 µs	Double
Subcarrier spacing	0.3125 MHz	0.15625 MHz	Half

Figure 5: – Comparison of the used physical layer implementations in IEEE 802.11a and IEEE 802.11p

Additional SEMs are defined for the 10 MHz and 5 MHz mode in the 802.11p standard For each bandwidth four different spectrum emission masks (SEM) for four different power classes are defined (power class A, B, C and D).
The 802.11p spectrum emission mask (10 MHz) of power class A is identical to the spectrum emission mask of the 802.11j standard.

The following Power classes are defined:

Power class	Max. output power (dBm)
Class A	0
Class B	10
Class C	20
Class D	28.8

Figure 6: – Power classes 802.11p

For WLAN the peak Power Spectral Density (PSD) is used as the reference power in the signal. All offset results are measured according to the peak PSD. Therefore the spectral masks are defined in dBr (dB relative).

In 802.11p the bandwidth of a channel is 10 MHz and the spectrum mask is defined up to 15 MHz offset from the center frequency of each channel in the half clocked mode.

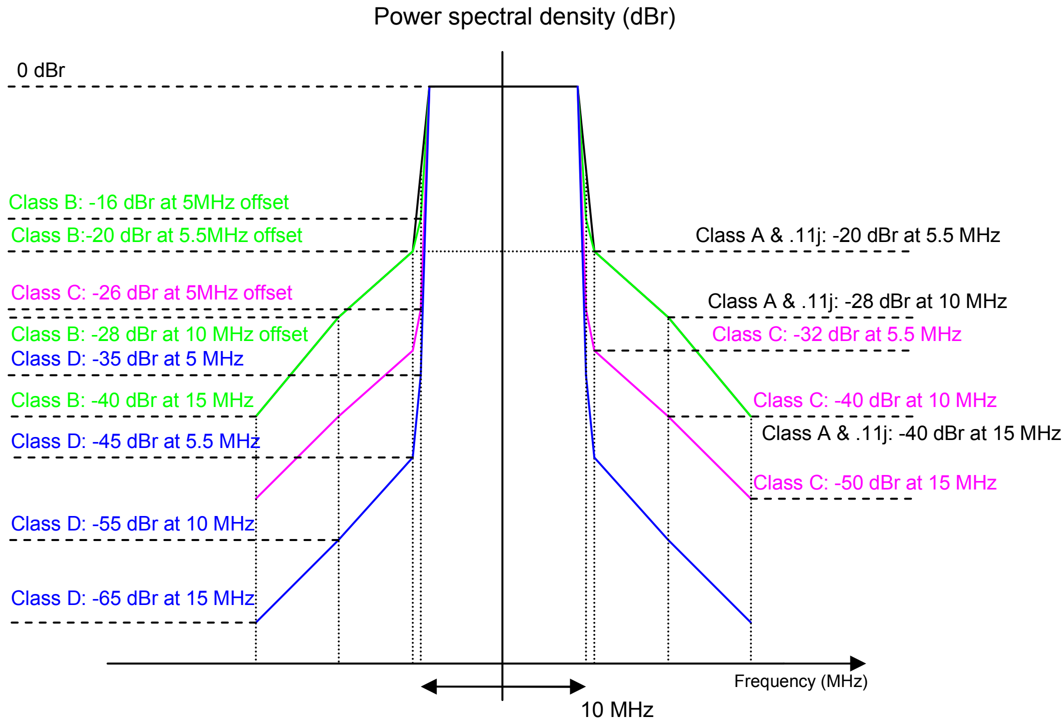

Figure 7: – IEEE 802.11p spectrum masks (10 MHz channel spacing)

In the 5 MHz channel spacing, the following SEM is defined in the 802.11p amendment.

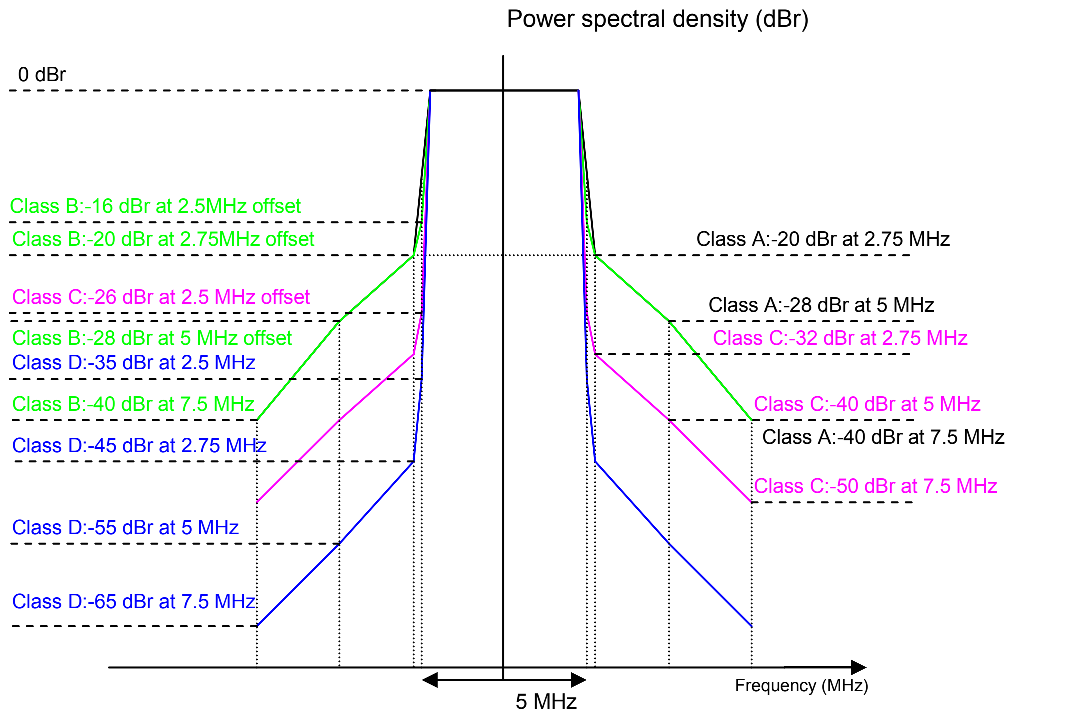

Figure 8: – IEEE 802.11p spectrum masks (5 MHz channel spacing)

Devices compliant to the 802.11p amendment will be required to meet a more stringent ACR requirement. The following table (Figure 9) shows the ACR specification for the OFDM PHY according to the 802.11-2007 standard, whilst Figure 10 provides the 11p amendment's proposed ACR requirements. NOTE: This, like the rest of the 11p amendment, is still in draft form and not finally approved.

Modulation	Coding rate	Adjacent channel rejection (dB)	Alternate adjacent channel rejection (dB)
BPSK	1/2	16	32
BPSK	3/4	15	31
QPSK	1/2	13	29
QPSK	3/4	11	27
16QAM	1/2	8	24
16QAM	3/4	4	20
64QAM	2/3	0	16
64QAM	3/4	-1	15

Figure 9: – ACR values of the 802.11-2007 standard

Modulation	Coding rate	Alternate adjacent channel rejection (dB)	Nonadjacent channel rejection (dB)
BPSK	1/2	28	42
BPSK	3/4	27	41
QPSK	1/2	25	39
QPSK	3/4	23	37
16QAM	1/2	20	34
16QAM	3/4	16	30
64QAM	2/3	12	26
64QAM	3/4	11	25

Figure 10: – ACR values of the 802.11p amendment

The values in dB are measured in average power relative to the channel average power of the adjacent channel.

2.3 IEEE 802.11 a, g, p Packet Format

The images below are a short overview of the packet format of 802.11 a, g, p. For detailed information, please refer to the Standard and/or to the WLAN 802.11 a, g, p Application Note from Rohde & Schwarz (1MA69).

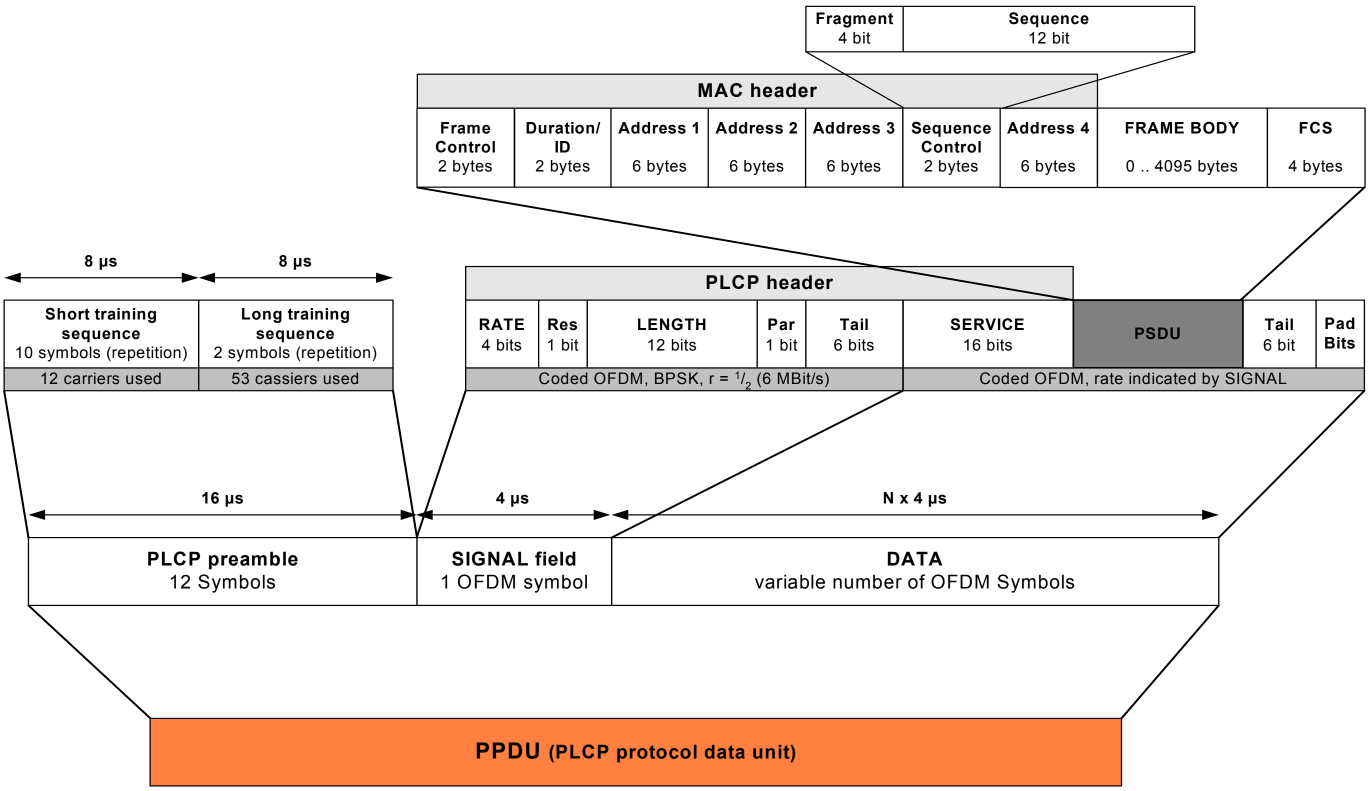

Figure 11 – 802.11a, g, p packet format

The Packet Format of the 802.11a standard is the same as the 802.11g, j, p standards.

2.4 IEEE 802.11p MAC Layer

The media access control (MAC) layer of the 802.11p amendment is also part of the 802.11-2007 standard. The 802.11 MAC is designed to be PHY independent.
Both MAC and PHY layers conceptually include management entities, called MAC sublayer management and PHY layer management entities (MLME and PLME) The management SAPs (service access point) within this model are the following:
— SME MLME SAP
— SME PLME SAP
— MLME PLME SAP

In 802.11p a new management information base (MIB) “dot11ocb” is defined into the MAC Layer Management Entity (MLME). When “dot11ocbenabled” is true additional options/constraints are added to an 802.11p device.
The additional options are:

- **No authentication service**
  which would be provided by the station management entity (SME) or by applications outside of the MAC sublayer.
- **No Deauthentification service**
- **Data confidentiality**

The MIB dot11ocb Bit has no Impact on the Phy and MAC Layers defined in 802.11.

Additionally all Stations belong a priori to one pre-defined “C2C” Independent Basic Service Set (IBSS). This can be achieved by reserved channels. They are also used for safety and traffic efficiency applications. So, no channel scanning is necessary, because dedicated predefined channels broadcast different categories.

3 802.11p Measurements

For R&D, quality assurance, production tests and regulatory tests, comprehensive tests of the physical and MAC layers are necessary.

Rohde & Schwarz offers a full range of WLAN measurement equipment, from signal generators and signal analyzers to wireless communication testers and protocol testers. As 802.11p is defined for mobile applications, also testing with a real world scenario under fading conditions is useful. Rohde & Schwarz also offers realtime faders in the R&S®AMU200 and R&S®SMU200 signal generators, allowing a WLAN-compliant signal to be generated and faded in one instrument.

3.1 802.11p Receiver Tests

For performing physical layer receiver tests, ideal signals have to be generated.
The following are typical receiver tests:

- Reference sensitivity
- Dynamic range
- Blocking characteristics
- In channel sensitivity
- Fading impacts
- Adjacent channel rejection (ACR)

A Rohde & Schwarz vector signal generator (R&S®SMU200A, R&S®SMATE200A, R&S®SMJ100A or R&S®SMBV100A) makes it very easy to set up an 802.11p signal within the WLAN option. Go to the integrated WLAN option (-K48 for 802.11a/b/j/g and -K54 for 802.11n) and select a WLAN 802.11a signal.
In the "Filter/Clipping" window, go to "Chip Rate Variation" and set 10 Mcps instead of 20 Mcps. See following Figure (12).

For pure baseband applications, signals can also be generated using the R&S®AMU200A, R&S®AFQ100A and R&S®AFQ100B with a WLAN option.
While the R&S®AMU200A also offers the integrated WLAN options, the R&S®AFQ100A and R&S®AFQ100B offer WLAN options with WINIQSIM2 (R&S®AFQ-K248 for 802.11a/b/j/g and R&S®AFQ-K254 for 802.11n). With either option, a standard-compliant WLAN signal with highly flexible parameterization can be generated.

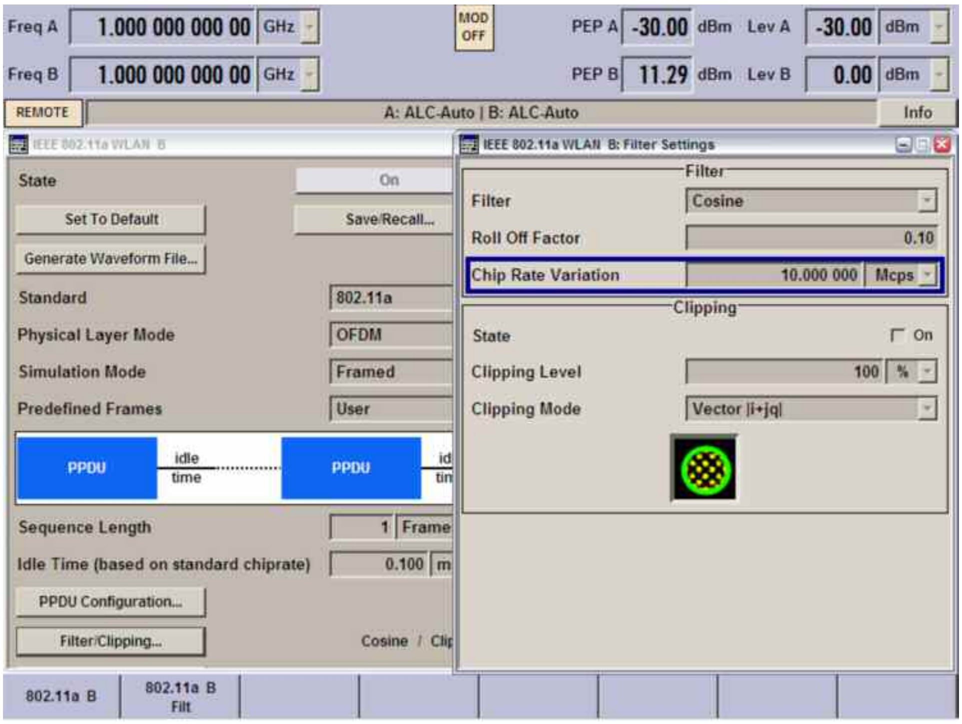

Figure 12: – R&S®SMU WLAN 11p signal generation

3.2 802.11p Receiver Tests under Fading Conditions

The 802.11p amendment is designed for vehicles. In moving environments, fading has an enormous impact on the received signal quality. Not only does the channel itself change very quickly versus time, but also a Doppler shift appears according to the relative velocity.
In such a critical environment, a repeatable realtime fading simulation with Rice, Doppler, etc., is needed.
Besides the ability to create standard-compliant signals, the R&S®SMU200A and R&S®AMU200A two-path signal generators also offer options for applying realtime fading to signals (fading simulator option -B14, fading simulator extension option -B15, dynamic fading option -K71, enhanced fading models option -K72 and MIMO fading option -K74). This makes it possible to test receivers under real-world fading conditions.
For 802.11a, b, g , the HiperLan Fading models are used. The Fading model for 802.11n is under definition. For 802.11p, currently no Fading model is defined.
Predefined fading scenarios are implemented not only for WLAN but also for a variety of other cellular communication standards, for example ITU fading models for WiMAX™ and extended ITU fading models for LTE.
In addition to preset fading scenarios, it is quite easy to modify the parameters such as speed, number of paths and type of fading, to create a user-defined fading profile.

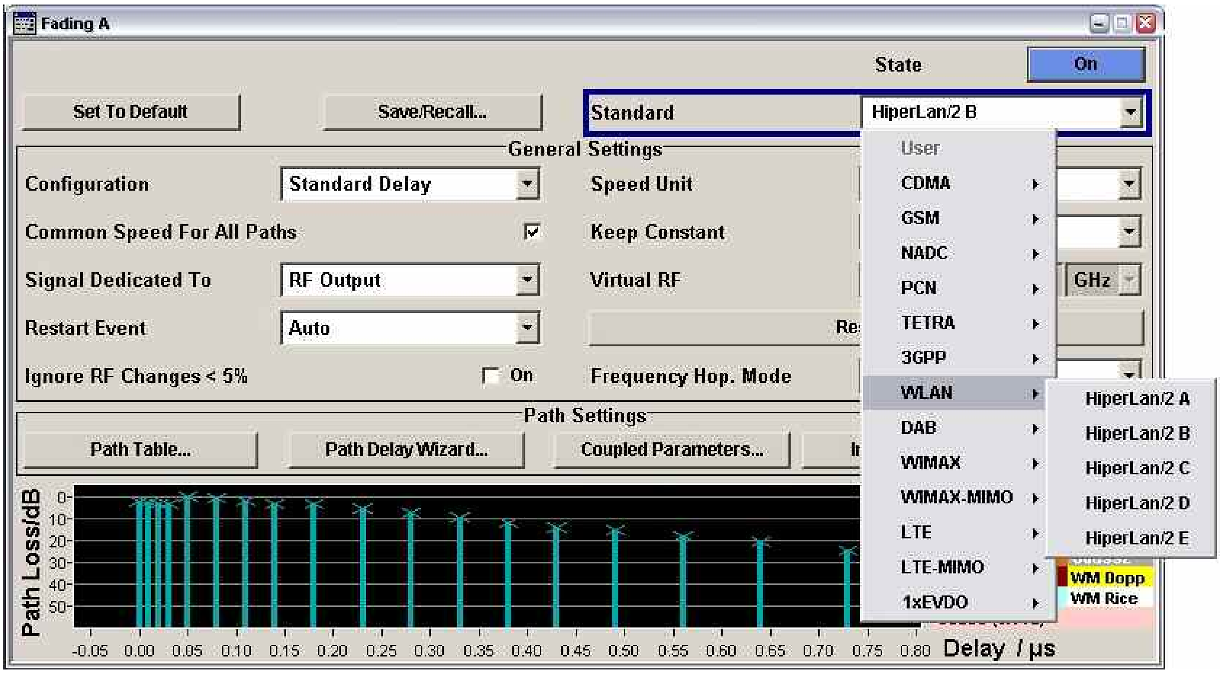

Figure 13: – Predefined fading settings of the R&S®SMU200

3.3 802.11p Transmitter Tests

To analyze the physical parameters of the signal generated from a device under test (DUT), a transmitter test must be performed. The following are typical transmitter tests:

- Transmit power
- Transmit signal quality such as modulation, EVM, etc.
- Output spectrum such as occupied bandwidth
- Out-of-band measurements such as adjacent channel leakage ratio (ACLR) or spurious

The WLAN transmitter tests are supported by the R&S®FSL, R&S®FSV , R&S®FSG and R&S®FSQ signal analyzers equipped with the required WLAN options (-K91 for 802.11a/b/g/j/p and -K91n for 802.11n).

3.3.1 802.11p Spectrum Emission Mask

To verify whether the DUT is inside the spectrum limits in line with 802.11p, the measured spectrum has to be compared with the configured spectrum emission mask (SEM).
Rohde & Schwarz analyzers provide two different ways for testing the signal versus the SEM:

- **Spectrum analyzer mode**
  In the general-purpose spectrum analyzer mode of the R&S®FSQ and R&S®FSV, the SEM values in line with the standard can be selected, loaded or manually entered. By selecting the sweep mode menu a manual parameterization of all relevant values like preamplifier or limit lines can be edited.

- **Analysis within the WLAN option (802.11j).**
  As the SEM of the 802.11j standard is identical to the SEM 802.11p power class A, the 802.11j setting can be used for measuring the 802.11p power class A modules. Both standards use the half clocked mode.

  Inside the WLAN option (-K91 and –K91n), the 802.11j standard should be selected. By switching to the spectrum measurement, the loaded SEM in line with 802.11j and 802.11p power class A can be seen. This mode also supports the demodulation of the symbols.

Application Note IEEE 802.11p
The Application Note can be downloaded from the Rohde & Schwarz Application Notes web page www.rohde-schwarz.com/appnote/1MA152 .

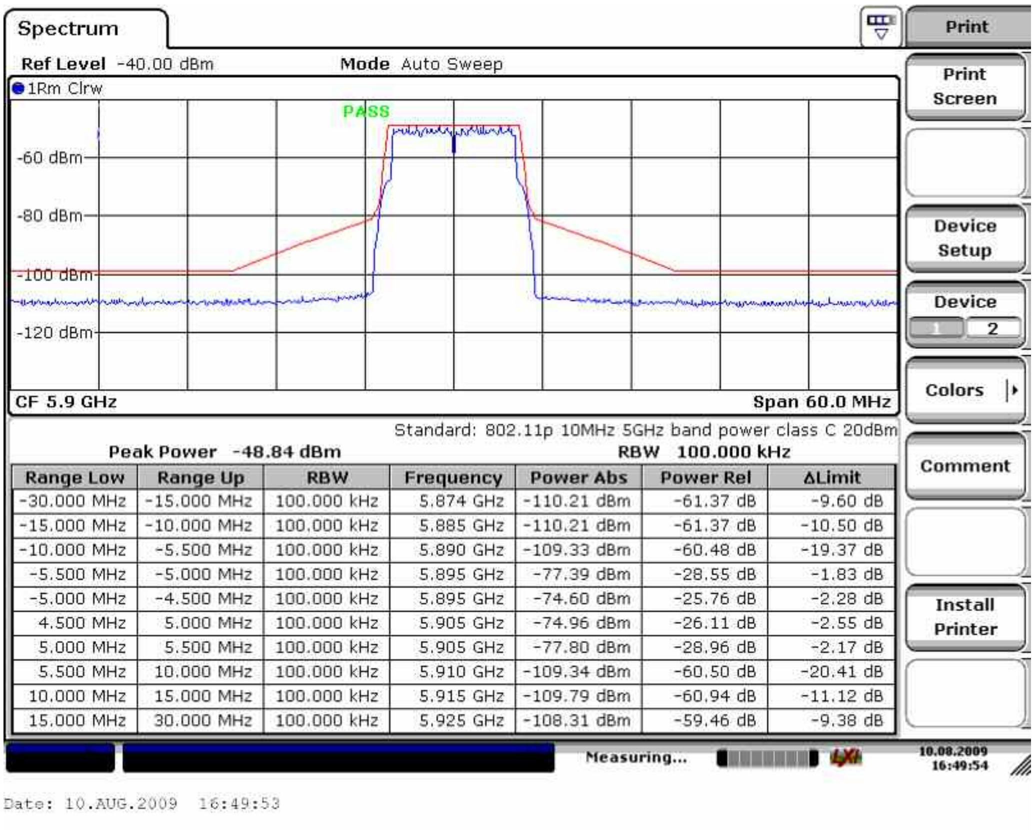

Figure 14: – 802.11p signal at 5.9 GHz with SEM power class C (FSV).

In the Spectrum Analyzer mode the SEM is loaded by pressing the “MEAS” Hard Key. The Soft Key “Spectrum Emission Mask” should then be pressed followed by the Soft Key “Load Standard”. The required SEM under WLAN can then be selected.

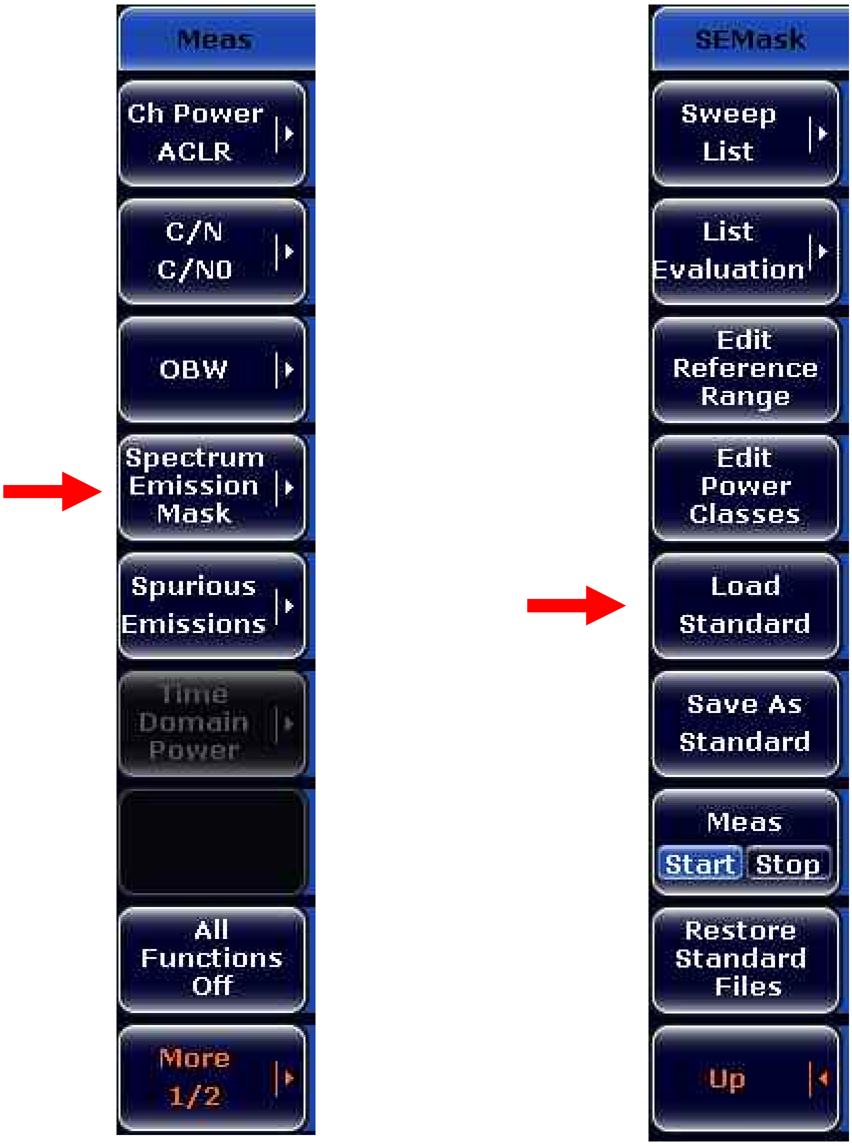

Figure 15: – R&S®FSV Menus for loading the SEM in the Spectrum Analyzer mode

3.3.2 Modulation Analysis

When selecting the WLAN option, the IEEE 802.11j standard can be selected. As 802.11p and 802.11j use the half clocked mode, the 802.11p standard-compliant signal can be demodulated as required.
Rohde & Schwarz supports all major measurements inside the WLAN option, such as:

- Modulation quality
  - EVM
  - I/Q imbalance
  - I/Q offset
- Spectrum flatness
- Transmit power
- Carrier spacing
- Symbol length
- Frame length
- Frequency offset
- and many more…

Please refer to the signal analyzer options for WLAN (-K90, -K91 and -K91n).

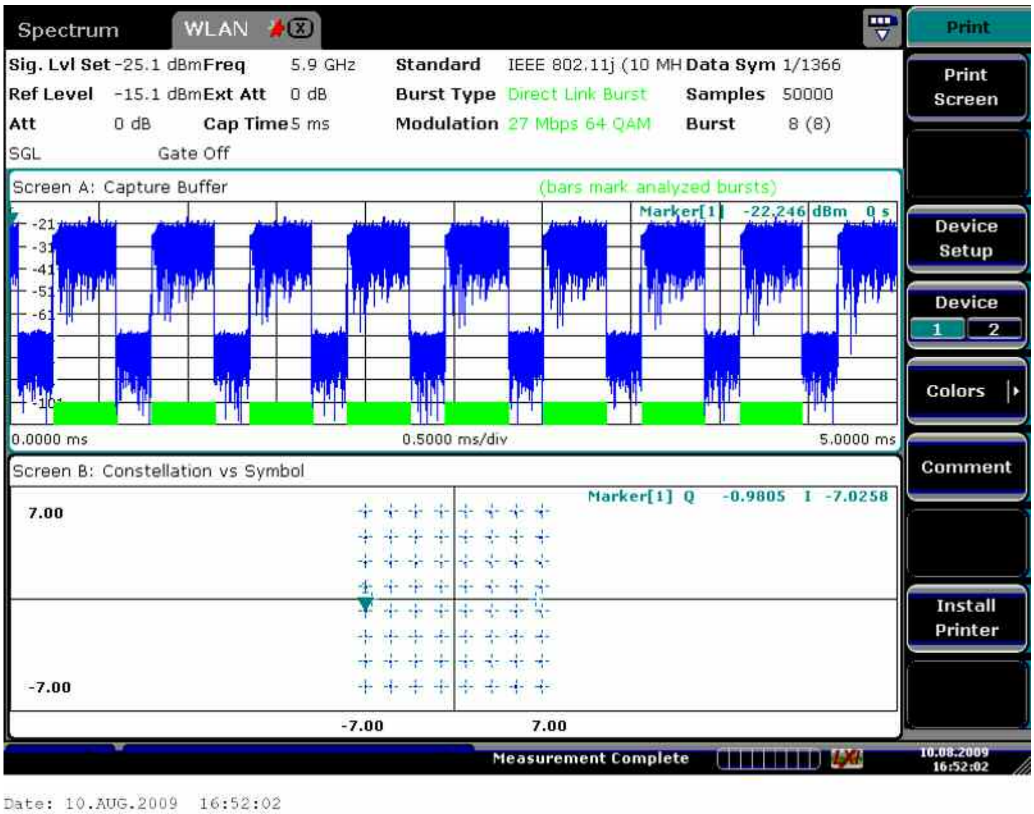

Figure 16: – Analysis of the 10 MHz WLAN 802.11p signal with R&S®FSV.

3.4 Production Tests

The multistandard R&S®CMW platform supports all major standards, including WiMAX™, LTE and WLAN. If the 802.11p DUT can be configured in an 802.11a mode with full clocked mode (20 MHz BW), all the fast production features provided by the instruments can be used, such as parallel testing. The R&S®CMW WLAN personality supports no signaling for the 802.11a/b/g/n standards.

3.5 Protocol Tests

For real-world application testing, design verification and analysis of the 802.11p MAC layer, the R&S®PTW70 provides an in-depth test suite enabling the configuration of individual tests. Based on the 802.11a/b/g protocol stack implementation, the R&S®PTW70 together with its ability to modify messages makes it possible to run a wide variety of test cases. For more specific 802.11p test functionality, please contact your Rohde & Schwarz sales engineer.

4 Conclusion

802.11p is part of the 802.11-2007 standard, as 802.11a. The 802.11p amendments use the 5 MHz, 10 MHz and 20 MHz mode of the 802.11-2007 standard. The physical Layer of the 802.11p standard is the same as the physical Layer of the 802.11a standard, except for the used sample rate. This application note explains how the sample rate in the test equipment can be changed and the how to load the according SEM according the 802.11p standard.
As 802.11p is used in C2C applications, security issues with higher reliability are requested. Rohde & Schwarz supports you by measuring 802.11p with high reliability.

5 Abbreviations

3GPP	3rd Generation Partnership Project
802.11	IEEE 802.11
BW	Bandwidth
C2C	Car to car
dBr	dB relative
Dot11ocb	dot11 Outside Context of BSS
DSRC	Dedicated short range communication
DUT	Device under test
EVM	Error vector magnitude
GPIB	General purpose interface bus
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronics Engineers
IPv6	Internet Protocol Version 6
LLC	Logical link control
MAC	Media access control layer
MIB	Management Information Base
MLME	MAC Layer Management Entity
MPDU	MAC Protocol Data Unit
OFDM	Orthogonal Frequency Division Multiplex
PHY	Physical layer
PLCP	Physical Layer Convergence Protocol
PPDU	Physical Protocol Data Unit
PSD	Power Spectral Density
PSDU	Physical Service Data Unit (Payload)
SEM	Spectrum emission mask
SME	Station Management Entity
V2V	Vehicle to vehicle
WAVE	Wireless access for vehicular environments
WLAN	Wireless local area network
WSMP	WAVE short message protocol

6 References

Rohde & Schwarz Application Notes

[1] 1MA77: R&S NRPView - PC Software for R&S NRP-Zxx Sensors
[2] 1EF59: DFS Analysis Tool, Dynamic Frequency Selection in the 5 GHz Band
[3] 1MA107: Transmitter Tests in Accordance with the CTIA Plan for Wi-Fi Mobile Converged Devices
[4] 1CM55: Power Measurements on WLAN Modules with the R&S CMU 200 and with CMUgo
[5] 1MA69: WLAN Tests According to Standard 802.11a/b/g
[6] 1GP56: 802.11 Packet Error Rate Testing
[7] 1MA135: Path Compensation for MS Fading Tests

7 Additional Information

This Application Note provides an overview of the differences between 802.11p and 802.11a/b/g/j.
For all topics concerning 802.11a/b/g/j/n measurements, please refer to the Rohde & Schwarz Application Notes for 802.11a/b/g/j/n and/or to our WLAN web page: www.rohde-schwarz.com/technology/wlan

8 Ordering Information

Ordering information		
Available software options		
Designation	**Type**	**Order No.**
WLAN 802.11a/b/j/g Application Firmware for R&S®FSL	FSL-K91	1302.0094.02
WLAN 802.11a/b/j/g/n Application Firmware for R&S®FSL	FSL-K91n	1308.7903.02
WLAN 802.11a/b/j/g Application Firmware for R&S®FSV	FSV-K91	1310.8903.02
WLAN 802.11a/b/j/g/n Application Firmware for R&S®FSV	FSV-K91n	1310.9468.02
WLAN 802.11a/b/j/g Application Firmware for R&S®FSQ	FSQ-K91	1157.3129.02
WLAN 802.11a/b/j/g/n Application Firmware for R&S®FSQ	FSQ-K91n	1308.9387.02
WLAN 802.11n Application Firmware for R&S®SMBV100A	SMBV-K54	1415.8160.02
WLAN 802.11a/b/g Application Firmware for R&S®SMBV100A	SMBV-K48	1415.8102.02
WLAN 802.11a/b/g Application Firmware for R&S®SMATE200A	SMATE-K48	1404.6703.02
WLAN 802.11n Application Firmware for R&S®SMATE200A	SMATE-K54	1404.7951.02
WLAN 802.11a/b/g Application Firmware for R&S®SMJ100A	SMJ-K48	1404.1001.02
WLAN 802.11n Application Firmware for R&S®SMJ100A	SMJ-K54	1409.2458.02
WLAN 802.11a/b/g Application Firmware for R&S®SMU200A	SMU-K48	1161.0266.02
WLAN 802.11n Application Firmware for R&S®SMU200A	SMU-K54	1408.7562.02
WLAN 802.11a/b/g Application Firmware for R&S®AFQ100A/B	SMU-K248	1401.6602.02
WLAN 802.11n Application Firmware for R&S®AFQ100A/B	SMU-K254	1401.5806.02
Fading Simulator for R&S®SMU200A	SMU-B14	1160.1800.02
Fading Simulator for R&S®AMU200A	AMU-B14	1402.5600.02
Fading Simulator Extension for R&S®SMU200A	SMU-B15	1160.2288.02
Fading Simulator Extension for R&S®AMU200A	AMU-B15	1402.5700.02

Figure 17: – Ordering information of the WLAN options.

The items listed above are the WLAN software options for our test instruments. If you already own an instrument, you can order the software option separately. You should choose the instrument that best suits your purpose regarding frequency, accuracy and other requirements such as fading. When placing an order, please note that for installing one of the above options, a base option (i.e. baseband) may be required.

The Analyzers Firmware –K91 supports the WLAN measurements IEEE 802.11a, b, g, j and p with changed clock rate. The Measurement Firmware –K91n supports IEEE 802.11 a, b, g, j, n and p with changed clock rate.

About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

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DQS REG. NO 1954 QM

Certified Environmental System
ISO 14001
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