Intelligent Transportation Systems Using IEEE 802.11p

Application Note

Products:

- R&S®FSW
- R&S®FSV3000
- R&S®SMW200A
- R&S®SMBV100A

For several years, automobile makers and government agencies have sought ways to improve safety on roadways and effectively manage traffic flow. As wireless communication systems are advancing, the vision of automobiles talking to each other and to roadside units is becoming a reality. These planned automotive wireless communication systems are known as ITS (Intelligent Transportation System). This paper will provide an overview of the current status of the ITS worldwide with a focus on the IEEE 802.11p PHY. Additionally, the paper provides information on test and measurement solutions for devices and components used in ITS.

Application Note

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ROHDE&SCHWARZ

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1 Introduction

Policy makers and the automobile industry strive to improve vehicle safety. A very promising technology proposes having vehicles communicate important information with other vehicles and/or roadside units. Further, it is predicted that non-vehicle devices such as smart phones, backpacks and bicycles will include the technology to communicate to vehicles. These devices would alert drivers to the presence of a bicyclist in the road or a pedestrian in a crosswalk greatly reducing the number of pedestrian related injuries/fatalities. These vehicle safety systems are known by many different acronyms/initials (e.g. V2V, V2I, DSRC, ITS, C-ITS, C2C, C2x). In this paper for consistency and brevity the generic term ITS (Intelligent Transportation System) will be used.

In addition to vehicle safety, traffic management is an important use case for ITS. Traffic management focuses on providing updated local information, maps and other relevant messages limited in space and/or time [1]. It is anticipated that this will, among other things, reduce the number of traffic jams, which will result in saved time for drivers and less pollution from carbon emissions from idling vehicles.

While details of the ITS systems (especially at the higher layers) vary depending on regional/regulatory issues, all of these systems plan IEEE 802.11p for the MAC and PHY layers. This paper will provide an overview of ITS activities and status worldwide. It is divided into 4 main parts: standards/specifications applicable for ITS, spectrum allocation and channel plans, 802.11p PHY details, and test and measurement solutions to aid in design and verification of ITS devices and systems.

2 ITS: A Global Overview

ITS is being planned globally. Table 1 provides a high level comparison of aspects of ITS in Japan, US, and EU.

	Japan	USA	Europe
Standard / Committee	ITS-Forum	IEEE802.11p/1609.x	CEN/ETSI EN302 663
Frequency range	755 – 765 MHz	5850 – 5925 MHz	5855 – 5925 MHz
No. of Channels	One 10 MHz channel	Seven 10 MHz channels (Two 20 MHz channels formed by combining 10 MHz channels)	Seven 10 MHz channels
Modulation	OFDM		
Data rate per channel	3 -18Mbit/s	3 -27Mbit/s	3 - 27Mbit/s
Output power	20 dBm (Antenna input)	23 - 33 dBm (EIRP)[1]	23-33 dBm (EIRP)
Communication	One direction multicasting service (broadcast without ACK)	One direction multicasting service, One to Multi communication, Simplex communication (broadcast without ACK, multicast, unicast with ACK)	
Upper protocol	ARIB STD-T109	WAVE (IEEE 1609) / TCP/IP	ETSI EN 302 665 (incl. e.g. GeoNetworking) TCP/UDP/IP

Table 1: High level global overview of ITS.

2.1 US Specifications for ITS

Figure 2-1 provides the ITS (DSRC/WAVE) protocol stack for the US with the associated specifications for the layers. Note that for safety applications the protocol stack is based on the WAVE (1609.x) specifications and not on IP. IP headers contain overhead bits that can lead to channel congestion; in a safety application this is not tolerable and led to the creation of the WAVE specs which, among other things, took care to reduce the number of overhead bits.

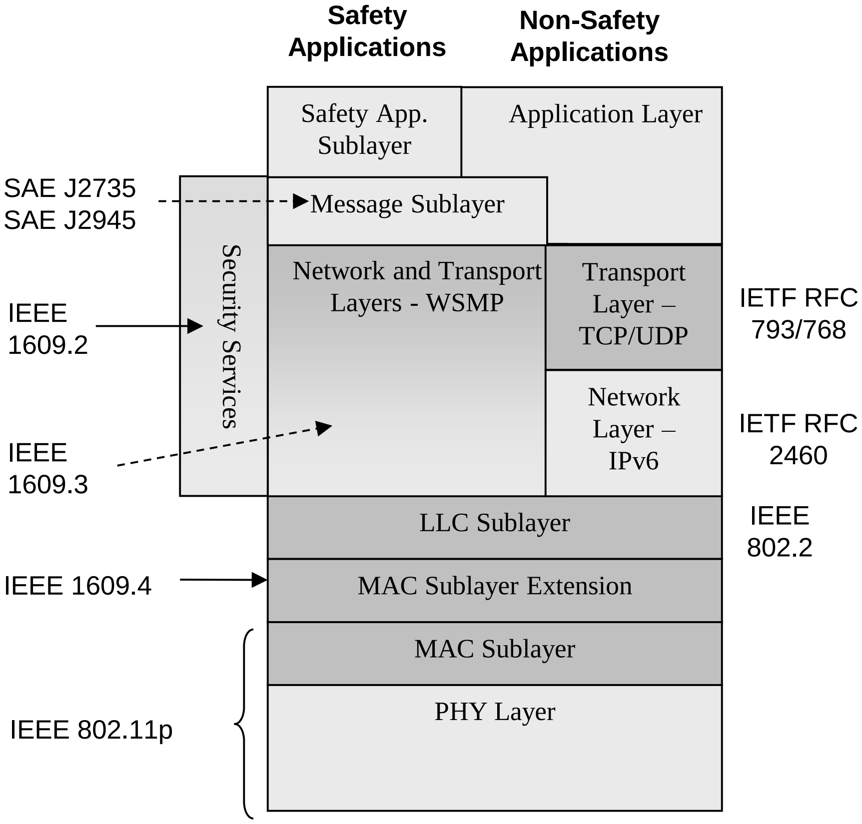


Figure 2-1: US ITS (DSRC/WAVE) Protocol Stack [2]

2.2 EU Specifications for ITS

In Europe, ETSI and CEN work together to develop a set of specifications for ITS in response to the European Commission Mandate M/453. The European ITS architecture is based on the ISO/OSI protocol. Two key ETSI specifications from the perspective of this paper are ETSI EN 302 665 which specifies the global architecture for communication of ITS [3] and ETSI EN 302 663 which specifies the European profile of the PHY and MAC using IEEE 802.11 as the base standard [4]. A complete listing of ETSI and CEN documents supporting ITS can be found in [5]. (Also see http://webapp.etsi.org/WorkProgram.) Figure 2-2 provides a high level overview of the European ITS protocol stack.

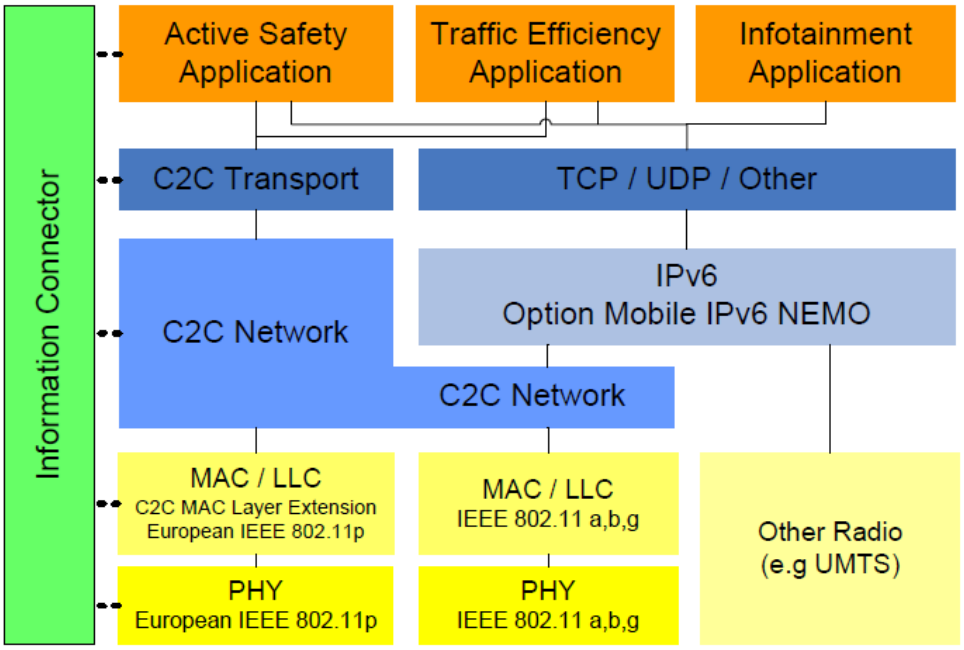


Figure 2-2: EU ITS Protocol Stack [6]

2.3 Japan Specifications for ITS

For Japan, ARIB STD-109 “700 MHz Band Intelligent Transport Systems” specifies the interface for vehicle to vehicle and vehicle to infrastructure communication. ARIB STD-109 includes general system overview, general and technical requirements for radio equipment, communication control system, and measurement methods for the transmitter, receiver, and controller. The ITS Forum (http://www.itsforum.gr.jp/E_index.html) fosters and promotes R&D and standardization for ITS and provides several key documents on their website:

- ITS Forum RC-011 v1.0: “700 MHz Band Intelligent Transport Systems- Test Items and Conditions for Mobile Station Interoperability Verification Guideline” which describes how to verify connectivity, security, and interoperability of land mobile stations using ARIB STD-109.
- ITS Forum RC-006 v1.0 “Experimental Guideline for Vehicle Communications System using 700 MHz-Band” specifies the radio communications interface of inter-vehicle communication using 700 MHz band with a goal for standardization and contributing to experiments on applications for safe driving.
- ITS Forum RC-009 v1.1 “Security Guideline for Driver Assistance Communications System” for ensuring the security of inter-vehicle and roadside to vehicle communication.
- ITS Forum RC-008 v1.0 “Operation Management Guideline for Driver Assistance Communications System” describes functions required for managing operation of an ITS system.

3 ITS Channel Plans

In the US, the FCC defined the channel plan shown in Figure 3-1 (see [2]). Channel 172 is known as the collision avoidance channel and the FCC designated that it is "exclusively for vehicle-to-vehicle safety communications for accident avoidance and mitigation, and safety of life and property applications" ([2]). The FCC designated channel 184 (Public Safety) "exclusively for high-power, longer-distance communications to be used for public safety applications involving safety of life and property, including road intersection collision mitigation" ([2]). Channel 178 (the control channel) is used to broadcast Service Advertisements, indicating how to access services on other "Service Channels". The maximum EIRP for 178 is 33 dBm for non-government services, but could be as high as 44.8 dBm for government services. The remainder of the channels could be used for public safety or for private services such as parking management and payment. In addition, channels 174 and 176 can be combined to form channel 175, and channels 180 and 182 can be combined to form channel 181. Channels 175 and 181 are then 20 MHz channels which could be used for static situations (such as while at a gas station) to download things such as maps or movies.

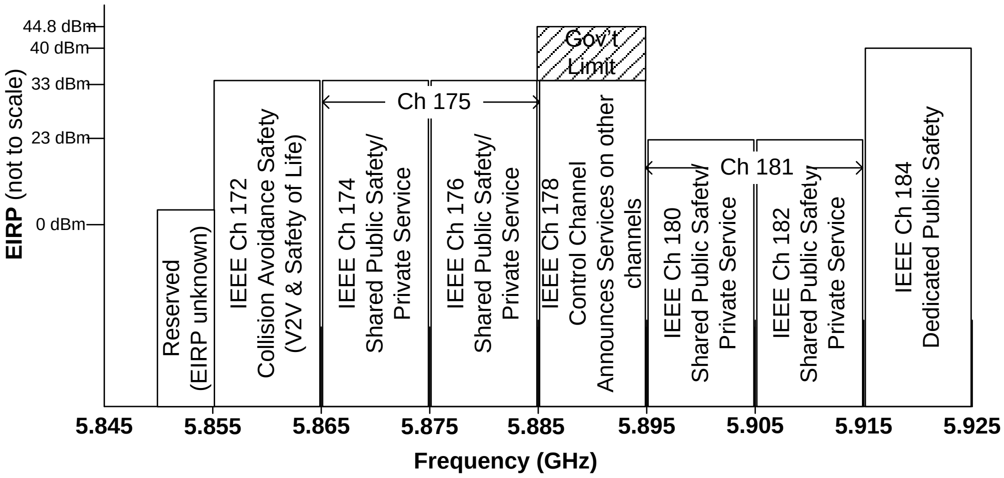


Figure 3-1: US ITS/DSRC channel plan

The European ITS channel plan shown in Figure 3-2 is similar but not exactly the same as the US ITS channel plan. In both cases, 7 channels are designated for ITS, however the channel usage and allowed EIRP (shown on the y-axis) per channel may differ between the US and Europe. In Europe, the channels are more commonly known by their channel types and in Figure 3-2 both the channel numbering based on the IEEE channel values and by their ETSI channel types are given. The ITS G5A band (IEEE channels 176, 178, and 180) contains the G5-CCH (Control Channel) and G5-SCH1 and G5-SCH2. These channels are dedicated to ITS safety applications. The ITS G5B band (IEEE channels 172 and 174) contains the channels G5-SCH3 and G5-SCH4 and is dedicated to ITS non-safety applications (e.g. traffic efficiency and service announcements). Note that the ITS G5B band is not allocated European wide. Thus local usage restrictions might apply.

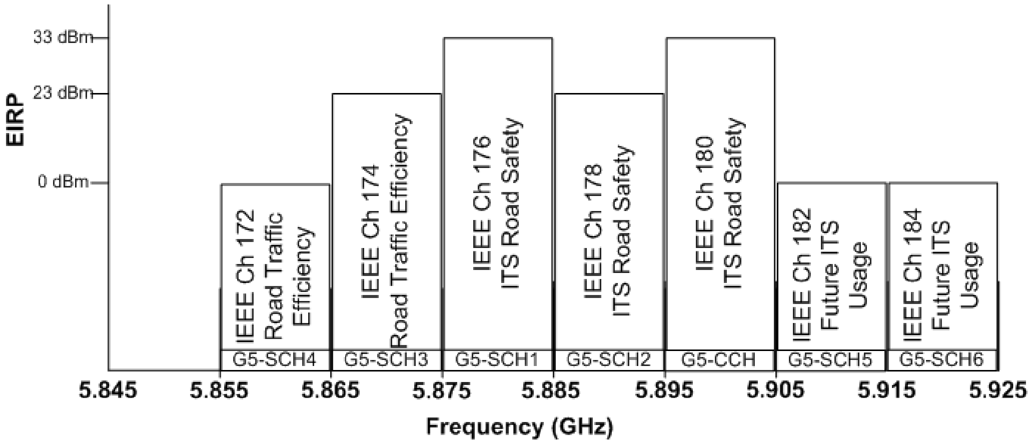


Figure 3-2: Europe ITS Channel Plan

In Japan, the ITS channel plan for safety applications is much simpler as it is only one 10 MHz channel in the 700 MHz band centered at 760 MHz. The transmitter antenna power is specified to be 10 mW or less per 1 MHz bandwidth on average.

4 IEEE 802.11p

Several important points were considered by the organizations researching and planning for ITS. One of these was cost. The 802.11 OFDM PHY (e.g. 802.11a) was already an established technology in the market place and it would provide an inexpensive solution (due in part to economies of scale). From a technical point of view, 802.11 also met many of the ITS needs. For example, an OFDM PHY is suited for mobile environments. Furthermore, the capability for ad-hoc type of communications offered by 802.11 meets the requirements related to the ad-hoc characteristic of C2C communication. The 802.11 OFDM PHY already defined several bandwidths (5, 10 and 20 MHz). The ITS community chose 10 MHz for their bandwidth for mobile communication due to the longer guard interval (compared to the 20 MHz channel bandwidth (see Table 2.) However, a few key modifications to the 802.11 OFDM PHY were needed to achieve a robust connection and a fast setup for moving vehicles which led to the creation of the 802.11p amendment.

4.1 IEEE 802.11p Physical Layer

This section will highlight the modifications to the 802.11 OFDM PHY made in 802.11p. For detailed information on the 802.11 OFDM PHY, see section 2 of [7] and section 18 of [8].

The 11p PHY is defined by the 802.11 OFDM PHY (section 18 of [8]). The section 18 PHY (often called 11a) specifies 5, 10 and 20 MHz bandwidths. The 5 and 10 MHz bandwidths can be achieved by using a reduced clock / sampling rate. 802.11a uses the full clocked mode with 20 MHz bandwidth while 802.11p uses the half clocked mode with 10 MHz bandwidth. Regardless of the bandwidth, the FFT size is 64 and the number of subcarriers is 52 (48 data subcarriers and 4 pilot subcarriers). Table 2 gives a comparison of key OFDM parameters as a function of the bandwidth.

Parameters	20 MHz Bandwidth	10 MHz Bandwidth	5 MHz Bandwidth
Bit rate (Mbit/s)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27	1.5, 2.25, 3, 4.5, 6, 9, 12, 13.5
Modulation mode	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Code rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4	1/2, 2/3, 3/4
Number of subcarriers	52	52	52
Symbol duration	4 µs	8 µs	16 µs
Guard time	0.8 µs	1.6 µs	3.2 µs
FFT period	3.2 µs	6.4 µs	12.8 µs
Preamble duration	16 µs	32 µs	64 µs
Subcarrier spacing	312.5 kHz	156.25 kHz	78.125 kHz

Table 2: 802.11 OFDM PHY Parameters as a function of channel bandwidth

Although the 11p OFDM PHY is specified by the 802.11 OFDM PHY, there are two important changes to the TX and RX specifications to support 11p/ITS-- a much stricter spectrum mask and stricter adjacent and non-adjacent channel rejection requirements (see 4.1.1 for details). These challenging requirements are necessary because trials/tests run by the VSC-A CAMP group [9] indicated that cross channel interference significantly disrupted communication when the interferer was adjacent to the target channel and/or when the distance between the transmitter and receiver was more than 10x the distance between the interferer and receiver. Cross channel interference is the interference effect that a transmission in one channel has on communications in another channel.

4.1.1 Changes in 802.11p Transmitter and Receiver Specifications

Adjacent and Nonadjacent Channel Rejection

Table 3 provides the enhanced adjacent and nonadjacent (sometimes called alternate) channel spec for 802.11p. The table gives the requirements for non-802.11p OFDM 802.11 devices and 11p. The adjacent channel requirement for 11p is 12 dB more difficult and the nonadjacent rejection is 10 dB more difficult than the OFDM specification.

Modulation	Coding Rate	Adjacent channel rejection (dB)		Nonadjacent channel rejection (dB)	
		11a/g/n	11p	11a/g/n	11p
BPSK	1/2	16	28	32	42
BPSK	3/4	15	27	31	41
QPSK	1/2	13	25	29	39
QPSK	3/4	11	23	27	37
16QAM	1/2	8	20	24	34
16QAM	3/4	4	16	20	30
64QAM	2/3	0	12	16	26
64QAM	3/4	-1	11	15	25

Table 3: Enhanced Adjacent Channel Rejection for 11p Compared to non-11p

Spectrum Emission Mask

The 802.11p mask is based on transmit mask M which according to a note in the 802.11 standard is equivalent to the class C mask. The 802.11p mask is considerably more difficult than the 802.11a/j (ie 802.11 OFDM PHY) mask.

Figure 4-1 shows the Class C spectrum emission mask and Table 4 lists the associated frequency offsets. For the masks of power classes A, B and D refer to Annex D of [8].

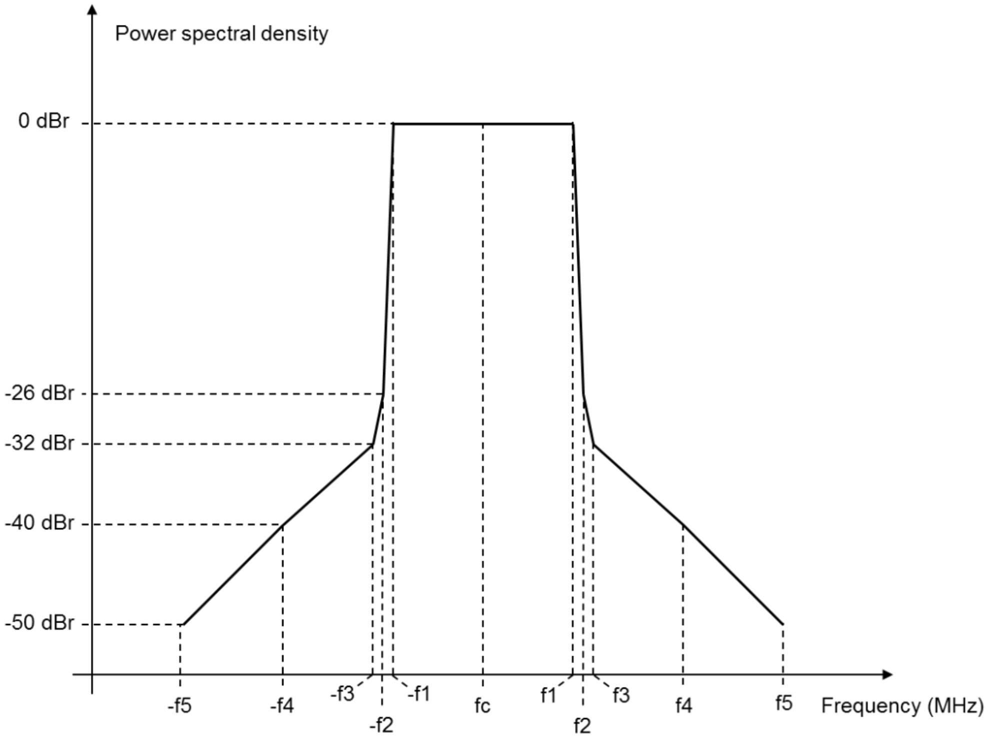


Figure 4-1: Class C spectrum emission mask for 802.11p

Frequency Offset	Channel Bandwidth		
	5 MHz	10 MHz	20 MHz
±f1	2.25	4.5	9
±f2	2.5	5.0	10
±f3	2.75	5.5	11
±f4	5.0	10	20
±f5	7.5	15	30

Table 4: Spectrum mask frequency offsets for 802.11p

5 802.11p Measurements

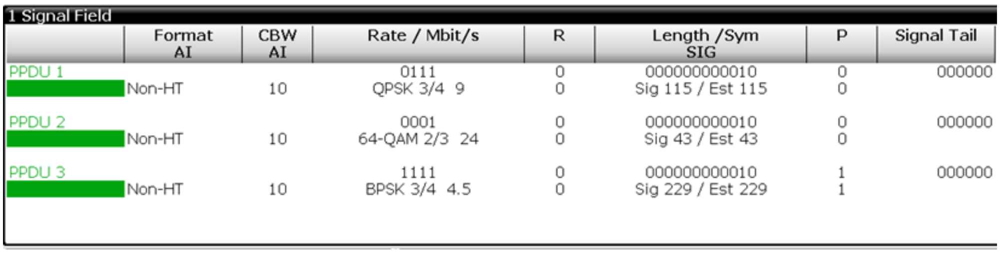
5.1 802.11p Transmitter Tests

Transmitter measurements are important in a wireless communication system. Some measurements verify that the signal at transmission will be what a receiver would expect to see (ignoring degradations that will occur due to fading, noise, etc.) and to verify that the signal will not interfere with devices operating in adjacent spectral bands. For safety critical systems like 11p these tests become even more important.

Transmitter tests can be divided into two main categories: modulation accuracy and spectrum quality. Spectrum quality would include, for example, spectrum mask, spurious emissions, and occupied bandwidth. Modulation accuracy tests would include, for example, EVM, spectral flatness, and center frequency leakage.

Fortunately, modern spectrum analyzers, such as the R&S®FSW and R&S®FSV3000 using the FSx-K91p option, are able to perform these measurements quickly and easily. The following section will describe the key 11p transmitter requirements and how to measure them.

The FSx-K91p option automatically detects the signal bandwidth and modulation type. This way a mixed signal configuration can easily be analyzed. The Signal Field Display (see Figure 5-1) gives an overview of the decoded Signal Field content of each burst.



1 Signal Field

	Format AI	CBW AI	Rate / Mbit/s	R	Length /Sym SIG	P	Signal Tail
PPDU 1 🟩	Non-HT	10	0111 QPSK 3/4 9	0 0	000000000010 Sig 115 / Est 115	0 0	000000
PPDU 2 🟩	Non-HT	10	0001 64-QAM 2/3 24	0 0	000000000010 Sig 43 / Est 43	0 0	000000
PPDU 3 🟩	Non-HT	10	1111 BPSK 3/4 4.5	0 0	000000000010 Sig 229 / Est 229	1 1	000000

Figure 5-1: Decoded Signal Field Information

5.1.1 802.11p Modulation Accuracy Measurements

Modulation accuracy measurements quantify the amount of signal quality degradation due to various sources of distortion like low SNR, I/Q impairments and poor frequency responses. The FSx-K91p offers standard compliant measurements according to 802.11 and additional options for in-depth analysis of DUT (Device Under Test) performance.

5.1.1.1 Transmitter Constellation Error

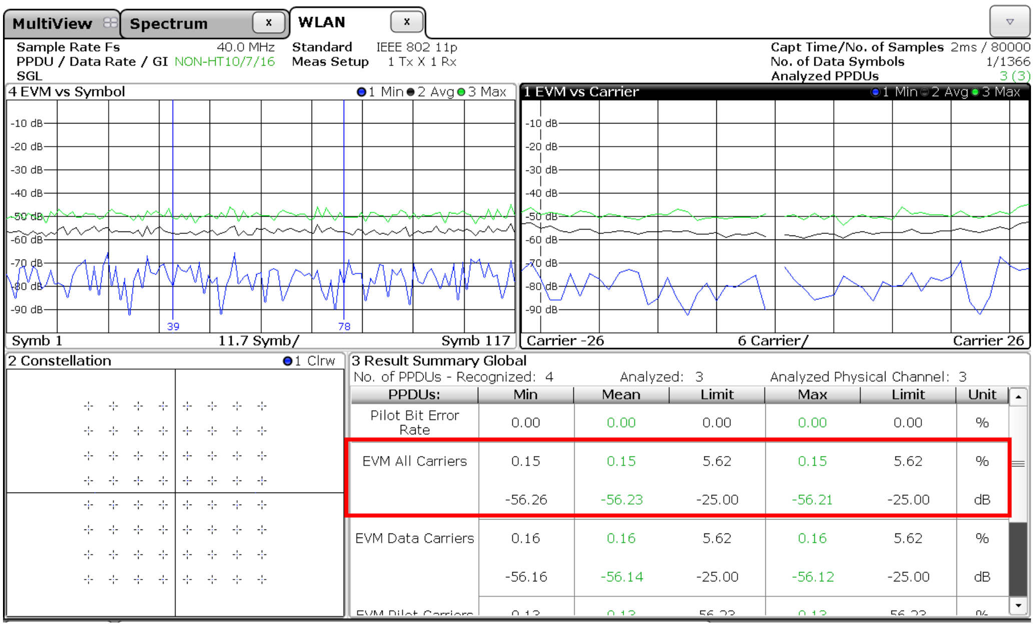
Relative constellation error (RCE), which is also referred to as Error Vector Magnitude (EVM), is a measure of how much an actual constellation point deviates from its ideal position. Modulation dependent limits for the 802.11 OFDM PHY are given in Table 5. Note that this requirement is the same regardless of the signal bandwidth. The transmitted signal must have at least 16 symbols per frame and should contain random data. EVM results must be averaged across at least 20 frames.

Modulation	Coding Rate	RCE (dB)
BPSK	1/2	-5
BPSK	3/4	-8
QPSK	1/2	-10
QPSK	3/4	-13
16QAM	1/2	-16
16QAM	3/4	-19
64QAM	2/3	-22
64QAM	3/4	-25

Table 5: RCE specification

For accurate estimation of the DUT EVM, the spectrum analyzer's own EVM must be very low in order not to distort the measurement. The excellent RF performance of the R&S®FSW leads to a very low residual EVM of only -56 dB (see Figure 5-2).

The FSx-K91p offers further result displays like EVM vs. Carrier and EVM vs. Symbol for detailed analysis the DUT behavior.



Sample Rate Fs 40.0 MHz
PPDU / Data Rate / GI NON-HT10/7/16
SGL
Standard IEEE 802 11p
Meas Setup 1 Tx X 1 Rx
Capt Time/No. of Samples 2ms / 80000
No. of Data Symbols 1/1366
Analyzed PPDUs 3 (3)

3 Result Summary Global
No. of PPDUs - Recognized: 4 Analyzed: 3 Analyzed Physical Channel: 3

PPDUs:	Min	Mean	Limit	Max	Limit	Unit
Pilot Bit Error Rate	0.00	0.00	0.00	0.00	0.00	%
EVM All Carriers	0.15	0.15	5.62	0.15	5.62	%
	-56.26	-56.23	-25.00	-56.21	-25.00	dB
EVM Data Carriers	0.16	0.16	5.62	0.16	5.62	%
	-56.16	-56.14	-25.00	-56.12	-25.00	dB

Figure 5-2: Analysis of a 10 MHz 802.11p signal with R&S®FSW shows a residual EVM of -56dB

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5.1.1.2 Transmitter Spectral Flatness

Spectral flatness measures the average power per subcarrier and is used for estimating the spectral distortion caused by the device under test (DUT) e.g. by the transmitter filter. Power variations across carriers must remain within specified limits shown in Figure 5-3. The limits are given relative to the average power of all non-null subcarriers.

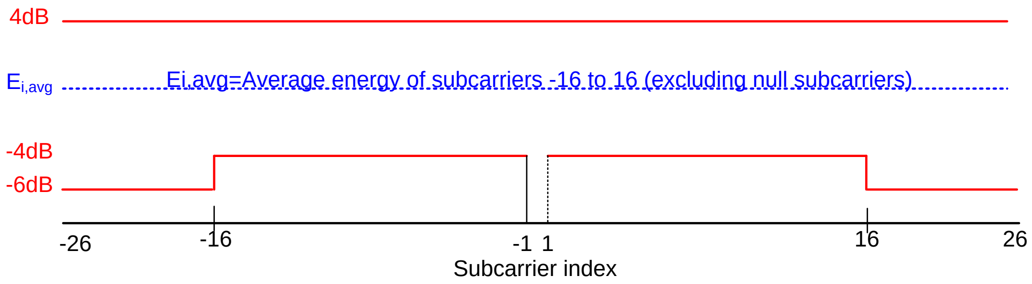


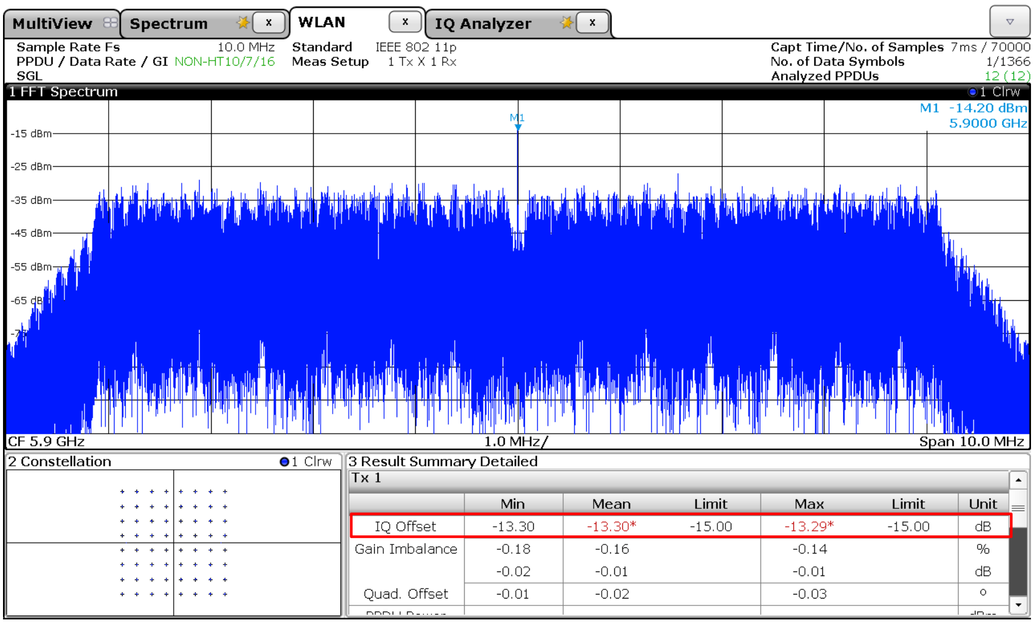
Figure 5-3: Spectral Flatness specification

Figure 5-4: FSW-K91p Spectral Flatness Display with Automatic Limit Line Check

5.1.1.3 Transmitter Center Frequency Leakage

802.11p does not use the DC carrier at the center frequency for transmission. Signal energy leaking through at this frequency reduces the DUT’s efficiency. Carrier leakage can also cause problems for receiver designs that use a direct down-conversion concept (zero IF receiver). Center Frequency Leakage measures the amount of signal energy present at the DC carrier. The leakage shall not exceed -15 dB relative to the total transmit power.

Figure 5-5 shows the result table with the IQ Offset measurement indicating the amount of center frequency leakage. The option automatically checks if specification limits are violated.



Sample Rate Fs 10.0 MHz
PPDU / Data Rate / GI NON-HT10/7/16
SGL
Standard IEEE 802 11p
Meas Setup 1 Tx X 1 Rx
Capt Time/No. of Samples 7ms / 70000
No. of Data Symbols 1/1366
Analyzed PPDUs 12 (12)

M1 -14.20 dBm
5.9000 GHz

Tx 1

	Min	Mean	Limit	Max	Limit	Unit
IQ Offset	-13.30	-13.30*	-15.00	-13.29*	-15.00	dB
Gain Imbalance	-0.18	-0.16		-0.14		%
	-0.02	-0.01		-0.01		dB
Quad. Offset	-0.01	-0.02		-0.03		°

Figure 5-5: IQ offset and other IQ impairments shown in the Result Table. The FFT Spectrum shows the carrier leakage at the center frequency.

5.2 802.11p Spectrum Quality

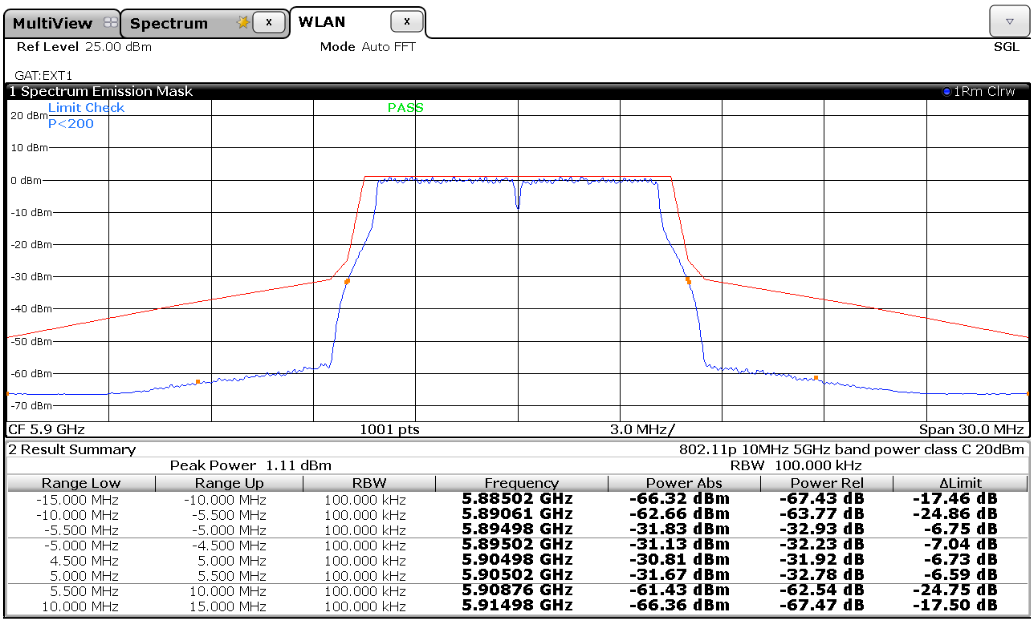
Spectrum Quality measurements analyze the DUT’s transmitter spectrum and any emissions outside the transmission band. To prevent distorting neighboring transmission channels, spectral power in these domains must stay below specified limits. The following are typical transmitter tests:

- Transmit power
- Occupied bandwidth
- Out-of-band measurements such as spectrum emission mask or spurious emissions

5.2.1 802.11p 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 applicable spectrum emission mask (SEM). The FSx-K91p application firmware offers spectrum masks for all power classes according to the 802.11 specification. Additionally regional masks for the U.S.A. (FCC 47 CFR) and Europe (ETSI EN 302 571) are included.

The SEM for power classes C and D put high demands on the dynamic range of the spectrum analyzer to be able to measure unwanted emissions down to -65 dBr with sufficient level accuracy. Figure 5-6 shows a measurement of a Class C device. At the outer frequency offsets of the mask (-50 dBr) the FSW has a large margin of about 17 dB to the mask limit. For Class D devices with an outer limit of -65 dBr the FSW still provides a margin of about 5 dB.



Ref Level 25.00 dBm

Mode Auto FFT

GAT:EXT1

2 Result Summary

802.11p 10MHz 5GHz band power class C 20dBm

Peak Power 1.11 dBm

RBW 100.000 kHz

Range Low	Range Up	RBW	Frequency	Power Abs	Power Rel	ΔLimit
-15.000 MHz	-10.000 MHz	100.000 kHz	**5.88502 GHz**	**-66.32 dBm**	**-67.43 dB**	**-17.46 dB**
-10.000 MHz	-5.500 MHz	100.000 kHz	**5.89061 GHz**	**-62.66 dBm**	**-63.77 dB**	**-24.86 dB**
-5.500 MHz	-5.000 MHz	100.000 kHz	**5.89498 GHz**	**-31.83 dBm**	**-32.93 dB**	**-6.75 dB**
-5.000 MHz	-4.500 MHz	100.000 kHz	**5.89502 GHz**	**-31.13 dBm**	**-32.23 dB**	**-7.04 dB**
4.500 MHz	5.000 MHz	100.000 kHz	**5.90498 GHz**	**-30.81 dBm**	**-31.92 dB**	**-6.73 dB**
5.000 MHz	5.500 MHz	100.000 kHz	**5.90502 GHz**	**-31.67 dBm**	**-32.78 dB**	**-6.59 dB**
5.500 MHz	10.000 MHz	100.000 kHz	**5.90876 GHz**	**-61.43 dBm**	**-62.54 dB**	**-24.75 dB**
10.000 MHz	15.000 MHz	100.000 kHz	**5.91498 GHz**	**-66.36 dBm**	**-67.47 dB**	**-17.50 dB**

Figure 5-6: SEM for 802.11p signal at 5.9 GHz and 10 MHz bandwidth operating at power class C (R&S®FSW).

5.2.2 Transmit Center Frequency and Symbol Clock Tolerance

This measurement determines the offset of the actual signal's center frequency from the desired center frequency. The symbol clock error is the difference between the transmitter and receiver sampling clocks. In both cases, the tolerance shall be within 20 ppm (parts per million) for 20 MHz and 10 MHz channels and within 10 ppm for 5 MHz channels. An OFDM signal with inaccuracies in symbol clock frequency or center frequency can lead to high constellation errors (see 5.1.1.1). Transmitter frequency inaccuracy may also result in failed spectrum mask and/or failure of the station to connect to an access point or to another station.

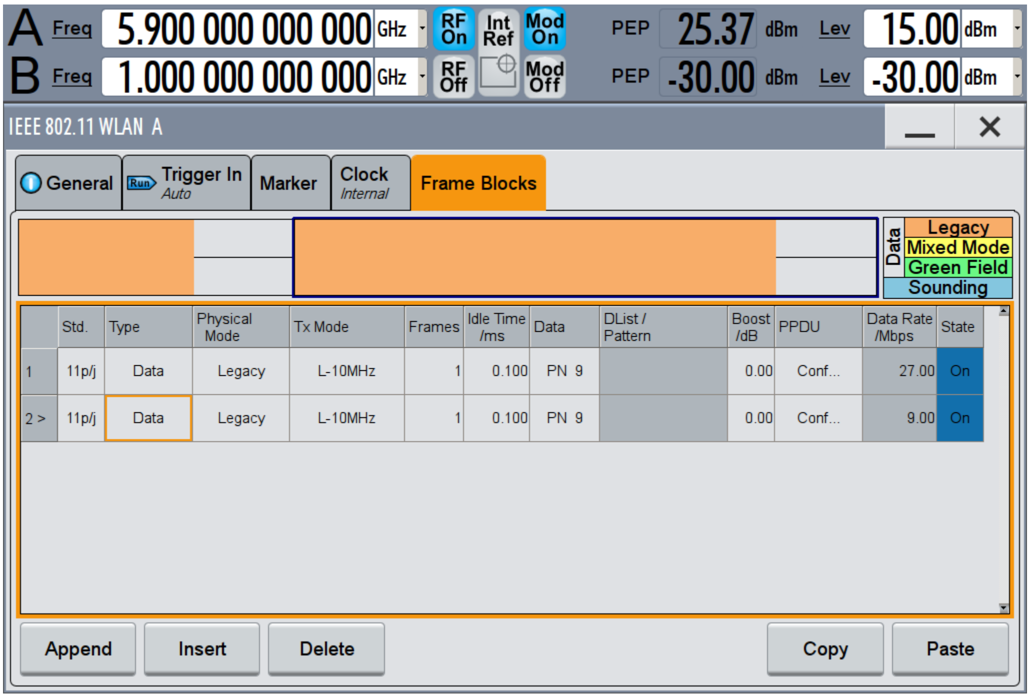
5.3 802.11p Receiver Tests

Receiver tests verify the DUTs ability to correctly receive and demodulate an incoming signal. Tests are typically performed at very low and very high input levels and in the presence of nearby interferers. The figure of merit for receiver tests is the Packet Error Rate (PER). It is the ratio of received packets containing bit errors to the total number of transmitted packets. A signal generator transmits a predefined number of packets and the DUT is queried for the number of correctly received packets.

For performing physical layer receiver tests, ideal signals with very low distortion have to be generated. Rohde & Schwarz vector signal generators like the R&S®SMW200Aor

R&S®SMBV100A make it very easy to set up an 802.11p signal. For pure baseband applications, signals can also be generated using the R&S®AFQ100A/B.

The WLAN option SMx-K54 includes the standards 802.11a/b/g/n and p. The Frame Sequencer can generate mixed signals with different parameters for each packet like bandwidth or data rate. To generate a standard-compliant WLAN 802.11p packet, simply select “11p/j” in the first column of Frame Sequencer table.



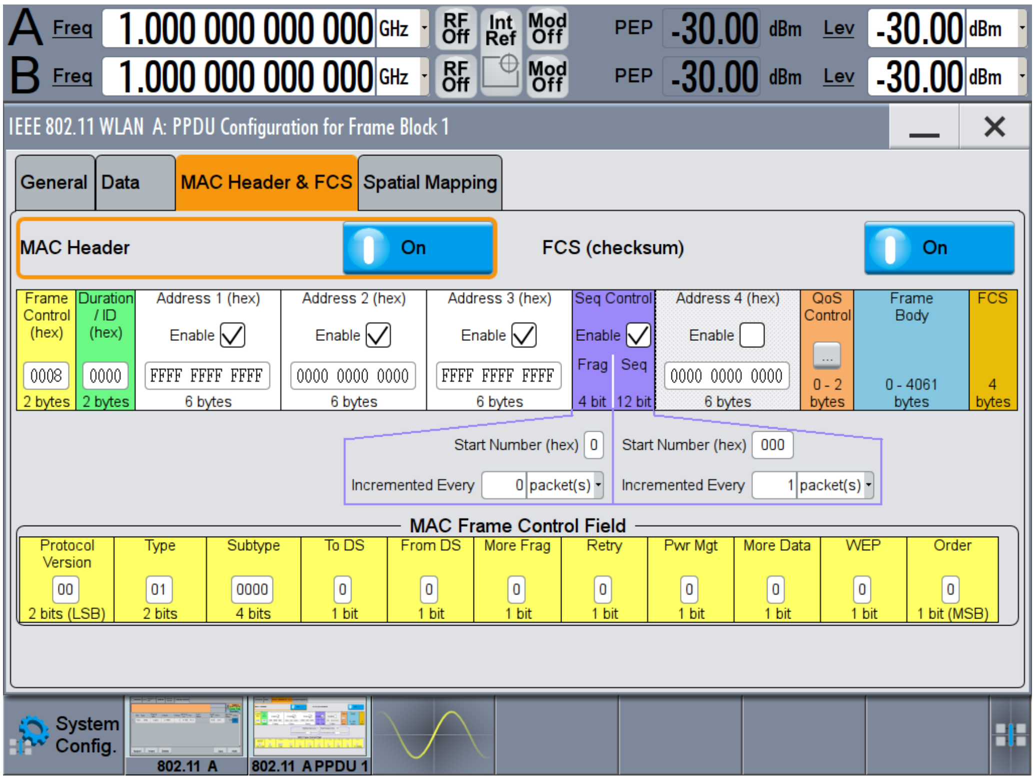
A Freq 5.900 000 000 000 GHz PEP 25.37 dBm Lev 15.00 dBm

B Freq 1.000 000 000 000 GHz PEP -30.00 dBm Lev -30.00 dBm

	Std.	Type	Physical Mode	Tx Mode	Frames	Idle Time /ms	Data	DList / Pattern	Boost /dB	PPDU	Data Rate /Mbps	State
1	11p/j	Data	Legacy	L-10MHz	1	0.100	PN 9		0.00	Conf...	27.00	On
2 >	11p/j	Data	Legacy	L-10MHz	1	0.100	PN 9		0.00	Conf...	9.00	On

Figure 5-7: R&S®SMW200A WLAN 11p signal generation.

An 802.11p conformant MAC header can be added to each frame with the option of including the Frame Check Sequence (FCS). All fields are freely configurable by the user. A typical MAC header for 11p is shown in Figure 5-8.



IEEE 802.11 WLAN A: PPDU Configuration for Frame Block 1

MAC Header: On

FCS (checksum): On

Frame Control (hex)	Duration / ID (hex)	Address 1 (hex)	Address 2 (hex)	Address 3 (hex)	Seq Control	Address 4 (hex)	QoS Control	Frame Body	FCS
		Enable ☑	Enable ☑	Enable ☑	Enable ☑	Enable ☐			
0008	0000	FFFF FFFF FFFF	0000 0000 0000	FFFF FFFF FFFF	Frag / Seq	0000 0000 0000			
2 bytes	2 bytes	6 bytes	6 bytes	6 bytes	4 bit / 12 bit	6 bytes	0 - 2 bytes	0 - 4061 bytes	4 bytes

Frag: Start Number (hex) 0, Incremented Every 0 packet(s)

Seq: Start Number (hex) 000, Incremented Every 1 packet(s)

MAC Frame Control Field

Protocol Version	Type	Subtype	To DS	From DS	More Frag	Retry	Pwr Mgt	More Data	WEP	Order
00	01	0000	0	0	0	0	0	0	0	0
2 bits (LSB)	2 bits	4 bits	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit (MSB)

Figure 5-8: MAC Header Configuration

5.3.1 Receiver minimum input sensitivity

The test analyzes the sensitivity of the DUT at very low input levels. The minimum input level where no more than 10% PER occurs is determined. The minimum sensitivity levels depend on the modulation and channel bandwidth and are given in Table 8.

Modulation	Coding Rate	20MHz (dBm)	10MHz (dBm)	5MHz (dBm)
BPSK	1/2	–82	–85	-88
BPSK	3/4	–81	–84	-87
QPSK	1/2	–79	–82	-85
QPSK	3/4	–77	–80	-83
16QAM	1/2	–74	–77	-80
16QAM	3/4	–70	–73	-76
64QAM	2/3	–66	–69	-72
64QAM	3/4	–65	–68	-71

Table 6: Receiver Minimum Sensitivity Specification

5.3.2 Receiver Maximum Input Level

Receiver maximum input level tests the ability of the receiver to demodulate an 11p signal with a high input level. A -30 dBm signal is applied at the antenna port and the PER is measured and must be below 10%.

5.3.3 Adjacent and Nonadjacent channel rejection

The adjacent channel rejection measures the ability of a receiver to demodulate and decode a desired signal in the presence of an interfering signal in an adjacent or nonadjacent channel. Figure 5-9 and Figure 5-10 illustrate the concept. For 802.11 OFDM, the desired signal's power is set 3 dB above the minimum sensitivity given in Table 6. The power of the interfering signal in the adjacent channel is increased until the measured PER of the wanted signal reaches 10%. The power difference for 11p devices between the desired signal and interfering signal at 10% PER must be greater or equal to the rate dependent value given in Table 7.

Modulation	Coding Rate	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

Table 7: Adjacent and Nonadjacent Channel Rejection Requirements

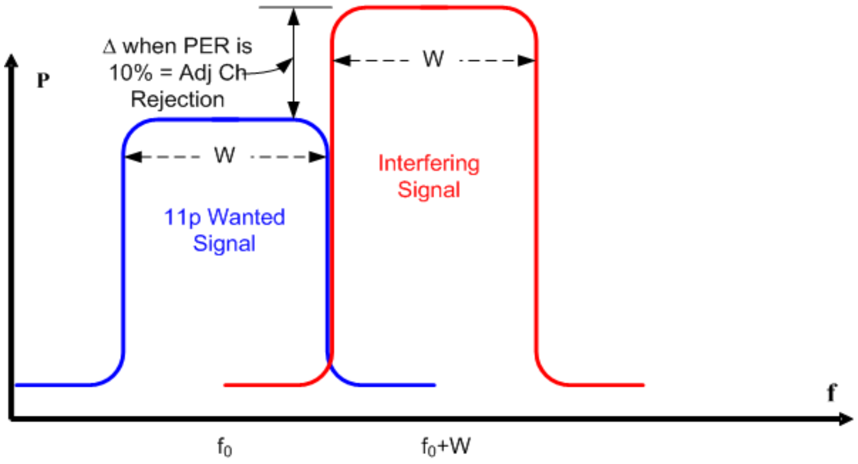


Figure 5-9: Adjacent channel rejection. For 802.11p, W= 10 MHz. Psig is set 3 dB above the bandwidth dependent sensitivity level given in Table 6

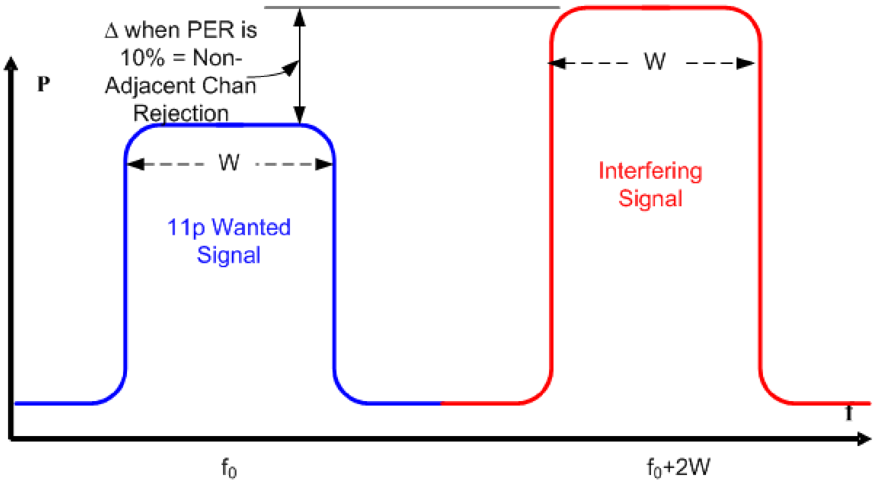


Figure 5-10: Nonadjacent channel rejection. For 802.11p, W= 10 MHz.

5.3.4 Clear Channel Assessment (CCA)

The clear channel assessment tests the ability of the 11p device to determine if a channel is free or occupied. If occupied, the 802.11 PHY indicates this by setting a CCA indication signal field to busy.

The device is required to detect whether the channel is busy with a probability greater than 90% within 4µs for a 20MHz channel, 8µs for a 10MHz channel and 16µs for a 5 MHz channel. The power level of the occupying signal is set to the minimum sensitivity for BPSK modulation (see Table 6).

The test setup (**Fehler! Verweisquelle konnte nicht gefunden werden.**) consists of a vector signal generator providing the occupying RF signal to the DUT. Further access to the CCA pin of the DUT is necessary. An oscilloscope triggered from the signal generator can be used to measure the time the DUT needs to detect an occupied channel.

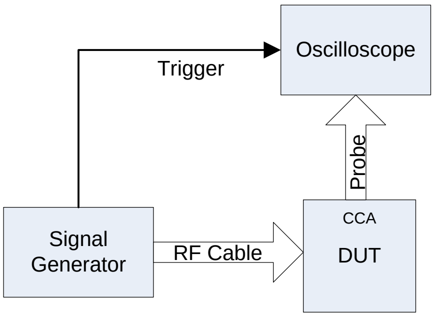


Figure 5-11: CCA Test setup

5.3.5 802.11p Receiver Tests under Fading Conditions

The 802.11p amendment is designed for vehicular environments. 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 Doppler shifts appear according to the relative velocity between transmitter and receiver. In such a critical environment, a repeatable real-time fading simulation with Rice, Doppler, etc., is needed. Although the 802.11 standard does not include specifications for the fading/channel models, other organizations (C2C and ETSI) have developed fading parameters in order to make realistic assessments of the ITS receiver performance.

The multipath propagation and Doppler shifts will depend on the conditions in which the vehicle is driven. For example, the fading profile for a vehicle driving on a highway will be different from a car driving in a congested metropolitan area with many buildings and obstacles. Thus, five fading scenarios have been defined and generally agreed:

- Rural LOS (Line of Sight): This scenario depicts an open environment devoid of buildings, large fences and vehicles.
- Urban Approaching LOS: This scenario applies to an urban environment where buildings are present. The vehicles are approaching each other and are able to see each other.
- Street Crossing NLOS: This scenario describes the case where two vehicles are approaching a blind intersection and cannot see each other (because, for example, a building is located at the corner of the intersection.)
- Highway LOS: This scenario refers to cars on multi-lane roadways (e.g. the German Autobahn or the US interstate). Vehicles are able to see each other.
- Highway NLOS: This scenario refers to cars on multi-lane roadways (e.g. the German Autobahn or the US interstate). However, in this case, a large truck is between the vehicles and the drivers are unable to see each other.

The University of Berkeley, CohdaWireless and Lund University performed independent field trials measuring delay spread and Doppler shift for the various scenarios. Using the data found during the field trials, they were able to define statistical models of the channel for each scenario. These models use a tapped delay line with each tap described by:

- Power (dB relative to reference level)
- A fixed delay (ns)
- Maximum Doppler frequency (Hz)
- Doppler spectrum profile (static or half bathtub)

In typical cellular channel models, a Rayleigh profile is used that is assumed to have zero mean and be symmetric around the carrier. In a vehicular environment where both the transmitter and receiver are moving, the Doppler spectrum becomes asymmetric because the multipath signals are absorbed by obstacles or the propagation environment is characterized by directional non-isotropic scattering [10]. An example provided in [11] is two cars approaching a blind intersection will tend to compress frequency on the direct path but may stretch frequency on a reflected path of a following truck. Therefore, the channel model developers selected a half bathtub (HalfBT) Doppler spectrum profile to describe the channel conditions more accurately.

ETSI and the Car 2 Car Consortium have incorporated these models as part of their draft specifications for ITS receiver tests; Table 8 through Table 12 provide the channel settings to model fading for the five scenarios.

	Tap1	Tap2	Tap3		Units
Power	0	-14	-17		dB
Delay	0	83	183		ns
Doppler	0	492	-295		Hz
Profile	Static	HalfBT	HalfBT		

Table 8: Rural LoS Tap Settings [11]

	Tap1	Tap2	Tap3	Tap4	Units
Power	0	-8	-10	-15	dB
Delay	0	117	183	333	ns
Doppler	0	236	-157	492	Hz
Profile	Static	HalfBT	HalfBT	HalfBT	

Table 9: Urban Approaching LoS Tap Settings [11]

	Tap1	Tap2	Tap3	Tap4	Units
Power	0	-3	-5	-10	dB
Delay	0	267	400	533	ns
Doppler	0	295	-98	591	Hz
Profile	Static	HalfBT	HalfBT	HalfBT	

Table 10: Crossing NLoS Tap Settings [11]

	Tap1	Tap2	Tap3	Tap4	Units
Power	0	-10	-15	-20	dB
Delay	0	100	167	500	ns
Doppler	0	689	-492	886	Hz
Profile	Static	HalfBT	HalfBT	HalfBT	

Table 11: Highway LoS [11]

	Tap1	Tap2	Tap3	Tap4	Units
Power	0	-2	-5	-7	dB
Delay	0	200	433	700	ns
Doppler	0	689	-492	886	Hz
Profile	Static	HalfBT	HalfBT	HalfBT	

Table 12: Highway NLOS [11]

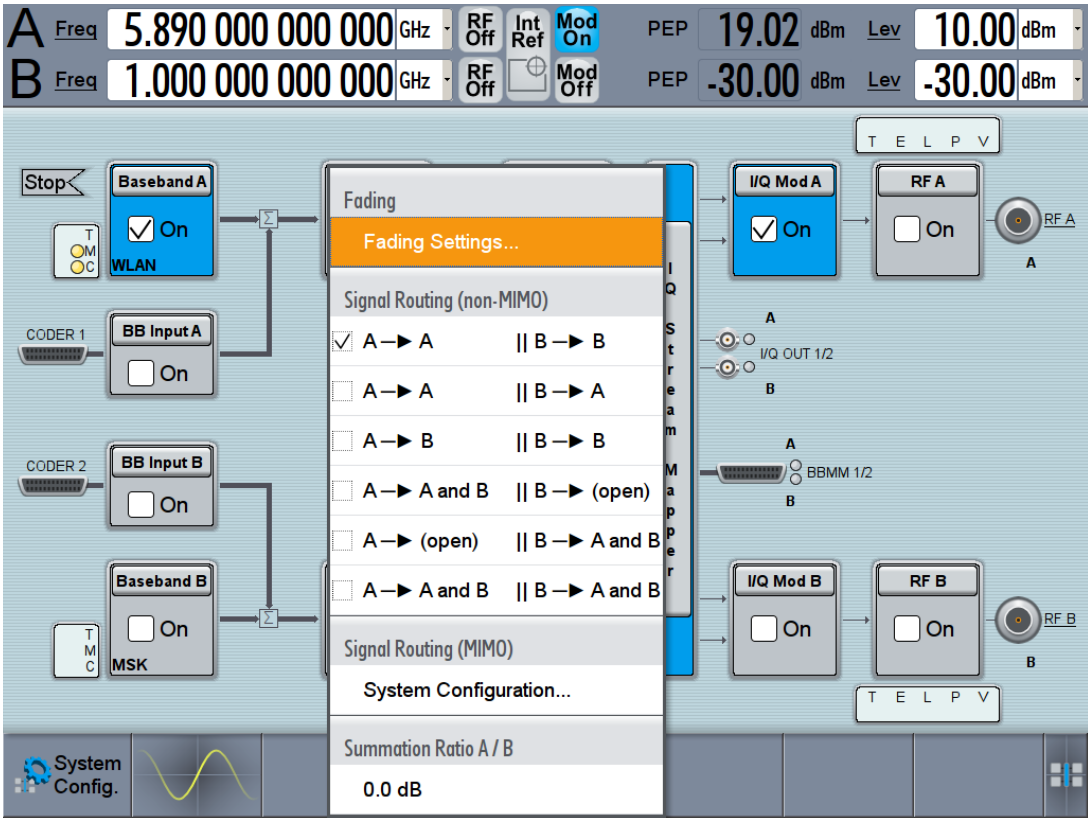
It is critical to test receiver performance under fading conditions. Testing receivers in ’real’ world is laborious and often impractical. A further problem is that fading conditions can typically not be repeated. A signal generator with real time fading capabilities to simulate the channel propagation conditions is needed to assess the receiver performance.

The R&S®SMW200A is the perfect tool for generating the standard compliant 802.11p signal and adding fading to the signal. In addition, it is a unique instrument in that it offers the possibility of two signal paths, which configured with the proper options, provides the capability to test devices supporting MIMO or RX diversity in fading (or without fading) conditions. The signal generator offers predefined fading settings for most digital communication systems (including ITS), but also provides the user flexibility to easily modify the parameters such as number of fading taps, tap delays, tap power, tap speed/Doppler shift, type of fading (e.g. Doppler, Rayleigh, Rician), etc. for user-defined channel conditions.

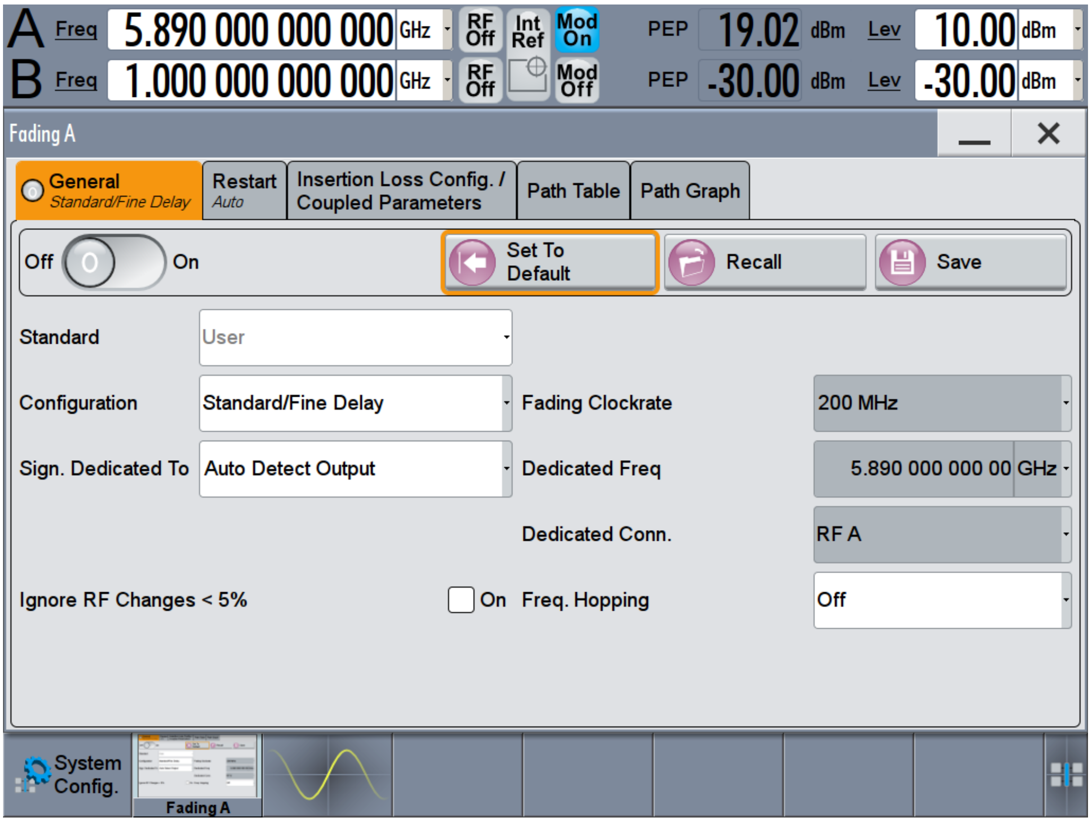
The following will illustrate how to configure the SMW to add fading for the highway LoS scenario defined in Table 11.

Select Fading on SMW:

The following menu is seen:



Select fading settings to open the fading configuration menus:



Standard: User

Configuration: Standard/Fine Delay

Sign. Dedicated To: Auto Detect Output

Fading Clockrate: 200 MHz

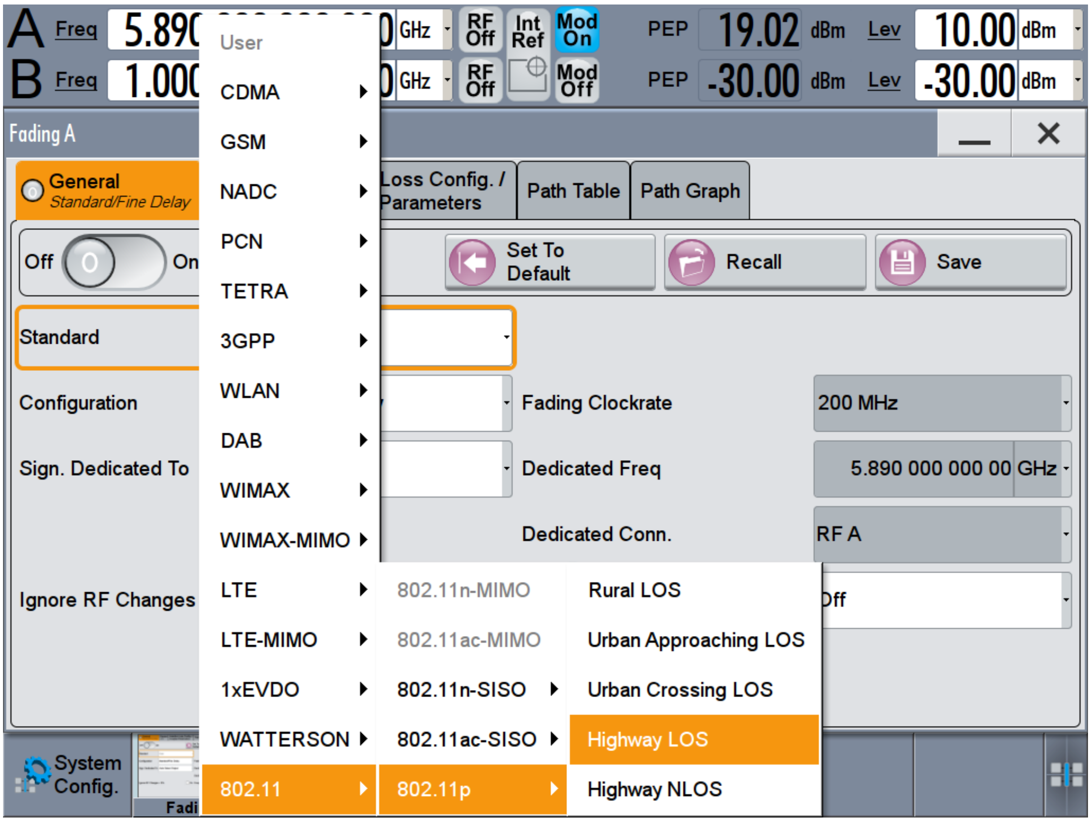
Dedicated Freq: 5.890 000 000 00 GHz

Dedicated Conn.: RF A

Ignore RF Changes < 5% ☐ On

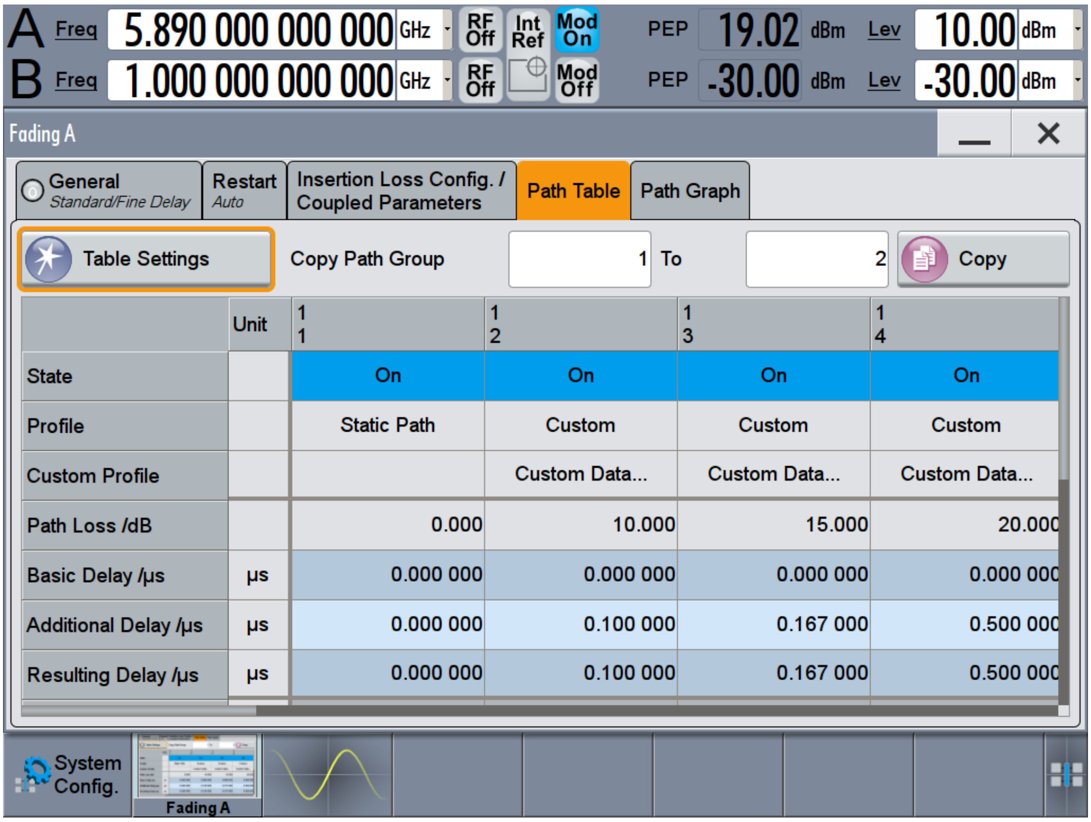
Freq. Hopping: Off

Click on the arrow in the standard field. Select the Highway LoS setting under 802.11p.



The display now shows that the standard is Highway LOS for 11p.

By selecting the path table tab, the SMW settings for the power and delay for the scenario can be verified.



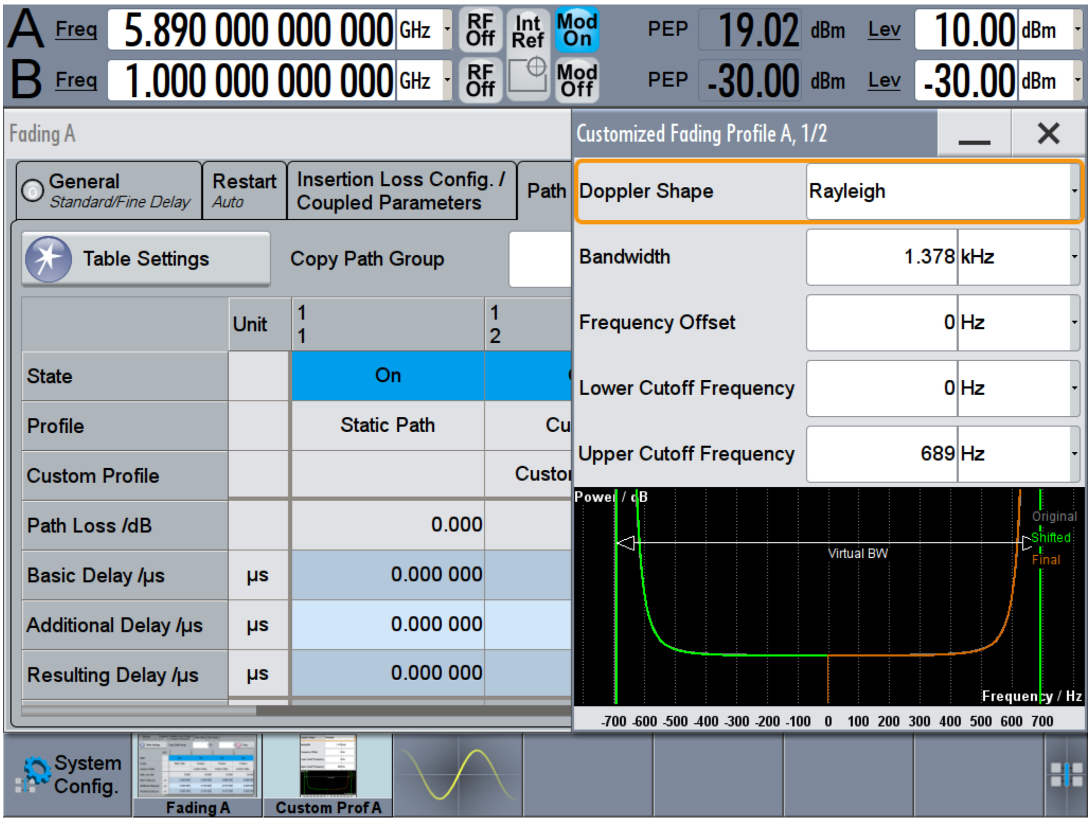
A Freq 5.890 000 000 000 GHz PEP 19.02 dBm Lev 10.00 dBm

B Freq 1.000 000 000 000 GHz PEP -30.00 dBm Lev -30.00 dBm

Copy Path Group 1 To 2

	Unit	1 1	1 2	1 3	1 4
State		On	On	On	On
Profile		Static Path	Custom	Custom	Custom
Custom Profile			Custom Data...	Custom Data...	Custom Data...
Path Loss /dB		0.000	10.000	15.000	20.000
Basic Delay /µs	µs	0.000 000	0.000 000	0.000 000	0.000 000
Additional Delay /µs	µs	0.000 000	0.100 000	0.167 000	0.500 000
Resulting Delay /µs	µs	0.000 000	0.100 000	0.167 000	0.500 000

The Doppler frequency for the half bathtub profile can be verified by clicking on custom data for each of the taps. For tap 2, the Doppler settings are shown here:



A Freq 5.890 000 000 000 GHz PEP 19.02 dBm Lev 10.00 dBm

B Freq 1.000 000 000 000 GHz PEP -30.00 dBm Lev -30.00 dBm

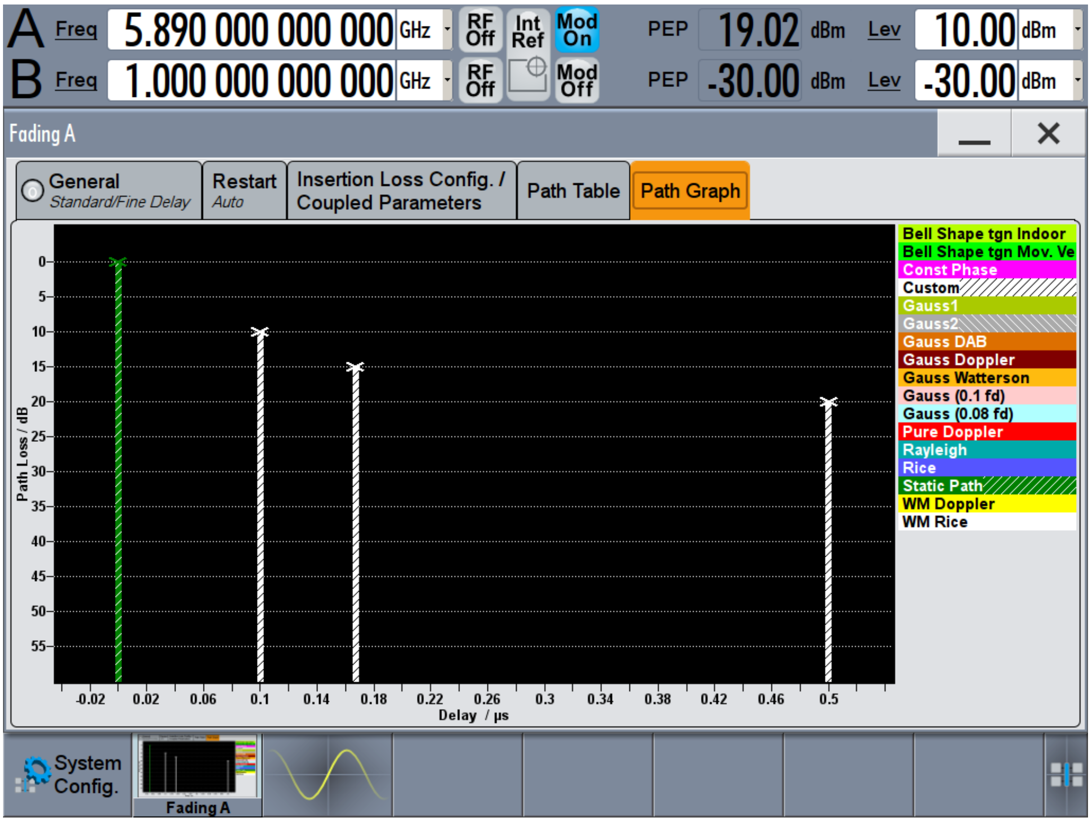
	Unit	1 1	1 2
State		On	
Profile		Static Path	Cu
Custom Profile			Custo
Path Loss /dB		0.000	
Basic Delay /µs	µs	0.000 000	
Additional Delay /µs	µs	0.000 000	
Resulting Delay /µs	µs	0.000 000	

Customized Fading Profile A, 1/2

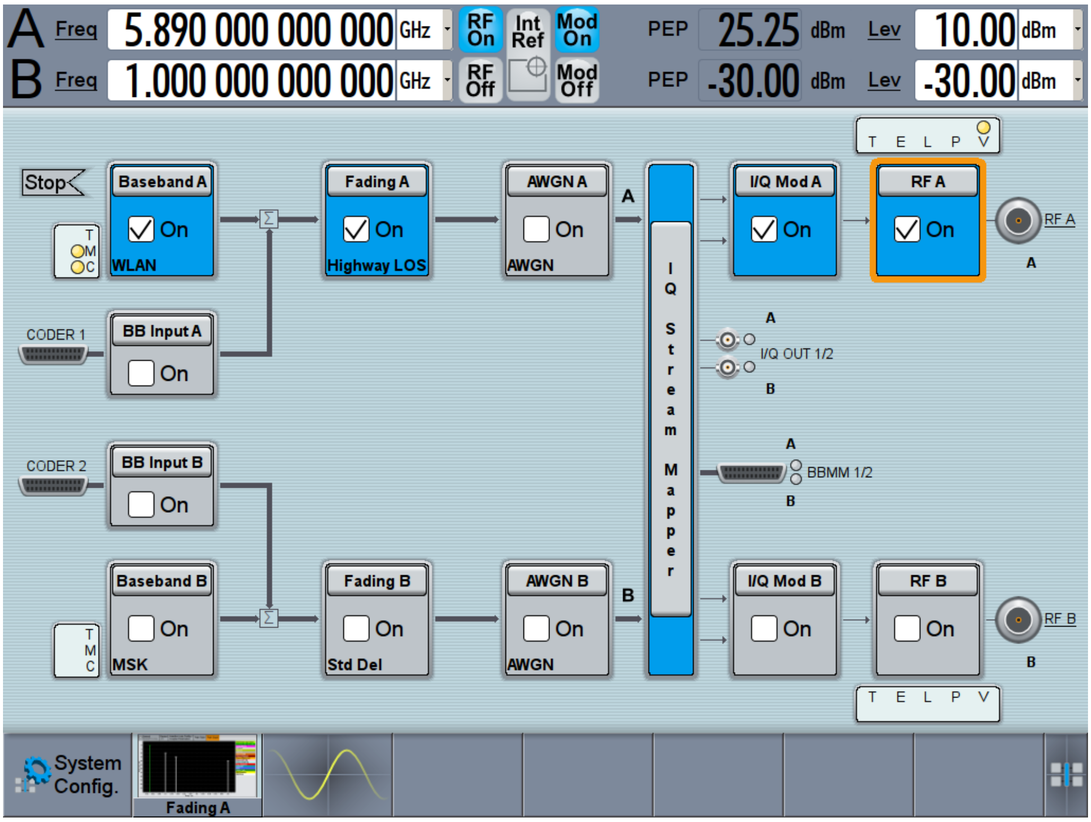
Doppler Shape	Rayleigh
Bandwidth	1.378 kHz
Frequency Offset	0 Hz
Lower Cutoff Frequency	0 Hz
Upper Cutoff Frequency	689 Hz

The bandwidth value is the value of the ‘original’ Doppler profile, ie the bandwidth that would be used if the profile were the full bathtub. For tap 2 of the highway LOS scenario, this value is 2*(689 Hz) = 1.378 KHz. Then, the cutoff frequency to achieve the half bathtub is 0 Hz for the lower cutoff frequency and 689 Hz for the upper frequency. Fortunately, the SMW takes care of the proper settings so the user need not worry about entering the values.

To see a graphical display of the tap settings, select that path’s graph tab:



After the desired profile has been selected, close or minimize the fading window and turn on the fading and the RF.


A Freq 5.890 000 000 000 GHz

PEP 25.25 dBm

Lev 10.00 dBm

B Freq 1.000 000 000 000 GHz

PEP -30.00 dBm

Lev -30.00 dBm

Baseband A ☑ On WLAN

Fading A ☑ On Highway LOS

AWGN A ☐ On AWGN

I/Q Mod A ☑ On

RF A ☑ On

BB Input A ☐ On

BB Input B ☐ On

Baseband B ☐ On MSK

Fading B ☐ On Std Del

AWGN B ☐ On AWGN

I/Q Mod B ☐ On

RF B ☐ On

6 Conclusion

Automotive companies and government agencies worldwide have been seeking ways to reduce road fatalities and improve traffic flow. Intelligent Transportation Systems using wireless communication hold great promise to answer these challenges. Because the MAC and PHY of the ITS is based on 802.11, the costs of the devices and systems can be kept relatively low. Unlike typical data services, ITS must be reliable; degradations due to cross channel interference, fading and channel congestion lead to more stringent transmitter and receiver requirements. Test equipment such as the R&S®FSW spectrum/signal analyzer and the R&S®SMW signal generator with fading options allow design engineers to easily test the ITS devices for compliance and performance.

7 Bibliography

Im aktuellen Dokument sind keine Quellen vorhanden.

8 Ordering Information

Ordering information		
Vector Signal Generator		
Product Description	**Type**	**Order No.**
Vector Signal Generator	SMW200A	1412.0000.02
Baseband Generator	SMW-B10	1413.1200.02
SMW-B11 Baseband Generator	SMW-B11	1159.8411.02
Baseband Main Module	SMW-B13	1141.8003.04
1st RF path	SMW-B10x	
2nd RF path	SMW-B20x	
AWGN	SMW-K62	
Fading		
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®FSV3000	FSV3-K91	1330.5100.02
WLAN 802.11a/b/j/g/n Application Firmware for R&S®FSV3000	FSV3-K91p	1330.5122.02
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

Designation	**Type**	**Order No.**
Signal and Spectrum Analysis Solutions		
FSV3000		
Signal- and Spectrum analyzer 10 Hz to 7.5 GHz	FSV3007	1330.5000.07
Signal- and Spectrum analyzer 10 Hz to 13.6 GHz	FSV3013	1330.5000.13
WLAN 802.11a/b/g/j Application Firmware	FSV3-K91	1330.5100.02
WLAN 802.11p Application Firmware	FSV3-K91p	1330.5122.02
WLAN 802.11ac Application Firmware	FSV3-K91ac	1330.5116.02
FSW		
Signal- and Spectrum analyzer 2 Hz to 8 GHz	FSW8	1312.8000.08
Signal- and Spectrum analyzer 2 Hz to 13 GHz	FSW13	1312.8000.13

WLAN 802.11a/b/g Application Firmware	FSW-K91	1313.1500.02
WLAN 802.11p Application Firmware	FSW-K91p	1321.5646.02
WLAN 802.11ac Application Firmware	FSW-K91ac	1313.4209.02
Signal Generation and Fading Solutions		
SMW200A		
Vector Signal Generator 100 kHz to 6 GHz	SMW200A	1412.0000.02
Fading Simulator	SMW-B14	1413.1500.02
IEEE 802.11 (a/b/g/n/p) Digital Standard	SMW-K54	1413.4139.02
IEEE 802.11ac Digital Standard	SMW-K86	
Software Options		
WLAN 802.11a/b/g Application Firmware	FSW-K91	1313.1500.02
WLAN 802.11p Application Firmware	FSW-K91p	1321.5646.02
WLAN 802.11ac Application Firmware	FSW-K91ac	1313.4209.02
WLAN 802.11a/b/g/j Application Firmware	FSV3-K91	1330.5100.02
WLAN 802.11p Application Firmware	FSV3-K91p	1330.5122.02
WLAN 802.11ac Application Firmware	FSV3-K91ac	1330.5116.02
IEEE 802.11 (a/b/g/n/p) Digital Standard	SMW-K54	1413.4139.02

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