

Products: SMIQ, SMV, AMIQ

## 802.11 Packet Error Rate Testing

### Application Note

When measuring the performance of 802.11 wireless LAN compatible receivers, Packet Error Rate (PER) tests are the method of choice today. This application note describes a simple way to conduct PER tests using signal generators on any 802.11 device, independent of their physical layer design (11b, 11a or 11g). The application software works with standard Windows™ drivers on any card independent of manufacturer. No additional hardware specific software is needed. Easy setup of the source signal is included with direct upload to an SMIQ or AMIQ.



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## 1 Overview

There are two standard methods for conducting PER Tests on an 802.11 device: 1. Obtain the raw data bits received by the Device Under Test (DUT) and compare them with the sent ones. With the measured Bit Error Rate (BER) the PER can be determined. 2. Read out a DUT-internal CRC mismatch counter. With the 32-bit CRC used by the 802.11 standard the probability of undetected erroneous packets is very small, only  $2.3E-10$ . Therefore the CRC mismatch method is commonly used, as the practical implementation costs are low.

For both methods a chip vendor specific software is required to directly get the results from the 802.11 device. If this is not available, it is possible to transmit packets with an unreliable protocol (like UDP) and count the missing packets on the receiver side, as the 802.11 device drops any packets with CRC errors. The second approach is not easily available when utilizing signal generators to provide the source signal. Devices typically need to establish a two-way network connection before they accept normal data traffic. So-called "golden devices" are needed as signal sources. The disadvantages are clear: Golden devices often do not provide ideal or even known signal performance. Drift effects over temperature or time affect signal quality and significantly influence the results of receiver characterization. Quasi-ideal signal sources like signal generators are often the better choice.

The method proposed here shows a convenient way to overcome all the disadvantages of the above solutions. Network traffic transmitted by a vector signal generator is received by devices using standard Windows drivers only; the application software provided enables PER measurement. All the different receiver tests like minimum / maximum input level or adjacent channel rejection can be conducted with a simple setup.

## 2 Principle of Operation

The first hurdle to get over is to make a device in normal operation mode accept data frames transmitted by a signal generator without an available reverse transmission channel. A closer look at network connection establishment in 802.11 reveals that first a set of Probe Request and Probe Response frames are exchanged between two active stations searching for each other. One station typically probes others by transmitting Probe Request frames and waits a specific period for an answer. If several frames have been sent and no answer occurs, it repeats the procedure on other

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channels (see Figure 2-1). If a Probe Response frame is received successfully in reply to a transmitted Probe Request, the searching station knows that two-way communication is possible with the answering station. Its MAC address is contained in the Probe Response frame and is therefore known to the searching station.

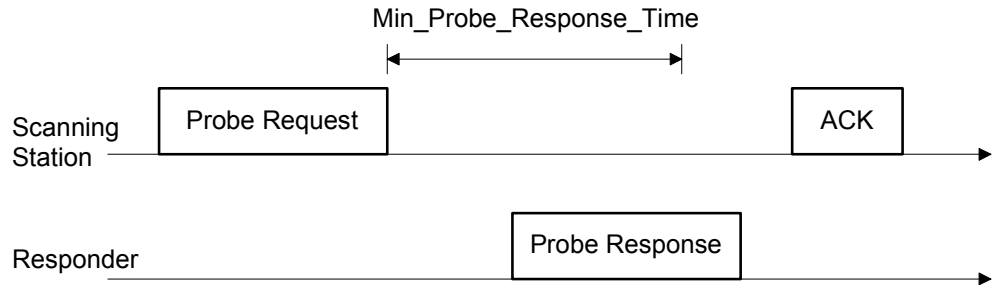


Figure 2-1: Probing procedure

After a successful procedure, both stations start transmitting Beacon frames containing information about the network. As long as the Beacons are received, network connection is established.

A trick makes the device accept data frames from the signal generator. The generator repeats a sequence of Beacon, Probe Response and Data frames over and over again, as shown in Figure 2-2. The Probe Response frames are directed to the DUT and usually fall in one of the device's receiving windows after a short period of time. The DUT accepts the Beacons from the generator and the transmitted Data frames are available to the higher layer network software. The Probe Response frames must be transmitted directly to the DUT; the MAC address of the DUT must be known and the signal configured accordingly.

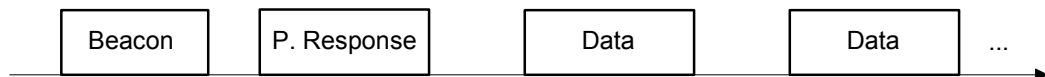


Figure 2-2: Sequence repeated by the signal generator






To determine the PER, count received and missing Data frames. The corrupted frames fail the CRC check in the card and are not handed over to the evaluation software. By marking all frames with numbers, finding the missing ones is easy.

### 3 Hardware and Software Requirements

#### 3.1 Hardware Requirements

Table 3-1 gives an overview on the possible signal generator & Arbitrary Waveform Generator (ARB) combinations suitable for PER testing of devices compatible to the different standards.

Table 3-1: Generator combinations suitable for the different standards

					
	SMIQ03B + B60	SMIQ06B + B60	SMIQ03B + AMIQ	SMIQ06B + AMIQ	SMV + AMIQ
802.11b	👍	👍	👍	👍	👍
802.11a	✘	👍	✘	👍	✘
802.11g	👍	👍	👍	👍	👍

Options required for SMIQ when using the internal SMIQB60 ARB:

- SMIQB20 + SMIQB11 + SMIQB60
- SMIQK19 (for 11a, 11b and 11g)

The discontinued options SMIQK16 and SMIQK18 are still supported. An installed SMIQK16 option enables 802.11b, and an SMIQK18 option enables 802.11a support. 802.11g is only available with an installed SMIQK19 option.

When using AMIQ as external ARB no options are required for the SMIQ.

Also, no options are required for an SMV, if used.

Options required for the AMIQ:

- AMIQK19 (for 11a, 11b and 11g)

The discontinued options AMIQK16 and AMIQK18 are still supported. An installed AMIQK16 option enables 802.11b, and an AMIQK18 option enables 802.11a support. 802.11g is only available with an installed AMIQK19 option.

Either AMIQ03 or AMIQ04 are applicable.

Additional hardware requirements:

- Windows compatible PC with cardbus or Mini-PCI slot to fit the DUT
- GPIB card (we recommend National Instruments)

#### 3.2 Software Requirements

- Windows 95 / 98 / ME or Windows NT / 2000 / XP
- GPIB drivers

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- VISA for your GPIB card (such as NI-VISA from National Instruments)
- Standard Windows network drivers for the DUT

### 4 Test Setup

Setting up the hardware for the tests is simple. Just connect the RF output of the generator to the DUT. An additional signal generator can be added to provide an interfering signal for the adjacent and non-adjacent channel rejection tests, in which case a power combiner is also required.

When setting the levels on the generators make sure that any losses from cables and combiners are taken into account. The 802.11 PER Test tool sets the crest factor in the signal generator so that the set output level corresponds to the mean frame power.

The instruments are controlled over GPIB from the same PC also hosting the DUT.

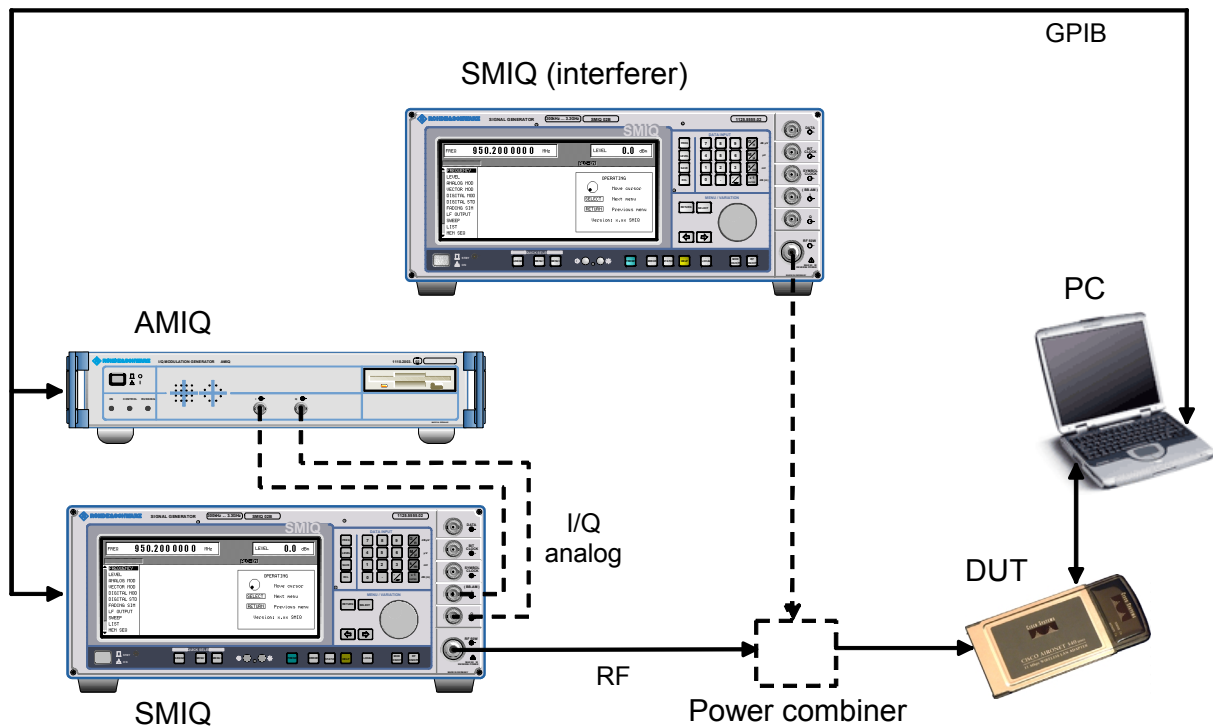


Figure 4-1: Test Setup

### 5 Software Installation

Install the 802.11 PER Test software by running the setup.exe. The required WinPcap driver package is also set up afterwards.

**Please make sure to reboot your system after installation. Otherwise the list of available network adapters might remain empty.**

# 6 Configuring the 802.11 PER Test Tool

The 802.11 PER Test tool includes a complete signal generation module, which enables calculation and uploading of a signal applicable for PER testing. As soon as the signal is set up and transmitted by the generator, an available 802.11 adapter can be chosen and the PER measurement is ready to start.

## 6.1 Configuring the Adapter

First set up the 802.11 device with “Adapter” – “Configure Adapter...” from the main menu.

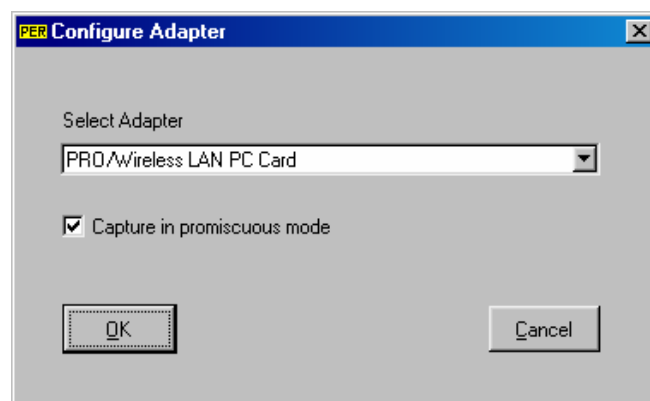


Figure 6-1: Configure Adapter

### **Select Adapter**

Select the 802.11 card to test here. With older Windows versions like Windows NT 4.0 you might not get the real names of your installed network adapters. In this case you have to figure out the right one if more than one card is installed.

### **Capture in promiscuous mode**

This has to be activated for most devices, but some (like Intel cards) require it to be turned off. Experiment if reception fails.

In the driver software which came with your card, set the card operating mode to “IBSS” (Independent Basic Service Set) or “Ad Hoc” and set the channel number to match the one configured in the signal setup dialogue.

### 6.2 Configuring the Signal

Select “Signal” – “Configure Signal...” from the main menu to set up the test signal parameters.

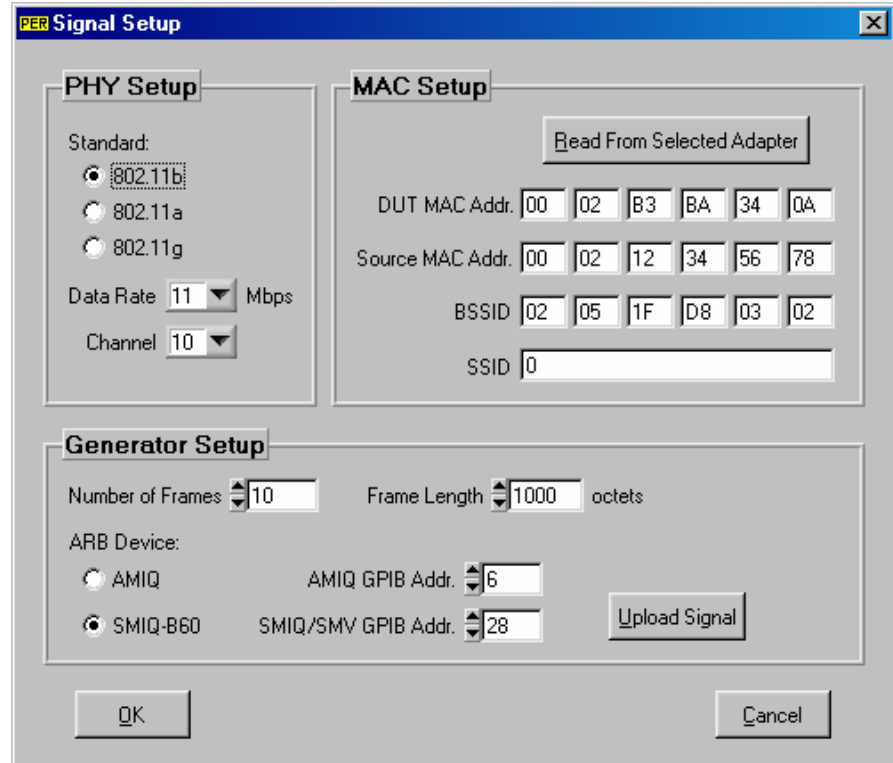


Figure 6-2: Signal Setup

#### 6.2.1 PHY Setup

##### **Standard**

Select one of the 802.11 PHY modes.

##### **Data Rate**

Select the data rate of the Data frames here. The Beacon and Probe Response frames are sent using the lowest rate possible with the selected PHY standard.

##### **Channel**

Select the transmitting channel. If an SMIQ or SMV is connected via GPIB, its frequency is automatically set to correspond to the channel number entered here.

### 6.2.2 MAC Setup

#### ***DUT MAC Addr.***

Enter the MAC address of the device to be tested. **This setting is absolutely essential, otherwise reception is not possible.**

Click on "Read From Selected Adapter" to automatically read out the DUT MAC address from the network adapter chosen in the "Configure Adapter" dialogue. This function works well under Windows 2000/XP. It is not available with Windows NT 4.0. We have not tested Windows 98/ME, but it should also work there.

#### ***Source MAC Addr.***

This address is used as the source address for all frames sent. The default setting usually works fine.

#### ***BSSID (Basic Service Set Identifier)***

The BSSID of the network formed by the generator. The default setting usually works fine.

#### ***SSID (Service Set Identifier)***

The SSID included in the Beacon and Probe Response frames. The default setting usually works, otherwise experiment with this parameter.

### 6.2.3 Generator Setup

#### ***Number of Frames***

The number of unique Data frames generated within one sequence. In principle there are only a few frames per sequence required, as the sequence is repeated over and over again. But best generate a significant number (at least 10, better 100). Every frame is sent with a different random data to simulate a signal closer to a real life scenario. There is also a number identifying every frame, and corrupted frames are detected by finding missing numbers. That means if the number of unique data frames is low, measurement errors occur more frequently at higher PERs. For example if five frames are generated with one sequence, and five corrupted frames in a row occur during the measurement, it is not possible for the software to detect these corrupted packets, resulting in measurement errors.

Experiment with this parameter. It is safe to have a low number (10 for example) if only low PER values are expected. Increase the number if measurement failures occur.

#### ***Frame Length***

The number of octets in the Data frame PSDU. This excludes the MAC header and the FCS bytes. For 802.11b this is 1024. For 802.11a this is 1000 bytes.

#### ***ARB Device***

Either an AMIQ or an SMIQB60 can be used as ARB. Due to lower memory in the SMIQB60 the number of frames per sequence is limited. This has implications on measuring high PER values.

As an example, the SMIQB60 can store a sequence of up to 11 frames with 1000 octets data at 11 Mbps using 802.11b. The AMIQ04 can handle a sequence with up to 565 frames of the same kind.



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### AMIQ / SMIQ/SMV GPIB Addr.

Set the GPIB addresses of the instruments here.

### Upload Signal

After setting all parameters, click on “Upload Signal” to calculate the signal and upload it to the ARB. The waveform is started automatically after a successful upload. When using an SMIQ with SMIQB60, the crest factor and frequency are also set. With an AMIQ, the program additionally tries to find an SMIQ or an SMV with the specified address on the same GPIB bus to automatically set its crest factor and frequency. If no SMIQ/SMV is found, the crest factor has to be set manually to obtain correct signal levels.

When performing a measurement, the PER evaluation module needs information about the transmitted signal. So any signal parameters set in the program must match the waveform played by the generator. Before quitting the program, make sure to save your settings. They have to be loaded again after starting the program if a measurement is about to be conducted with a waveform already stored in the generator.

## 6.3 Running the PER Test

Before starting any PER measurement, make sure that the parameters in the “Configure Signal” dialog match the signal currently played by the generator. Measurement might otherwise fail or give incorrect results.

After picking the right adapter, click “Start” to run the measurement.

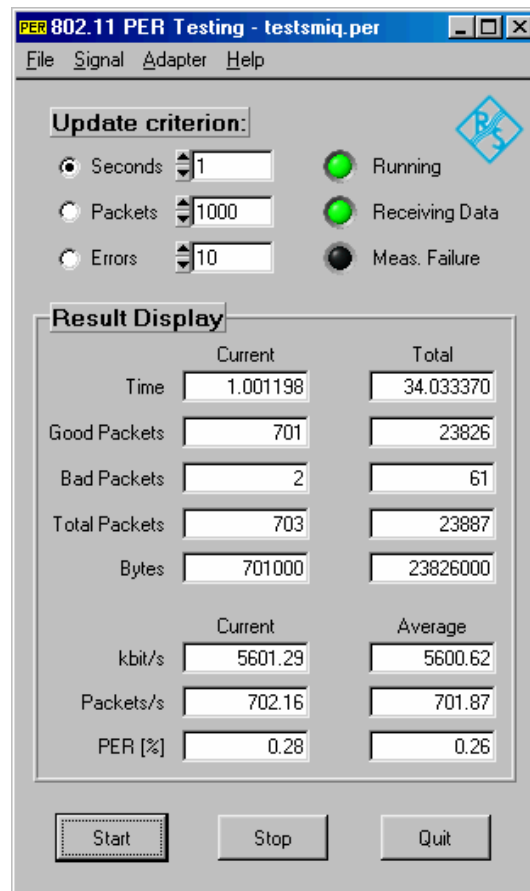


Figure 6-3: The 802.11 PER Test tool main screen

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### **Update criterion**

The measurement results are updated after either a specified period of time, or a number of received (good + bad) packets, or a number of occurred errors. As soon as the selected criterion is reached, the results are calculated from the obtained packets and the display is updated.

### **Result display**

The left column shows the measurement results of the currently obtained row of packets, the right column gives the total or average since the measurement start.

The **Bytes**, **kbit/s** and **Packets/s** values are calculated from the received number of good packets only. Bad packets, Beacons and Probe Response frames are not counted.

If a measurement failure due to long runs of bad packets is suspected, the gathered **PER** result is displayed in red.

## 7 A short introduction to statistics for PER testing

Prior to the PER test, the number of packets to be used as a basis for the PER calculation has to be defined. Since faulty packets occur randomly, measured PER values are as a rule difficult to reproduce. Plus, the number of packets tested directly influences measurement accuracy. The 802.11 standards define no measurement times, just the maximum tolerable PER for the receiver tests (such as 10% in 802.11a). However, information can be found in the statistics literature that correlates measurement time with measurement accuracy, thus offering test engineers a guide to planning the test.

As a first step towards measuring the PER, a discrete random variable can be determined. Without using statistical data as a basis, it is assumed that errors will occur with probability  $p$ . If we decide to examine  $n$  packets, the probability  $p_k$  (exactly  $k$  packets will be identified with errors) will exhibit a binomial distribution:

$$p_k = \binom{n}{k} p^k (1-p)^{n-k}$$

The relative frequency:

$$\hat{p} = \frac{k}{n},$$

which is determined by a measurement, approaches the actual error probability  $p$  as  $n \rightarrow \infty$ .

Since  $p$  will not be immediately known, making an infinite number of measurements to determine  $p$  is not practicable. The measured, relative frequency  $\hat{p}$  will, however, in most cases deviate from the expected value  $p$ . Of interest is the confidence interval  $[p_l ; p_u]$ ; this is the range including  $\hat{p}$  in which the expected value  $p$  will occur with a given probability  $P$ . The confidence interval is determined by means of the F distribution:

$$p_u = \frac{(k+1)F}{n-k+(k+1)F} \quad \text{where } F \left\{ \begin{matrix} v_1=2(k+1); v_2=2(n-k); \frac{1-P}{2} \end{matrix} \right\}$$

$$p_l = \frac{k}{k+(n-k+1)F} \quad \text{where } F \left\{ \begin{matrix} v_1=2(n-k+1); v_2=2k; \frac{1-P}{2} \end{matrix} \right\}$$

given

$$p_l \leq p \leq p_u$$

The values  $v_1$  and  $v_2$  are the two degrees of freedom of the F distribution, and  $P$  is the probability with which the expected value actually occurs in the calculated confidence interval. The values to be substituted for  $F$  are

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derived from the inverse, one-sided F distribution. The F distribution cannot be inverted analytically, so it has to be inverted numerically. The F values can also be taken from a table, where available.

Example 1:

$n = 100$  packets are analyzed, and  $k = 5$  of these are identified with errors. The confidence interval is to be calculated with a confidence level of  $P = 99\%$ : the actual expected value will be outside this interval in only  $1\%$  of all cases.

Result:  $p_l = 1.09\%$ ,  $p_u = 13.51\%$

Note the width of the confidence interval obtained for the above parameter values. The upper value of the confidence interval is still above the stipulated maximum PER of  $10\%$ .

Example 2:

$n = 1000$ ,  $k = 100$ ,  $P = 99\%$

Result:  $p_l = 7.70\%$ ,  $p_u = 12.79\%$

A test length of 1000 packets should suffice in practice.

Example 3:

$n = 1000$ ,  $k = 75$ ,  $P = 99\%$

Result:  $p_l = 5.51\%$ ,  $p_u = 9.90\%$

Here the upper value of the confidence interval is just below the stipulated maximum value of  $10\%$  PER. This means that of 1000 packets tested, 75 can be tolerated as errored, which can be regarded as a practicable evaluation limit.

## 8 Abbreviations

ARB	Arbitrary Waveform Generator
BSSID	Basic Service Set Identification
DUT	Device Under Test
FCS	Frame Check Sequence
IBSS	Independent Basic Service Set
MAC	Medium Access Control
PER	Packet Error Rate
PHY	Physical Layer
PSDU	PLCP Service Data Unit
SSID	Service Set Identifier

## 9 References

- [1] ANSI/IEEE Std 802.11 [ISO/IEC 8802-11:1999(E)], Part 11: Wireless LAN MAC and PHY Specifications, LAN/MAN Standards Committee of the IEEE Computer Society, 1999 Edition
- [2] IEEE Std 802.11a-1999 [ISO/IEC 8802-11:1999/Amd 1:2000(E)], Part 11: Wireless LAN MAC and PHY Specifications, High-Speed Physical Layer in the 5 GHz Band, LAN/MAN Standards Committee of the IEEE Computer Society, 1999
- [3] IEEE Std 802.11b-1999, Part 11: Wireless LAN MAC and PHY Specifications, Higher-Speed Physical Layer Extension in the 2.4 GHz Band, LAN/MAN Standards Committee of the IEEE Computer Society, 1999
- [4] IEEE Std 802.11g, Part 11: Wireless LAN MAC and PHY Specifications, Further Higher-Speed Physical Layer Extension in the 2.4 GHz Band, LAN/MAN Standards Committee of the IEEE Computer Society, 2003
- [5] Signals for Wireless LANs, Part I: 802.11b, Application Note 1GP49, Rohde & Schwarz, 2002

### 10 Ordering information

#### I/Q Modulation Generator

AMIQ03	4 Msamples	1110.2003.03
AMIQ04	16 Msamples	1110.2003.04

Options:		
AMIQK19	Digital Standard IEEE 802.11	1122.3200.02

#### Vector Signal Generator:

SMIQ03B	300 kHz to 3.3 GHz	1125.5555.03
SMIQ04B	300 kHz to 4.4 GHz	1125.5555.04
SMIQ06B	300 kHz to 6.4 GHz	1125.5555.06
SMV03	9 kHz to 3.3 GHz	1147.7509.13

Options:		
SMIQB11	Data Generator	1085.4502.04
SMIQB12	Memory Extension	1085.2800.04
SMIQB20	Modulation Coder	1125.5190.02
SMIQB60	Arbitrary Waveform Generator	1136.4390.02
SMIQK19	Digital Standard IEEE 802.11	1154.8307.02

#### Application Software:

The 802.11 PER Testing application software can be downloaded from the Rohde&Schwarz website:  
<http://www.rohde-schwarz.com>



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