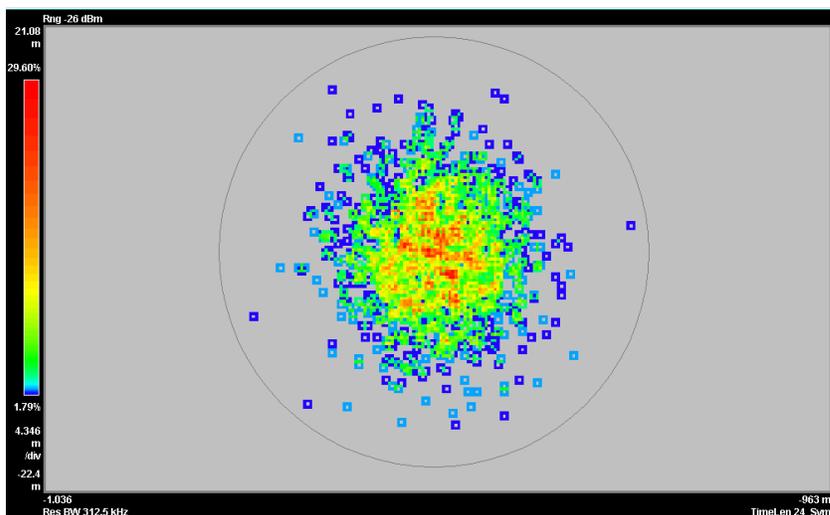


# Keysight Technologies

## Making Custom OFDM Measurements Using the Keysight 89600 VSA Software with Option BHF

### Application Note



This application note describes how to configure the Keysight Technologies Inc. 89600 VSA software with Option BHF custom OFDM modulation analysis to analyze and troubleshoot new, custom, proprietary, generic, or non-standard OFDM signals. Example files are developed and are available for further examination in the 89600 VSA software's demo signal library and Help text. The only hardware required for demonstration is a PC.

# Introduction

OFDM (Orthogonal Frequency-Division Multiplexing) signals have gained great acceptance in communications systems due to their inherent noise immunity and transmission efficiency. But troubleshooting and analyzing these systems, particularly for new, custom, generic, or non-standard OFDM formats, is difficult. The 89600 VSA software with Option BHF custom OFDM modulation analysis provides many data traces and tables to help the OFDM designer, including those developing multi-user or MIMO systems.

Multi-carrier modulation schemes, such as OFDM, represent significant challenges for those seeking to verify PHY-layer characteristics. Most OFDM signals are designed to an open commercial standard, and so are the tools that test them. While traditional spectrum analysis can measure simpler parameters such as frequency, power level, and spectral mask, the more in-depth quality measurements require special capabilities found only in vector signal analysis tools flexible enough to work with custom OFDM systems.

The 89600 VSA software with Option BHF custom OFDM modulation analysis provides an easy-to-use, text file-driven approach to describing generic and proprietary OFDM signals requiring that no special software be developed.

Once the custom OFDM signal is properly described, the 89600 VSA software's troubleshooting capability can be brought to bear on it, including displaying error traces, such as EVM by time or frequency, IQ constellations, tabular data such as OFDM data burst info displaying EVM, power, modulation format, and resource units assigned for preamble pilot, and data subcarriers. Error summary information per channel provides information on EVM (pilot, data, and preamble EVM), frequency, symbol clock, and common pilot errors, as well as IQ errors such as offset, quadrature errors, gain imbalance and time skew.

Statistical information such as CCDF and CDF traces is also available on these signals, even before demodulation begins. In addition, the 89600 VSA software can operate with data taken from over 30 supported waveform acquisition platforms, including simulation software, logic analyzers, oscilloscopes, and signal analyzers. This allows you to examine your custom OFDM signals anywhere in your block diagram. Automate design verification tests using SCPI or any supported .NET language.

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## OFDM overview

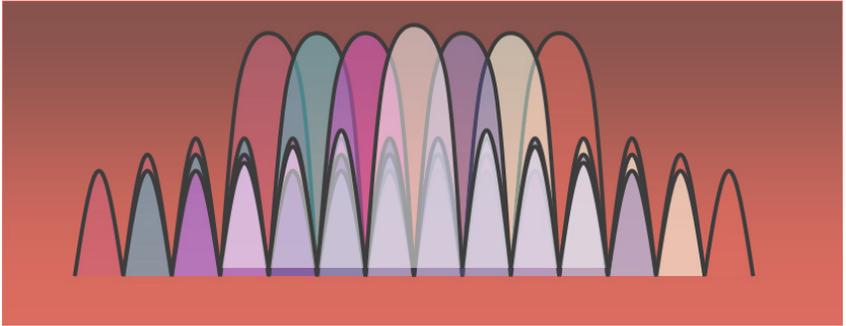


Figure 1. OFDM is a multi-carrier scheme where closely spaced carriers overlap. Nulls in each carrier's spectrum land at the center of all other carriers for zero inter-carrier interference.

OFDM uses a multicarrier scheme to achieve transmission efficiencies (data rate per Hz of bandwidth) similar to traditional, single-carrier schemes (QPSK, QAM, etc.), but with better immunity to common channel impairments. It does so by clocking many carriers simultaneously, but at proportionately slower symbol rates compared to single carrier modulation (SCM) schemes.

The multi-carrier scheme is robust in the presence of single-frequency interferers and noise, because (unlike SCM) the loss of an individual carrier (or several) is not fatal to the entire transmission. OFDM is also tolerant of multipath; spectral dropouts only affect a limited number of carriers, and the OFDM signal structure lends itself to strong equalization schemes, which can further reduce the effects of multipath.

It can be made even more tolerant to multipath with the addition of more channels and MIMO signal processing techniques. Using OFDM allows some important assumptions to be made about the signal for MIMO operation. For example, the modulation bandwidth for each sub-carrier is small enough to assume the RF path can be represented by a single complex coefficient.

Multi-carrier signals such as OFDM offer useful benefits for many digital communications applications, but with a tradeoff in signal and design complexity. OFDM signals are subject to the same sorts of design problems as any vector-modulated signal, but these can be difficult to uncover and troubleshoot without OFDM-specific signal analysis tools.

### Try the 89600 VSA software, for free

Download the 89600 VSA software and use it free for 14 days to make measurements with your analysis hardware, or use our recorded demo signals by selecting File > Recall > Recall Demo > Custom OFDM > on the 89600 VSA software toolbar.

The signals and configuration files shown in this application note are all available there.

[www.keysight.com/find/89600\\_trial](http://www.keysight.com/find/89600_trial)

## Demodulation Configuration

Before selecting the custom OFDM mode, ensure that the 89600 VSA software's basic acquisition parameters are set correctly for the signal under test. Enter the appropriate center frequency, span, input range, etc., and verify that the entire signal is visible in a spectrum display. Information on setting up the VSA software is available in the Help text.

Once these basic parameters are entered, you can use the 89600 VSA software to perform CCDF and various other power, time, and frequency measurements, even before you begin custom OFDM demodulation.

The OFDM examples in this document are based on an 802.11a/g OFDM signal. The configuration developed in this application note can be used with the 89600 VSA software example signal found at **File > Recall > Recall Demo > Custom OFDM > CustomOFDM\_80211a.htm**. Note that no hardware besides the PC is needed to run or view these signals in demo mode. Further, when setting up measurements for your own system, you can make measurements on software-based signals such as those developed in MATLAB, or properly formatted .txt files. See the 89600 VSA software Help text topic on "Supported File Formats" for more information.

The 89600 VSA software Option BHF custom OFDM demodulation software is configured with the following three steps:

1. Set up the signal for basic spectrum analysis and then enter the high-level FFT parameters for the OFDM signal under test
2. Describe the detailed signal structure of the 89600 VSA software, in the form of 3-4 configuration files that define each subcarrier in each symbol
3. Configure the measurement setup, e.g. synchronization type, result length, etc.

Step 1: Enter the basic signal and FFT parameters

After recalling the basic signal, select **MeasSetup > Measurement Type > Custom OFDM**, and then **MeasSetup > Custom OFDM Demod Properties**. In the Format section of the Format tab properties dialog box, enter the five numeric values shown in Figure 2. These values are specific to the signal under test, and will normally be found in the early part of its technical standard.

Notes:

- Enter the FFT Length, which must be a power of 2. Maximum FFT size is  $2^{16}$ , or 65,536.
- Enter a Guard Interval, usually a value between 1/16 (.0625) and 1/4 (.25). It must be entered in decimal notation.
- Enter the number of Guard Lower Subcarriers and Guard Upper Subcarriers. The number of active subcarriers is generally fewer than the FFT size, with empty guard subcarriers allocated on either side of the signal. The number of active subcarriers is usually odd, due to the null subcarrier in the center, and equal quantities on either side. This results in an odd number of guard subcarriers. Most standards define the lower guard region with one more subcarrier than the upper. The 89600 VSA software can handle either case with no problem.

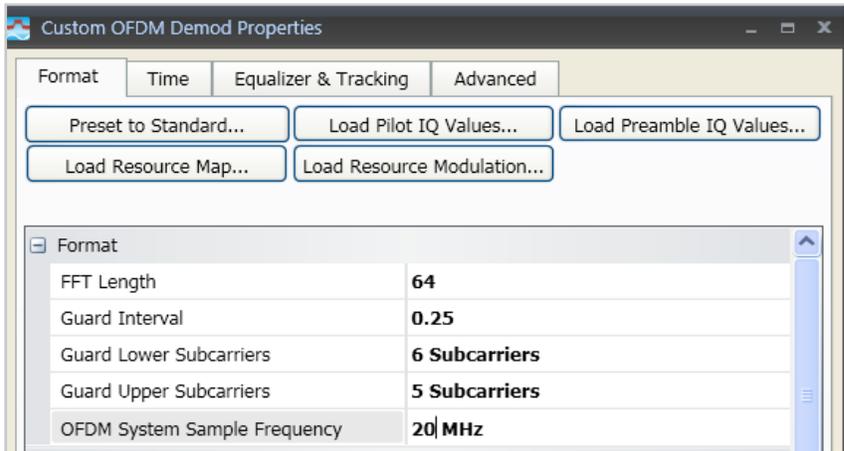


Figure 2. Format section of custom OFDM demodulation properties Format tab, showing FFT parameters for 802.11a/g OFDM signal.

## Step 2: Define the detailed OFDM signal format

The OFDM signal is described to the 89600 VSA software via 4 text files:

- The Resource Map file defines the function of each subcarrier in each symbol, describing whether it is a preamble, pilot, data or null subcarrier
- The Resource Modulation file defines the modulation format expected for each subcarrier shown in the Resource Map
- The Preamble IQ file defines the expected I and Q values for each preamble subcarrier
- The Pilot IQ file defines the expected I and Q values for each pilot subcarrier

These are all simple text files, consisting of numeric values separated by spaces, commas, tabs, or CR/LF. The file extension may be .txt or .csv. For clarity, it may be useful to organize these files with one row of values per symbol, but this is entirely optional. Note that an example of each of these files is included for use with the simple demo signal, CustomOFDM\_80211a.sdf. Since these are all just text files, you can use any easily available word processor to create or edit them, including Notepad or Microsoft® Word.

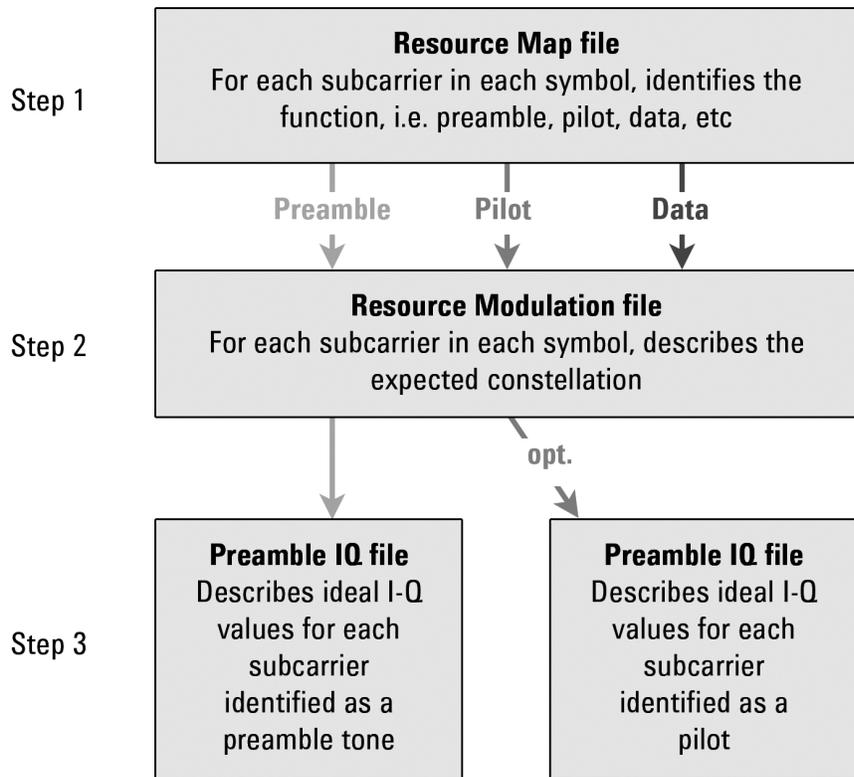


Figure 3. Steps for developing the configuration files required to define custom OFDM signals.





## QAM identifiers

Note that the Resource Modulation value does not define the modulation type directly. Rather, it is an index for the QAM Identifier table, which provides an index for the QAM Level table. Both of these tables are located on the Format tab of Demod Properties, and can be edited by the user. In the example in Table 4, a Resource Modulation value of 4 points to the 4th value (counting from zero) in the QAM Identifier table, which is also 4. Then, QAM Identifier = 4 points to the 4th value in the QAM Level table, which is 6, for 64QAM.

QAM Identifiers	0, 1, 2, 3, 4, 5
QAM Levels	0, 1, 2, 4, 6, 8

Resource Mod. value	QAM Identifier table	QAM Level table
0	0	0 = unknown
1	1	1 = BPSK
2	2	2 = QPSK
3	3	4 = 16QAM
4	4	6 = 64QAM
5	5	8 = 256QAM

Table 4. Default QAM Identifier and QAM Level tables. Here, a Resource Mod value of “4” indicates 64QAM.

The advantage to this scheme is that large blocks of subcarrier modulation definitions can be changed quickly and easily, without modifying the Resource Modulation file. Table 5 shows how all subcarriers defined as 64QAM can be changed to 16QAM by modifying a single value in the QAM Identifier table. After this change, Resource Mod value 4 still points to the 4th value in the QAM Identifier table, but the resulting index into the QAM Level table is now a 3. The third value in the QAM Level table is 4, for 16QAM.

QAM Identifiers	0, 1, 2, 3, 3, 5
QAM Levels	0, 1, 2, 4, 6, 8

Resource Mod. value	QAM Identifier table	QAM Level table
0	0	0 = unknown
1	1	1 = BPSK
2	2	2 = QPSK
3	3	4 = 16QAM
4	4	6 = 64QAM
5	5	8 = 256QAM

Table 5. Modified QAM Identifier and QAM Level tables. Resource Modulation value “4” now indicates 16QAM.

## QAM Level

Option BHF custom OFDM supports the following QAM Level values which represent the listed modulation formats as shown in Table 6.

QAM level	Modulation	QAM Level	Modulation
1	BPSK	6	64QAM
2	QPSK	7	128QAM
3	8PSK	8	256QAM
4	16QAM	9	512QAM
5	32QAM	10	1024QAM

Table 6. Supported modulation formats and associated QAM Level values.

## Auto-detecting the modulation format

A Resource Modulation value set to zero (unknown) is a special case that can greatly simplify the custom OFDM setup. This value instructs the demodulation software to detect the format empirically, based on a statistical algorithm. This algorithm computes a single result (format) for all subcarriers marked as zero, so it will normally be used for a group of subcarriers, spread across one or more symbols, that all have the same format.

## Placeholder values

The Resource Modulation file must always have the same number of values as the Resource Map file. However, not all Resource Modulation values are actually used by the demodulation algorithm because some subcarriers have no modulation (Resource Type 4 or 5) and some are defined in separate I-Q files (Resource Types 1 and 3, see the Preamble IQ and Pilot IQ sections). The Resource Modulation values provided for these subcarriers will thus be ignored, and can be set to any number desired-- even numbers assigned to other formats. In the example Resource Modulation file shown in Figure 6, zero is used as a placeholder, even though it usually signifies an 'unknown' format, for in Preamble IQ and Pilot IQ files, the IQ data implicitly defines the constellation.

## Preamble IQ file

This file contains I and Q values for every preamble subcarrier (Resource Type 3) shown in the Resource Map file. Each time the demodulation software encounters a “3” in the Resource Map file, it reads the next two values from the Preamble IQ file and uses them as the ideal I-Q location for that preamble subcarrier. For correct demodulation, it is important to not swap the values--I comes first, then Q.

I-Q values are interpreted as being relative to the average constellation power, i.e. the “constellation reference power,” which is defined as 1.00. A preamble subcarrier boosted by 3 dB would thus have a magnitude of 1.414, e.g.  $0+j1.414$ ,  $1.00+j1.00$ , etc.

In most OFDM signals, preamble subcarriers are of constant magnitude, and may or may not be boosted relative to the constellation reference power. The phase of each preamble subcarrier is usually one of two (BPSK) or four (QPSK) values, and typically follows a pseudo random bit sequence (PRBS) defined by the standard. All of this information must be known in order to construct the Preamble IQ file.

The quantity of values in the Preamble IQ file is equal to twice the total number of preamble subcarriers, summed across all preamble symbols. It contains values only for preamble subcarriers-- not data, pilot or null subcarriers.

In the following example, the first I-Q pair is read as  $1.47 + j1.47$ , and refers to the first preamble subcarrier designated by the Resource Map file in Table 2, i.e. the third subcarrier in the first symbol. Based on these I-Q values, the 89600 VSA software expects this preamble subcarrier to have a magnitude of 2.03 and phase of 45 degrees, relative to the constellation reference power.

## Preamble IQ file contents

First preamble subcarrier =  $1.47 + j1.47$

1.47	1.47	-1.47	-1.47	1.47	1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	etc.	
1.47	1.47	-1.47	-1.47	1.47	1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	-1.47	etc.	
-1.00	0.00	0.00	1.00	-1.00	0.00	0.00	1.00	-1.00	0.00	0.00	1.00	-1.00	0.00	0.00	-1.00	0.00	etc.	
1.00	0.00	1.00	0.00	-1.00	0.00	-1.00	0.00	1.00	0.00	1.00	0.00	-1.00	0.00	1.00	0.00	-1.00	0.00	etc.

### Meaning

Short training sequence  
(12 I-Q x 2 symbols)

Long training sequence  
(52 I-Q x 2 symbols)

Figure 5. Example Preamble I-Q file for 802.11a/g OFDM signal.

## Pilot IQ file

Similar to the Preamble IQ file, the values in this file provide the ideal I-Q locations for each known pilot (resource type = 1) shown in the Resource Map file. The quantity of values in this file is thus equal to twice the number of pilots defined in the Resource Map.

## Unknown pilots

In many cases, it will be simpler to define the pilots as unknown (Resource Type = 2), and specify only the expected constellation shape, e.g., BPSK, and boosting level. Based on this information, the 89600 VSA software will determine the ideal states empirically and not require a Pilot IQ file. No knowledge of the Pilot PRBS sequence is therefore required.

Note that known pilots (Resource Type = 1) allow the demodulation software to synchronize more reliably under poor signal-to-noise conditions. In addition, the received pilot PRBS sequence is verified against the sequence defined in the Pilot IQ file, so it can detect coding errors in the signal under test.

Known pilots can also be used for synchronization, for the case where signals have no preamble. This is not possible with unknown pilots.

In summary, the choice of known vs. unknown pilots affects the values entered into the configuration files as shown in Table 7.

Pilot type	Resource Map value	Pilot I-Q file	Resource Modulation file values
Known	1	File required; defines the ideal I-Q states	Specify either actual modulation format or "unknown"
Unknown	2	File not required	Specify either actual modulation format or "unknown"

Table 7. Description of pilot IQ values as used in resource map.

### Notes:

- For BPSK pilots that are rotated to lie entirely on the vertical (Q) axis, always use an unknown modulation format, and either:
  - a) unknown pilots; or b) known pilots plus a valid Pilot IQ file.
- Unknown pilots are assumed to have magnitudes of 1.00 relative to the constellation reference power. If they do not, a relative boosting factor must be specified on the Format tab.

### Step 3: Configure the measurement parameters

The setup options for the custom OFDM demodulation software are similar to those provided for the 89600 VSA software's existing OFDM formats. More complete descriptions can be found in the 89600 VSA software's Help text. The following items summarize important setup parameters.

Format tab	
Signal is bursted	Check this box for burst or pulsed signals, unless you're using a continuously transmitting signal (as in early system development, perhaps). If you select this parameter, you should also set the 3 pulse search parameters on the Time tab's Details section.
Details: Boosting	By default, the 89600 VSA software assumes that all modulation types are scaled the same way, i.e. their average power is 1.00. This section of the setup menu allows separate scaling factors for each modulation type, for unknown pilots, and for each user number (see Advanced Topics).
Time tab	
Measurement Interval and Measurement Offset	These settings allow you to select the number of symbols to be displayed.
Result Length	Selects the number of symbols to be demodulated.
Result Length	If this parameter is set to "automatic," the 89600 VSA software demodulates only to the end of the current burst.
Result Length selection	If this parameter is set to "automatic," the 89600 VSA software demodulates only to the end of the current burst.
Search Length	This parameter sets the amount of waveform to acquire per measurement. Typically it is recommended that you set the value equal to two burst "on" times plus one burst "off" time.
Pulse Search enable	If this parameter is enabled, the software automatically aligns the measurement with the rising edge of the RF envelope. If you do not enable this parameter, use triggering to position the first symbol near the start of the time record.
Equalizer & Tracking tab	
Equalizer Use Data/Pilots/Preamble	The 89600 VSA software can use some or all of the subcarriers for Equalizer training. This parameter allows you to choose which of these to use. Note: To analyze an OFDM signal that has no preamble, de-select Equalizer Use Preamble in this section, and configure the 89600 VSA software for known pilots.
Equalizer Averaging mode	The 89600 VSA software takes channel response data across multiple symbols. This parameter determines whether the channel response should be averaged using EqualWeight or LeastSquares. Equal weight averaging is generally more effective at noise reduction, and is recommended unless otherwise required by the standard.
Track Amplitude/Phase/Timing	These parameters specify whether the 89600 VSA software tracks amplitude, phase, or timing changes in the pilot subcarriers. When any parameter is set to true by checking the check box, the Common Pilot Error trace will show the appropriate parameter tracking. This is useful for troubleshooting signals, as it can often highlight the major error source.

### Step 3: Configure the measurement parameters (continued)

#### Advanced tab

Extended Frequency Lock Range      Checking this setting allows the 89600 VSA software demodulation algorithm to remain locked with a larger center frequency offset. However, this results in a tradeoff of some degree of noise immunity.

Synchronization mode      This selection controls the type of synchronization used to synchronize to the start of an OFDM burst. The two available choices are TimeCorrelation and CyclicPrefix. Use TimeCorrelation for traditional preamble or pilot-based sync. The CyclicPrefix setting may be of value for unknown, missing, or poorly-formed preambles.

## Advanced Topics

So far the example signal and measurements discussed dealt with “basic OFDM” analysis. Option BHF supports more complex OFDM analysis, including multi-user (OFDMA) and MIMO transmission. The simple 802.11a signal used as an example does not support either of these. In the examples which follow, appropriate signals have been used. Note that these are not included in the demo files, but are presented here as simple discussion examples.

### Multi-user OFDM (OFDMA)

In some forms of OFDM, the physical resource (i.e. the set of subcarriers) is shared among multiple users. Multiple user versions of OFDM are often called OFDMA, for “Orthogonal Frequency Division Multiple Access.” In these systems, the subcarriers for one user may have different modulation formats and/or power levels than those for other users, making it desirable to view measurement results on a per-user basis.

To accomplish this, each subcarrier in the Resource Map can be assigned to an arbitrary User Number between 0 and 7. The User Number and Resource Type are entered into the Resource Map as a single 6-bit number, equal to (User Number x 8) + Resource Type.

User	User	User	Type	Type	Type
0	1	1	0	0	0
000 = User 0 (default)			000 = Data		
001 = User 1			001 = Pilot		
010 = User 2 (etc.)			011 = Preamble (etc.)		

#### Examples shown:

Resource Type is 000 (= data subcarrier)  
 User number is 011 (= 3)  
 Resource Map value is 24  
 = (User Number x 8) + Resource Type

Table 8. Creating combined User Numbers and Resource Types for use in Resource Map for multi-user systems.

When programmed for multiple users, the 89600 VSA software's Data Burst Info table displays individual results for each user, as shown in Figure 6.

	EVM(dB)	Pwr(dB)	ModFmt	RU
Preamble	-48.759	7.27	QPSK	150
Pilot	-39.151	0.0042	BPSK	384
Data	-38.011	0.0078	***	9216
All	-38.368	0.2712	***	9750
User0	-38.522	0.4936	QPSK	5167
User1	-38.632	0.0814	16-QAM	1128
User2	-38.822	-0.1951	64-QAM	71
User3	-38.031	0.0338	QPSK	3384
Zero	-38.368	38.368	None	300

Figure 6. Data Burst Info table, showing results tabulated by User Number.

User numbers are valuable even for non-OFDMA signals in the following ways.

- When using the unknown modulation format, autodetection is performed separately for each User Number, so that several regions can be autodetected independently.
- Constellation reference power (i.e. boosting ratio) can be set separately for each user by User Number, enabling measurements of signals with multiple power levels.

## MIMO analysis

The 89600 VSA software's Option BHF custom OFDM software can be configured to recover and analyze up to 8 MIMO transmission streams. This is accomplished using the same configuration files described earlier in this note, but with certain modifications.

Configuration details depend on the type of MIMO signal being analyzed. This note deals with 2 types, described in Table 9. For further clarity, examples of each type currently used are also listed.

MIMO type	Characteristics
Type 1 (non-overlapping)	Any given pilot or preamble subcarrier is transmitted on only one antenna at a time, and is null on all other antennas. (Examples: WiMAX™, LTE)
Type 2 (overlapping)	All preamble and pilot subcarriers are transmitted on all antennas at all times. (Example: 802.11n)

Table 9. Description of the 2 MIMO signal types discussed in this application note.

For both types of MIMO signals, it is assumed that any given data subcarrier is transmitted simultaneously on all antennas, and has the same modulation format on all antennas. Further, Option BHF custom modulation analysis assumes that all MIMO modulation performed uses an equal number of receive and transmit antennas, e.g., 2x2, 3x3, etc.

## Configuring type 1 MIMO

To further illustrate this class of signals, i.e., non-overlapping, consider the simple MIMO signal shown in Table 10.

	Antenna 0	Antenna 1
Preamble	P x P x P x P x P x	x P x P x P x P x P
Symbol 1	1 0 0 x 0 0 1 0 0 x	x 0 0 1 0 0 x 0 0 1
Symbol 2	x 0 0 1 0 0 x 0 0 1	1 0 0 x 0 0 1 0 0 x
Symbol 3	1 0 0 x 0 0 1 0 0 x	x 0 0 1 0 0 x 0 0 1
Symbol 4	x 0 0 1 0 0 x 0 0 1	1 0 0 x 0 0 1 0 0 x

Table 10. Type 1 MIMO signal description (simplified example).

Note the non-overlapping preamble tones (P) in the first symbol, and the non-overlapping pilot tones (1) in the subsequent symbols. The required configuration file modifications are as follows:

### Resource Map file

For each preamble or pilot subcarrier, treat the Resource Type value as a 9-bit number, with the upper three bits representing the antenna number. Thus, to assign an Antenna Number, add (antenna number x 64) to the Resource Type. When an Antenna Number is assigned to a resource, the analysis software assumes that resource is active on that antenna only, and null on all other antennas. The Antenna Number may change from symbol to symbol.

Ant	Ant	Ant	User	User	User	Type	Type	Type	<i>Examples shown:</i>
0	0	1	0	0	0	0	1	1	Resource Type is 3 (= preamble subcarrier)
000 = Ant. 0 (default)			000 = User 0 (default)			000 = Data			User number is 0 (default)
001 = Ant. 1			001 = User 1			001 = Pilot			Antenna Number is 1
010 = Ant. 2 (etc.)			010 = User 2 (etc.)			011 = Preamble (etc.)			Resource Map value = 67 = (Ant Number x 64) + Resource

Table 11. Creating Resource Type values for multi-antenna, multi-user signals.

For the simplified MIMO signal shown in this Type 1 MIMO example, the modified Resource Map would appear as follows. Notice how it describes the signals on both antennas at once.

Resource Map										
Preamble	3	67	3	67	3	67	3	67	3	67
Symbol 1	1	0	0	65	0	0	1	0	0	65
Symbol 2	65	0	0	1	0	0	65	0	0	1

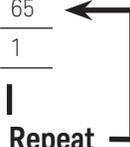


Table 12. Resource Map for Type 1 MIMO example showing modified values.

## Resource Modulation file

This file requires no modification. As before, it contains one Resource Modulation value for each subcarrier shown in the Resource Map file.

## Preamble and Pilot IQ files

Because these files also describe multiple signals at once, they will generally have more entries than a SISO file. Beyond that, the basic rules still apply: include one I-Q pair, scaled to the constellation reference power, for each preamble or pilot shown on the Resource Map (omitting data, null and guard subcarriers), and enter them in the same sequence as they appear in the Resource Map file.

In the simple MIMO Resource Map example used, the preamble tones alternate between antenna 0 and antenna 1. In the Preamble IQ file, the values alternate the same way. See Table 13 for an example.

Preamble IQ file:	$I_{ant0} Q_{ant0} I_{ant1} Q_{ant1} I_{ant0} Q_{ant0} I_{ant1} Q_{ant1} I_{ant0} Q_{ant0} I_{ant1} Q_{ant1} \text{ etc ...}$
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Table 13. Preamble IQ file showing alternating I-Q values for each antenna.

The same is true for the Pilot IQ file, where additional lines are needed because the pilot sequence repeats across multiple symbols. See Table 14.

Pilot IQ file (symbol n):	$I_{ant0} Q_{ant0} I_{ant1} Q_{ant1} I_{ant0} Q_{ant0} I_{ant1} Q_{ant1}$
(symbol n+1):	$I_{ant1} Q_{ant1} I_{ant0} Q_{ant0} I_{ant1} Q_{ant1} I_{ant0} Q_{ant0}$

Table 14. Pilot IQ file for simplified Type 1 MIMO signal.

## Configuring Type 2 MIMO

This class of signals, where all preamble and all pilot subcarriers are transmitted on all antennas, is represented by the following simplified example. Again, representing these signals is handled within the configuration files as shown in this section.

	Antenna 0	Antenna 1
Preamble	P x P x P x P x P x	P x P x P x P x P x
Symbol 1	1 0 0 0 0 0 1 0 0 0	1 0 0 0 0 0 1 0 0 0
Symbol 2	0 0 0 1 0 0 0 0 0 1	0 0 0 1 0 0 0 0 0 1
Symbol 3	1 0 0 0 0 0 1 0 0 0	1 0 0 0 0 0 1 0 0 0
Symbol 4	0 0 0 1 0 0 0 0 0 1	0 0 0 1 0 0 0 0 0 1

Table 15. Type 2 MIMO signal (simplified example). Notice how preamble (P) and pilot (1) subcarriers are overlapping, i.e. active on both antennas simultaneously.

## Resource Map file

Because the preamble and pilots are used simultaneously on both antennas, it is not necessary to assign an antenna number. Instead, one further bit is used in the Resource Map value to indicate that the given resource is present on all antennas. This is bit #10, which means that a multi-antenna resource will have a value of (512 + Resource Type).

Multi	Ant	Ant	Ant	User	User	User	Type	Type	Type
1	X	X	X	0	0	0	0	1	1
0 = No	xxx = (value ignored)			000 = User 0 (default)			000 = Data		
1 = Yes				001 = User 1			001 = Pilot		
				010 = User 2 (etc.)			011 = Preamble (etc.)		

### Examples Shown:

Resource type is 3  
(= preamble subcarrier)

User number 0 (default)  
Multi-antenna = yes  
Resource map = 515

= (Multi x512) + Resource

Table 16. Calculating Resource Map file values for Type 2 MIMO signals.

For the simplified Type 2 MIMO signal shown in Table 16, the Resource Map would be as shown in Table 17.

Resource Map										
Preamble	515	0	515	0	515	0	515	0	515	0
Symbol n	513	0	0	0	0	0	513	0	0	0
Symbol n+1	0	0	0	513	0	0	0	0	0	513



Table 17. Resource Map file for simplified Type 2 MIMO example.

Resource Modulation file

This file requires no modification. As before, it contains one Resource Modulation value for each subcarrier shown in the Resource Map file.

Preamble and Pilot IQ files

Although the preamble and pilot subcarriers are present on both antennas simultaneously, they will generally not have the same I-Q values, so they must be specified separately. In their respective IQ files, the complete set of IQ data for antenna 0 is provided first, followed by the IQ data for antenna 1, and so on.

The 89600 VSA software assumes that the number of antennas to be analyzed is equal to the number of hardware inputs currently selected on the 89600 VSA software's Input > Channels menu.

The Preamble IQ file for the simplified MIMO signal will thus include two lines, one for antenna 0 and one for antenna 1. Each line contains the I-Q pairs that describe the five preamble tones on that antenna. See Table 18.

Pilot IQ file (ant 0):	$I_{ant0}$	$Q_{ant0}$								
(ant 1):	$I_{ant1}$	$Q_{ant1}$								

Table 18. Preamble IQ file for simplified Type 2 MIMO example signal.

Likewise, the Pilot IQ file for this signal will contain data for two symbols on antenna 0 (because of the two-symbol repeat sequence), followed by data for two symbols on antenna 1. See Table 19.

Pilot IQ file (ant 0):	$I_{ant0} \quad Q_{ant0} \quad I_{ant0} \quad Q_{ant0}$	symbol n
(ant 0):	$I_{ant0} \quad Q_{ant0} \quad I_{ant0} \quad Q_{ant0}$	symbol n+1
(ant 1):	$I_{ant1} \quad Q_{ant1} \quad I_{ant1} \quad Q_{ant1}$	symbol n
(ant 1):	$I_{ant1} \quad Q_{ant1} \quad I_{ant1} \quad Q_{ant1}$	symbol n+1

Table 19. Pilot IQ file for simplified Type 2 MIMO example signal.

Summary

OFDM signals present a rich set of user benefits, as well as complex troubleshooting. The 89600 VSA software with Option BHF custom OFDM modulation analysis provides a way to address both. Using easy-to-understand text-based files for signal description, it allows designers of new, custom, or non-standard OFDM signals to troubleshoot and analyze their signals. With simple extensions, the files also define multiple-user or up to 4x4 MIMO signals, further increasing the range of signals addressed.

This application note provides the user with descriptions and examples of each file. For further information, see the 89600 VSA software Help text.

Used with any of the over 30 platforms supported, the 89600 VSA software with Option BHF custom modulation analysis can analyze signals anywhere in the block diagram. As it is software-based, test signals developed in MATLAB or other software program can be used prior to actual hardware measurements to easily validate the 89600 VSA software demodulation setup, or to make measurements on the test signal itself.

# Appendix A

## Option BHF setup parameters

<b>Data acquisition</b>	
Required configuration data	Symbol resource map, resource modulation type, preamble IQ, Pilot IQ
Supported subcarrier types	Data, pilot, unknown pilot, preamble, null
Resource modulation formats supported	BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM, 512QAM, unknown
Input configuration file formats	.txt, csv
MIMO spatial streams supported	2x2, 3x3, 4x4
<b>Adjustable parameters</b>	
<b>Signal format parameters setup</b>	
Preset to standard	802.11a provided as example
Configuration file setup	
Load pilot IQ values	Downloads text file listing pilot IQ values for each subcarrier/symbol combination
Load preamble IQ values	Downloads text file listing preamble IQ values for each subcarrier combination
Load resource map	Downloads text file listing subcarrier type, user ID, antenna number, all antennas for each carrier/symbol combination
Load resource modulation	Text file listing expected constellation for each subcarrier in each symbol
Manual configuration parameters	
FFT length	Get/set the FFT length used for OFDM transmission; must be a power of 2 up to 64K
Guard interval	Get/set the guard interval (cyclic prefix)
Guard lower subcarriers	Get/set the number of lower guard subcarriers which will be ignored for results
Guard upper subcarriers	Get/set the number of upper guard subcarriers which will be ignored for results
Mirror frequency spectrum	Enables/disables time-domain conjugation, which mirrors the frequency domain around the center frequency
OFM system sample frequency	Get/set the OFDM FFT sample rate
Format details	
Pilot IQ values	Specifies ideal I-Q values for each subcarrier identified as a pilot
Preamble IQ values	Specifies ideal I-Q values for each subcarrier identified as a preamble tone
QAM identifiers	Each entry provides index into QAMLevels array
QAM levels	Each entry in array specifies modulation type
Resource map	Specifies the subcarrier type for each
Resource modulation	Specifies modulation used on each resource (subcarrier/symbol time)
Resource repeat index	Tells the analyzer where to loop after it reaches the end of the Resource Map file; for resource maps which include a repeating pattern of similarly-formatted symbols so that it is only necessary to define the pattern once
Burst signal status	Specifies whether the signal is bursted (pulsed) or continuous
Number of transmitter antennas	Get/set the number of transmitter antennas; max 4
Transmitter window beta	Get/set how much windowing was used in the transmitter to smooth the transition between symbols
Boosting details	Advanced parameters for OFDMA systems

## Option BHF setup parameters (continued)

QAM identifier boost levels	Get/set the boost power level for each QAM identifier
Unknown pilot boost level	Get/set the boosting level used for unknown pilot subcarriers
User boost levels	Get/set the boost power level for each user
<b>Time parameters</b>	<b>Accesses the signal capture configuration parameters used to select the pulse search length and isolate a segment of the time record for further viewing and data analysis</b>
Measurement interval	Get/set the time length, in symbols, of the measurement region used for computing and displaying the trace data results
Measurement offset	Get/set the time offset, in symbols, to the measurement region used for computing and displaying the trace data results
Result length	Get/set the maximum number of symbols analyzed, including preamble symbols
Result length selection	Enable/disable auto-determination of result length
Search length	Get/set the measurement acquisition length, in seconds
Pulse search details	Sets pulse search and automatic threshold status (on/off); sets pulse search threshold value in dB
<b>Equalizer and tracking</b>	<b>Specifies equalizer and pilot tracking parameters</b>
Equalizer training	Equalizer training using any/all of data, pilots, preamble
Equalizer details	Sets details of equalizer behavior
Averaging mode	Gets/sets averaging mode used when averaging equalizer across multiple symbols
Pilot tracking	Track any/all of amplitude, phase, timing
<b>Advanced parameters</b>	<b>Accesses advanced parameters used to adjust demodulation measurements and displays</b>
EVM normalized by reference	Specifies whether EVM calculations are normalized by the IQ Reference signal power
Extended frequency lock range	Get/set extended frequency lock range plus lock range width, in subcarriers
Symbol time adjustment	Get/set symbol time adjustment to adjust the “useful symbol time period” (TFFT) within the “OFDM extended symbol time period” (TS)
Synchronization mode	Get or set the synchronization mode used when synchronizing to the signal, either time correlation or cyclic prefix
Display parameters	Enables/disables the display of any/all: data subcarriers, EVM in %, pilot subcarriers, preamble subcarriers, subcarrier color based on user ID, sync correlation in %, zero subcarriers
Normalize IQ traces	Enables/disables normalization of IQ Meas, IQ Ref, and Error Vector traces

## Appendix B

### Option BHF available measurements

<b>Measurement results</b>	
<b>Channel data</b>	<b>These results are available for data appearing at channels 1 to n (n&lt;4) of the measurement platform</b>
CCDF	Displays the complementary cumulative distribution function (CCDF) for the selected input channel
CDF	Cumulative distribution function for the data in the measurement interval
Correction	Correction curve used to correct for the frequency response of the input hardware and input digital filtering
Instantaneous spectrum	Spectrum computed before data is averaged
PDF	Probability density function (PDF) of the signal
Raw main time	Raw time data read from the input hardware or playback file for the selected channel, prior to correction or resampling
Search time	Time record data after resampling and time adjustment, used to search for the pulse (or burst)
Spectrum	Averaged Instantaneous Spectrum display
Time	Time record before digital demodulation and after pulse search
<b>Demodulation data</b>	<b>These results are available for each spatial stream in MIMO systems</b>
ChN channel frequency response	Channel frequency response for the specified spatial stream and measurement hardware input channel X (where X is the number of the channel)
ChN equalizer impulse response	Equalizer impulse response between the selected data stream and input channel X (where X is the selected channel)
ChN instantaneous channel frequency response	Non-averaged ChX Ch Frequency Response trace data
ChN instantaneous equalizer impulse response	Non-averaged ChX Ch equalizer impulse response trace data
Common pilot error	Shows the difference between the measured and ideal pilot subcarrier symbols
Error vector spectrum	Computed difference between IQ Measured vector value and IQ Reference vector value, showing the signal EVM vs. frequency (subcarrier), a complex value at each subcarrier for each OFDM symbol
Error vector time	Signal EVM vs. time (symbols); a complex value at each subcarrier at each symbol-time showing the difference between IQ Meas and IQ Ref
IQ measured	Measured IQ symbol values of the subcarriers, with one complex value for each subcarrier for each symbol-time in the burst
IQ reference	Reference IQ symbol values of the subcarriers, with one complex value for each subcarrier for each symbol-time in the burst
RMS error vector spectrum	Computed difference between IQ Measured vector value and IQ Reference vector value, a complex value at each subcarrier for each OFDM symbol. The RMS Error Vector Spectrum is the RMS average EVM for each subcarrier for all symbols within the burst

## Option BHF available measurements (continued)

RMS error vector time	Average error vector magnitude at each symbol-time
Symbols	Demodulated symbol data (raw binary bits) for each OFDM symbol and subcarrier detected
<b>Cross channel data</b>	This data incorporates all input channels and provides data for MIMO measurements
MIMO channel frequency response	Shows an overlay of all the individual Stream(X) Channel(X) Frequency Response trace data results for the current MIMO measurement; enables easy viewing and comparison of each measurement stream(X) channel(X) frequency response trace data result on a single display
OFDM burst info	Table showing what fields were detected in the burst along with EVM, power level, modulation format, and number of resource units for each field
OFDM equalizer MIMO condition number	Vector containing the “condition number” of the equalizer channel frequency response matrices; one condition number value for each subcarrier
OFDM error summary	Table providing a wide range of error information per physical channel plus an average of all channels

## Additional Resources

### Literature

89600 VSA software Opt BHF Custom OFDM modulation analysis, Technical Overview, literature number 5990-6625EN

89600 VSA software, Brochure, literature number 5990-6553EN

89600 VSA software, Configuration Guide, literature number 5990-6386EN

89600 VSA software Opt 200 Basic VSA and Opt 300 Hardware Connectivity, Technical Overview, literature number 5990-6405EN

*Understanding the use of OFDM in 802.16*, Keysight Measurement Journal, literature number 5989-6649EN

Concepts of Orthogonal Frequency Domain Modulation, Microwave Journal, Dave Whipple, Keysight Technologies:

[http://www.mwjjournal.com/2008/DownloadablePDFs/Whipple\\_OFDM\\_Keysight.pdf](http://www.mwjjournal.com/2008/DownloadablePDFs/Whipple_OFDM_Keysight.pdf)

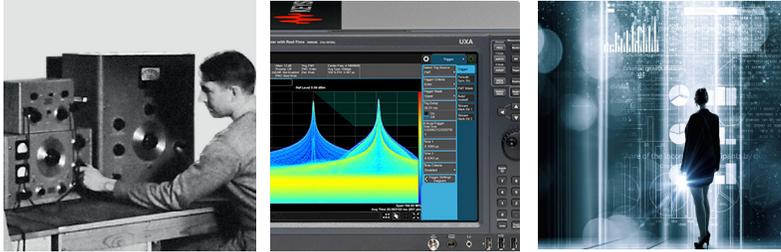
### Web

[www.keysight.com/find/89600VSA](http://www.keysight.com/find/89600VSA)  
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