

Keysight Technologies

Custom OFDM Signal Generation Using SystemVue

Application Note

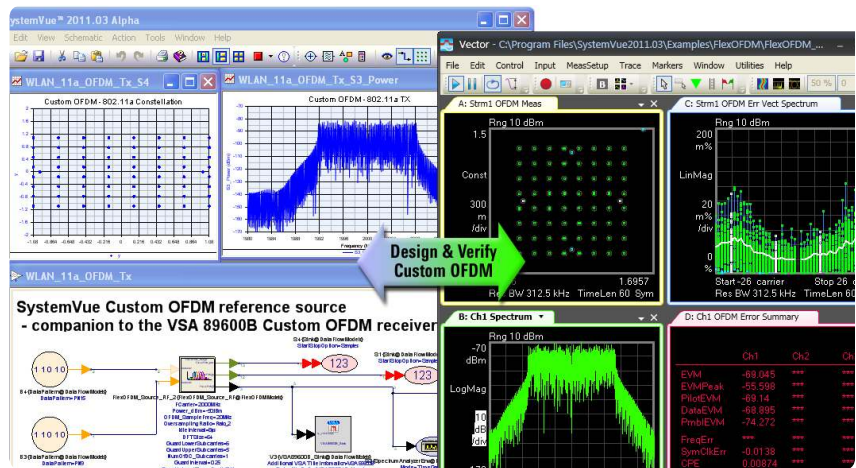
Introduction

Orthogonal frequency-division multiplexing (OFDM) has developed into a popular scheme for wideband digital communication, both wireless and over cables (copper wires). This application note provides an introduction to OFDM technology and explains how to use the Keysight Technologies, Inc. SystemVue software to generate custom OFDM/OFDMA signals. It also details the method for linking OFDM signals from 89600B SystemVue to the Keysight Vector Signal Analysis (VSA) software for demodulation. Commercial availability of both products is scheduled for Q1 2011.

A demonstration video for this application note can be found at <http://www.keysight.com/find/eesof-systemvue-videos>

As background, Keysight SystemVue (Releases 2010.01 and later) includes a free OFDM blockset as part of its base platform. SystemVue 2011.03 adds a new, highly-parameterized OFDM reference source built from this underlying blockset and adds a convenient, tabbed user interface that layers on top of the source. The resulting “flexible OFDM source” can be configured to create custom OFDM signals for a wide variety of purposes, including:

- creating typical OFDM signals compatible with a variety of new, emerging standards
- exploring new proprietary OFDM variations and algorithms to suit particular applications
- supporting secure and military formats, such as the Wideband Networking Waveform (WNW), with a minimum of customization
- creating and downloading test signals into measurement equipment for hardware verification



Orthogonal Frequency-Division Multiplexing (OFDM)

OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method and is essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT). It is used in such diverse applications as digital television and audio broadcasting, wireless networking and broadband internet access. OFDM has also been adopted in some military communication systems. For example, the WNW format is the next generation high-throughput military waveform developed under the Joint Tactical Radio System (JTRS) Ground Mobile Radio (GMR) program.

The SystemVue custom OFDM source can be used to explore a variety of industry standards and formats.

Cable

- ADSL and VDSL broadband access, via POTS copper wiring.
- Power line communication (G3-PLC, PRIME) used in “smart grid” applications.
- Multimedia over Coax Alliance (MoCA) home networking.
- ITU-T G.hn, a standard that provides high-speed local area networking over existing home wiring (power lines, phone lines and coaxial cables).
- DVB-C2, an enhanced version of the DVB-C digital cable TV standard.

Wireless

- Wireless LAN (WLAN) radio interfaces IEEE 802.11a, g, n and ac.
- Digital radio systems DAB/ EUREKA 147, DAB+, Digital Radio Mondiale, HD Radio, T-DMB and ISDB-TSB.
- Terrestrial digital TV systems DVB-T and ISDB-T, DVB-T2, an enhanced version of DVB-T.
- Terrestrial mobile TV systems DVB-H, T-DMB, ISDB-T and MediaFLO forward link.
- Wireless MAN/fixed broadband wireless access (BWA) standard IEEE 802.16 (WiMAX™).
- The mobile broadband wireless access IEEE 802.16e (Mobile WiMAX™) and WiBro.
- 3GPP Long Term Evolution (LTE) fourth-generation mobile broadband standard downlink.
- The wireless personal area network (PAN) ultra-wideband (UWB) IEEE 802.15.3a (802.11ad implementation suggested by WiMedia Alliance), WiGIG/IEEE 802.

Flexible OFDM Structure

The structure of a typical OFDM waveform created with SystemVue is shown in Figure 1. One frame consists of idle, preamble (Preamble 1 and Preamble 2) and payload data (Data 1 and Data 2). SystemVue 2011.03 allows a user to configure these fields from user-specified parameters using a simple graphical user interface (GUI). Users can configure their own OFDM frames according to their requirements. The Idle can be turned OFF by setting IdleInterval=0 μ s or Idle=0. Each preamble (Preamble 1 and Preamble 2) can be switched ON or OFF. Data 2 (Payload 2) also can be turned ON or OFF. Data 1 (Payload 1) should be always present (mandatory).

This frame structure can meet the needs of most of the OFDM systems above. For example, the IEEE 802.11a/g/n frame consists of idle, two preambles (short and long preamble), one OFDM symbol of SIGNAL, and several OFDM symbols of data (payload). The frame configuration conforms to IEEE802.11a/g/n frame structure requirements. Similarly, the DVB-T/H and ISDB-T frame only consists of several OFDM symbols (payload). We can turn idle, Preamble 1, Preamble 2 and Data 2 OFF to meet this DVB-T/H and ISDB-T frame structure using the SystemVue custom OFDM source GUI. According to the different frame of the OFDM system, we can control idle, preamble and data switches to configure a customized OFDM frame.

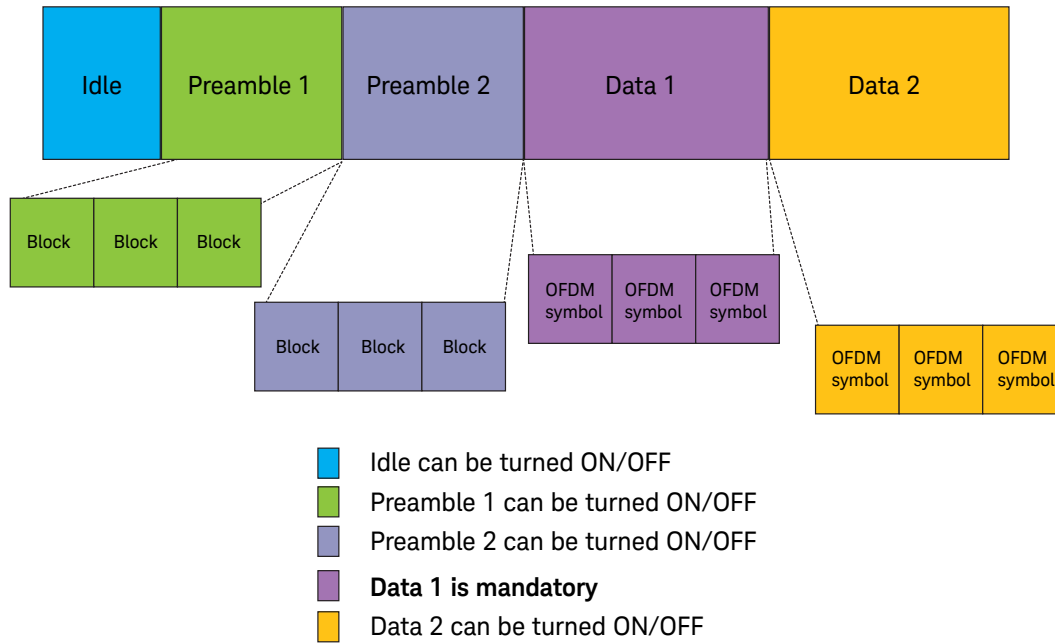


Figure 1: The frame structure of a flexible OFDM system

Both the Preamble 1 sequence and Preamble 2 sequence can be defined in the frequency domain or time domain, according to the system specification in the flexible OFDM application. WLAN series standards (802.11a/g/n/ac) define their preambles in the frequency domain and need to use the Inverse Fast Fourier Transform (IFFT) to transfer the frequency-domain sequence into time-domain signals. WiGIG and MoCA define their preambles in the time domain and therefore, do not need IFFT when transferring the frequency-domain sequence into the time domain. According to different OFDM standards, we can set preambles to the frequency domain or time domain in a very flexible way.

There are two kinds of pilots (Pilot1 and Pilot2) supported in Data 1 and Data 2 payloads. Both Pilot1 and Pilot2 can be turned ON or OFF, separately. Each OFDM system has its own pilot structure.

In the following section, we introduce preamble structure, payload OFDM symbol structure and pilot structure, respectively.

Preamble Structure

In most OFDM systems (including 802.xx series standards 11a/n/g/11ac, PLC standards G3-PLC, etc...), data transmission is in burst (non-continuous) mode. Because of the burst nature of data transmission and the fast acquisition times needed, these systems use preamble-based methods to acquire symbol timing and carrier frequency synchronization at the wireless receiver.

Moreover, the preambles are also used for things like automatic gain control (AGC) adaptation, channel estimation and initial phase reference estimation. Audio (DAB, ISDB-TSB and etc) and video OFDM systems (DVB-T/H/T2/C2, ISDB-T and etc) do not have any preamble because their data transmission is continuous. For these continuous OFDM systems, the pilots (continuous and scattered pilots) are used for timing and frequency synchronization and channel estimation instead of preamble. Figure 2 shows the structure of preamble in an OFDM system.

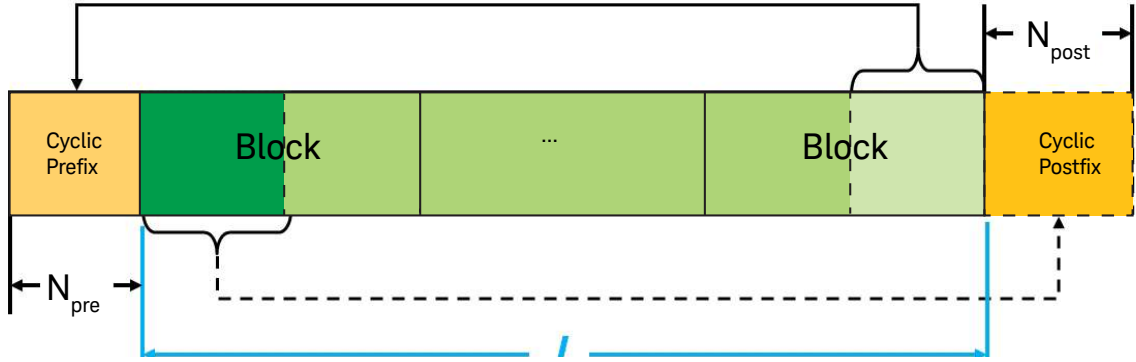


Figure 2: Preamble structure of flexible OFDM system

According to the OFDM standards, preambles are defined in either the frequency domain or time domain. In SystemVue, this is controlled with a parameter Preamble_FrequencyDomain (YES, NO). The preamble consists of several repeat blocks, and a cyclic prefix or cyclic postfix as shown in Figure 2.

$$L = \begin{cases} DFTSize \times R, & \text{frequency domain} \\ BlockSize \times R, & \text{time domain} \end{cases} \quad (1)$$

where R is defined as the repeat times (Preamble1_RepeatTimes or Preamble2_RepeatTimes) of the preamble sequence.

$$N_{post} = N_{pre} = L \times G_i \quad (2)$$

where G_i is defined as the guard interval of the preamble (Parameter Preamble_GuardInterval). The preamble only has one guard interval prefix (prefix or postfix), which is controlled by the parameter Preamble_GuardPosition.

Payload OFDM Symbol Structure

The payload OFDM signal is generated by performing an IFFT on the complex-valued signal points that are produced using various modulation formats (e.g., QPSK, 16-QAM, 64-QAM, and 1024-QAM) allocated to individual subcarriers.

An OFDM symbol is built by appending a cyclic prefix to the beginning of each block generated by IFFT. Figure 3(a) shows this OFDM structure with cyclic prefix guard interval. The length of the cyclic prefix is chosen so that a channel group delay will not cause successive OFDM symbols or adjacent subcarriers to interfere.

In some OFDM systems (such as WiMedia), the guard interval is filled with zeros instead of the cyclic prefix. Figure 3(b) shows this OFDM structure with zeros prefix. A parameter `GuardIntervalType` (CyclicShift, Zeros) allows users to select either a cyclic shift or zeros.

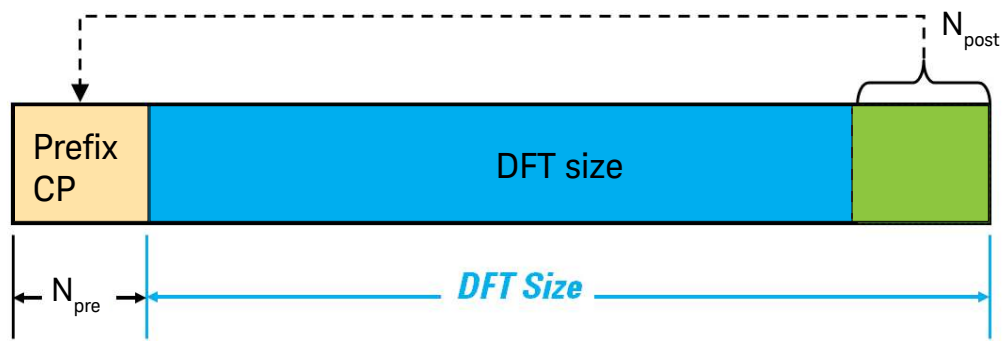


Figure 3(a) Payload OFDM symbol with cyclic prefix



Figure 3(b) Payload OFDM symbol with zeros prefix

Pilot Structure

There are two kinds of pilots (Pilot1 and Pilot2) supported in Data 1 and Data 2 payloads of the flexible OFDM system. Each pilot (Pilot 1 or Pilot2) can be turned ON or OFF according to the requirement. The pilots can be used for such things as phase tracking, channel estimation, and coarse and fine frequency synchronization. Each OFDM system has its own unique pilot pattern requirements.

There are four major pilot patterns in current OFDM standards (Figure 4). They include:

- In Figure 4(a), the OFDM systems do not include a pilot. In some cable OFDM systems (e.g., the ERDF G3-PLC system), there should not be any pilot because the pre-equalizer is adopted.
- Figure 4(b) represents OFDM systems that have continuous pilots. WLAN series standards (802.11a/g/n) only have continuous pilots (pilot subcarrier indexes are fixed in all OFDM symbols). These continuous pilots are used for phase tracking in Figure 4(b) because these OFDM systems have a preamble sequence for channel estimation.
- Figure 4(c) shows OFDM systems with scattered pilots. Mobile WiMAX and 3GPP LTE cell communication standards are examples of systems with scattered pilots (that is, the pilot subcarrier indexes are alterable in each OFDM symbol). In this case, the scattered pilots are used for channel estimation because these OFDM system have preambles or synchronization channels for timing and frequency synchronization.
- Figure 4(d) represents OFDM systems that have both continuous and scattered pilots. Video standards (e.g., ISDB-T and DVB-T/H/T2/C2) have scattered pilots and continuous pilots. The scattered pilots are used for channel estimation, while the continuous pilots are used for timing and frequency synchronization.

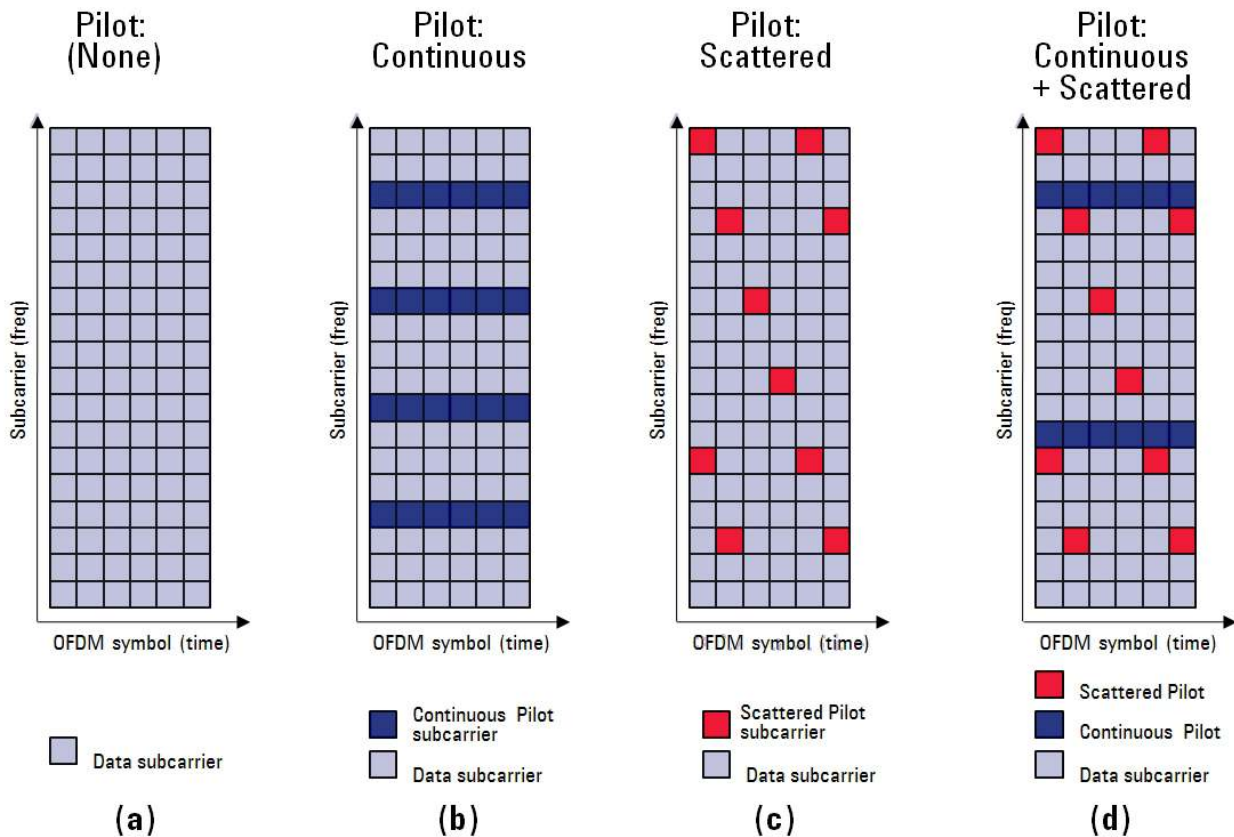


Figure 4: Pilot structure of flexible OFDM source

SystemVue's custom OFDM source also supports various pilot patterns (e.g., random pattern) by allowing the user to input each pilot subcarrier index and its value. This provides the user additional control beyond the four pilot patterns shown above.

Mapping Relationship between the OFDM Subcarrier and IFFT Buffer

Figure 5 shows the OFDM symbol structure in the frequency domain (before the Inverse Discrete Fourier Transform (IDFT)). From Figure 5, an OFDM symbol is made up from subcarriers, the number of which determines the DFT size used. There are two subcarrier types:

1. Used subcarriers: Includes data subcarriers and pilot subcarriers. Data subcarriers are for data transmission, while pilot subcarriers are for various estimation purposes.
2. Null subcarriers: No transmission at all, for guard bands (lower and upper guard subcarriers), non-active subcarriers and the DC subcarrier.

The purpose of the guard bands is to enable the signal to naturally decay and create the FFT “brick wall” shaping. Figure 6 shows the mapping of frequency subcarriers into the IFFT buffer.

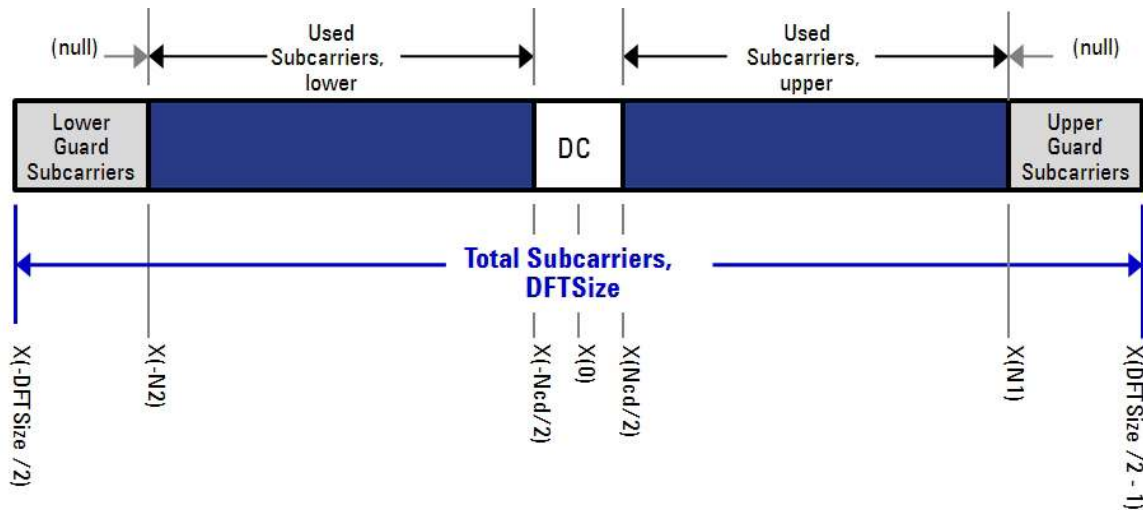


Figure 5: OFDM frequency description

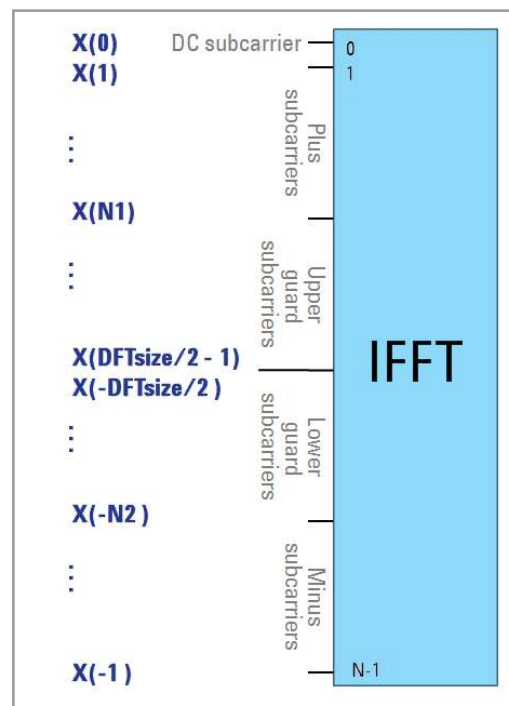


Figure 6: Mapping OFDM subcarriers into the IFFT buffer

Parameters DFTSize, GuardLowerSubcarriers, GuardUpperSubcarriers, and NumOfDC_Subcarriers can determine the used subcarriers index (lower, upper), NULL subcarriers (lower, upper) index and DC subcarriers index. After getting these subcarrier index values, it is easy to set the OFDM source parameters.

The following math language code is used to explain how to calculate the subcarriers index of used subcarriers, NULL subcarriers and DC subcarriers in Figure 5.

```
N=DFTSize; % DFT or IFFT size
M1= GuardUpperSubcarriers; % Upper frequency guard subcarriers
M2=GuardLowerSubcarriers; % Lower frequency guard subcarriers
Ndc=NumOfDC_Subcarriers; % it must be 0 or odd positive integer
U =N-M1-M2-Ndc; % U is the number of used subcarriers
OFDM_Index=[-N/2:N/2-1]; % frequency subcarrier index of one OFDM symbol
Index1 =OFDM_Index (M2+1:N-M1); % this subcarrier index vector includes DC
% subcarriers' indexes which can be used
% for preamble, such as 802.11a preamble sequence
% consists of DC subcarrier

if (Ndc=0)
    Index2 =Index1; % if the num of DC subcarriers is 0 (w/o DC),
% vector Index2 is same as Index1
else
    L=length(Index1) % if the number of DC subcarriers> 0 (with several DC subcarriers),
    Half_U=U/2; % vector Index2 is same as Index1 except number of DC subcarriers' indexes
    Index2 (1:Half_U)=Index1 (1:Half_U); % the values in vector Index2 are the
% subcarrier indexes of pilot and data.
    Index2 (Half_U+1:U)=Index1 (L-Half_U+1:L); % The pilot and data subcarriers' indexes
% must be in vector Index2.
end
```

There are two important variables (Index1 and Index2) in the above math language code. Index1 is used for the preamble subcarrier index setting and Index2 is used for the data subcarrier and pilot subcarrier setting.

Here are typical values for 2 common applications:

IEEE 802.11a	MoCA
DFTSize=64	DFTSize=256
GuardLowerSubcarriers=6	GuardLowerSubcarriers=13
GuardUpperSubcarriers=5	GuardUpperSubcarriers=12
NumOfDC_Subcarriers=1	NumOfDC_Subcarriers=7
Index1=[-26:26]	Index1=[-115:115]
Index2=[-26:-1,1:26]	Index2=[-115:-4,1:115]

The SystemVue Flexible OFDM User Interface

Parameter Relationships

In the user interface of the SystemVue custom OFDM source, several key top-level parameters enable or disable sets of underlying values and settings. For example, the parameter `OFDMSubcarrierAllocationType` (values = “Fixed” or “Alterable”) determines parameters `Data_NumOfCarriers`, `Pilot1_NumOfCarriers` if `Pilot1_Enable=ON`, `Pilot2_NumOfCarriers` (if `Pilot2_Enable=ON`), and `EVMRef_NumOfCarriers` are a single value or row vector, respectively.

OFDM Subcarrier Allocation Type

If the data subcarrier and pilot subcarrier index are fixed (e.g., MoCA and 802.11a/n), then the parameter `OFDMSubcarrierAllocationType` must be set to “Fixed.”

If data subcarrier and pilot subcarrier indexes can change in each OFDM symbol (such as LTE, DVB-T2/C2 and etc), then the parameter `OFDMSubcarrierAllocationType` should be set to a value of “Alterable.”

These choices then turn on and off additional parameters and determine array sizes, which are documented in the manual for the custom OFDM source.

Flexible OFDM GUI | System

When we place the `FlexOFDM_Source_RF` model into the schematic and double click on it, we see the GUI of `FlexOFDM_Source_RF`. In the next several sections, we introduce each page of `FlexOFDM_Source_RF` GUI.

Figure 7 shows the system parameters GUI of the OFDM source. There are three kinds of parameters included in this GUI, including:

1. System parameters

<code>FCarrier</code>	Frequency carrier (in MHz).
<code>Power_dBm</code>	Transmit power (in dBm).
<code>OFDM_SampleFreq</code>	OFDM System frequency (in MHz). It also can be named as bandwidth in some OFDM systems.
<code>OversamplingRatio</code>	Oversampling ratio (choose between 1x, 2x, 4x, 8x, and 16x).
<code>IdleInterval</code>	Idle interval (in μ s) between two consecutive frames.
<code>SymbolWindowing_Enable</code>	Symbol windowing function is used or not (OFF, ON).
<code>RC_SlopeLength</code>	Raised-cosine slope length of symbol windowing.

2. OFDM parameters

<code>DFTSize</code>	DFT size.
<code>GuardLowerSubcarriers</code>	Guard lower subcarriers.
<code>GuardUpperSubcarriers</code>	Guard upper subcarriers.
<code>NumOfDC_Subcarriers</code>	Number of DC subcarriers.
<code>GuardIntervalType:</code>	Guard interval type (values = “Cyclic Shift” or “Zeros”)
<code>SubcarrierAllocationType</code>	Subcarrier allocation type per each OFDM symbol within a frame (values = “Fixed” or “Alterable”)

Figure 7: flexible OFDM System GUI

3. Frame parameters

Preamble1_Enable	Preamble1 is used in OFDM frame (OFF, ON).
Preamble2_Enable	Preamble2 is used in OFDM frame (OFF, ON).
Data2_Enable	Data2 is enabled (OFF, ON).
Pilot1_Enable	Pilot1 is enabled (OFF, ON).
Pilot2_Enable	Pilot2 is enabled (OFF, ON).
Data1_NumOfSym	Number of OFDM symbols of Data1
Data2_NumOfSym	Number of OFDM symbols of Data2. It is displayed as gray if Data2_Enable=OFF, which means that it cannot be modified.

After setting this System GUI, some key parameters (e.g., subcarrier frequency spacing, IDFT period, and Guard interval duration) can be calculated directly.

Subcarrier frequency spacing	$\Delta F = \text{OFDM Sampling rate} / \text{DFTSize}$
OFDM Sample Time	$T_s = 1 / \text{OFDM Sampling rate}$
IDFT/DFT period	$T_{DFT} = \text{DFTSize} * T_s$
Guard Interval duration	$T_{GI} = \text{GuardInterval} * T_{DFT}$
Symbol Interval	$T_{SYM} = T_{DFT} + T_{GI}$

Flexible OFDM GUI | Preamble

After we set the OFDM system parameters in Figure 7, we can set the preamble parameters -- if the OFDM system has preamble (either one of Preamble1_Enable and Preamble2_Enable is ON or both of them are all ON). Otherwise, this GUI will disappear.

The screenshot shows the 'Preamble' tab of the Flexible OFDM GUI. It contains several sections for configuring preamble parameters:

- Preamble FrequencyDomain:** Radio buttons for YES (selected) and NO.
- Preamble1 GuardPosition:** Radio buttons for Prefix (selected) and Postfix.
- Preamble2 GuardPosition:** Radio buttons for Prefix (selected) and Postfix.
- Preamble1 Parameter:**
 - Prml1 Seq: $[2 + 2j, 0, 0, 0, 2 + 2j, 0, 0, 0, 2 + 2j]$
 - Prml1 GuardInterval: 0.25
 - Prml1 RepeatTimes: 1
- Preamble2 Parameter:**
 - Prml2 Seq: $[1.414 - 1.414j, 0, -1.414 - 1.41j]$
 - Prml2 GuardInterval: 0.25
 - Prml2 RepeatTimes: 1

Other visible parameters include NumOfCarriers (201), DimCarrierIndex (0:Row Vector selected), and CarrierIndex ([-100:100]).

Figure 8: Flexible OFDM Preamble GUI

Figure 8 depicts the GUI for the preamble setting and shows all parameters of Preamble1 and Preamble2 when both preambles are turned ON. When either Preamble1_Enable or Preamble2_Enable is OFF, its corresponding parameters are grayed. As an example, in Figure 9 the parameters of Preamble2 are grayed when Preamble2_Enable=OFF. These grayed parameters cannot be set.

This screenshot shows a close-up of the 'Preamble2 Parameter' section. The fields are grayed out, indicating they are disabled:

- Prml2 Seq: $[1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, 1]$
- Prml2 GuardInterval: 0.25
- Prml2 RepeatTimes: 2

Figure 9: Preamble2 GUI when Preamble2_Enable is turned OFF

Figure 10 depicts the preamble GUI when there is at least one preamble available (either Preamble1_Enable or Preamble2_Enable) and it is defined in the time domain.

The screenshot shows a software interface with tabs: System, Preamble (selected), Pilot, Data, Data2, and Configuration File. Under the Preamble tab, there are three main sections:

- Preamble FrequencyDomain:** Two radio buttons, YES and NO. The NO button is selected.
- Preamble1 GuardPosition:** Two radio buttons, Prefix and Postfix. The Prefix button is selected.
- Preamble2 GuardPosition:** Two radio buttons, Prefix and Postfix. The Prefix button is selected.
- Preamble1 Parameter:** A group of four input fields:
 - Prml1 Seq: [1.281,1.071,-0.501,-1.212,-0.8]
 - Prml1 GuardInterval: 0
 - Prml1 RepeatTimes: 1
 - Prml1 BlockSize: 4608
- Preamble2 Parameter:** A group of four input fields:
 - Prml2 Seq: [1.269,1.156,-0.461,-1.398,-0.8]
 - Prml2 GuardInterval: 0
 - Prml2 RepeatTimes: 1
 - Prml2 BlockSize: 1728

Figure 10: Preamble GUI when Preamble_FrequencyDomain=NO

The SystemVue custom OFDM source provides a number of parameters for configuring the preamble. These parameters include:

Preamble_FrequencyDomain	Preamble is in frequency domain ("YES") or time domain ("NO").
Preamble_DimCarrierIndex	Dimension of Preamble_CarrierIndex (RowVector, FromFile). This parameter determines how to input subcarrier indexes of Preamble_CarrierIndex. If RowVector is selected, then the Preamble_CarrierIndex is input directly as row vector. Otherwise, the carrier index of preamble is read from a text or binary file. Please refer to the manual of Data Flow Models OFDM_SubcarrierMux for more information
Preamble_NumOfSubcarriers	Number of subcarriers of preamble.
Preamble_CarrierIndex	Subcarrier indexes of preamble. Its value range should be within Index1, which is calculated in the code in Mapping Relationship between the OFDM Subcarrier and IFFT Buffer.
Preamble1_BlockSize	Blocksize of Preamble1 if Preamble_FrequencyDomain=No.
Preamble1_RepeatTimes	Repeat times of Preamble 1.
Preamble1_GuardPosition	Guard interval position of Preamble 1 (Prefix, Postfix).
Preamble1_GuardInterval	Guard interval of Preamble1.
Preamble1_Seq	Preamble sequence of Preamble 1.
Preamble2_BlockSize	Blocksize of Preamble2 if Preamble_FrequencyDomain=No.
Preamble2_RepeatTimes	Repeat times of Preamble 2
Preamble2_GuardPosition	Guard interval position of Preamble 2 (Prefix, Postfix).
Preamble2_GuardInterval	Guard interval of Preamble2.
Preamble2_Seq	Preamble sequence of Preamble 2.

If Preamble_FrequencyDomain=NO, then parameters Preamble_DimCarrierIndex, Preamble_NumOfSubcarriers and Preamble_CarrierIndex are inactive. Otherwise, Preamble1_BlockSize and Preamble2_BlockSize are inactive. All these parameters will disappear in the GUI when the corresponding parameters are set.

Flexible OFDM GUI | Data

After setting the OFDM system and preamble parameters, we next turn our attention to the data (payload) and pilot settings.

Figure 11 shows the GUI of Data1 (payload). If Data2_Enable=ON, that means the OFDM frame has one more payload defined in the Data2 tab and an additional GUI is shown in Figure 12.

The screenshot shows the 'Data' tab in the Flexible OFDM GUI. It contains two main sections: 'Data' and 'EVMRef'. The 'Data' section has 'NumOfCarriers' set to 192, 'Dim Carrier Index' with '0:Row Vector' selected, and 'CarrierIndex' set to [-100:-89, -87:-64, -62:-39, -37:-14]. The 'EVMRef' section has 'NumOfCarriers' set to 200, 'Dim Carrier Index' with '0:Row Vector' selected, and 'CarrierIndex' set to [-100:-1, 1:100]. Below these is the 'Data1' section with 'MappingType' set to 1:QPSK. The tabs at the top are System, Preamble, Pilot, Data, Data2, and Configuration File.

Figure 11: Flexible OFDM Data1 (Payload) GUI

The parameters of Data1 and Data2 payloads are as follows:

Data_NumOfCarriers	Number of subcarriers of Data1 and Data2 in one OFDM symbol
Data_DimCarrierIndex	Dimension of Data_CarrierIndex (RowVector, FromFile). This parameter determines how to input subcarrier indexes of Data_CarrierIndex. If RowVector is selected, then Data_CarrierIndex is input directly as row vector. Otherwise, the carrier index of Data1 and Data2 is read from a text or binary file. Please refer to the manual of Data Flow Models OFDM_SubcarrierMux for more information.
Data_CarrierIndex	Subcarriers indexes of Data1 and Data2. Its value range should be within Index2, which is calculated in the code in Mapping Relationship between the OFDM Subcarrier and IFFT Buffer.
Data1_MappingType	Mapping type of Data1 payload (BPSK, QPSK, QAM16, QAM64, QAM256 and User Defined). If User Defined is selected, we can input complex values of its constellation.
Data1_MappingTable	Mapping table of Data1 when User Defined is selected in Data1_MappingType
Data2_MappingType	Mapping type of Data1 payload (BPSK, QPSK, QAM16, QAM64, QAM256 and User Defined)
Data2_MappingTable	Mapping table of Data1 when User Defined is selected in Data2_MappingType.
EVMRef_NumOfCarriers	Number of EVM reference subcarriers in one OFDM symbol.
EVMRef_DimCarrierIndex	Dimension of EVMRef_CarrierIndex (RowVector, FromFile). This parameter determines how to input subcarrier indexes of EVMRef_CarrierIndex. If RowVector is selected, EVMRef_CarrierIndex is input directly as row vector. Otherwise, the carrier index of EVM reference is read from a text or binary file. Please refer to the manual of Data Flow Models OFDM_SubcarrierMux for more information.
EVMRef_CarrierIndex	Subcarriers indexes of EVM Reference. Its value range should be within Index2, which is calculated in the code in Mapping Relationship between the OFDM Subcarrier and IFFT Buffer.

When Data2_Enable is OFF, the Data2 GUI disappears and all parameters of Data2 are inactive. This GUI is shown in Figure 12.

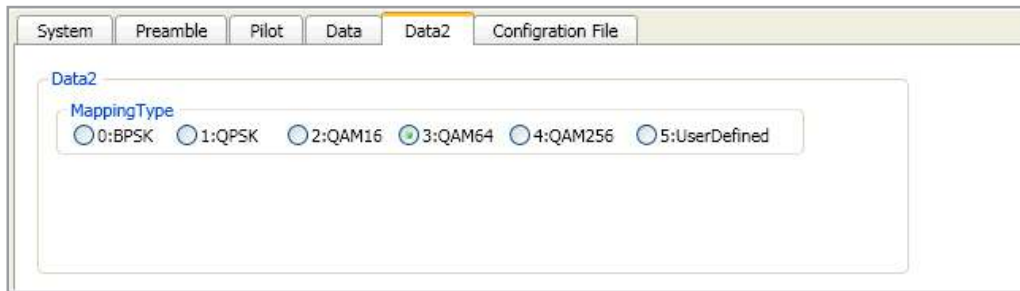


Figure 12: Flexible OFDM Data2 (Payload) GUI

When Data1_MappingType or Data2_MappingType is selected as UserDefined, its mapping values for the look-up table should be input or read from the file in Data1_MappingTable or Data2_MappingTable. Figure 13 depicts the GUI when Data1_MappingTable=User Defined. The mapping table can be input directly or read from a text file.



Figure 13: GUI of Data1_MappingType=User Defined

If we click the input panel in Figure 13, an edit window appears that allows us to input complex values of the constellation. After inputting these values, we click the OK. Figure 14 shows the mapping table with these constellation complex values as input.

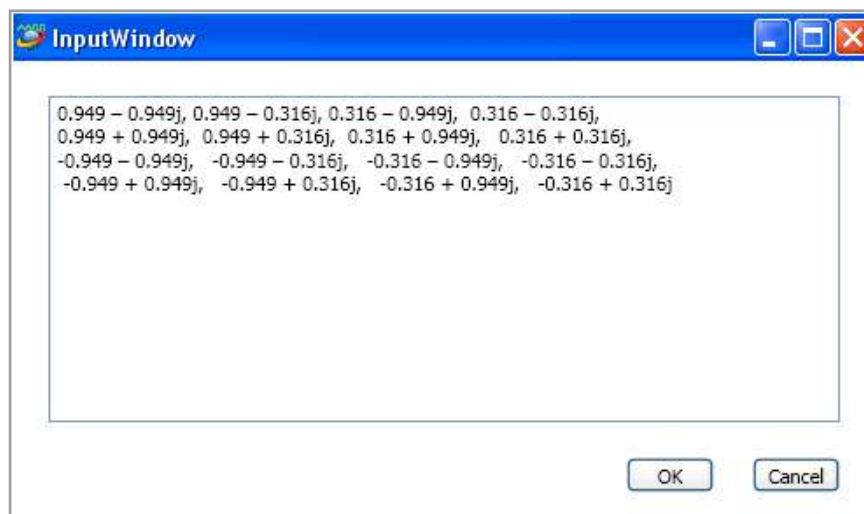


Figure 14: Input constellation complex values of Data1_MappingType=User Defined

Flexible OFDM GUI | Pilot

After setting Data1 and Data 2 payload parameters, we can now set the Pilot characteristics using the GUI. Figure 15 shows the GUI of the pilot when Pilot2_Enable=OFF.

Most OFDM communications (e.g., IEEE 802 series) have only one kind of pilot (continuous or scattered). In this case, one of the Pilot1_Enable and Pilot2_Enable can be turned ON, while the other should be turned OFF.

Some OFDM communication systems (e.g., G3-PLC) do not have any pilot and therefore, both Pilot1_Enable and Pilot2_Enable should be turned OFF.

System Preamble **Pilot** Data Data2 Configuration File

Pilot

Dim Carrier Index: ☒ 0:Row Vector ☐ 1:FromFile

MappingType: ☒ 0:BPSK ☐ 1:QPSK ☐ 2:Others

Pilot1

NumOfCarriers: 8

CarrierIndex: [-88, -63, -38, -13, 13, 38, 63, 88]

Sequence: [-1, 1, -1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, 1, -1, -1]

Pilot2

NumOfCarriers: 1

CarrierIndex: [0]

Sequence: []

Figure 15: Flexible OFDM Pilot GUI

Most video OFDM systems (e.g., DVB-T and DVB-T2) have two kinds of pilot (continuous and scattered). Consequently, both Pilot1_Enable and Pilot2_Enable should be enabled. Figure 16 shows the Pilot GUI setting of a DVB-C2 system.

System **Pilot** Data Data2 Configuration File

Pilot

Dim Carrier Index: ☒ 0:Row Vector ☐ 1:FromFile

MappingType: ☒ 0:BPSK ☐ 1:QPSK ☐ 2:Others

Pilot1

NumOfCarriers: [569, 569, 569, 569, 569, 37, 38, 37, 37, 37, 37, 37, 37, 37, 37, 37, 37]

CarrierIndex: [-1704, -1698, -1692, -1686, -1680, -1674, -1668, -1662, -1656, -1650, -1644, -1638, -1632, -1626, -1620, -1614, -1608, -1602]

Sequence: [1, 1, -1, -1, 1, -1, -1, 1, 1, 1, 1, -1, -1, 1, 1, -1, -1, 1]

Pilot2

NumOfCarriers: [0, 0, 0, 0, 0, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30, 30]

CarrierIndex: [-1608, -1488, -1398, -1314, -1254, -1218, -1182, -1146, -1110, -1074, -1038, -1002, -966, -930, -894, -858, -822, -786]

Sequence: [-2.333, 2.333, 2.333, 2.333, 2.333, -2.333, -2.333, 2.333, 2.333, -2.333, -2.333, 2.333, 2.333, -2.333, -2.333, 2.333, 2.333, -2.333]

Figure 16: DVB-C2 Pilot GUI

There are a number of parameters available to configure the pilot. These parameters include:

Pilot_MappingType	Mapping type of Pilot (BPSK, QPSK, and others). This parameter is only used to generate external configuration files for Keysight's VSA 89600B software. The Keysight VSA S89600B needs to know the modulation type of the pilot when it demodulates the OFDM waveforms generated by the SystemVue OFDM source.
Pilot_DimCarrierIndex	Dimension of Pilot1_CarrierIndex and Pilot2_CarrierIndex (RowVector, FromFile). This parameter determines how to input subcarrier indexes of Pilot1_CarrierIndex and Pilot2_CarrierIndex. If RowVector is selected, Pilot1_CarrierIndex and Pilot2_CarrierIndex are input directly as row vector. Otherwise, the carrier index of Pilot1 and Pilot2 is read from a text or binary file. Please refer to the manual of Data Flow Models OFDM_SubcarrierMux for more information.
Pilot1_NumOfCarriers	Number of subcarriers of Pilot1 in one OFDM symbol.
Pilot1_CarrierIndex	Subcarriers indexes of Pilot1. Its value range should be within Index2, which is calculated in the code shown in the Mapping Relationship between the OFDM Subcarrier and IFFT Buffer.
Pilot1_Seq	Pilot1 sequence in all payload OFDM symbols (Data_NumOfSym in Equation 5).
Pilot2_NumOfCarriers	Number of subcarriers of Pilot2 in one OFDM symbol.
Pilot2_CarrierIndex	Subcarriers indexes of Pilot2. Its value range is defined in Index2.
Pilot2_Seq	Pilot2 sequence in all payload OFDM symbols (Data_NumOfSym in Equation 5).

Flexible OFDM GUI: Exporting Configuration Files

After customizing the various OFDM system parameter settings, SystemVue can further export configuration files needed to set up the VSA 89600B software for demodulation and analysis, both for simulated signals, as well as for hardware measurements. Figure 17 shows the SystemVue setup screen for exporting the VSA 89600B configuration files.

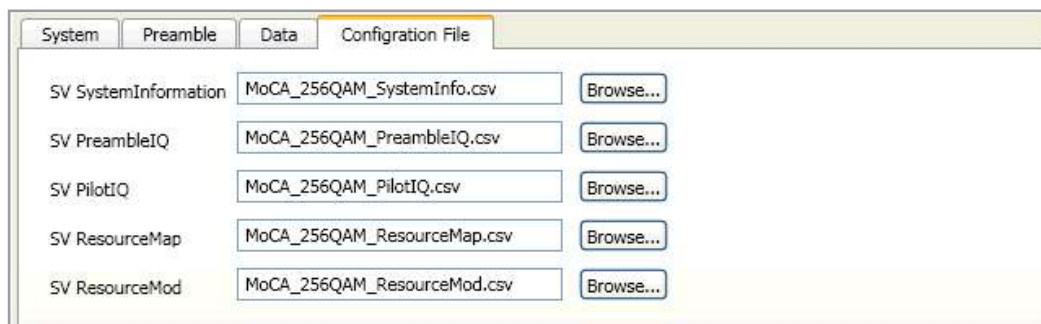


Figure 17: Flexible OFDM GUI of VSA 89600B Configuration Files

There are five configuration files generated from the SystemVue OFDM source. These files include:

SV_SystemInfo.csv	Input file name to output OFDM system parameters. This information helps set parameters in Keysight's VSA 89600B software. Figure 18 shows the system information output by SystemVue's OFDM source.
SV_PreambleIQ.csv	Input file name to sink preamble I and Q values for each preamble OFDM symbol. Its format is defined in the Keysight 89600 Vector Signal Analyzer flexible OFDM Analysis Option BHF document. [16] Please refer to this document for more information. Note that this file will be NULL if the system does not have any preamble or time-domain preamble.

1	FCarrier: 900000000.000000 Hz			
2	Power: 0.000010 W			
3	OFDM System Sample Frequency: 50000000.000000 Hz			
4	Upsampling ratio: 2			
5	Subcarrier Space: 195312.500000 Hz			
6				
7	FFT Length: 256			
8	Guard Lower Subcarriers: 13			
9	Guard Upper Subcarriers: 12			
10	DC Subcarriers: 7			
11	Guard Interval: 0.250000			
12				
13	Preamble is in frequency domian: YES			
14	Preamble1 is ON or OFF: ON			
15	Preamble2 is ON or OFF: OFF			
16				
17	Data1 number of OFDM symbols: 20			
18	Data2 is ON or OFF: OFF			
19				
20	Pilot1 is ON or OFF: OFF			
21	Pilot2 is ON or OFF: OFF			
22				
23	Symbol windowing function is ON or OFF: ON			

Figure 18: OFDM System Information of the OFDM source

SV_PilotIQ.csv	Input file name to sink pilot I and Q values for all Data1 and Data2 OFDM symbols. Its format is defined in the Keysight 89600 Vector Signal Analyzer flexible OFDM Analysis Option BHF document. [16] Please refer to this document for more information. Note that this file will be NULL if the system does not have any pilot. There is always one line for I and Q values of pilots per each OFDM symbol.
SV_ResourceMap.csv	Input file name to sink resource mapping per each OFDM symbol. Its format is defined in the Keysight 89600 Vector Signal Analyzer flexible OFDM Analysis Option BHF document. [16] Please refer to this document for more information. Note that there is only one line to sink Data 1 and Data 2 resource mapping in this file if SubcarrierAllocationType=Fixed.
SV_ResourceMod.csv	Input file name to sink resource modulation per each OFDM symbol. Its format is defined in the Keysight 89600 Vector Signal Analyzer flexible OFDM Analysis Option BHF document. [16] Please refer to this document for more information. Note that there is only one line to sink Data 1 and Data 2 resource mapping in this file if SubcarrierAllocationType=Fixed.

Four of the configuration files (SV_PreambleIQ.csv, SV_PilotIQ.csv, SV_ResourceMap.csv, and SV_ResourceMod.csv) can be loaded into the VSA 89600B custom OFDM window directly. Figure 19 depicts the VSA 89600B Custom OFDM “Demodulation Properties”, where these files are loaded manually into the VSA 89600B.

Custom OFDM Demodulation Properties	
Format Time Equalizer & Tracking Advanced	
Preset to Standard... Load Pilot IQ Values... Load Preamble IQ Values... Load Resource Map... Load Resource Modulation...	
Format FFT Length 256 Guard Interval 0.25 Guard Lower Subcarriers 13 Subcarriers Guard Upper Subcarriers 12 Subcarriers Mirror Frequency Spectrum ☐ OFDM System Sample Frequency 50 MHz	
Format: Details Pilot IQ Values Preamble IQ Values QAM Code Words QAM Identifiers QAM IQ Points QAM Levels Resource Map Resource Modulation Resource Repeat Index Signal is Bursted Transmitter Antennas Transmitter Window Beta	
Format: Details: Boosting QAM Identifier Boost Levels Unknown Pilot Boost Level User Boost Levels	

Figure 19: VSA 89600B custom OFDM “Demodulation Properties”

From Figure 19, the OFDM format parameters seen in the VSA are: FFT Length, Guard Interval, Guard Lower Subcarriers, Guard Upper Subcarriers and OFDM System Sample Frequency. As can be seen in Figure 18, the SystemVue OFDM source also outputs these same OFDM system parameters. These parameters can be manually entered into the VSA 89600B software.

Examples

SystemVue provides examples with several pre-configured OFDM waveforms. These examples include:

- WLAN IEEE 802.11a;
- Fixed WiMAX™ IEEE 802.16;
- WiGIG/802.11ad (Wireless Gigabit Alliance);
- MoCA (Multimedia over Coax Alliance);
- DVB-C2;
- ERDF G3-PLC; and
- Berdrola PRIME-PLC.

All of these examples can be found in the C:\Program Files\SystemVue2011.03\Examples\Flex OFDM directory. They show how the Keysight SystemVue OFDM source can generate various commercial OFDM waveforms (WLAN 802.11a/g/n, among others), as well as custom OFDM waveforms (such as the military communication WNW).

WiGIG/802.11ad

The Wireless Gigabit Alliance is an organization promoting the adoption of multi-gigabit speed wireless communications technology operating over the unlicensed 60 GHz frequency band. Parameters of the WiGIG in an OFDM system include:

Parameter	Value
NSD: Number of data subcarriers	336
NSP: Number of pilot subcarriers	16
NDC: Number of DC subcarriers	3
NST: Total number of subcarriers	355
NSR: Number of subcarriers occupying half of the overall BW	177
ΔF : Subcarrier frequency spacing	5.15625 MHz (2640 MHz/512)
Fs: OFDM sample rate	2640 MHz
Fc: SC chip rate	1760 MHz = $2/3 F_s$
Ts: OFDM sample time	0.38 ns = $1/F_s$
Tc: SC chip time	0.57 ns = $1/F_c$
TDFT: IDFT/DFT period	0.194 μ sec
TGI: Guard interval duration	48.4 ns = TDFT/4
Tseq	72.7 ns = $128 \times T_c$
TSTF: Detection sequence duration	1091 ns = $15 \times T_{seq}$
TCE: Channel estimation sequence duration	655 ns = $9 \times T_{seq}$
TSYM: Symbol interval	0.242 μ s = TDFT + TGI

Figure 20 shows the SystemVue 2011.03 workspace configured to act as a WiGIG source.

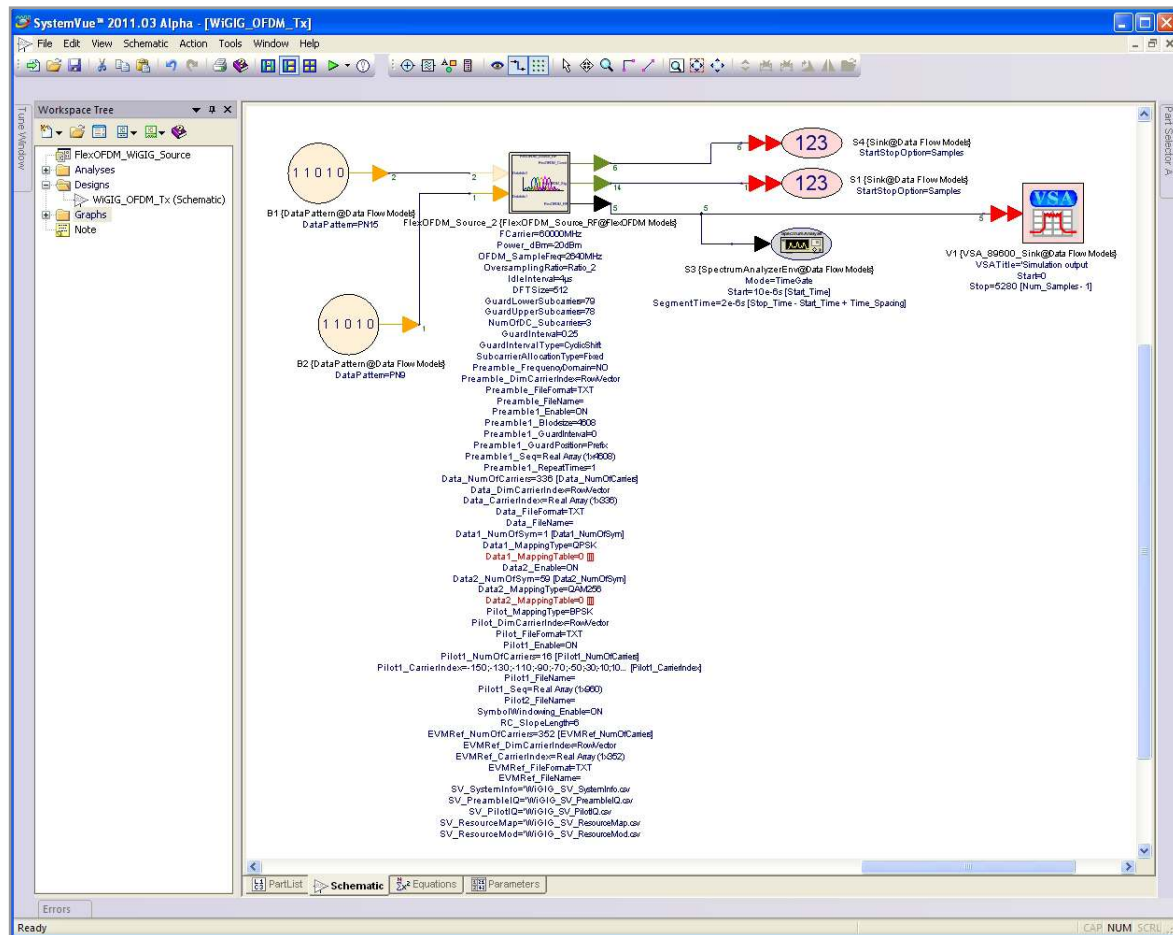


Figure 20: Schematic of WiGIG source created using SystemVue's custom OFDM source

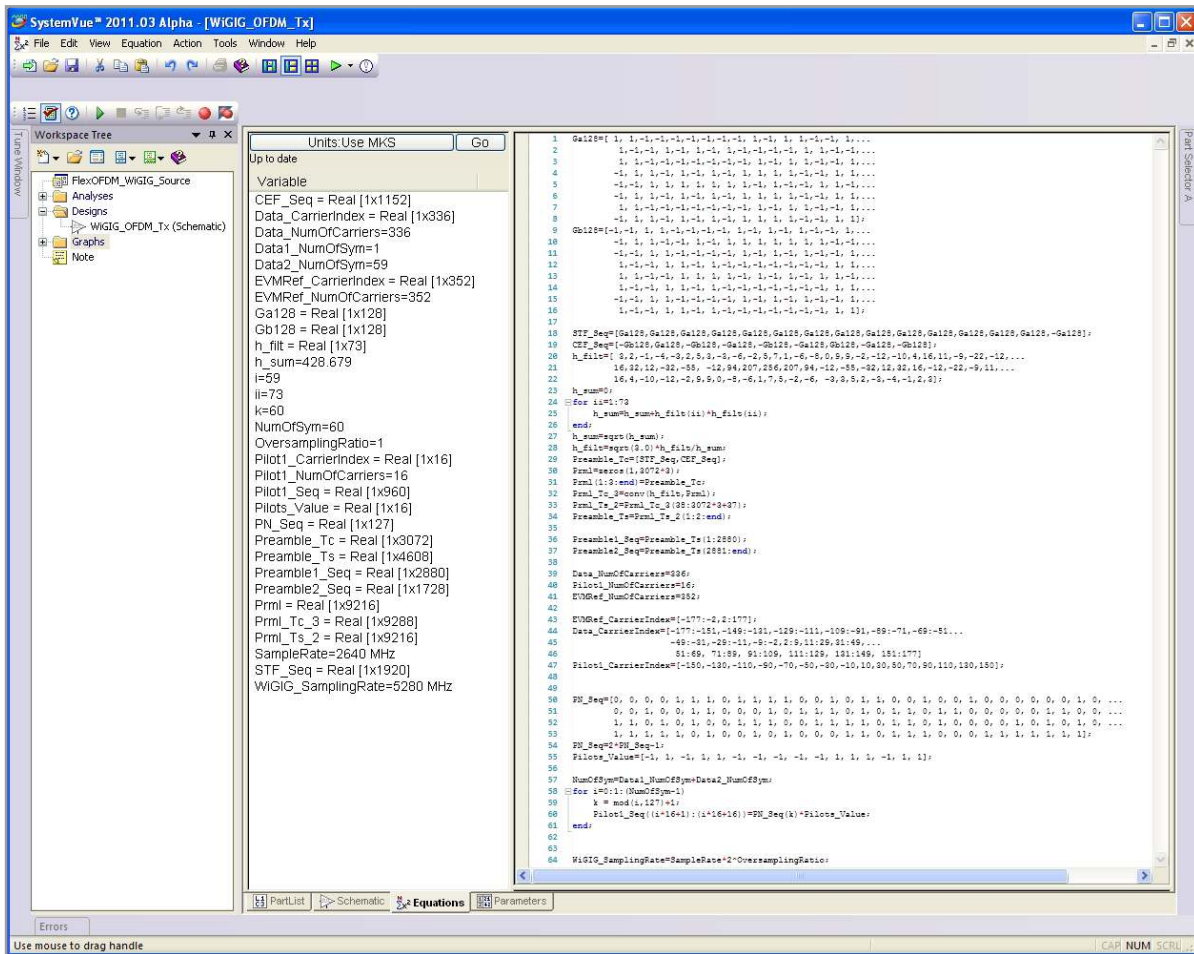


Figure 21: Equations of the WiGIG source

Keysight's SystemVue combines C++ dataflow models and the math language engine (or MATLAB directly) into one development environment. The PartList, Schematic, Equations, and Parameters panel is shown in left-hand corner of Figure 20. We can write math language code in the Equations part and the Equation variables can be used to control parameters of the dataflow models in the Schematic part. By clicking the Equations in Figure 20, we can see the Equation part in Figure 21. The preamble sequence, pilot sequence and subcarrier index, among others, are generated as variables in Equations. These variables are used to set the flexible OFDM GUI. Figure 22 shows the spectrum of WiGIG in SystemVue.

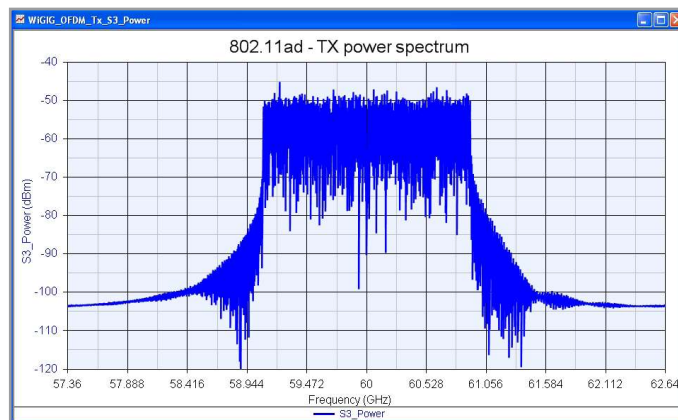


Figure 22: Spectrum of 802.11ad (60 GHz WiGIG)

MoCA is the universal standard for home entertainment networking. It is the only home entertainment networking standard that appeals to all three pay TV segments – cable, satellite and Internet Protocol Television (IPTV). The current MoCA specification can support multiple streams of HD video, deliver up to 175-Mbps net throughput and offer an unparalleled user experience via parameterized quality of service (PQoS).

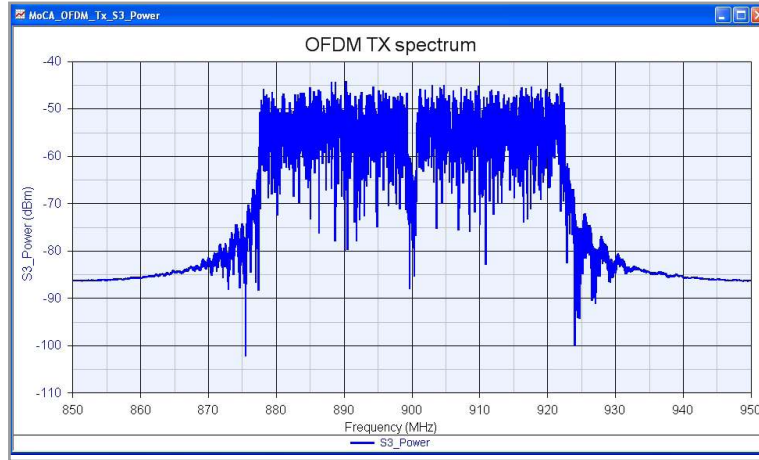


Figure 24: Spectrum of MoCA in SystemVue

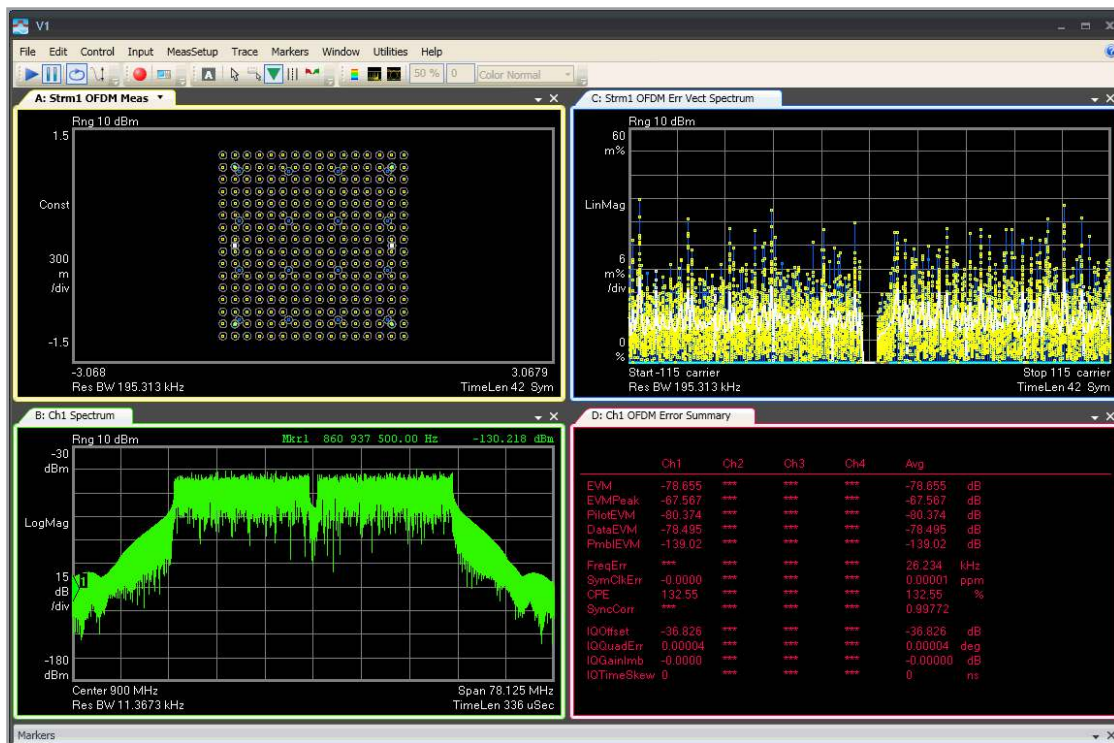


Figure 25: Results of VSA 89600B Custom OFDM

Summary

OFDM technology is a key enabling technique for wideband and emerging communication systems. The SystemVue OFDM source capability can generate a variety of OFDM waveforms to meet custom requirements, as well as standard-compliant waveforms. The SystemVue OFDM source also can be demodulated by Keysight's VSA 89600B software using the platform's custom OFDM demodulation personality. This application note covered the basics of how to generate custom OFDM waveforms using SystemVue. It also detailed how to link with the VSA 89600B software to create a complete design-to-test capability for these complex systems.

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