



Agilent X-Series Signal Analyzer

This manual provides documentation
for the following analyzers:

PXA Signal Analyzer N9030A

MXA Signal Analyzer N9020A

EXA Signal Analyzer N9010A

CXA Signal Analyzer N9000A

N9064A & W9064A VXA Signal Analyzer Measurement Application Measurement Guide



Agilent Technologies

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1 Introduction

This section provides overall information on the Agilent N9064A (formerly 89601X) VXA Signal Analyzer Measurement Application and describes the measurements made by the analyzer. Installation instructions for adding this option to your analyzer are provided in this section, in case you purchased this option separately.

What Does the Agilent N9064A VXA Signal Analyzer Measurement Application Do?

The N9064A VXA is a full-featured vector signal analyzer that can help determine if an RF modulated source or transmitter is working correctly. There are standard and optional measurements for complete analysis and demodulation of most communications signals.

- The Vector Analysis measurement (included in Option 1FP) provides:
 - Spectrum analysis and Time Domain analysis with Signal Tracking
 - Band Power, Occupied Bandwidth, and ACP measurements
 - Markers, Marker Coupling, Triggering
 - Time Gating
 - Frequency Counter
- The Analog Demodulation measurement (included in Option 1FP) will perform all the above and will also analyze and demodulate signals that use the following modulation formats:
 - AM, FM, PM
- The Digital Demodulation measurement (Option 2FP) will analyze and demodulate signals that use the following modulation formats:
 - MSK
 - QPSK
 - 8PSK
 - BPSK
 - $\pi/4$ DQPSK
 - DQPSK
 - $\pi/8$ D8PSK
 - D8PSK
 - Offset QPSK
 - QAM16, 32, 64, 128, 256, 512, 1024
 - DVB QAM 16, 32, 64, 128, 256
 - FSK 2, 4, 8, 16 states
 - VSB8, VSB16
 - APSK16, 32, 16 w/dub, 32 w/dub

What Does the Agilent N9064A VXA Signal Analyzer Measurement Application Do?

- Standard communications formats provided by Option 2FP include:
 - Cellular: IS-95 Base and Mobile, GSM, EDGE, CDPD, NADC, PDC, PHP, 3GPP (W-CDMA)
 - Wireless Networking: 802.11b, HIPERLAN/1 (HBR and LBR), Bluetooth, ZigBee 868, 915, and 2450
 - Digital Video: DTV8, DTV16, DVB16, DVB32, DVB64, DVB128, DVB256, DVB 16APSK with code rates 2/3 to 9/10, DVB 32 APSK with code rates 3/4 to 9/10.
 - Other: APCO 25, DECT, TETRA, VDL Mode 3
- With other digital demod options, the N9064A VXA will also demodulate more complicated signals that conform to the following standard communications formats:
 - Option 3FP - WLAN 802.11 a/b/g, OFDM and DSSS

NOTE

For CDMA signals, N9064A VXA can analyze digital modulation for a single code channel only. If multiple code channels are transmitted, synchronization will fail, and incorrect EVM results will be obtained. For modulation quality measurements of multiple code channels, Modulation Accuracy and Code Domain measurements must be performed by a full-featured standard-based measurement application, like N9073 for W-CDMA.

Installing Application Software

When you want to install a measurement application after your initial hardware purchase, you actually only need to license it. All of the available applications are loaded in your analyzer at the time of purchase.

So when you purchase an application, you will receive an entitlement certificate that is used to obtain a license key for that particular measurement application. Enter the license key that you obtain into the N9020A Signal Analyzer to activate the new measurement application. See below for more information.

For the latest information on Agilent Signal Analyzer measurement applications and upgrade kits, visit the following internet URL.

http://www.agilent.com/find/sa_upgrades

Viewing a License Key

Measurement personalities purchased with your instrument have been installed and activated at the factory before shipment. The instrument requires a unique **License Key** for every measurement application purchased. The license key is a hexadecimal string that is specific to your measurement application, instrument model number and serial number. It enables you to install, or reactivate that particular application.

Press **System, Show, System** to display which measurement applications are currently licensed in your analyzer.

Press **System, More, Licensing. . .** to view the license keys for the installed measurement applications.

NOTE

You may want to keep a copy of your license key in a secure location. You can print out a copy of the display showing the license numbers to do this. If you should lose your license key, call your nearest Agilent Technologies service or sales office for assistance.

Obtaining and Installing a License Key

If you purchase an additional application that requires installation, you will receive an "Entitlement Certificate" which may be redeemed for a license key for one instrument. Follow the instructions that accompany the certificate to obtain your license key.

Installing a license key for the selected application can be done automatically using a USB memory device. To do this, you would put the license file on the USB memory device at the root level. Follow the instructions that come with your software installation kit.

Installing a license key can also be done manually using the license management application in the instrument. It is found through the instrument front panel keys at **System, Licensing. . .**, or internally at C:\Programming Files\Agilent\Licensing.

NOTE

You can also use these procedures to reinstall a license key that has been accidentally deleted, or lost due to a memory failure.

Missing and Old Measurement Application Software

All the software applications were loaded at the time of original instrument manufacture. It is a good idea to regularly update your software with the latest available version. This assures that you get any improvements and expanded functionality that is available.

Because the software was loaded at the initial purchase, there may be additional measurement applications that are now available. If the application you are interested in licensing is not available, you will need to do a software update. (Press **System**, **Show**, **System**.)

Check the Agilent internet website for the latest software versions available for downloading:

http://www.agilent.com/find/pxa_software
http://www.agilent.com/find/mxa_software
http://www.agilent.com/find/exa_software
http://www.agilent.com/find/cxa_software

You must load the updated software package into the analyzer from a USB drive, or directly from the internet. An automatic loading program is included with the files.

Introduction

Installing Application Software



2 Making N9064A VXA Measurements

This chapter describes procedures used to set up measurements for analysis of various types of modulated signals. Details of the steps necessary for accurate vector signal analysis of digital and analog signals are provided, and examples of the measurement capability of the N9064A (formerly 89601X) VXA are shown.

NOTE

For CDMA signals, the N9064A VXA Digital Demod measurement can analyze digital modulation for a single code channel only. If multiple code channels are transmitted, synchronization will fail, and incorrect EVM results will be obtained. For modulation quality measurements of multiple code channels, Modulation Accuracy and Code Domain measurements use an X-Series full-featured standard-based measurement application, like N9073 for W-CDMA.

Introduction

This chapter provides measurement procedures and also shows example results obtained using the N9064A VXA measurement application. When correctly set up, the N9064A VXA demodulates basic communications, cellular, and wireless connectivity formats and performs a suite of vector signal analysis measurements to analyze digital modulation quality.

There are three fundamental measurements available in this mode: **Vector Analysis**, **Analog Demod** (standard with N9064A option 1FP), and **Digital Demod** (available separately as N9064A Option 2FP). WLAN Option 3FP provides DSSS and OFDM signal measurement capability, available separately. Procedures specific to WLAN signals are also shown.

NOTE

Before you can begin making measurements, make sure you have N9064A VXA installed.

1. Press **Mode**, and check to make sure that **Vector Signal Analyzer** is available.
2. Press **Meas**, and check to make sure that **Vector Analysis** and **Analog Demod** are available.
3. For Digital Demod measurements, check to make sure that Digital Demod (Option 2FP) is available.

In case you have purchased this firmware separately as an optional upgrade, refer to [“Installing Application Software” on page 16](#).

The following main subjects are presented in this chapter:

- [“Measuring Analog Signals” on page 22](#)

This section describes how to use the Analog Demod measurement to view the RF parameters of analog signals, and make mode-level settings.

- [“Viewing Other Analog Demod Measurement Results” on page 35](#)

This section describes the different results available in the Analog Demod measurement.

- [“Measuring Digital Signals” on page 45](#)

This section describes steps to set up N9064A Option 2FP to demodulate industry standard radio formats or to use the flexible modulation settings to demodulate various digital signals.

- [“Viewing Other Digital Demod Measurement Results” on page 65](#)

This section describes the different results available in the Digital Demod measurement.

N9064A VXA Options Compatibility

The following N9064A VXA options are compatible for use with this measurement application:

Opt.	Name	Req'd	Type	Also enabled by 89601A or NA option	Description
IFP	Basic Modulation Analysis	Yes	Std	200	Non-demod vector signal analysis measurements (See appropriate section below for feature details)
2FP	Full Digital Demodulation Analysis	No	Std	AYA	Flexible modulation analysis measurements (See appropriate section below for feature details)
3FP	WLAN Modulation Analysis	No	Std	B7R	IEEE 802.11b DSSS/CCK/PBCC signal modulation analysis and IEEE 802.11a/b/g (and related standards) OFDM signal modulation analysis

Measuring Analog Signals

Analog Demod Measurement Overview

Making successful N9064A VXA measurements of digital signals is easy when you follow these eight main steps. The procedure overview below provides links in blue to a detailed procedure and description for each step:

[“Set Up the Test Equipment and DUT” on page 23](#)

This step configures the analyzer connections for an RF measurement.

[“Select the Mode and Preset the Analyzer” on page 47](#)

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

[“Select and Configure the Analyzer Input” on page 48](#)

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

[“Acquire and Stabilize the Signal” on page 49](#)

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

[“Demodulate the Signal” on page 50](#)

Demodulation is performed by using a specific N9064A VXA demod option, like Option 3FP for WLAN, if installed, or the Analog Demod measurement. Both contain a number of modulation standard presets that enable rapid measurement of modulation quality for a wide variety of signals.

[“Configure the Display” on page 53](#)

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

[“Optimize your Results” on page 55](#)

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

[“Print or Save Your Measurement Results” on page 57](#)

Your measurement result data can be exported or saved as a trace that can be replayed by the instrument. The graphical results can be printed or saved a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Set Up the Test Equipment and DUT

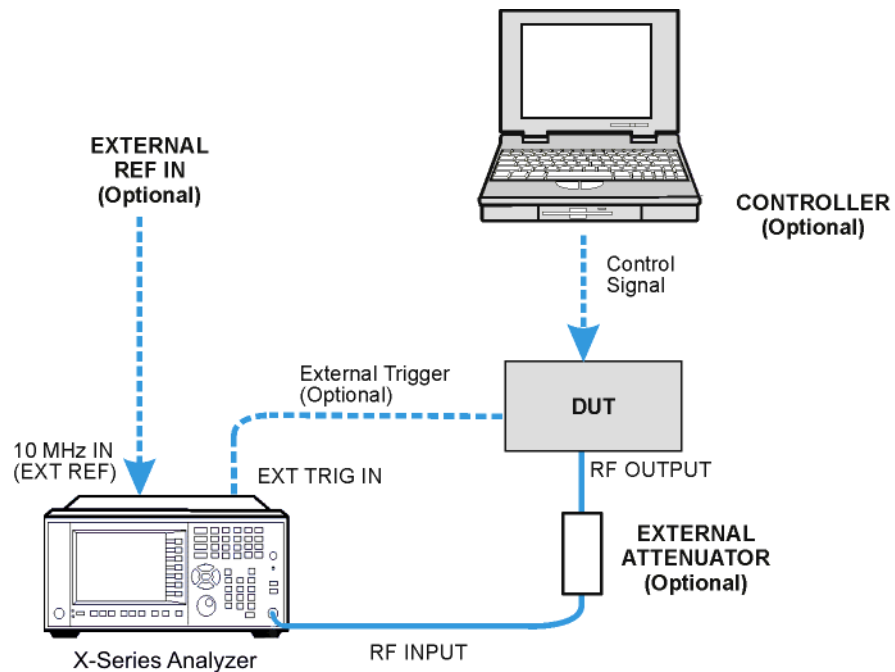
This step configures the analyzer connections for an RF measurement.

Making the Initial Signal Connection

CAUTION

Before connecting a signal to the instrument, make sure the instrument can safely accept the signal level provided. The signal level limits are marked next to the connectors on the front panel.

Figure 2-1 Analog Demod Measurement Setup



Wlan_setup

The device under test (DUT) is connected to the RF input port. The DUT may possibly be controlled externally by a computer. External attenuator, external trigger and external reference are optional. Using the appropriate cables, connect the equipment as shown.

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Select the Mode and Preset the Analyzer

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

Step	Action	Notes
1 Select the Mode.	a. Press MODE, Vector Signal Analyzer .	The default measurement for N9064A VXA is Vector Analysis. Settings made here will be used by Demod measurements later.
2 Preset the analyzer.	a. Press the green Mode Preset button for the factory preset. b. To recall a user-defined Preset: Press User Preset , User Preset to preset the current mode.	

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Select and Configure the Analyzer Input

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

Step	Action	Notes
1 Select and configure the analyzer Input settings.	a. Press Input/Output, RF Input, 75 Ohm Input Z , if needed.	The default RF impedance is 50 Ohms.
2 OR If available, you can recall a saved instrument state to establish a group of measurement settings.	a. Press Recall, State b. Select a Register that contains the state to be retrieved. OR c. Press From File... which opens an Explorer window to browse to your state file location.	Registers 1-6 display the date the last state was saved to help identify which state is saved in each register. TIP Using saved states insure repeatable measurements. See “Print or Save Your Measurement Results” on page 33 for details of saving states.
3 OR If available, you can recall a saved measurement trace for display.	a. Press Recall, Data (Import) b. Press Trace to select the trace that will contain the stored data. c. Press Open... which opens an Explorer window to browse to your state file location.	

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Acquire and Stabilize the Signal

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

Step	Action	Notes
1	<p>Observe the Spectrum (upper) graph: set the center frequency to your signal's carrier frequency.</p> <ol style="list-style-type: none"> Press FREQUENCY Channel. Use the front-panel keypad to input the center frequency. Press a units key, like GHz, to complete the entry. 	<p>Settings made in the Vector Analysis measurements will be used by Demod measurements later.</p> <p>TIP The center frequencies of the analyzer and input signal must match to within $\pm 5\%$.</p>
2	<p>Set the input power range for your signal.</p> <ol style="list-style-type: none"> Press AMPTD Y Scale, Range. Enter the total signal power at the analyzer input. 	<p>Check: Downrange by step until the overload indicator is displayed as "OV" in the top right corner of the graph. Range back up 1 step.</p>
3	<p>Set the frequency span to view your entire signal. Make sure the entire signal is captured in the Spectrum graph.</p> <ol style="list-style-type: none"> Press SPAN X Scale. Use the front-panel keypad to input the frequency span. Press a units key, like MHz, to complete the entry. You can also use the rotary knob to visually set the span. 	<p>Check: The signal's spectrum should occupy 50-90% of the span, and not extend beyond the edges. It should appear as a distinct, elevated region of noise 20 dB or more above the analyzer noise floor. Broad, glitching sidebands indicate bursts or other transients, which can be handled with triggering or the Burst Search function in Demod settings.</p>
4	<p>Observe the Main Time (lower) graph: set trigger parameters (if used)</p> <ol style="list-style-type: none"> Press Trigger. Select the correct input for the trigger signal. Set levels as required. 	<p>Observe the Time Domain waveform to see if it is stable. You can come back to the Main Time window to see if Demod settings made in later steps have stabilized the waveform.</p> <p>TIP Triggering is unnecessary for most signals.</p>

Click to Go Back to ["Measuring Analog Signals" on page 22](#)

Demodulate the Signal

Demodulation of AM, FM and PM signals is performed by using the Analog Demod measurement.

Step	Action	Notes
1	For signals using analog modulation select and configure the Analog Demod measurement.	For signals using digital modulation select the Digital Demod measurement. See “Measuring Digital Signals” on page 45.
2	Set the input power range for your signal.	Check: Downrange by 1 step; the overload indicator should be displayed as “OV” in the top right corner of the graph.
3	Select the modulation type.	
4	Use signal tracking for unstable signals	

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Configure the Display

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

Step	Action	Notes
1 Use a Preset View for fast, powerful results displays.	<ul style="list-style-type: none"> a. Press View/Display. b. Select a Preset View from a selection of useful combinations of related data trace displays. 	For details of the Preset Views see Preset Views below.
2 OR If desired, choose a custom screen layout.	<ul style="list-style-type: none"> a. Press View/Display, Layout. b. Select a layout that will provide your desired arrangement. 	You can choose up to 4 panes to display your trace data.
3 Customize your layout by assigning a data trace to a measurement display.	<ul style="list-style-type: none"> a. Press Trace/Detector, Select Trace. b. Select the trace number to change. c. Press Data to display a menu of trace groups. d. Select the trace data for assignment to the graph. e. Repeat trace assignment for any other traces in the layout as needed. 	When you press Trace/Detector, Select Trace , the trace numbers are displayed on the screen to help you identify the traces for selection.

Analog Demod Preset Views

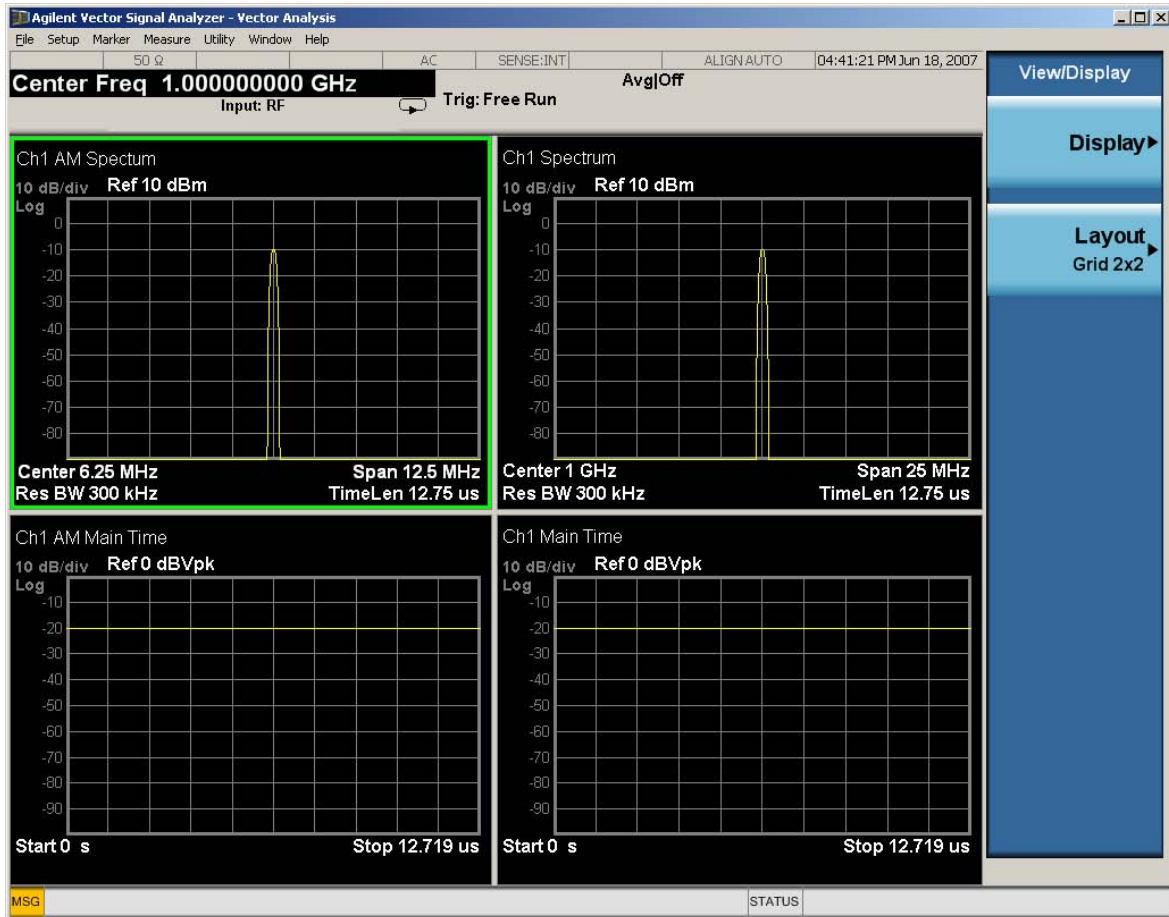
Analog Demod preset displays include Demod/Spectrum Time and Statistics views.

View Presets affect the trace layout, trace data assignment, scaling and formatting but do not affect hardware measurement setup.

Demod Spectrum/Time Preset View

This preset shows a quad layout with the Demod Spectrum in trace 1, Demod Main Time in trace 2, the input Spectrum in trace 3, and the input Main Time in trace 4.

Figure 2-2 Demod Spectrum/Time Preset View



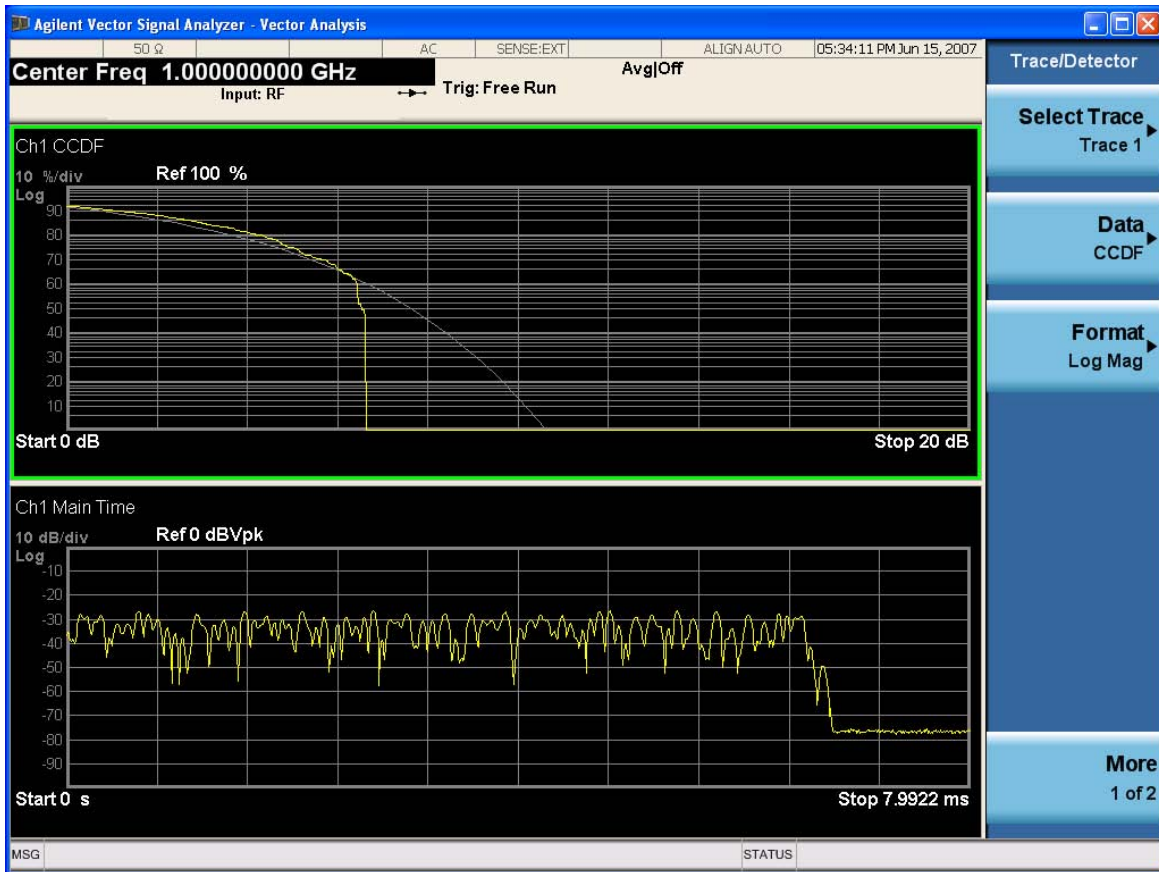
Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Making N9064A VXA Measurements Measuring Analog Signals

Statistics Preset View

This preset shows a quad layout with the Demod Spectrum in trace 1, Demod Main Time in trace 2, the input Spectrum in trace 3, and the input Main Time in trace 4.

Figure 2-3 Statistics Preset View



Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Optimize your Results

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

Step	Action	Notes
1	Select a graph for optimization	
	a. Use the Next Window key (boxes with arrows) below the display to move the green outline "focus" to activate a graph for customization.	
2	Optimize the X Scale.	
	a. Press SPAN X Scale, Scale/Div .	
	b. Use the front-panel keypad to input the scale/div.	
	c. Press a units key, like μs , to complete the entry.	
	OR	
	a. Press SPAN X Scale, More, X Scale Auto to enable the instrument to complete the scaling.	
3	Optimize the Y Scale.	
	a. Press AMPTD YScale, Scale/Div .	
	b. Use the front-panel keypad to input the scale/div.	
	c. Press a units key, like μs , to complete the entry.	
	OR	
	a. Press AMPTD YScale, Auto Scale to enable the instrument to complete the scaling.	
4	Use a Marker to indicate and measure signal characteristics.	
	a. Press Marker, Select Marker .	
	b. Select the desired marker number for your display.	
	c. Press Marker Function, Select Marker to assign a function to the marker.	
	d. Select either Band/Interval Power , or Band/Interval Density , to turn on/off the markers.	
	e. Adjust either the Power Calc settings or Density Calc settings, depending on which function you have selected.	
	f. Press Marker, Delta to set a Delta marker on/off and adjust its position on the graph.	
		For more information on Markers see the Markers section under Measurement Setup in Help.

Step	Action	Notes
5 Add titles, or make other changes to the measurement graphs.	<ul style="list-style-type: none">a. Press View/Display, Display, System, Settings to adjust other parts of the display for all measurement windows.b. Press View/Display, Display, Annotation, to turn on/off various parts of the display annotation.c. Press View/Display, Display, Title, Change Title to create a title for the graph.d. Press View/Display, Display, Graticule to turn graticules on/off.e. Press View/Display, Display, Display Line to turn a reference line on/off and adjust its position on the graph.	For more information on Display settings see the Display section under Analyzer Setup in Help.

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Print or Save Your Measurement Results

Your measurement results data can be saved as traces that can be reviewed by the instrument, or exported for analysis. The graphical results can be printed or saved a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Step	Action	Notes
1	<p>Print your measurement results.</p> <ol style="list-style-type: none"> Press Page Setup and a Windows dialog box opens that enables you to set print parameters, including printer selection. Press Print. 	<p>Set up your printer using the Windows Printer control panel.</p> <p>The Print front-panel key is equivalent to performing File, Print, OK in Windows. It immediately performs the currently configured Print to the current printer.</p>
2	<p>Save your measurement results.</p> <ol style="list-style-type: none"> Press Save, and select Data (Export) to save a data trace, or Screen Image, to save the display as a bitmap file. Press Save As... a Windows Explorer dialog box opens to enable you to name the file and select the file location. Press Quick Save to save repeated measurements in the same format and to the same location as you specified in the last Save procedure. Files saved using Quick Save are numbered sequentially and dated for later reference. 	<p>CAUTION Don't save files to the C: or E: drives as they will be overwritten by software upgrades. Use the User Data (D:) drive for file storage or save your results to an external USB drive.</p> <p>TIP For repeated measurements, create a directory for your saved files during the initial Save set up. All subsequent Quick Save results will be easier to manage when grouped in the same directory</p>
3	<p>If desired, save your measurement state for re-use later.</p> <ol style="list-style-type: none"> Press Save, and select State to save your current measurement settings for re-use later. Select a Register number for storage or press To File... a Windows Explorer dialog box opens to enable you to name the file and select the file location. 	<p>When you save a measurement state, only the settings for the current measurement are saved.</p>

Making N9064A VXA Measurements
Measuring Analog Signals

Step	Action	Notes
4 If desired, save your measurement state as a User Preset .	a. Press User Preset, Save User Preset to save your current measurement settings as a quickly retrievable Mode-level state.	When you save a User Preset the current settings for all measurements in the mode are saved.

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Viewing Other Analog Demod Measurement Results

This section provides some examples of Analog Demod measurement results of a FM signal. Results available include graphical displays of various trace data as well as tabular results available remotely. These graphic results may be viewed separately, or combined into views. For more information on Views see [“Configure the Display” on page 28](#).

Graphical Analog Demodulation Measurement Results

To help pin-point modulation problems, the Analog Demodulation measurement provides many different graphs and numeric results tables. The following procedure shows you how to obtain the results displays using an FM signal (defined below).

You can assign any available data to any of the traces displayed on the screen. The list below of data types may also be viewed in various formats, depending on the data, like eye diagrams, constellation, spectrum, etc.

Digital Demod Measurement Data Include:

1. Instantaneous Main Time
2. Main Time
3. Gated Time
4. Instantaneous Spectrum
5. Spectrum
6. Auto Correlation
7. Power Spectral Density (PSD)
8. Probability Density Function (PDF)
9. Cumulative Density Function (CDF)
10. Complementary Cumulative Density Function (CCDF)
11. Occupied BW Summary
12. ACP Summary
13. Raw Main Time

For more information on what these data traces are, see the User's and Programmer's Guide section or Help on Trace/Detector, Data.

Click to Go Back to [“Measuring Analog Signals” on page 22](#).

Example Measurement - Analog Demod

Agilent ESG Series Vector Signal Generator Settings

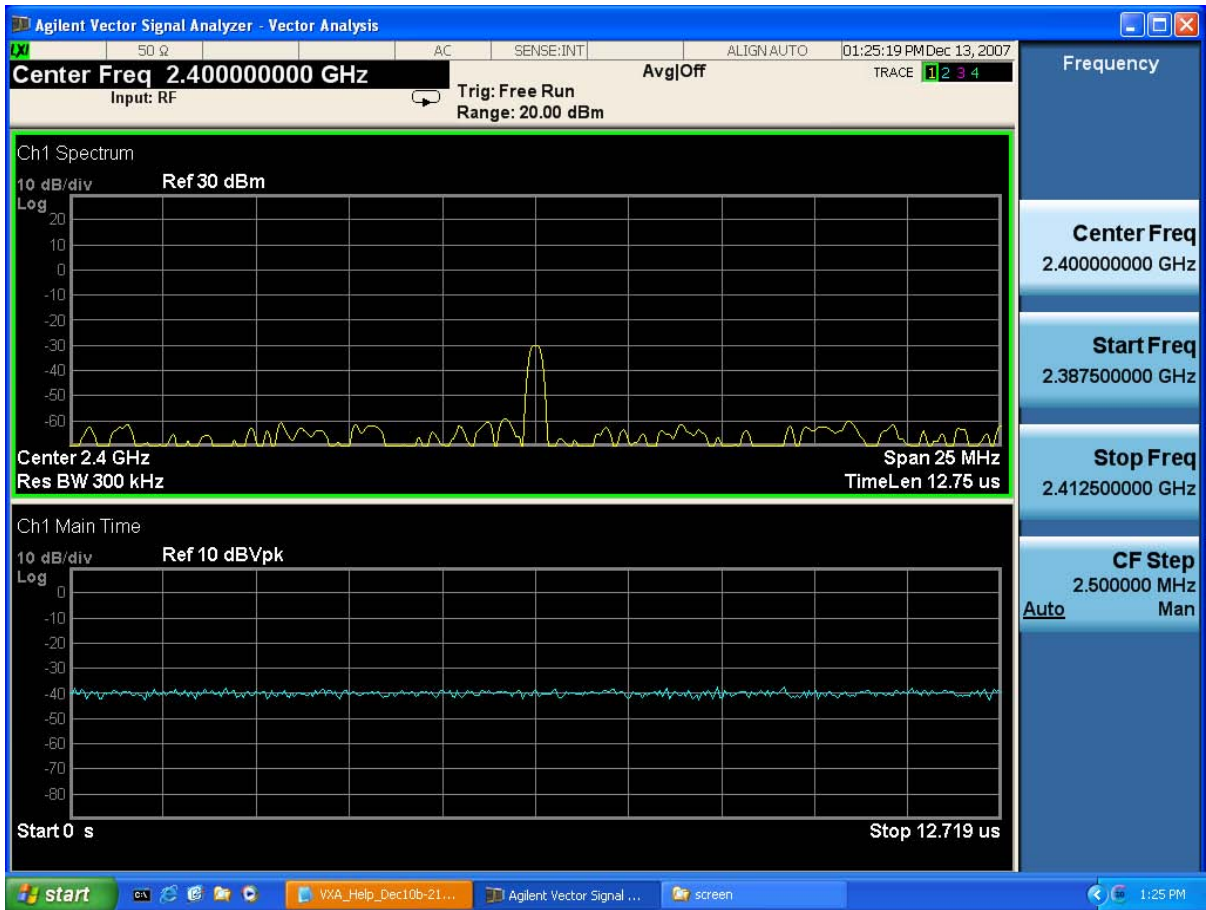
Frequency: 2.4 GHz
Power (Signal Amplitude): -30 dBm
Modulation: FM
FM Rate 100 KHz
3.2 kHz deviation

This procedure demonstrates how to see different results views available for the Analog Demod measurement. This example assumes the signal is correctly applied to the input.

Step	Action	Notes
1 Preset the analyzer.	a. Press Mode Preset .	
2 Select the Vector Analysis measurement.	a. Press Meas, Vector Analysis .	
3 Set the frequency.	a. Press Frequency, 2.4 GHz .	
4 View the measurement.	a. View the Vector Analysis measurement default Spectrum and Ch1 Main Time view.	See the following figure.

Step	Action	Notes
------	--------	-------

5



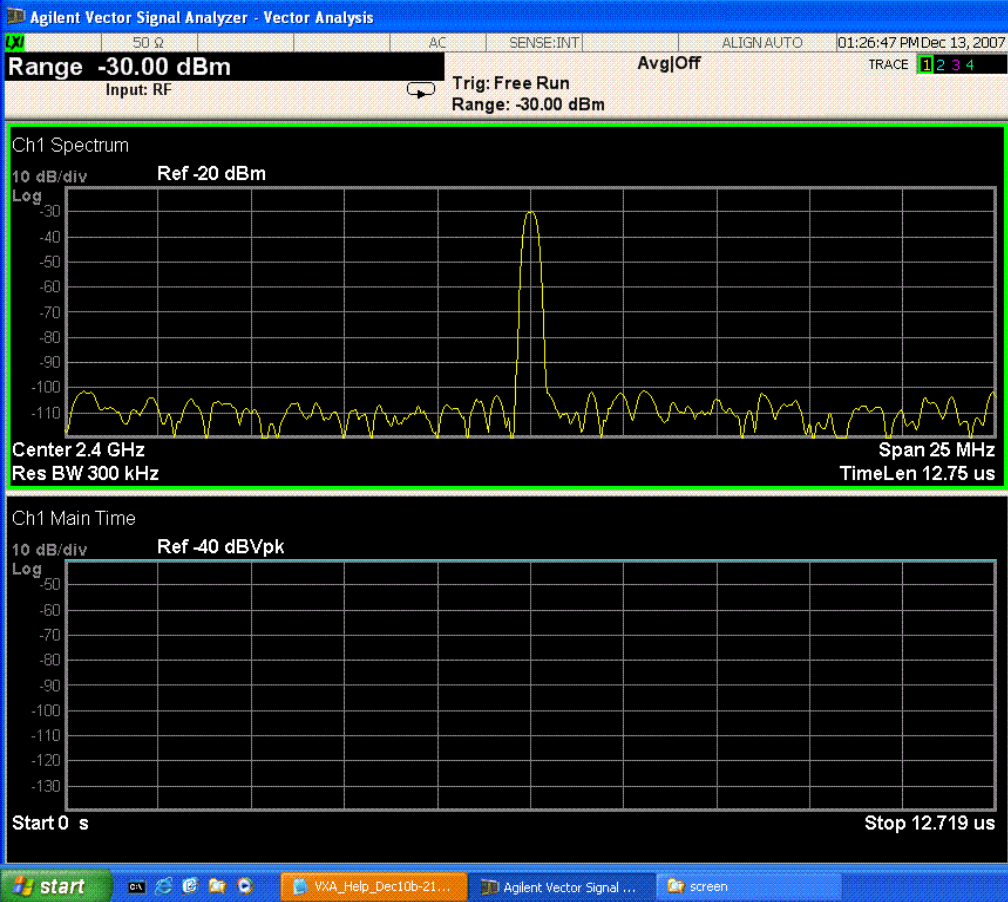
6 Adjust the input power range of the analyzer:

- Press **Range, -30, dBm**.

A carrier is present at 2.4 GHz with a signal strength of about -30 dBm. The default Ref Level is 30 dBm.

The noise floor will lower and the signal to noise ratio will increase. (See the following figure)

Making N9064A VXA Measurements Measuring Analog Signals

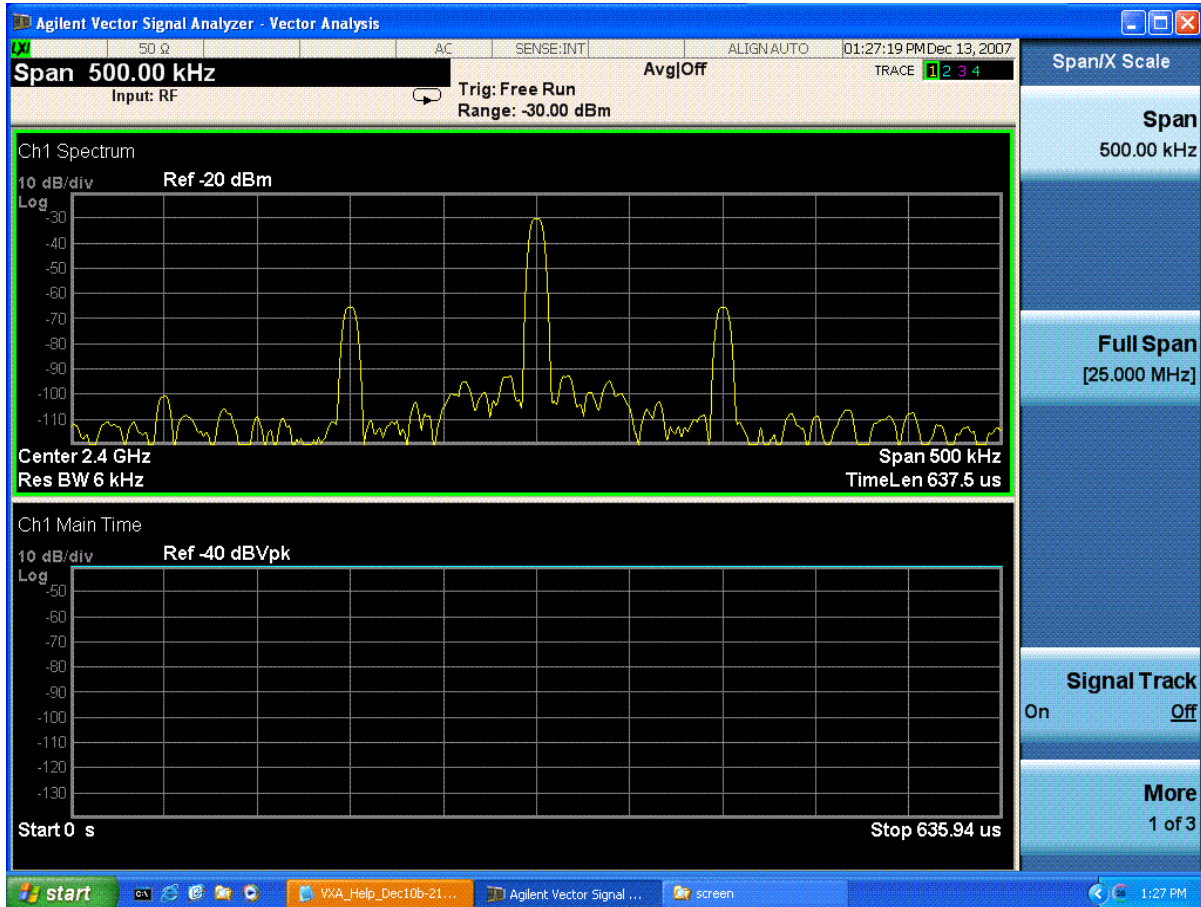
Step	Action	Notes
7		<p data-bbox="1255 384 1398 411">Amptd / Y Scale</p> <p data-bbox="1295 438 1411 495">Auto Scale [Trace 1]</p> <p data-bbox="1312 552 1411 606">Range -30.00 dBm</p> <p data-bbox="1354 1106 1411 1161">More 1 of 3</p>
8	<p data-bbox="203 1268 423 1295">Adjust the span.</p> <p data-bbox="469 1268 980 1367">a. Press Span and the down arrow until the entire signal spectrum is visible in the Spectrum view.</p>	<p data-bbox="1053 1268 1411 1402">Note the default span (with N9020A-B25) is set at 25 MHz. No sidebands are visible at the span.</p> <p data-bbox="1053 1423 1411 1591">500 kHz per division seems to fit nicely. (See the following figure). Now at least 2 sidebands are visible, and Analog Demod can proceed.</p>

Step

Action

Notes

9



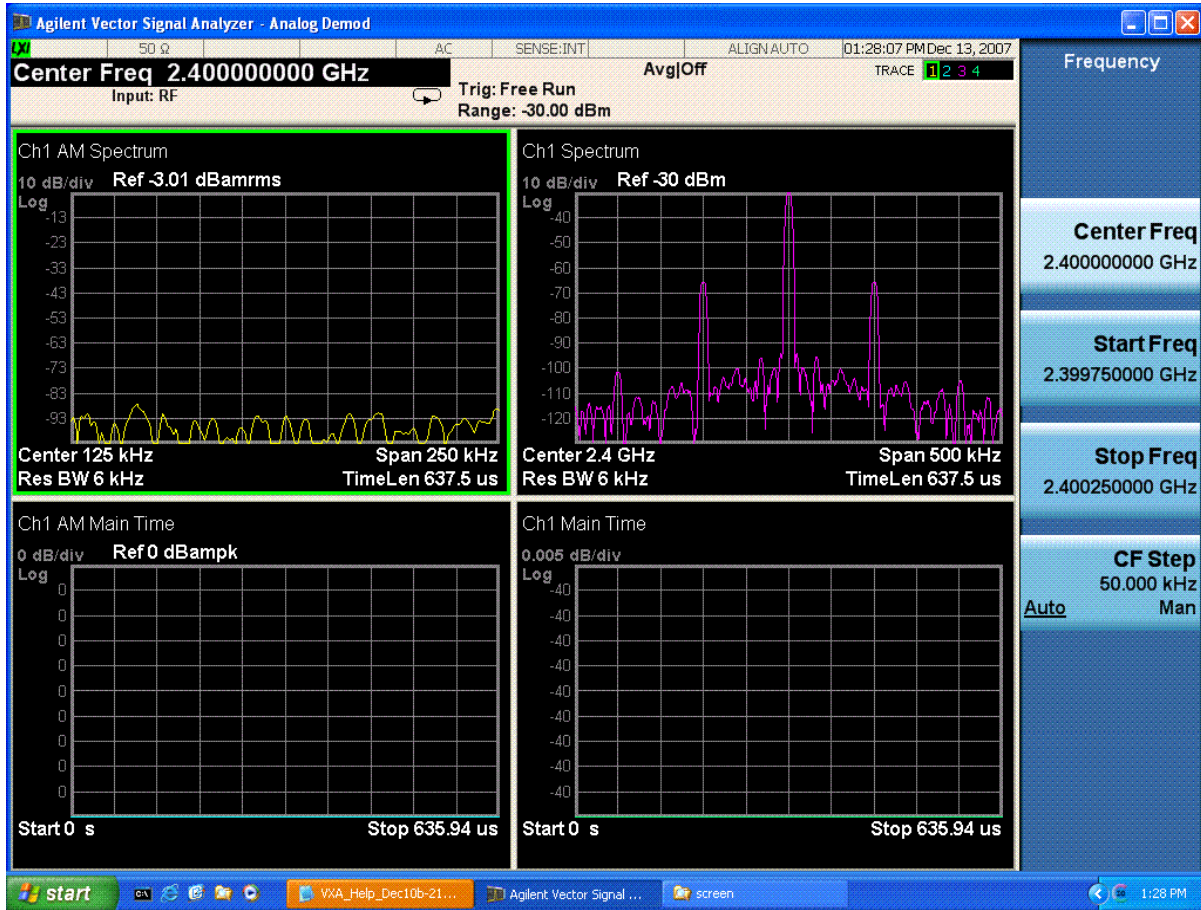
10 Initiate the Analog Demod measurement.

- a. Press **Meas, Analog Demod**.
- b. View the default Analog Demod Spectrum Time Preset View which displays AM Spectrum in trace 1, AM Main Time in trace 2, the input Spectrum in trace 3, and the input Main Time in trace 4.

Note the default view displays trace 1 data as AM Spectrum with no signal visible. That means no AM modulating frequency under 250 kHz was detected, indicating this may be an FM signal. (See following figure).

Making N9064A VXA Measurements
 Measuring Analog Signals

Step	Action	Notes
11		



- 12** Select FM demodulation setup.
- Press **Meas Setup, Demod, Demod Setup**.
 - Select **FM** from the menu of available choices.

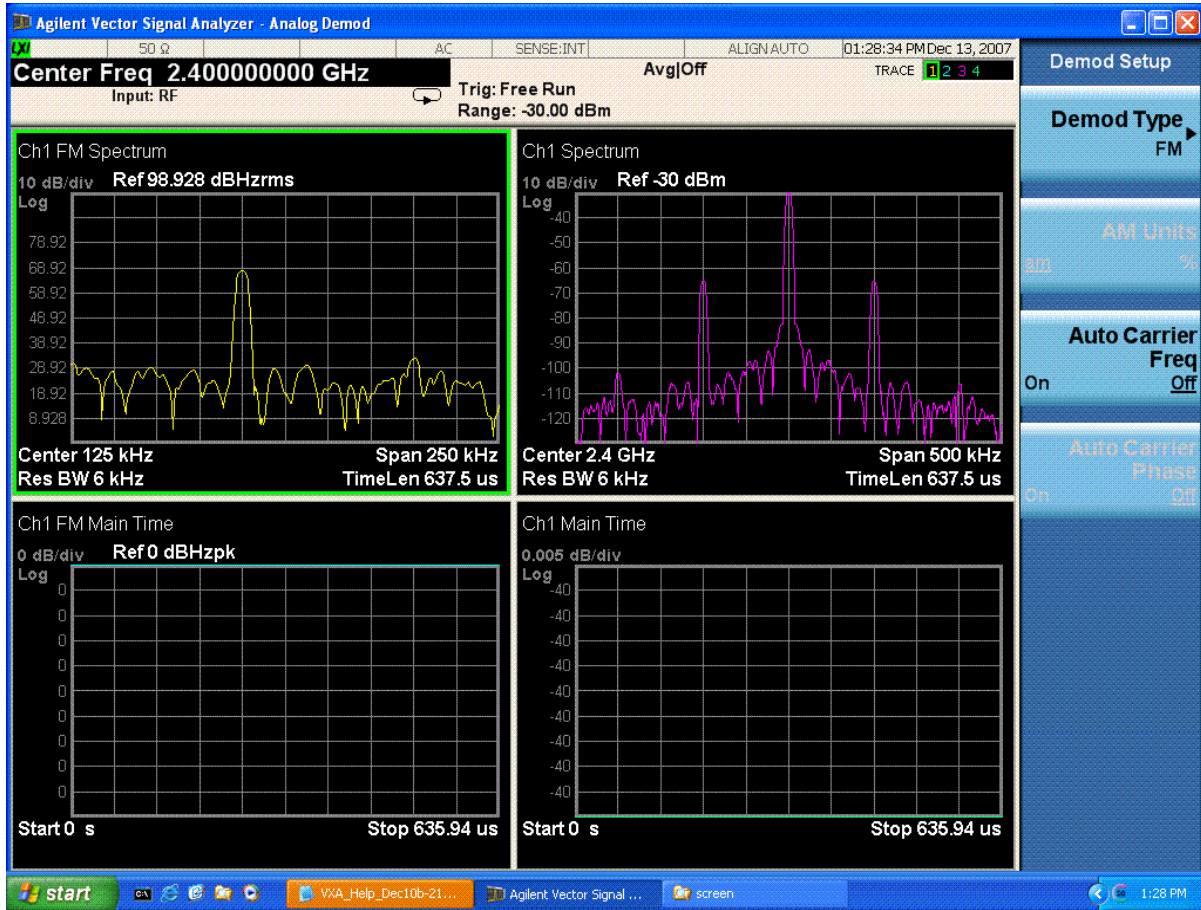
- 13** View the Demod FM Spectrum.
- View the Demod FM Spectrum in trace 1. Shows a strong carrier signal. See the following figure.

Step

Action

Notes

14



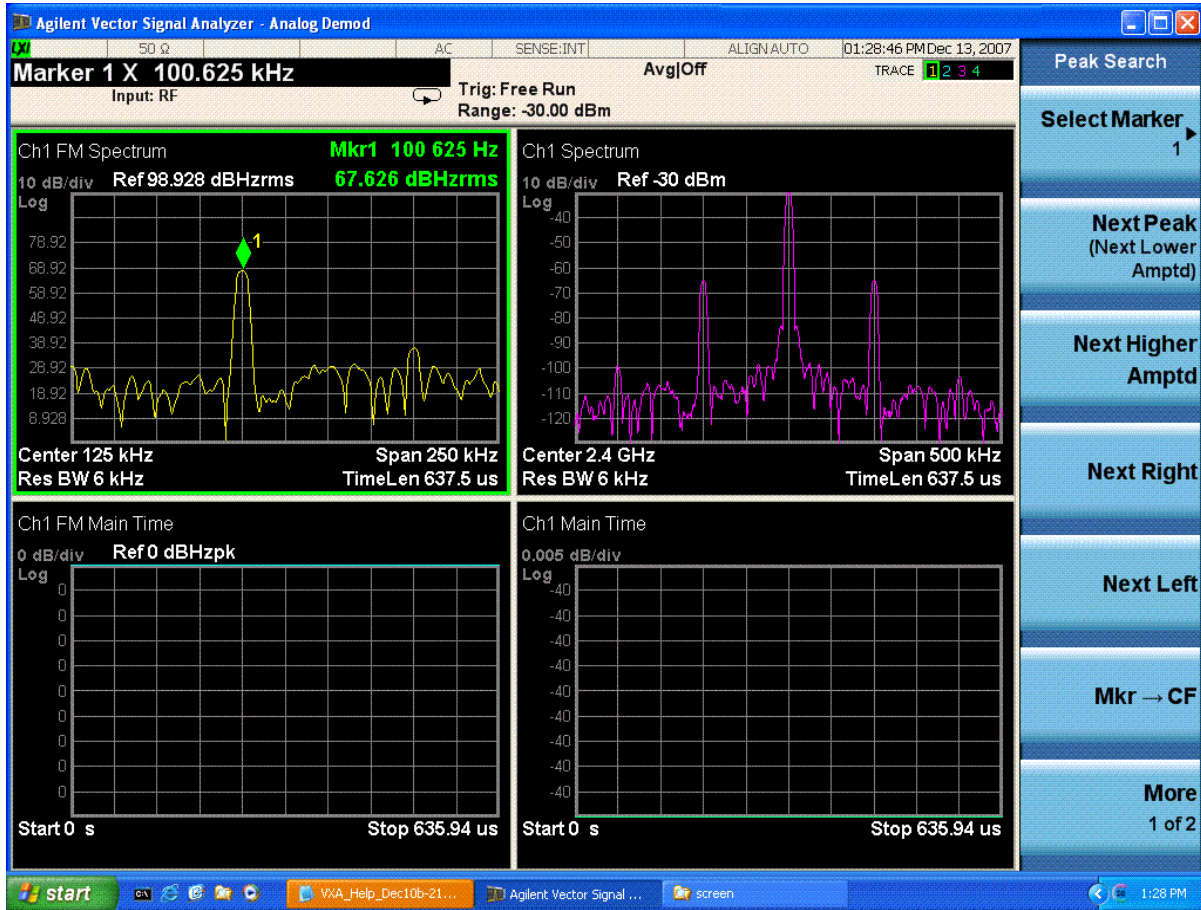
15 Put a marker on trace 1 that measures the FM modulating frequency.

a. Press **Peak Search**.

Trace 3 displays FM Main Time, the time record of the demodulated signal, but it needs adjustment, as does trace 4.

Making N9064A VXA Measurements
Measuring Analog Signals

Step	Action	Notes
16		



- 17 Move the focus (green outline) to trace 3.
- Press the **Next Window** key or press **Trace/Detector, Select Trace, Trace 3**.

- 18 Optimize the scaling.
- Press **Amplitude, Auto Scale**.

The time record of the modulating signal is now clearly visible. See following figure.

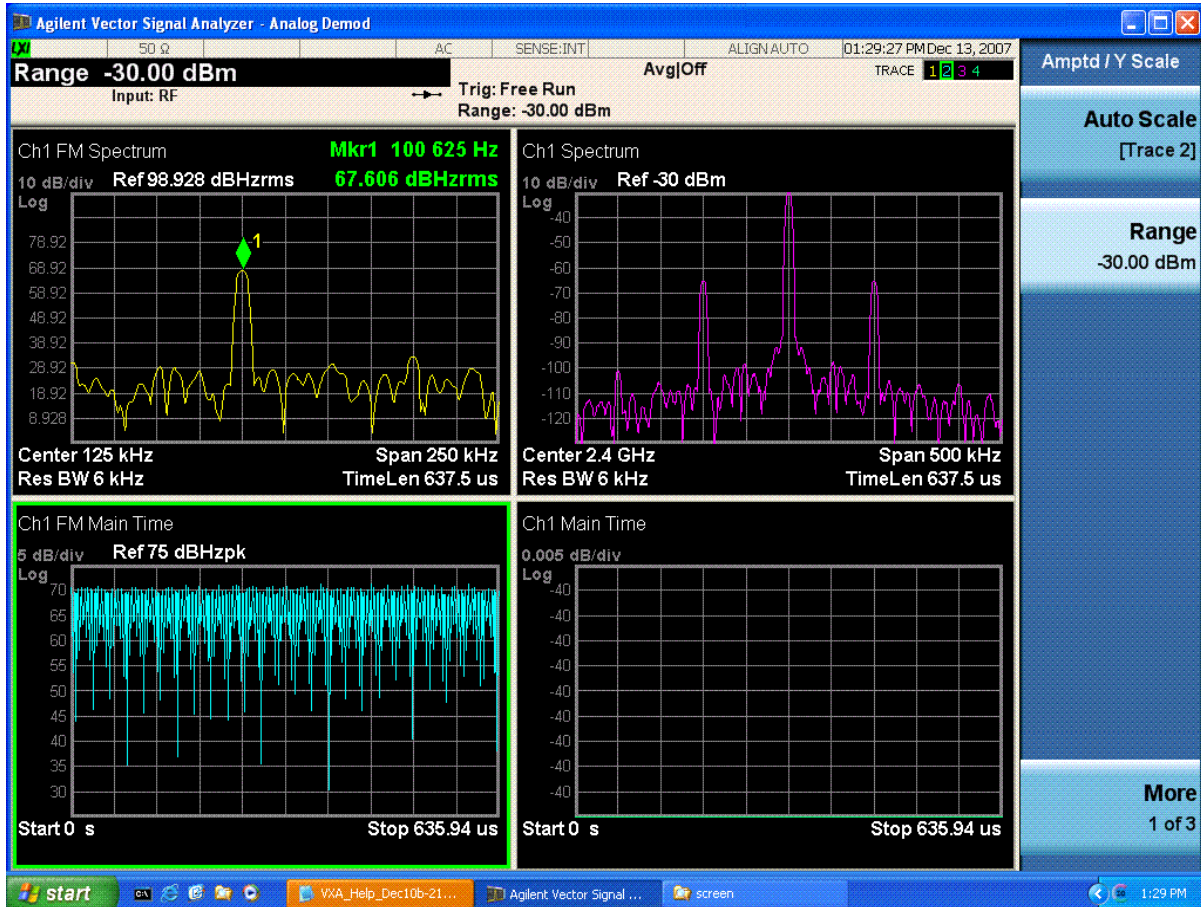
We can now proceed to display other useful data in the remaining trace 4 graph.

Step

Action

Notes

19



20 Select trace 4. a. Press **Trace/Detector, Select Trace, Trace 4**. Trace numbers are shown to help identify which graphs display traces.

21 Select CCDF data. a. Press **Data, Statistical**. b. Select **CCDF** from the menu of available data. Not all data applies to all traces. The data for CCDF is assigned to Trace 4. See the following figure. Available data depends on the modulation selected in **Demod Setup, Demod Type**.

Making N9064A VXA Measurements

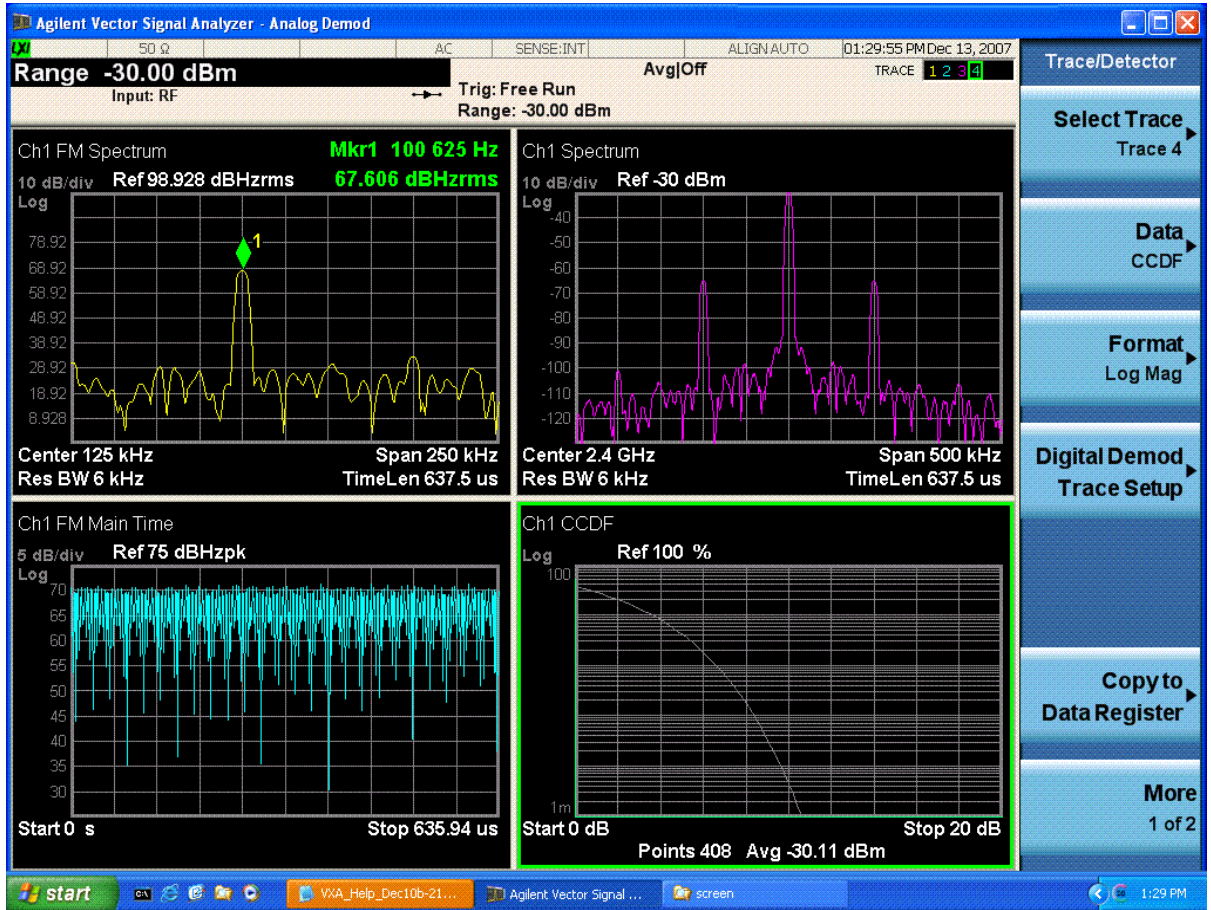
Measuring Analog Signals

Step

Action

Notes

22



If you have a problem, and get an error message, see “Interpreting Error Codes” on page 131.

Measuring Digital Signals

Digital Demod Measurement (Option 2FP) Overview

Making successful N9064A VXA measurements of digital signals is easy when you follow these eight main steps. The procedure overview below provides links in blue to a detailed procedure and description for each step:

[“Set Up the Test Equipment and DUT” on page 46](#)

This step configures the analyzer connections for an RF measurement.

[“Select the Mode and Preset the Analyzer” on page 47](#)

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

[“Select and Configure the Analyzer Input” on page 48](#)

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

[“Acquire and Stabilize the Signal” on page 49](#)

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

[“Demodulate the Signal” on page 50](#)

Demodulation is performed by using the Digital Demod measurement. It contains a number of modulation standard presets that enable rapid measurement of modulation quality for a wide variety of signals.

[“Configure the Display” on page 53](#)

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

[“Optimize your Results” on page 55](#)

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

[“Print or Save Your Measurement Results” on page 57](#)

Your measurement result data can be exported or saved as a trace that can be replayed by the instrument. The graphical results can be printed or saved a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Set Up the Test Equipment and DUT

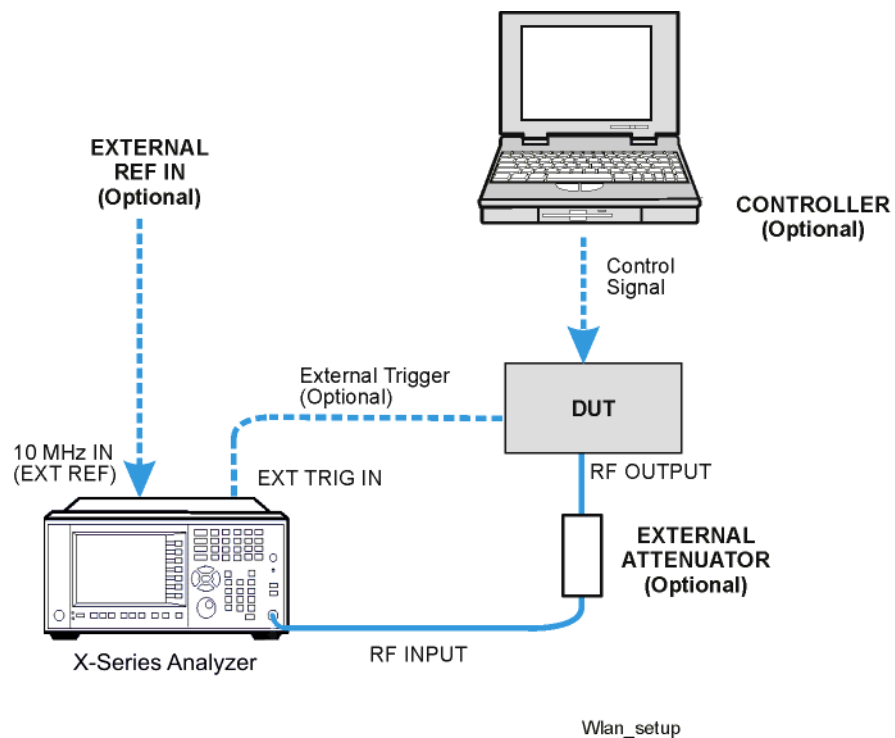
This step configures the analyzer connections for an RF measurement.

Making the Initial Signal Connection

CAUTION

Before connecting a signal to the instrument, make sure the instrument can safely accept the signal level provided. The signal level limits are marked next to the connectors on the front panel.

Figure 2-4 Digital Demod Measurement Setup



The device under test (DUT), which generates WLAN signals, is connected to the RF input port. The DUT may possibly be controlled externally by a computer. External attenuator, external trigger and external reference are optional. Using the appropriate cables, connect the equipment as shown.

Click to [Go Back to "Measuring Analog Signals" on page 22.](#)

Select the Mode and Preset the Analyzer

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

NOTE

The stand-alone N9064A VXA application can analyze digital modulation for a single code channel only. If multiple code channels are transmitted, synchronization will fail, and incorrect results will be obtained. For modulation quality measurements of signals with multiple code channels, Modulation Accuracy and Code Domain measurements use an X-Series full-featured standard-based measurement application, like N9073 for W-CDMA.

Step	Action	Notes
1	Select the Mode. a. Press MODE, Vector Signal Analyzer .	The default measurement for N9064A VXA is Vector Analysis. Settings made here will be used by Demod measurements later.
2	Preset the analyzer. a. Press the green Mode Preset button for the factory preset. b. To recall a user-defined Preset: Press User Preset , User Preset to preset the current mode.	

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Select and Configure the Analyzer Input

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

Step	Action	Notes
1 Select and configure the analyzer Input settings.	<ul style="list-style-type: none"> a. Press Input/Output, RF Input, 75 Ohm Input Z, if needed. b. Press AMPTD Y Scale, Range and enter the total signal power at the analyzer input. 	The default RF impedance is 50 Ohms.
2 OR If available, you can recall a saved instrument state to establish a group of measurement settings.	<ul style="list-style-type: none"> a. Press Recall, State b. Select a Register that contains the state to be retrieved. <p>OR</p> <ul style="list-style-type: none"> c. Press From File... which opens an Explorer window to browse to your state file location. 	<p>Registers 1-6 display the date the last state was saved to help identify which state is saved in each register.</p> <p>TIP Using saved states insure repeatable measurements. See Step 8 for details of saving states.</p>
3 OR If available, you can recall a saved measurement trace for display.	<ul style="list-style-type: none"> a. Press Recall, Data (Import) b. Press Trace to select the trace that will contain the stored data. c. Press Open... which opens an Explorer window to browse to your state file location. 	

Click to Go Back to [“Measuring Analog Signals” on page 22.](#)

Acquire and Stabilize the Signal

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

Step	Action	Notes
1	<p>Observe the Spectrum (upper) graph: set the center frequency to your signal's carrier frequency.</p> <ol style="list-style-type: none"> Press FREQUENCY Channel. Use the front-panel keypad to input the center frequency. Press a units key, like GHz, to complete the entry. 	<p>Most settings made in the Vector Analysis measurements will be used by Demod measurements later.</p> <p>TIP The center frequencies of the analyzer and input signal must match to within $\pm 3\%$ of the symbol rate ($\pm 1\%$ for 64QAM and $\pm 0.2\%$ for 256QAM).</p>
2	<p>Set the input power range for your signal.</p> <ol style="list-style-type: none"> Press AMPTD Y Scale, Range. Enter the total signal power at the analyzer input. 	<p>Check: Downrange by step until the overload indicator is displayed as "OV" in the top right corner of the graph. Range back up 1 step.</p>
3	<p>Set the frequency span to view your entire signal. Make sure the entire signal is captured in the Spectrum graph.</p> <ol style="list-style-type: none"> Press SPAN X Scale. Use the front-panel keypad to input the frequency span. Press a units key, like MHz, to complete the entry. <p>You can also use the rotary knob to visually set the span.</p>	<p>Check: The signal's spectrum should occupy 50-90% of the span, and not extend beyond the edges. It should appear as a distinct, elevated region of noise 20 dB or more above the analyzer noise floor. Broad, glitching sidebands indicate bursts or other transients, which can be handled with triggering or the Burst Search function in Demod settings.</p>
4	<p>Observe the Main Time (lower) graph: set trigger parameters (if used)</p> <ol style="list-style-type: none"> Press Trigger. Select the correct input for the trigger signal. Set levels as required. 	<p>Observe the Time Domain waveform to see if it is stable. You can come back to the Main Time window to see if Demod settings made in later steps have stabilized the waveform.</p> <p>TIP Triggering is unnecessary for most signals. For TDMA and other burst signals, as the Vector Signal Analyzer will readily acquire a "framed" signal.</p>

Click to Go Back to ["Measuring Analog Signals" on page 22.](#)

Demodulate the Signal

Demodulation is performed by using a specific N9064A VXA demod option, like Option 3FP for WLAN, if installed, or one of the flexible Digital or Analog Demod measurements. Both contain a number of modulation standard presets that enable rapid measurement of modulation quality for a wide variety of signals.

NOTE The stand-alone N9064A VXA application can analyze digital modulation for a single CDMA code channel only. For EVM and Code Domain measurements on signals with multiple code channels, use an X-Series full-featured standard-based measurement application, like N9073 for W-CDMA.

Step	Action	Notes
1 For signals using digital modulation select the Digital Demod measurement.	a. Press Meas, Digital Demod .	For signals using analog modulation select the Analog Demod measurement. See “Measuring Analog Signals” on page 22.
2 For signals that conform to a known standard, you can preset the analyzer to a standard.	a. Press Meas Setup, Preset to Standard . b. Select from the Std Presets provided.	If installed, use your standard-specific N9064A VXA option for your signal of interest: See: “Making N9064A VXA Measurements” on page 19
3 For signals that conform to a known format, configure Demod Setup with a Modulation Format as needed.	a. Press Meas, Digital Demod . b. Press Demod Setup , and if known, press Modulation Format and select from the modulation formats provided.	Modulation formats available include QAM, PSK, MSK, FSK, DVB QAM, VSB, APSK, and EDGE. Submenus enable you to specify a variety of formats for your signal of interest.

Step	Action	Notes
4	<p>For signals that don't conform to an established format, configure Demod Setup as needed.</p> <p>a. Press Meas, Digital Demod. Press Demod Setup, Symbol Rate and enter a frequency value.</p> <p>b. Press Meas Interval and enter a value to set the number of symbols to be measured.</p> <p>c. Press Points/Symbol and enter a value to set the number of samples per symbol to be measured.</p> <p>d. Press More, and set Meas Filter and Alpha/BT parameters.</p> <p>e. If the signal is bursted or has a sync pattern, press Burst/Sync Search and select the Search Length or Sync Pattern to be searched.</p>	<p>TIP The symbol rate needs to be entered to an accuracy of 10-100 ppm.</p>
		<p>NOTE Result length is important for bursted signals, as you don't want to include data symbols taken before or after the burst (i.e. you don't want to demodulate noise)</p>
		<p>TIP If the alpha is unknown, estimate it from $(60 \text{ dB BW}/3 \text{ dB BW}) - 1$. EVM peaks between symbols mean an incorrect alpha, but won't usually affect the EVM% readout (except in GSM). In the worst case, start with 0.3 and manually adjust up or down for lowest intersymbol peaks.</p>
		<p>TIP Burst search length can be longer than a time record; set it to the burst "off" time plus twice the burst "on" time to insure a complete burst in every search.</p>
5	<p>Increase your measurement accuracy by using Equalization</p> <p>a. For Digital Demod, press Meas Setup, Adaptive Equalizer and toggle Filter to On. Try using the default settings before making adjustments.</p> <p>b. For other demod measurements, press Mode Setup, Fixed Equalization and select Normal. Try using the default settings before making adjustments</p>	<p>For more information about Adaptive Equalization see "Using Adaptive Equalization" on page 61 and the Adaptive Equalizer section under Measurement Setup.</p>
		<p>For more information about Fixed Equalization see the Fixed Equalizer section under Analyzer Setup.</p>

Step	Action	Notes
6 Final Checks	<p>a. The EVM% result should be fairly consistent from measurement to measurement.</p> <p>b. EVM vs. symbol trace should be noise-like, but fairly uniform (short peaks are OK).</p> <p>c. Make sure you have selected the correct Range for the signal of interest. Check that the OV1 overload indicator is not displayed.</p> <p>d. If these methods do not improve “noisy” characteristics of your measurement, you may need to supply more signal gain ahead of the RF input to the analyzer. Make sure you use the analyzer’s ability to correct for external gain and attenuation:</p> <p>Press Input/Output, Ext RF Atten and input a value. You may enter a positive number to correct for external attenuation or input a negative number to correct the power measurements for external gain.</p>	<p>Result peaks may indicate faulty triggering or incorrect synchronization.</p> <p>Abrupt changes within the EVM trace signify problems, as do sloping or V-shaped distributions.</p>

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Configure the Display

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

Step	Action	Notes
1 Use the Preset View for fast, powerful results displays.	<ul style="list-style-type: none"> a. Press View/Display. b. Select a Preset View for a useful combination of related data trace displays. 	For details of the Preset View see Preset View below.
2 OR If desired, choose a custom screen layout.	<ul style="list-style-type: none"> a. Press View/Display, Layout. b. Select a layout that will provide your desired arrangement. 	You can choose up to 4 panes to display your trace data.
3 Customize your layout by assigning a data trace to a measurement display.	<ul style="list-style-type: none"> a. Press Trace/Detector, Select Trace. b. Select the number of the trace to change. c. Press Data to display a menu of trace groups. d. Select the trace data for assignment to the graph. e. Repeat trace assignment for any other traces in the layout as needed. 	When you press Trace/Detector, Select Trace , the trace numbers are displayed on the screen to help you identify the traces for selection.

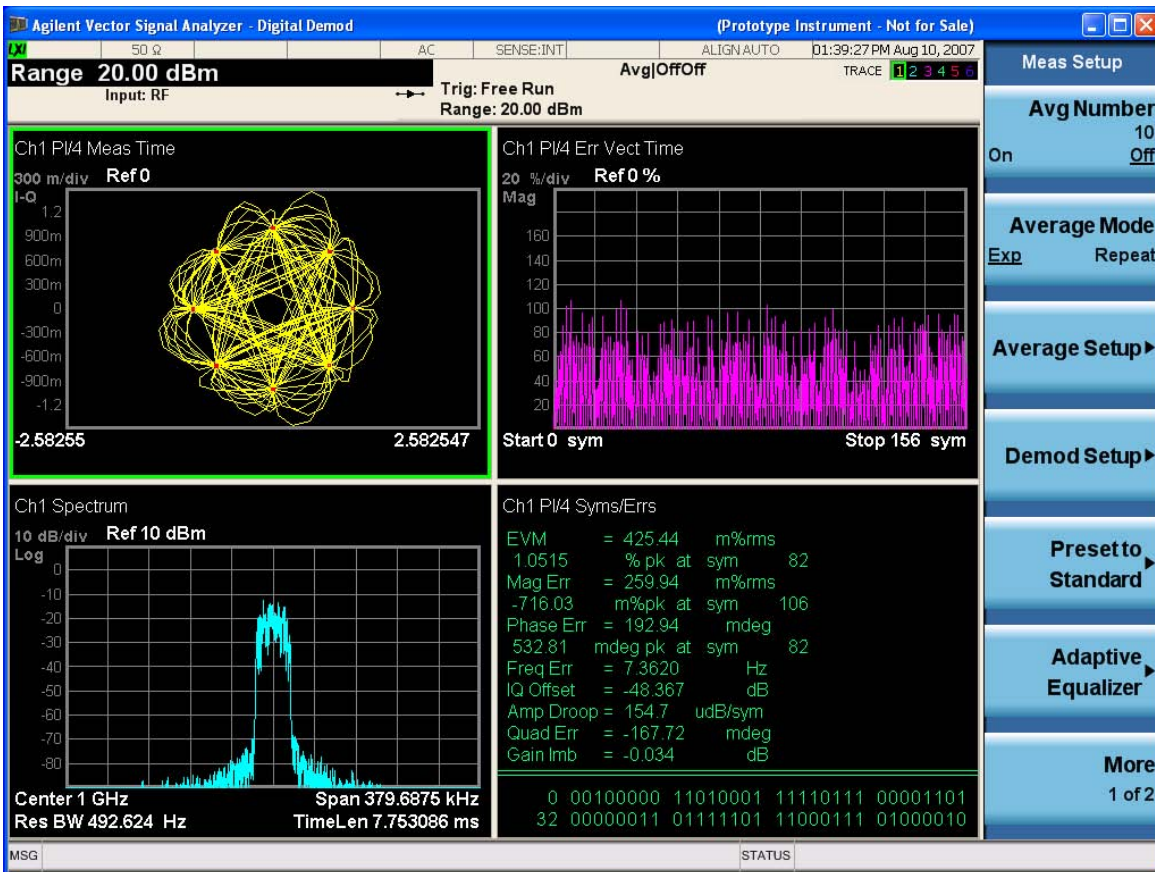
Digital Demod Preset View

This preset displays a quad layout with the IQ Meas Time in trace 1, Spectrum in trace 2, Error Vector Time in trace 3, and the Symbol/Error table in trace 4. See the following figure.

Making N9064A VXA Measurements

Measuring Digital Signals

Figure 2-5 Digital Demod Preset View- Demod Quad



Click to Go Back to “Measuring Analog Signals” on page 22.

Optimize your Results

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

Step	Action	Notes
1 Select a graph for optimization	a. Use the "Next Window" key (boxes with arrows) below the display to move the green outline "focus" to activate a graph for customization.	
2 Optimize the X Scale.	a. Press SPAN X Scale, Scale/Div. b. Use the front-panel keypad to input the scale/div. c. Press a units key, like μs , to complete the entry. OR a. Press SPAN X Scale, More, X Scale Auto to enable the instrument to complete the scaling.	
3 Optimize the Y Scale.	a. Press AMPTD YScale, Scale/Div. b. Use the front-panel keypad to input the scale/div. c. Press a units key, like μs , to complete the entry. OR a. Press AMPTD YScale, More, Auto Scale to enable the instrument to complete the scaling.	
4 Use a Marker to indicate and measure signal characteristics.	a. Press Marker, Select Marker. b. Select the number of the maker desired for your display. c. Press Marker Function, Select Marker to assign a function to the marker. d. Select either Band/Interval Power or Band/Interval Density to turn on/off the markers. e. Adjust either the Power Calc settings or Density Calc settings, depending on which function you have selected. f. Press Marker, Delta to set a Delta marker on/off and adjust its position on the graph.	For more information on Markers see the Markers section under Measurement Setup in Help.

Step	Action	Notes
5	<p>Add titles, or make other changes to the measurement graphs</p> <ol style="list-style-type: none">Press View/Display, Display, System, Settings to adjust other parts of the display for all measurement windows.Press View/Display, Display, Annotation, to turn on/off various parts of the display annotation.Press View/Display, Display, Title, Change Title to create a title for the graph.Press View/Display, Display, Graticule to turn graticules on/off.Press View/Display, Display, Display Line to turn a reference line on/off and adjust its position on the graph. <p>Click to Go Back to “Measuring Analog Signals” on page 22.</p>	<p>For more information on Display settings see the Display section under Analyzer Setup in Help.</p>

Print or Save Your Measurement Results

Your measurement results data can be saved as traces that can be replayed by the instrument, or exported for analysis. The graphical results can be printed or saved as a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Step	Action	Notes
1	<p>Print your measurement results.</p> <ol style="list-style-type: none"> Press Page Setup and a Windows dialog box opens that enables you to set print parameters, including printer selection. Press Print. 	<p>Set up your printer using the Windows Printer control panel.</p> <p>The Print front-panel key is equivalent to performing File, Print, OK in Windows. It immediately performs the currently configured Print to the current printer.</p>
2	<p>Save your measurement results.</p> <ol style="list-style-type: none"> Press Save, and select Data (Export) to save a data trace, or Screen Image to save the display as a bitmap file. Press Save As... a Windows Explorer dialog box opens to enable you to name the file and select the file location. Press Quick Save to save repeated measurements in the same format and to the same location as you specified in the last Save procedure. Files saved using Quick Save are numbered sequentially and dated for later reference. 	<p>TIP For repeated measurements, create a directory for your saved files during the initial Save set up. All subsequent Quick Save results will be easier to manage when grouped in the same directory.</p> <p>CAUTION Don't save files to the C: or E: drives as they will be overwritten by software upgrades. Use the User Data (D:) drive for file storage or save your results to an external USB drive.</p>
3	<p>If desired, save your measurement state for re-use later.</p> <ol style="list-style-type: none"> Press Save, and select State to save your current measurement settings for re-use later. Select a Register number for storage or press To File... a Windows Explorer dialog box opens to enable you to name the file and select the file location. 	<p>When you save a measurement state, only the settings for the current measurement are saved.</p>

Making N9064A VXA Measurements

Measuring Digital Signals

Step	Action	Notes
4 If desired, save your measurement state as a User Preset .	a. Press User Preset, Save User Preset to save your current measurement settings as a quickly retrievable Mode-level state.	When you save a User Preset the current settings for all measurements in the mode are saved.

Click to Go Back to [“Measuring Analog Signals”](#) on page 22.

Tips When Using Digital Demodulation

- I/Q Reference or FSK Reference: the analyzer does not need an ideal signal to generate the reference signal. The analyzer uses your signal to internally generate the ideal, reference signal.
- Carrier Lock and Detection: the analyzer does not need a sync word to perform carrier locking or detection. See also the next paragraph on “Center Frequency.”
- Center Frequency: the analyzer's center frequency must be close to the transmitted carrier frequency to achieve carrier lock. The required proximity of the center frequency to the carrier frequency varies depending on the signal type, symbol rate, and system noise. If symbol locking appears poor, you may achieve better carrier locking by observing the “Freq Err” value in the symbol table (for QAM, PSK, and MSK formats) of any successfully locked measurement and add that amount to the center frequency. As a general rule, the carrier-frequency-to-center-frequency error should be within 3% of the symbol rate.
- Symbol Clock: the analyzer does not need an external symbol clock; the analyzer internally generates the symbol clock.
- Maximum Symbol Rate: The maximum symbol rate depends on the alpha of your system and on the span (information bandwidth). See the [symbol rate] softkey for details.
- Span: The minimum span (information bandwidth) depends on the alpha of your system and on the symbol rate. The maximum span is limited by the symbol rate. See the [span] softkey for details.
- Time Gating: time gating is not available for digital demodulation.
- Averaging: averaging is not available for any Digital Demod trace data, but may be applied to numeric error data in the error summary table by turning on averaging. Three types of averaging are available: rms (video), which computes an rms average of each rms error update in the error summary table; rms exponential, which is like rms (video) except that averaging continues past the average count with an exponential weight; and continuous peak hold, which keeps track of the peak rms error of each update in the error summary table.
- Accuracy: To meet specifications, your signal and its modulation must be fully contained in the selected measurement span.

If you have a problem, and get an error message, see [“Interpreting Error Codes” on page 131](#).

Using Burst/Sync Search

Synchronization words (or patterns) are often used to resolve carrier phase ambiguity on non-differential modulation formats. It is important to realize that synchronization words are optional and are not necessary to achieve carrier locking.

Measuring Digital Signals

Burst/Sync Search lets you use a synchronization pattern to isolate a segment of your signal for display and analysis. The analyzer searches through demodulated data to find your synchronization pattern and then uses the **Search Length** to determine how many symbols to search as the syncword.

Triggering is used to determine when the analyzer starts searching for a specified syncword or burst in data and **Search Length** determines when the analyzer stops searching.

This procedure demonstrates how to set burst/sync properties. This procedure assumes you are already in the **Vector Signal Analyzer** mode, and you have selected **Digital Demod** under the **MEASURE** menu:

Step	Action	Notes
1 Access the synchronization menu.	a. Press Meas Setup, Demod Setup, Burst/Sync Search .	
2 Select the synchronization type.	a. Select either Burst Search or Sync Search and toggle it to On .	Available synchronization types are either Burst Search or Sync Search .
3 If you have selected Sync Search, set the sync search pattern.	a. Press Sync Pattern . b. Select from available patterns, or input a custom pattern. c. Press OK .	
4 Set Search Length , the length of time you want to search the burst or the synchronization pattern.	a. Press Search Length . b. Enter a numeric value. c. Select a unit, like ms .	Your trigger signal determines when the analyzer begins accumulating data for the search length. The analyzer begins to demodulate your signal when it receives a valid trigger, and capture data for the duration of Search Length .
5 Set the synchronization bit pattern.	a. Set the synchronization bit pattern in hexadecimal values.	
6 Set the synchronization offset.	a. Press Sync Offset . b. Enter a numeric value. c. Press Enter .	Synchronization offset range depends on the length of the sync pattern or the search length. Synchronization offset determines the relative position of the measured data from the beginning of the burst or sync pattern.

Using Adaptive Equalization

Equalization removes linear errors from modulated signals by dynamically creating and applying a FIR (feed-forward) compensating filter. Using equalization enables measurement of impaired channels and can be used to isolate linear from non-linear error mechanisms. For more concept information on equalization see ["Modulation quality measurements"](#) on page 232.

This procedure demonstrates how to setup the equalizer. This procedure assumes you are already in the **Vector Signal Analyzer** mode and you have selected **Digital Demod** under the **MEASURE** menu.

TIP If available for your signal of interest, use **Preset to Standard** to make sure all settings are correct for the demod function you are using.

Step	Action	Notes
1 Access the equalization menu.	a. Press Meas Setup, Adaptive Equalization.	
2 Set the equalization filter length.	a. Press Filter Length. b. enter a numeric value in symbols c. Press Enter.	TIP Available filter length values range from 3 to 99 symbols. When selecting a filter length, the best filter length is the smallest that meets your measurement requirements. For example, measurements at the transmitter may only need a few symbols in length. Measurements in multi-path environments require longer filter lengths.
3 Set the equalization convergence:	a. Press Convergence. b. Enter a numeric value. c. Press Enter.	You can set convergence values from 0.001 to 100. Convergence determines how quickly the equalization filter coefficients converge to the estimated values for each measurement. Larger values converge faster. Values set too large can cause the adaption algorithm to become unstable, limiting the minimum EVM or SNR. TIP At the start of your measurement set the convergence high, to quickly shape the filter. Then decrease the convergence to fine-tune the filter to the optimum shape to get the best EVM results.

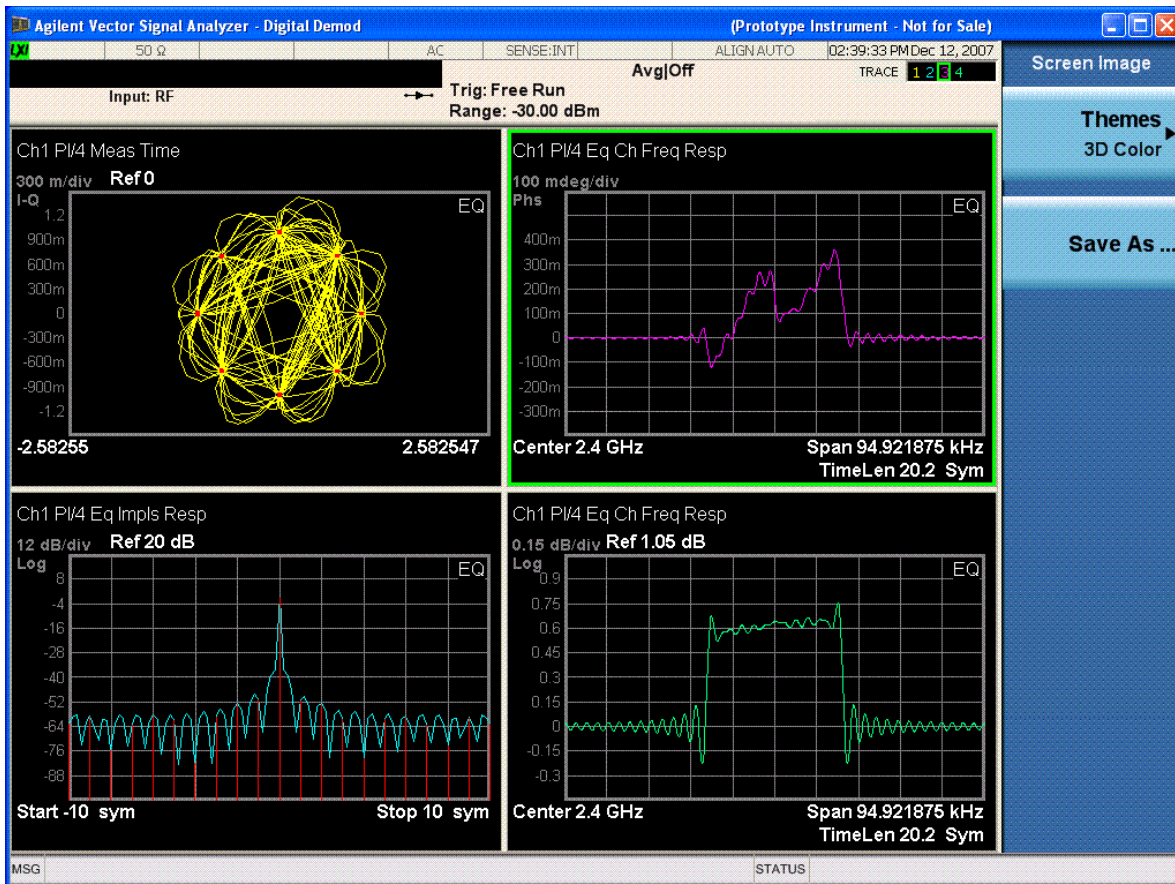
Step	Action	Notes
4 Turn Adaptive Equalization on.	a. Press Filter . b. Toggle the setting to On .	<p>When equalization is first enabled, the equalization filter has a unit impulse response. The length of the filter determines the position of the unit impulse response in the filter. The impulse is located in the center of the filter for short filter lengths. As the filter length increases, the impulse moves, proportionally, towards the start of the filter to handle channels with large delay-spread.</p> <p>The equalization filter has a unit response when you:</p> <ul style="list-style-type: none">• First run the equalizer.• Reset the equalizer filter• Change points/symbol• Change the measured or reference filter• Change the symbol rate• Change the clock delay adjustment• Change the equalizer filter length• Change the modulation format• Preset the mode <p>Aside from the above conditions, the equalizer uses the last computed filter coefficients when you enable equalization. For example, if you used equalization in a previous measurement, the coefficients from the previous measurement are used, unless you reset the equalization filter (or change one of the settings as mentioned in the above list). It is good practice to reset the equalization filter to initialize the filter coefficients before starting the measurement.</p>
5 Reset the equalization filter.	a. Press Reset Filter Coefficients .	Once you reach the desired EVM results after resetting the equalization filter, hold the filter coefficient values.

Step	Action	Notes
6 Hold the filter coefficient values.	a. Press Hold and toggle to On .	<p>When Hold is On, the analyzer does not update the filter coefficients. Instead, the analyzer uses the last updated coefficients before selecting hold.</p> <p>When Hold is Off, the analyzer uses the results of the current measurement to update the filter coefficients for the next measurement. The equalization algorithm chooses coefficients that produce a modulation quality result that is less impacted by the presence of linear distortion.</p>
7 You can view the equalizer graphically.	a. Press Trace/Detector . b. Select a trace. c. Press Data, Response . d. Select ChFrequency Response or EQ Impulse response .	<p>The example shown in the following figure is an NADC signal.</p> <p>The Eq Ch Frequency Response (trace 4) shows the frequency response channel for which the equalizer is correcting. Ch Frequency Response is computed as the inverse of the equalization filter's frequency response. The data is complex and is normally displayed in units of magnitude and phase.</p> <p>The Eq Impulse Response (trace 2) shows the impulse response of the equalization filter.</p> <p>The Eq Ch Frequency Response (trace 3) shows the phase response of the equalization filter.</p>

Making N9064A VXA Measurements Measuring Digital Signals

Step	Action	Notes
------	--------	-------

8



- | | | |
|--|---|---|
| <p>9 You can select other result formats to display the equalizer data for a selected trace:</p> | <ol style="list-style-type: none"> Press Trace/Detector, Format. select a graphic display format appropriate for the type of trace data assigned to the trace. | <p>Click to Go Back to “Measuring Analog Signals” on page 22.</p> |
|--|---|---|

Viewing Other Digital Demod Measurement Results

This section provides examples of Digital Demod measurement results of a W-CDMA signal. Results available include graphical displays of various trace data as well as tabular results available remotely. These graphic results may be viewed separately, or combined into customized views. For more information on Views see [“Configure the Display” on page 53](#).

Graphical Digital Demodulation Measurement Results

To help pin-point modulation problems, the Digital Demodulation measurement provides many different graphs and numeric results tables. The following procedures show you how to obtain the results displays using a W-CDMA signal (defined below).

You can assign any available data to any of the traces displayed on the screen. The list below of data types may also be viewed in various formats, depending on the data, like eye diagrams, constellation, spectrum, etc.

Digital Demod Measurement Data Include:

1. Instantaneous Main Time
2. Main Time
3. Gated Time
4. Instantaneous Spectrum
5. Spectrum
6. Auto Correlation
7. Power Spectral Density (PSD)
8. Probability Density Function (PDF)
9. Cumulative Density Function (CDF)
10. Complementary Cumulative Density Function (CCDF)
11. Occupied BW Summary
12. ACP Summary
13. Raw Main Time

For more information on what these data traces are, see the User's and Programmer's Guide section or Help on Trace/Detector, Data.

Click to Go Back to [“Measuring Analog Signals” on page 22](#).

Example Measurement - Digital Demod

Agilent ESG Series Vector Signal Generator Settings

Radio Standard: W-CDMA (3GPP)
Link: Forward
Active channel: 1 DPCH (data channel)
Frequency: 2.412 GHz
Power (Signal Amplitude): -30 dBm
Modulation: QPSK
Symbol rate: 3.84 Msps

This procedure demonstrates how to see different results views available for the Digital Demod measurement.

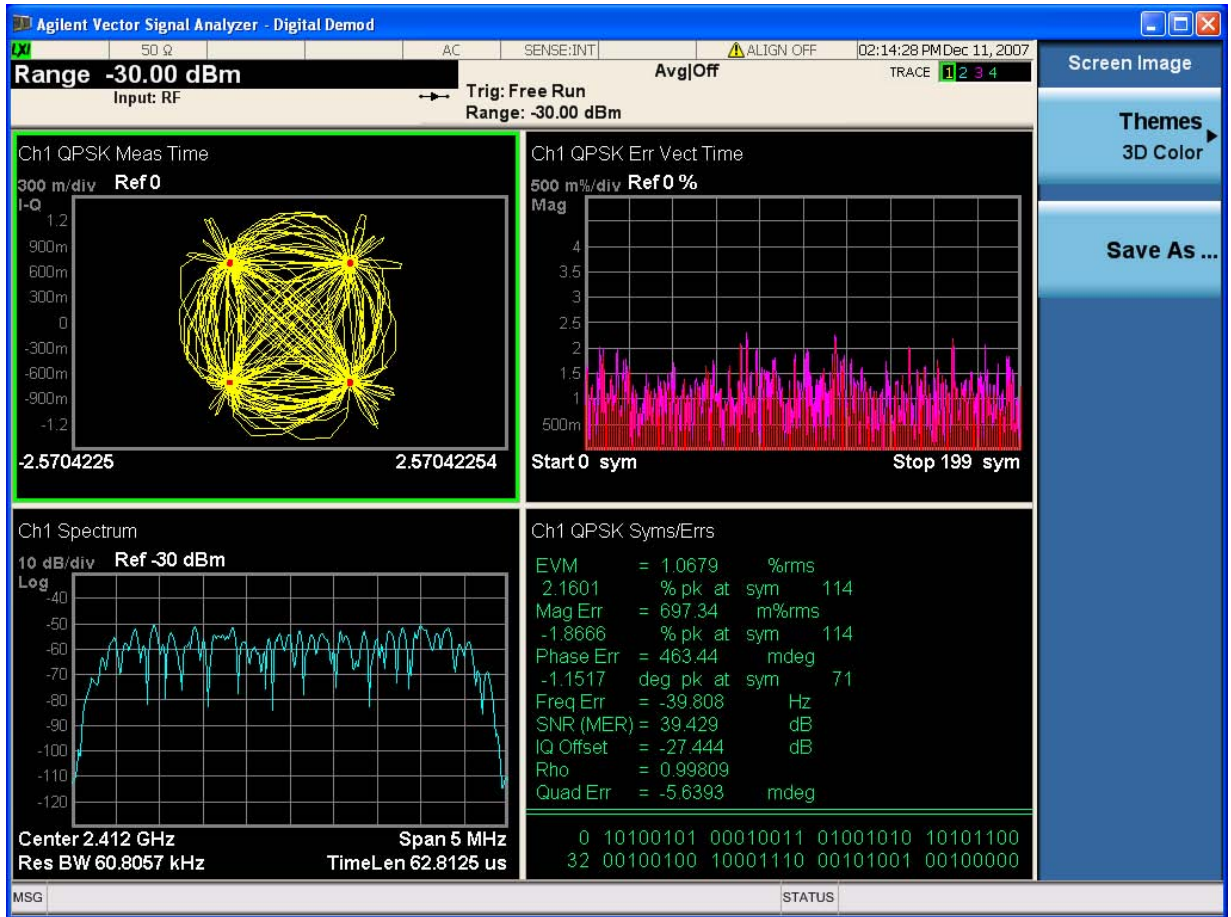
Step	Action	Notes
1	Follow the Measuring Digital Signals procedure.	a. Follow the procedure “Measuring Digital Signals” on page 45 before continuing.
2	View the default Demod Quad Preset View.	a. View a quad layout with the IQ Meas Time in trace 1, Spectrum in trace 2, Error Vector Time in trace 3, and the Symbol/Error table in trace 4. See the following figure.

Step

Action

Notes

3



4 Select Trace 3.

a. Press **Trace/Detector, Select Trace, Trace 3.**

Trace numbers are shown to help identify which Data is assigned to the Trace. See the following figure.

Making N9064A VXA Measurements

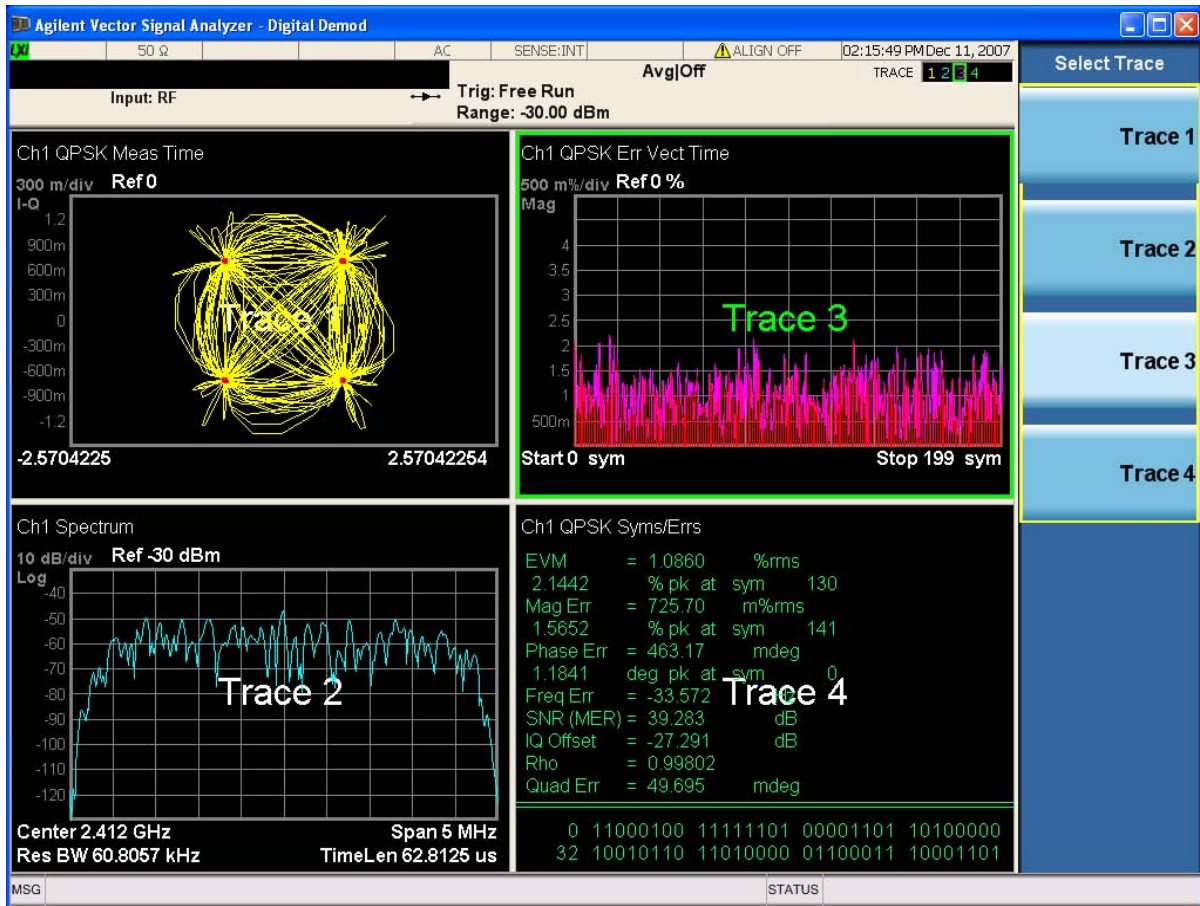
Measuring Digital Signals

Step

Action

Notes

5



6 Select Error Vector Spectrum data.

- Press **Data, Demod, Demod Error**.
- Select **Error Vector Spectrum** from the menu of available data.

NOTE Not all data applies to all traces.

The data for Error Vector Spectrum is assigned to Trace 3. See the following figure.

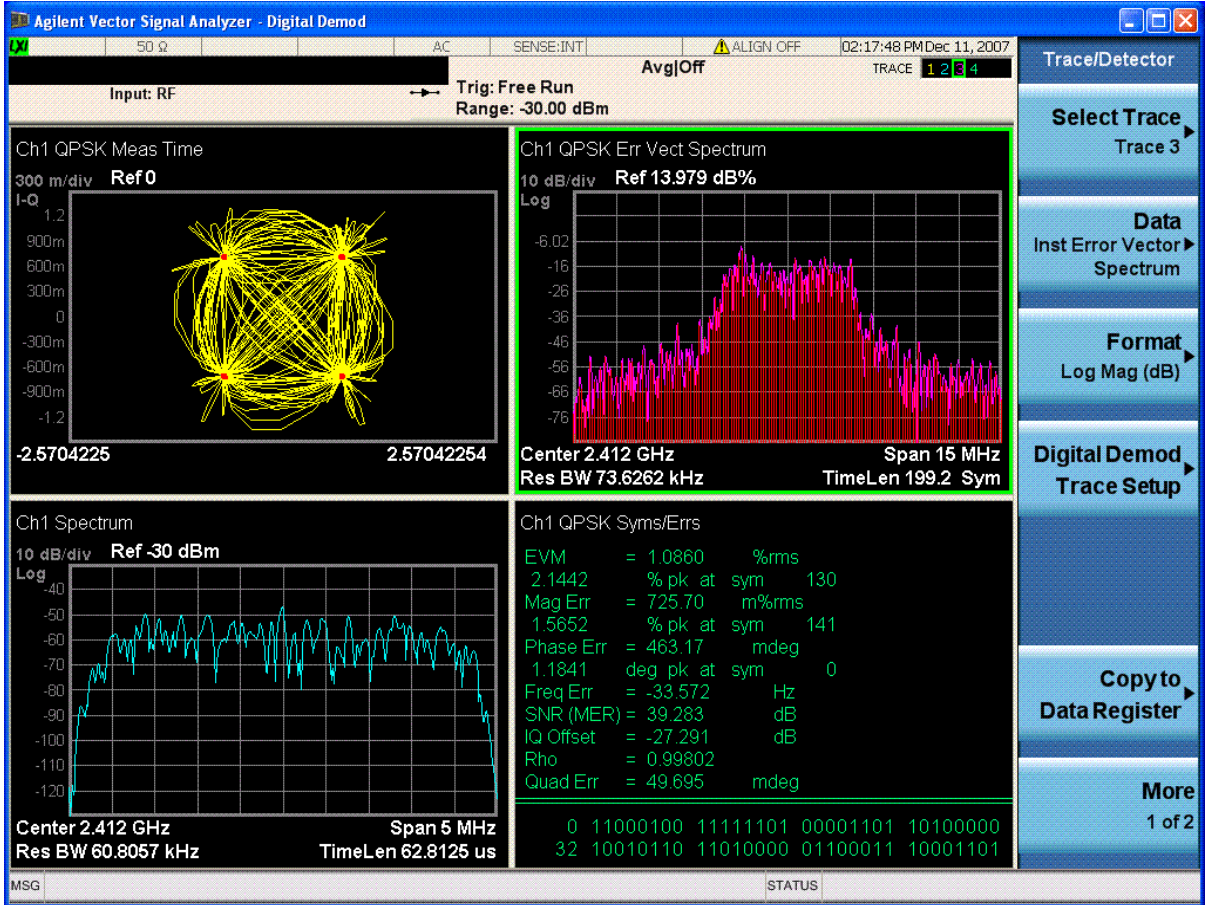
NOTE Available data depends on the Modulation Format selected in Demod Setup

Step

Action

Notes

7



8 Enlarge the trace 3 graph to use the whole display.

a. Press the **Zoom** key (center gray key below the display).

Markers can be assigned to the active trace. See the following figure.

Making N9064A VXA Measurements

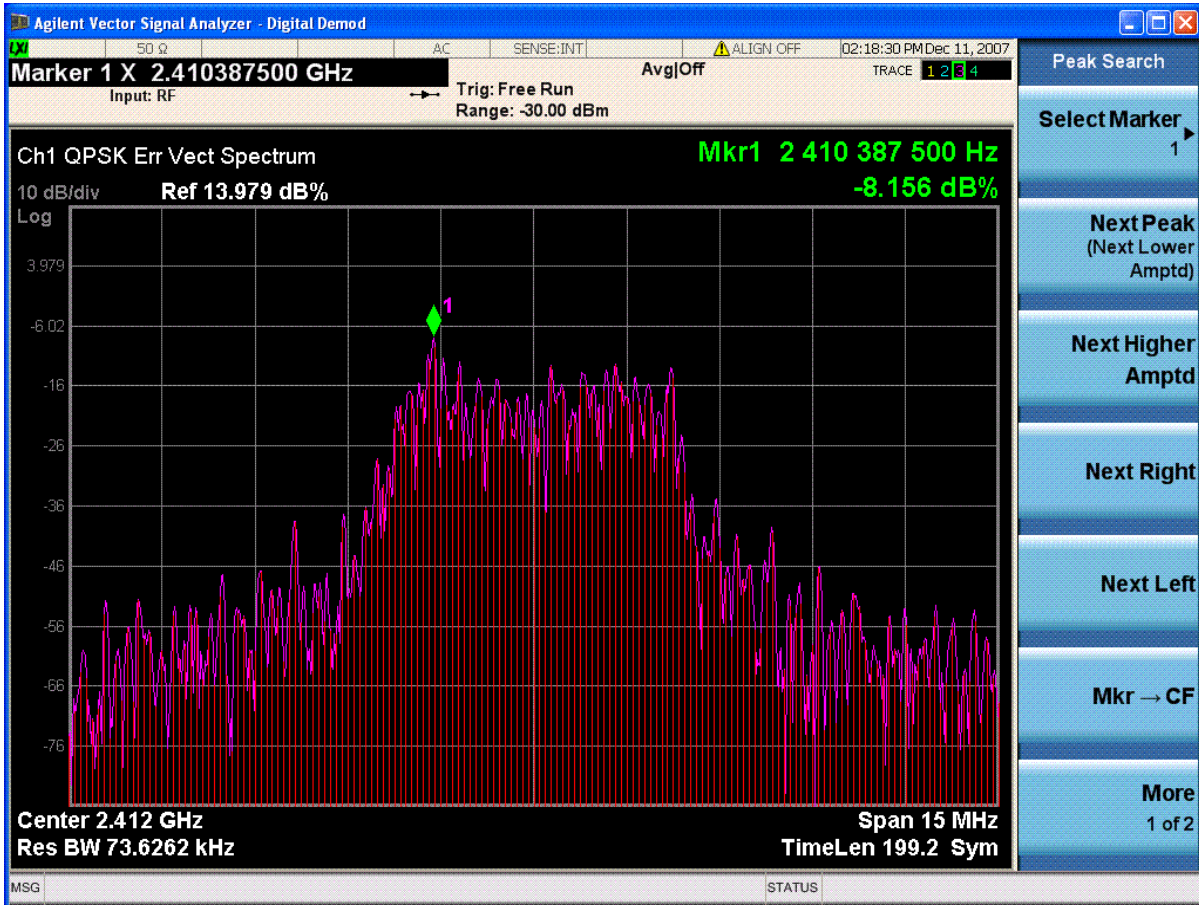
Measuring Digital Signals

Step

Action

Notes

9



If you have a problem, and get an error message, see “Interpreting Error Codes” on page 131.

Troubleshooting N9064A VXA Measurements

The following table provides some possible causes and remedies to a common signal analyzer measurement problem- failure to lock onto a signal for demodulation.

For information of error messages see [“Interpreting Error Codes”](#) on page 131.

Possible Causes	Solutions
Signal not present	Check connections
Carrier too far from center frequency	Adjust center frequency
Input is over-loaded or under ranged	Adjust input range
Frequency span is too narrow	Increase frequency span
Signal is pulsed	Set pulse search ON
Signal is pulsed and result length is longer than pulse	Decrease result length
Signal is too noisy	Try selecting the Low SNR Enhancement checkbox (Advanced Tab of Demod Properties). Must be in a modulation format that supports Low SNR Enhancement.
Wrong symbol rate	Enter correct symbol rate (not bit rate)
Wrong filter selections	Select proper meas and ref filters, & correct setting for alpha/BT.
Wrong modulation format	Select correct modulation format
I/Q offset too large	Reduce LO feedthrough (or DC offset for I+jQ receiver)
I/Q misaligned using I+jQ receiver	Ensure that ch1 and ch2 trigger delays are correct



3 Making 802.11 a/b/g WLAN Measurements

This chapter describes procedures used for making measurements of WLAN signals. Instructions to help you set up and perform the measurements are provided, and examples of WLAN measurement results for analysis of various WLAN modulation formats are shown.

The following subjects are presented in this chapter:

- “What does the N9064A Option 3FP Do?” on page 75
- “Making Option 3FP WLAN OFDM Measurements” on page 76
- “Measuring WLAN OFDM Signals” on page 79
- “Example Measurement - WLAN DSSS” on page 119
- “Making Option 3FP WLAN DSSS Measurements” on page 105
- “Measuring WLAN DSSS Signals in 8 Steps” on page 108
- “Example Measurement - WLAN OFDM Demod” on page 90

Introduction

This chapter provides measurement procedures and also shows example results obtained using the N9064A VXA measurement application. When correctly set up, the N9064A VXA demodulates basic communications, cellular, and wireless connectivity formats and performs a suite of vector signal analysis measurements to analyze digital modulation quality.

NOTE

Before you can begin making measurements, make sure you have N9064A and Option 3FP installed:

1. Press **Mode**, and check to make sure that **Vector Signal Analyzer** is available.
2. Press **Meas**, and check to make sure that **WLAN OFDM** and **WLAN DSSS** are available.

In case you have purchased this firmware separately as an optional upgrade, refer to [“Installing Application Software”](#) on page 16.

There are three fundamental measurements available in this mode: **Vector Analysis**, **Analog Demod** (standard with N9064A option 1FP), and **Digital Demod** (available separately as N9064A Option 2FP). WLAN Option 3FP provides DSSS and OFDM signal measurement capability, available separately. Procedures specific to WLAN signals are also shown.

NOTE

For CDMA signals, the N9064A VXA Digital Demod measurement can analyze digital modulation for a single code channel only. If multiple code channels are transmitted, synchronization will fail, and incorrect EVM results will be obtained. For modulation quality measurements of multiple code channels, Modulation Accuracy and Code Domain measurements use an X-Series full-featured standard-based measurement application, like N9073 for W-CDMA.

The following main subjects are presented in this chapter:

- [“Making Option 3FP WLAN OFDM Measurements”](#) on page 76.

This section describes steps to set up the WLAN OFDM measurement to demodulate OFDM signals.

- [“Making Option 3FP WLAN DSSS Measurements”](#) on page 105.

This section describes steps to set up the WLAN DSSS measurement to demodulate DSSS signals.

What does the N9064A Option 3FP Do?

The N9064A VXA Signal Analyzer measurement application with Option 3FP provides modulation analysis of IEEE 802.11b DSSS/CCK/PBCC and IEEE 802.11a/g OFDM signals.

There are two measurements available- WLAN DSSS and WLAN OFDM. Measurement features include:

- One configuration standard preset for IEEE Std 802.11b and IEEE Std 802.11g WLAN-DSSS/CCK/PBCC (Wireless LAN - Direct Sequence Spread Spectrum) standard signals.
- Support for decoding the optional IEEE Std 802.11b or IEEE Std 802.11g PBCC modes.
- Support for demodulating the preamble of 802.11g DSSS-OFDM bursts (the OFDM payload can be demodulated using the analyzer's WLAN-OFDM mode)

Some of the measurements above contain pass/fail indicators that quickly give a visual indication of standards conformance.

You can also customize signal parameters and parameter limits of each measurement, based on user-defined constraints and tolerances. The settings will be used thereafter in making one-button measurements.

Making Option 3FP WLAN OFDM Measurements

Measurement Features

Features specific to the **WLAN OFDM** measurement include:

- Standard OFDM demodulation presets:
 - IEEE std 802.11a/g OFDM
 - HIPERLAN/2
 - IEEE std 802.11g DSSS-OFDM
 - IEEE 802a/g Turbo Mode
 - IEEE 802.11p DSRC
 - IEEE 802.11j 10 MHz
- Variable carrier spacing (default 312.5 kHz)
- Pulse Search
- IQ Meas constellation measurement data
- Equalizer response measurement data
- Common Pilot Error measurement data
- Enhanced Error Vector trace data display
- Mirrored (flipped) frequency spectrums used to remove the effects of high-side mixing or complex conjugation mismatches in simulated data.
- Measurement offset and interval (similar to time gating) used to select specific data segments for analysis
- By-pass 802.11g CCK WLAN-DSSS preamble to demodulate the 802.11a data payload.
- Automatic detection or manual selection of subcarrier modulation.
- Guard interval selection
- Automatic detection or manual selection of result length.

Some Digital Demodulation features are not available for WLAN OFDM demodulation:

- Measurement/Reference filter
- Sync search
- IQ Mag error and IQ Phase error trace data
- Time gating (does offer measurement offset/interval feature)

WLAN OFDM Measurement Results

The following **WLAN OFDM** demodulation results are available:

- Demodulation Trace Results
 - IQ Meas (measured IQ symbol values of the subcarriers)
 - IQ Reference (ideal IQ symbol values of the subcarriers)
 - Error Vector Time
 - RMS Error Vector Time
 - Error Vector Spectrum
 - RMS Error Vector Spectrum
 - Common Pilot Error
 - Preamble Error
 - Preamble Frequency Error
- Demodulation Result Tables
 - Data Symbols and Errors, including:
 - RMS EVM, displayed in both dB and %
 - Pilot EVM
 - Common Pilot Error (CPE)
 - Frequency Error and Symbol Clock Error
 - IQ errors, including IQ Offset, Quadrature Error, and IQ Gain Imbalance
 - Synchronization Sequence Cross-correlation
 - Detected values, including Modulation Format, number of payload data octets (bytes), number of symbols, code rate, and Bit Rate
- Demodulation Equalizer Results
 - Ch Frequency Response
 - Instantaneous Ch Frequency Response
 - Equalizer Impulse Response
- Statistical Results
 - CDF
 - CCDF
 - PDF

- Other results common to the Vector Analysis measurement:
 - Time
 - Spectrum, averaged and unaveraged
 - Search Time
 - Raw Main Time

Measuring WLAN OFDM Signals

WLAN OFDM Measurement Overview

Making successful N9064A VXA measurements of WLAN OFDM signals is easy when you follow these eight main steps. The procedure overview below provides links in blue to a detailed procedure and description for each step:

[“Set Up the Test Equipment and DUT” on page 80](#)

This step configures the analyzer connections for an RF measurement.

[“Select the Mode and Preset the Analyzer” on page 81](#)

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

[“Select and Configure the Analyzer Input” on page 82](#)

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

[“Acquire and Stabilize the Signal” on page 83](#)

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

[“Demodulate the Signal” on page 84](#)

Demodulation is performed by using a specific N9064A VXA demod option, like Option 3FP for WLAN, if installed, or the Digital Demod measurement. Both contain a number of modulation standard presets that enable rapid measurement of modulation quality for a wide variety of signals.

[“Configure the Display” on page 86](#)

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

[“Optimize your Results” on page 87](#)

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

[“Print or Save Your Measurement Results” on page 89](#)

Your measurement result data can be exported or saved as a trace that can be replayed by the instrument. The graphical results can be printed or saved a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Set Up the Test Equipment and DUT

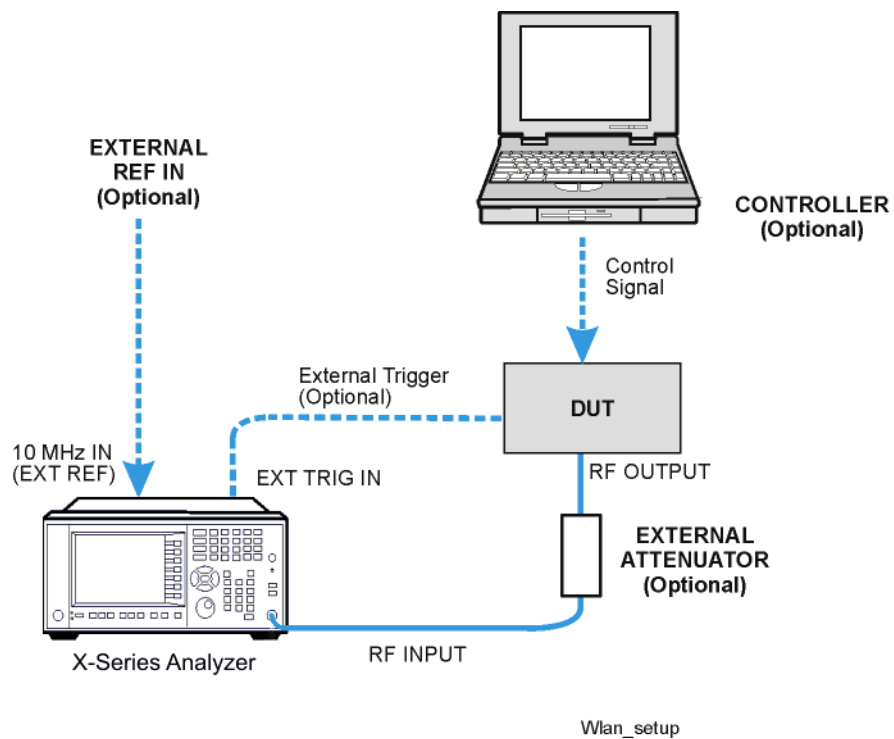
NOTE Before you can begin making measurements, make sure you have N9064A Option 3FP installed. In case you have purchased this firmware separately as an optional upgrade, refer to “Installing Application Software” on page 16.

This step configures the analyzer connections for an RF measurement.

Making the Initial Signal Connection

CAUTION Before connecting a signal to the instrument, make sure the instrument can safely accept the signal level provided. The signal level limits are marked next to the connectors on the front panel.

Figure 3-1 WLAN OFDM Measurement System



The device under test (DUT), which generates WLAN signals, is connected to the RF input port. The DUT may possibly be controlled externally by a computer. External attenuator, external trigger and external reference are optional. Using the appropriate cables, connect the equipment as shown.

Select the Mode and Preset the Analyzer

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

Step	Action	Notes
1 Select the Mode.	a. Press MODE, Vector Signal Analyzer .	The default measurement for N9064A VXA is Vector Analysis. Settings made here will be used by Demod measurements later.
2 Preset the analyzer.	a. Press the green Mode Preset button for the factory preset. b. To recall a user-defined Preset: Press User Preset, User Preset to preset the current mode.	

Click to Go Back to [“WLAN OFDM Measurement Overview”](#) on page 79.

Select and Configure the Analyzer Input

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

Step	Action	Notes
1 Select and configure the analyzer Input settings.	a. Press Input/Output, RF Input, 75 Ohm Input Z , if needed. b. Press AMPTD Y Scale, Range and enter the total signal power at the analyzer input.	The default RF impedance is 50 Ohms. Check: Downrange by step until the overload indicator is displayed as "OV" in the top right corner of the graph. Range back up 1 step.
2 OR If available, you can recall a saved instrument state to establish a group of measurement settings.	a. Press Recall, State . b. Select a Register that contains the state to be retrieved. OR c. Press From File... which opens an Explorer window to browse to your state file location.	Registers 1-6 display the date the last state was saved to help identify which state is saved in each register. TIP Using saved states insure repeatable measurements. See Step 8 for details of saving states.
3 OR If available, you can recall a saved measurement trace for display.	a. Press Recall, Data (Import) . b. Press Trace to select the trace that will contain the stored data. c. Press Open... which opens an Explorer window to browse to your state file location.	

Click to Go Back to ["WLAN OFDM Measurement Overview"](#) on page 79.

Acquire and Stabilize the Signal

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

Step	Action	Notes
1	<p>Observe the Spectrum (upper) graph: set the center frequency to your signal's carrier frequency.</p> <ol style="list-style-type: none"> Press FREQUENCY Channel. Use the front-panel keypad to input the center frequency. Press a units key, like GHz, to complete the entry. 	<p>Settings made in the Vector Analysis measurements will be used by Demod measurements later.</p> <p>TIP The center frequencies of the analyzer and input signal must match to within $\pm 3\%$ of the symbol rate ($\pm 1\%$ for 64QAM and $\pm 0.2\%$ for 256QAM).</p>
2	<p>Set the frequency span to view your entire signal. Make sure the entire signal is captured in the Spectrum graph.</p> <ol style="list-style-type: none"> Press SPAN X Scale. Use the front-panel keypad to input the frequency span. Press a units key, like MHz, to complete the entry. 	<p>You can also use the rotary knob to visually set the span.</p> <p>Check: The signal's spectrum should occupy 50-90% of the span, and not extend beyond the edges. It should appear as a distinct, elevated region of noise 20 dB or more above the analyzer noise floor. Broad, glitching sidebands indicate bursts or other transients, which can be handled with triggering or the Burst Search function in Demod settings.</p>
3	<p>Observe the Main Time (lower) graph: set trigger parameters (if used)</p> <ol style="list-style-type: none"> Press Trigger. Select the correct input for the trigger signal. Set levels as required. 	<p>Observe the Time Domain waveform to see if it is stable. You can come back to the Main Time window to see if Demod settings made in later steps have stabilized the waveform.</p> <p>TIP Triggering is unnecessary for most signals. For TDMA and other burst signals, as the Vector Signal Analyzer will readily acquire a "framed" signal.</p>

Click to Go Back to ["WLAN OFDM Measurement Overview"](#) on page 79.

Demodulate the Signal

Demodulation is performed by using a specific N9064A VXA demod option, like Option 3FP for WLAN, if installed, or one of the flexible Digital or Analog Demod measurements. Both contain a number of modulation standard presets that enable rapid measurement of modulation quality for a wide variety of signals.

Step	Action	Notes
1	For signals using digital modulation select and configure the Digital Demod measurement.	
2	a. Press Meas, WLAN OFDM . b. Enter the total signal power at the analyzer input.	Check: Downrange by 1 step; the overload indicator should be displayed as "OV" in the top right corner of the graph.
3	a. Press Meas, Digital Demod . b. Press Demod Setup, Symbol Rate and enter a frequency value. c. Press Meas Interval and enter a value to set the number of symbols to be measured. d. Press Points/Symbol and enter a value to set the number of samples per symbol to be measured. e. Press More , and set Meas Filter and Alpha/BT parameters. f. If the signal is bursted or has a sync pattern, press Burst/Sync Search and select the Search Length or Sync Pattern to be searched.	<p>TIP The symbol rate needs to be entered to an accuracy of 10-100 ppm.</p> <p>NOTE Result length is important for bursted signals, as you don't want to include data symbols taken before or after the burst (i.e. you don't want to demodulate noise).</p> <p>TIP If the alpha is unknown, estimate it from (60 dB BW/3 dB BW) - 1. EVM peaks between symbols mean an incorrect alpha, but won't usually affect the EVM% readout (except in GSM). In the worst case, start with 0.3 and manually adjust up or down for lowest intersymbol peaks.</p> <p>TIP Burst search length can be longer than a time record; set it to the burst "off" time plus twice the burst "on" time to insure a complete burst in every search.</p>

Step	Action	Notes
4 Use Signal Tracking for unstable signals.	a. Press Span X Scale, Signal Track . b. Toggle the setting to On .	Unstable signals will give varying measurement results. This setting will slow down your measurement, but may dramatically improve accuracy.
5 Increase your measurement accuracy by using Equalization.	a. For Digital Demod , press Meas Setup, Adaptive Equalizer and toggle Filter to On . Try using the default settings before making adjustments. b. For other demod measurements, press Mode Setup, Fixed Equalization and select Normal . Try using the default settings before making adjustments	For more information about Adaptive Equalization see “Using Adaptive Equalization” on page 61 and the Adaptive Equalizer section under Measurement Setup. For more information about Fixed Equalization see the Fixed Equalizer section under Analyzer Setup.
6 Final Checks.	a. The EVM% result should be fairly consistent from measurement to measurement. b. EVM vs. symbol trace should be noise-like, but fairly uniform (short peaks are OK). c. If these methods do not improve “noisy” characteristics of your measurement, you may need to supply more signal gain ahead of the RF input to the analyzer. Make sure you use the analyzer’s ability to correct for external gain and attenuation: Press Input/Output, Ext RF Atten and input a value. You may enter a positive number to correct for external attenuation or input a negative number to correct the power measurements for external gain.	Result peaks may indicate faulty triggering or incorrect synchronization. Abrupt changes within the EVM trace signify problems, as do sloping or V-shaped distributions.

Click to Go Back to [“WLAN OFDM Measurement Overview” on page 79](#).

Configure the Display

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

Step	Action	Notes
1 Use a Preset View for fast, powerful results displays.	a. Press View/Display . b. Select a Preset View from a selection of useful combinations of related data trace displays.	For details of the Preset Views see Preset View below.
2 OR If desired, choose a custom screen layout.	a. Press View/Display, Layout . b. Select a layout that will provide your desired arrangement.	You can choose up to 4 panes to display your trace data.
3 Customize your layout by assigning a data trace to a measurement display.	a. Press Trace/Detector, Select Trace , and select the number of the trace to change. b. Press Data to display a menu of trace groups and select the trace data for assignment to the graph. c. Repeat trace assignment for any other traces in the layout as needed.	When you press Trace/Detector, Select Trace , the trace numbers are displayed on the screen to help you identify the traces for selection.

Click to Go Back to [“WLAN OFDM Measurement Overview”](#) on page 79.

Optimize your Results

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

Step	Action	Notes
1 Select a graph for optimization.	a. Use the "Next Window" key (boxes with arrows) below the display to move the green outline "focus" to activate a graph for customization.	
2 Optimize the X Scale.	a. Press SPAN X Scale, Scale/Div. b. Use the front-panel keypad to input the scale/div. c. Press a units key, like μs , to complete the entry. OR a. Press SPAN X Scale, More, X Scale Auto to enable the instrument to complete the scaling.	
3 Optimize the Y Scale.	a. Press AMPTD YScale, Scale/Div. b. Use the front-panel keypad to input the scale/div. c. Press a units key, like μs , to complete the entry. OR a. Press AMPTD YScale, Auto Scale to enable the instrument to complete the scaling.	
4 Use a Marker to indicate and measure signal characteristics.	a. Press Marker, Select Marker. b. Select the desired marker number for your display. c. Press Marker Function, Select Marker to assign a function to the marker. d. Select either Band/Interval Power , or Band/Interval Density , to turn on/off the markers. e. Adjust either the Power Calc settings or Density Calc settings, depending on which function you have selected. f. Press Marker, Delta to turn a Delta marker on/off and adjust its position on the graph.	For more information on Markers see the Markers section under Measurement Setup in Help.

Making 802.11 a/b/g WLAN Measurements
Making Option 3FP WLAN OFDM Measurements

Step	Action	Notes
5	<p>Add titles or make other changes to the measurement graphs.</p> <ol style="list-style-type: none">Press View/Display, Display, System, Settings to adjust other parts of the display for all measurement windows.Press View/Display, Display, Annotation, to turn on/off various parts of the display annotation.Press View/Display, Display, Title, Change Title to create a title for the graph.Press View/Display, Display, Graticule to turn graticules on/off.Press View/Display, Display, Display Line to turn a reference line on/off and adjust its position on the graph.	For more information on Display settings see the Display section under Analyzer Setup in Help.

Click to Go Back to [“WLAN OFDM Measurement Overview”](#) on page 79.

Print or Save Your Measurement Results

Your measurement results data can be saved as traces that can be replayed by the instrument, or exported for analysis. The graphical results can be printed or saved as a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Step	Action	Notes
1 Print your measurement results.	a. Press Page Setup and a Windows dialog box opens that enables you to set print parameters, including printer selection. b. Press Print .	Set up your printer using the Windows Printer control panel. The Print front-panel key is equivalent to performing File, Print, OK in Windows. It immediately performs the currently configured Print to the current printer.
2 Save your measurement results.	a. Press Save , and select Data (Export) to save a data trace, or Screen Image . to save the display as a bitmap file. b. Press Save As... a Windows Explorer dialog box opens to enable you to name the file and select the file location. c. Press Quick Save to save repeated measurements in the same format and to the same location as you specified in the last Save procedure. Files saved using Quick Save are numbered sequentially and dated for later reference.	TIP For repeated measurements, create a directory for your saved files during the initial Save set up. All subsequent Quick Save results will be easier to manage when grouped in the same directory. CAUTION Don't save files to the C: or E: drives as they will be overwritten by software upgrades. Use the User Data (D:) drive for file storage or save your results to an external USB drive.
3 If desired, save your measurement state for re-use later.	a. Press Save , and select State to save your current measurement settings for re-use later. b. Select a Register number for storage or press To File... a Windows Explorer dialog box opens to enable you to name the file and select the file location.	When you save a measurement state, only the settings for the current measurement are saved.
4 If desired, save your measurement state as a User Preset .	a. Press User Preset, Save User Preset to save your current measurement settings as a quickly retrievable Mode-level state.	When you save a User Preset the current settings for all measurements in the mode are saved.

Click to Go Back to [“WLAN OFDM Measurement Overview”](#) on page 79.

Example Measurement - WLAN OFDM Demod

This procedure demonstrates how make a measurement and see different results views available for the WLAN OFDM Demod measurement.

Agilent ESG Series Vector Signal Generator Settings

Figure 3-2 WLAN OFDM Example - Agilent WLAN Signal Studio Setup

Carrier 0 (Main) - 802.11a Advance	
1. Capability	
Capability	Advanced
State	ON
2. Carrier Basic	
Format	802.11a
Number of Frames	1
Generation Mode	Framed
Idle Interval	100.000 us
Frequency Offset	+0.000000 Hz
Relative Power	0.00 dB
3. Coding and Modulation	
Data Rate	8 Mbps (OFDM)
Modulation	BPSK
Convolutional Coder	ON
Encoder Rate	1/2
Interleaver	ON
OFDM Scrambler	ON
Scrambler Initialization	93
Reserved Service Bits	0
Subcarrier Mask	52 Active Subcarriers
4. Payload Configuration	
Payload	
PN9; 1024 Bytes Data; MAC Header ON; MAC FCS ON	
Total Length per Frame	1058 Byte(s)
Data Type	PN9
Data Length	1024 Byte(s)
MAC Header	General Format
MAC FCS	ON
Increment Sequence Number	ON
Sequence Number Increment by: (Frames)	1
Increment Fragment Number	OFF
5. Spectrum Control	
Windowing Length	8
Filter	None

Step	Action	Notes
1	Preset the analyzer.	a. Press Mode Preset .
2	Initiate the Vector Analysis measurement.	a. Press Meas, Vector Analysis .
3	Set the frequency.	a. Press Frequency, 1.8 GHz .
4	View the measurement.	a. View the Vector Analysis measurement default Spectrum and Ch1 Main Time view. See the following figure.

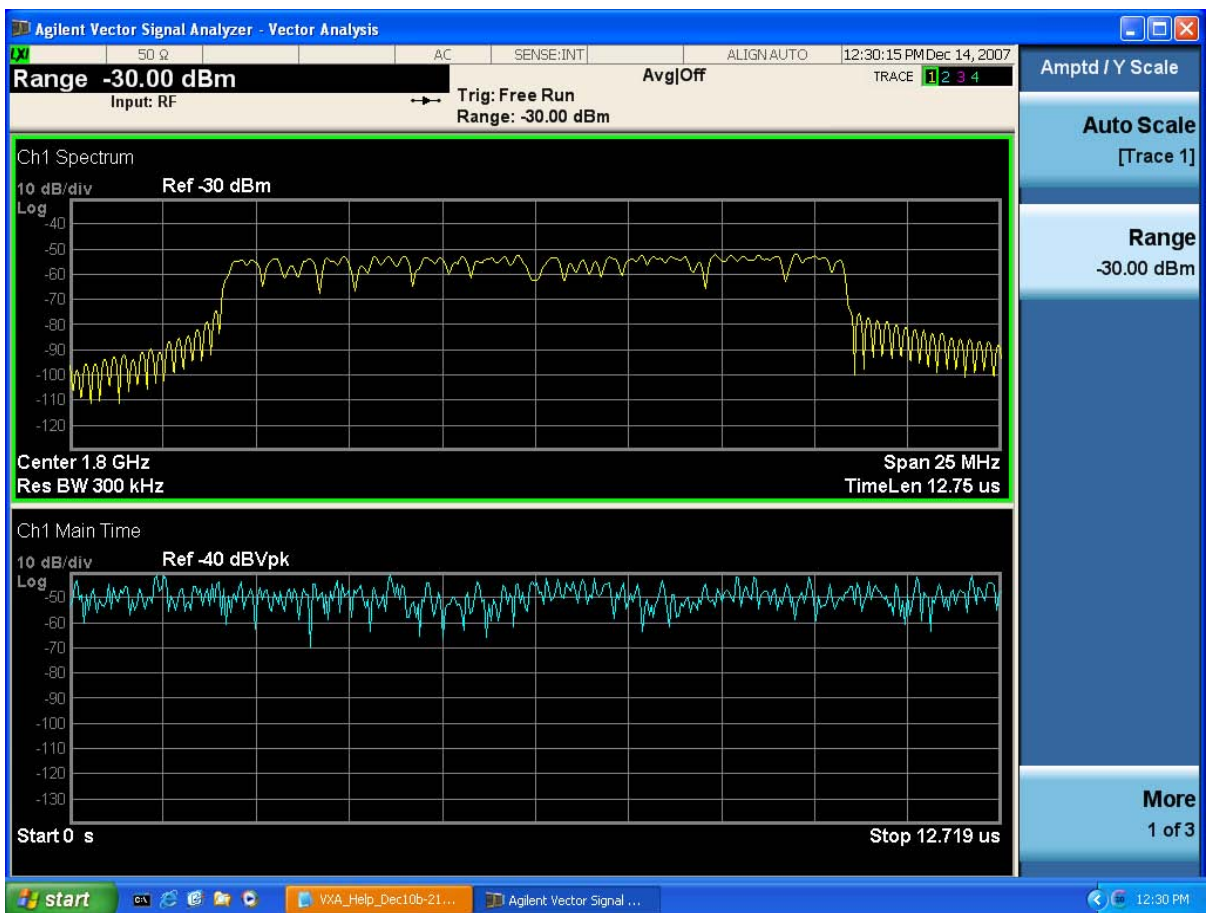
5



Making 802.11 a/b/g WLAN Measurements
Making Option 3FP WLAN OFDM Measurements

Step	Action	Notes
6	Adjust the input power range of the analyzer. a. Press Range, -30, dBm .	<p>NOTE A wide carrier is present centered around 1.8 GHz with a signal strength of about -50 dBm. The default Ref Level is 30 dBm.</p> <p>The noise floor will lower and the signal to noise ratio will increase. See the following figure.</p> <p>NOTE The default span (with N9020A-B25) is set at 25 MHz.</p>

7

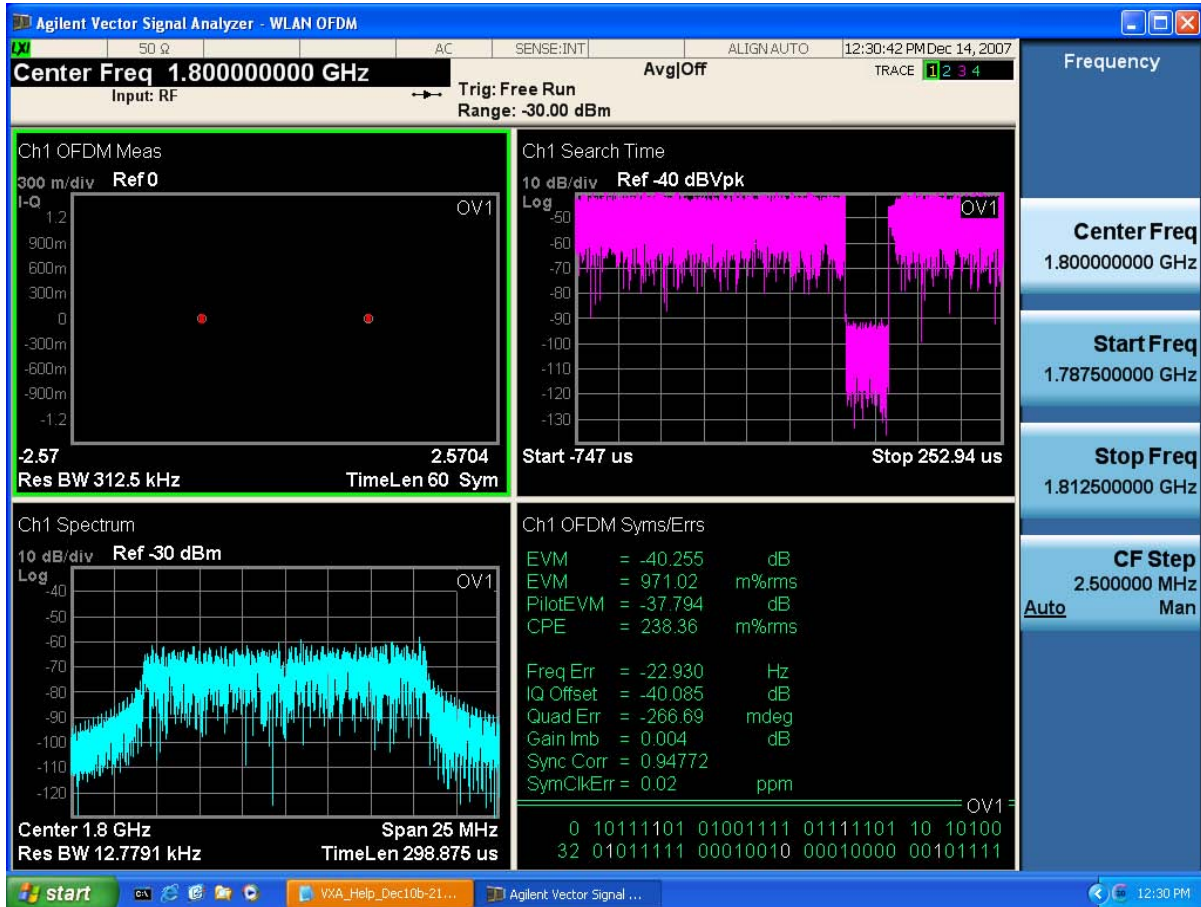


Step	Action	Notes
8 Initiate the OFDM Demod measurement.	a. Press Meas, WLAN OFDM .	<p>View the default OFDM Demod Basic View which displays IQ Meas Time in I-Q format in trace 1, Spectrum in Log Mag (dB) format in trace 2, Search Time in Log Mag (dB) format in trace 3, and Symbols/Errors in trace 4. See the following figure.</p> <p>The Preset View: Basic softkey does an immediate action of changing the layout and view to this state. This Preset View is an action, not a state.</p> <p>This layout is the layout set by Meas Preset and is good for insuring that the signal is being demodulated correctly, as well as giving visibility to many basic demodulation setup problems.</p>
		<hr/> <p>CAUTION OV1 displayed in the upper-right hand corner of the graphs indicates that the signal is “over range” and the results are invalid, even though the Range was set at -30 dBm, and the displayed signal is well below the Reference Level of -30 dBm. This is because the peak power of an OFDM signal is well above the average level, by approximately 8 dB.</p> <hr/>

Making 802.11 a/b/g WLAN Measurements
 Making Option 3FP WLAN OFDM Measurements

Step	Action	Notes
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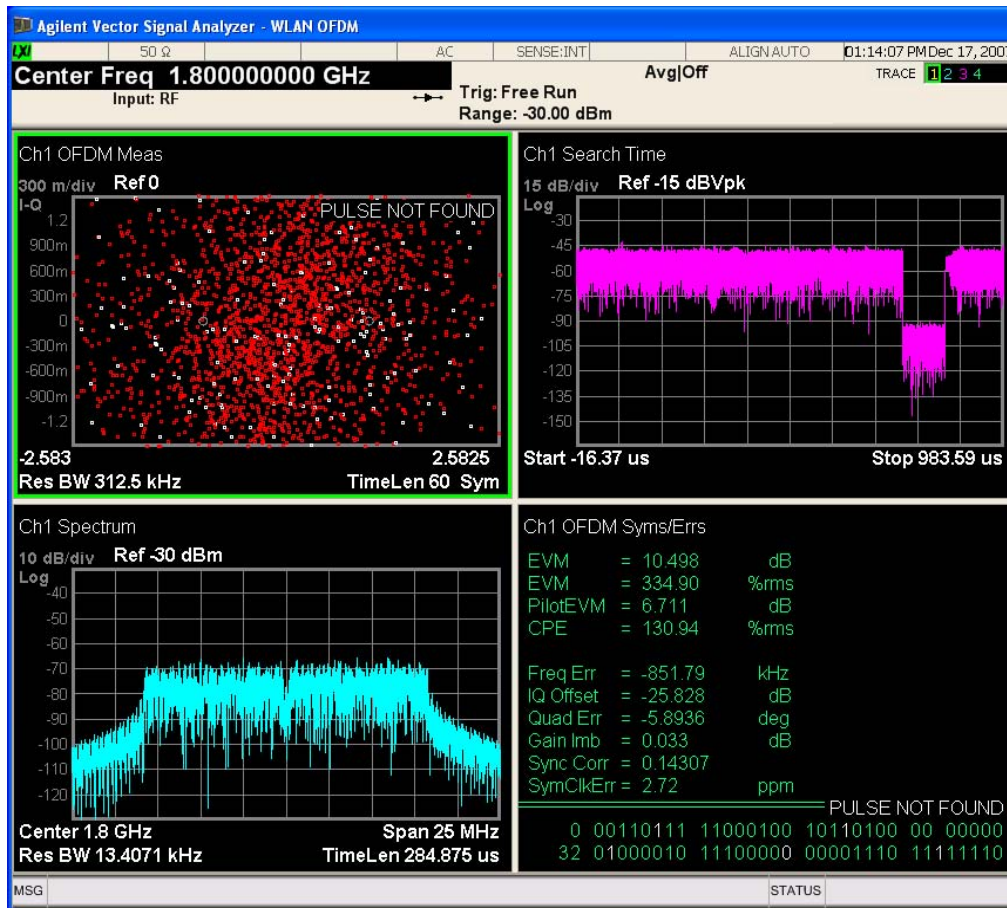
9



Step	Action	Notes
10 Correct the input power range of the analyzer.	<ol style="list-style-type: none">Press Amplitude, Range.Use the Up Arrow key to increase the range by steps until the OV1 indication no longer appears.	<p>The measured results will probably improve with valid data.</p> <p>The following graph is another common condition in an OFDM Demod measurement that requires adjustment. Notice the OFDM Meas Time in trace 1 displays a random constellation pattern, instead of a well-defined BPSK graph.</p>
		<hr/> <p>CAUTION PULSE NOT FOUND (or SYNC NOT FOUND) displayed in the upper-right hand corner of the constellation graph indicates that no measurement synchronization with the signal occurred and the results are invalid. Note the poor EVM measurement in the summary in the trace 4 window.</p> <hr/>

Step	Action	Notes
------	--------	-------

11



12 Correct Search Time of the analyzer.

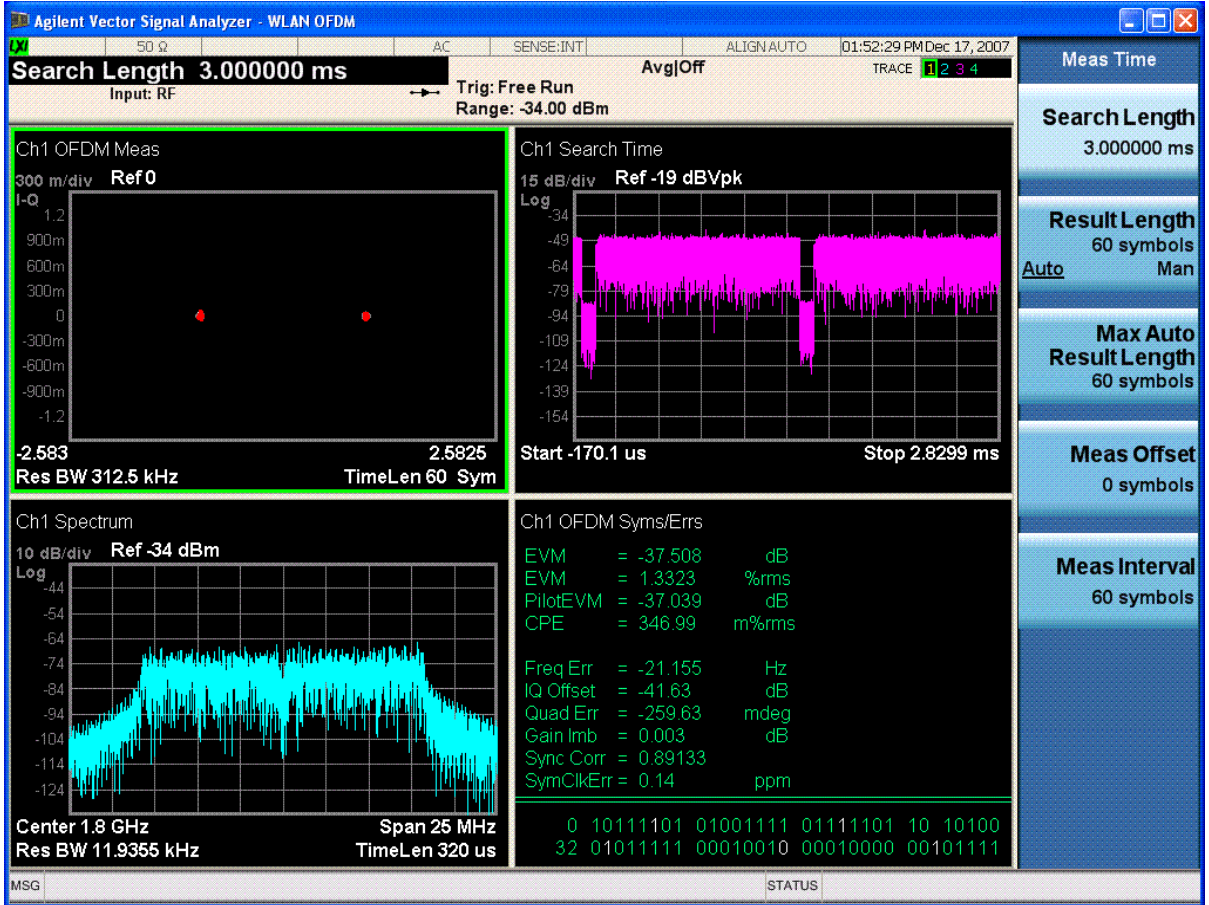
- a. Press **Meas Setup**, **Meas Time**, **Search Length**.
- b. Increase the Search Length until the NOT FOUND indication no longer appears.

The measured results will probably improve with a valid measurement.

Below is shown a OFDM Demod Basic View with the errors in Steps 6 and 8 corrected. Note the well-defined BPSK constellation in the OFDM Meas Time graph in trace 1 and the capture of an entire "on" period in Search Time in trace 3. See the following figure.

Step Action Notes

13



Using OFDM Preset Views

You can use Preset Views to conveniently see other measurement results for OFDM signals:

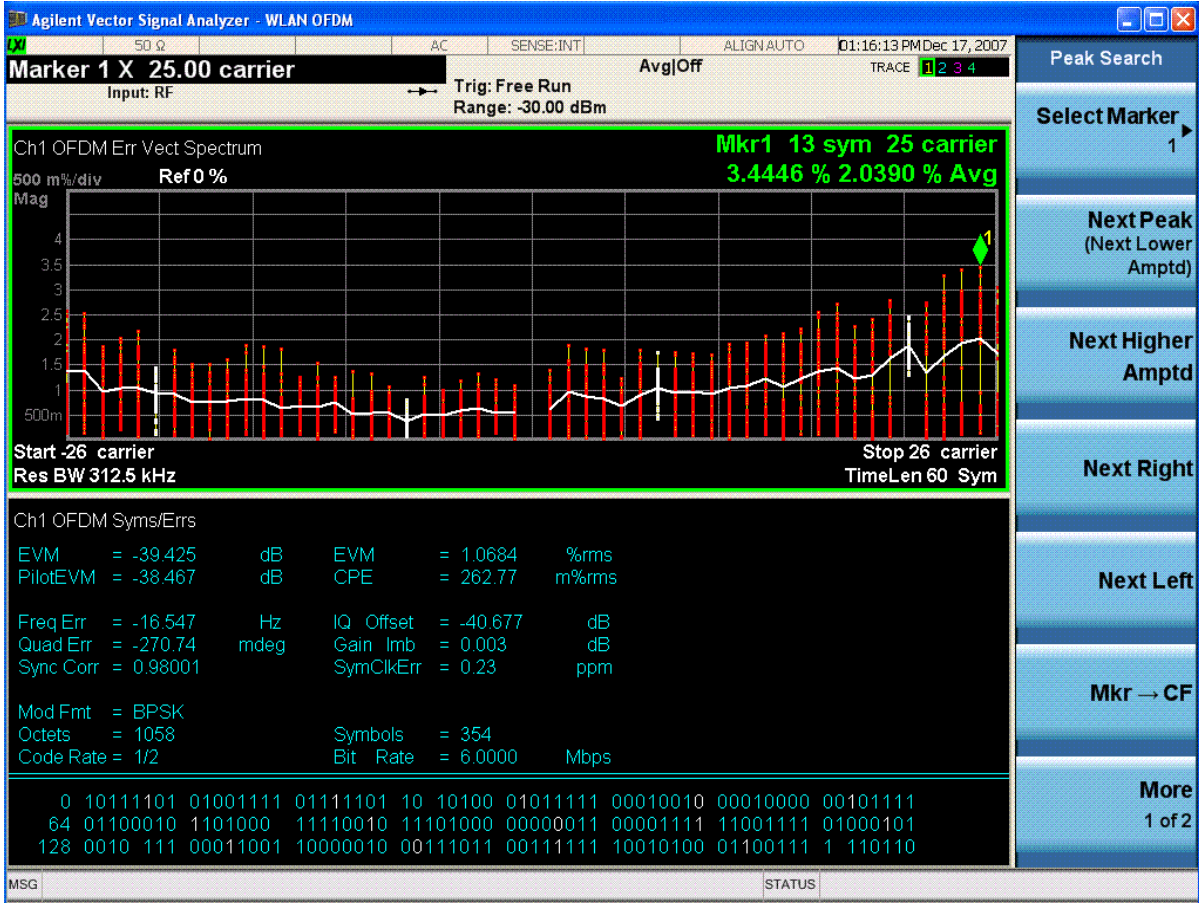
Step	Action	Notes
1 View a graph of EVM Error Spectrum and a summary results display.	a. Press View/Display, Preset View: EVM .	<p>This layout is for more detailed EVM analysis.</p> <p>The Preset View: EVM softkey does an immediate action of changing the layout and view to this state. This Preset View is an action, not a state.</p> <p>You can use markers to conveniently see measurement results for OFDM carries in the signal:</p> <p>For example, press Peak Search to see a marker placed at the carrier with the highest EVM Error and a summary of the results for that carrier displayed. See the following figure.</p>

Step

Action

Notes

2



3 Display the Power Preset View.

a. Press **View/Display, Preset View: Power.**

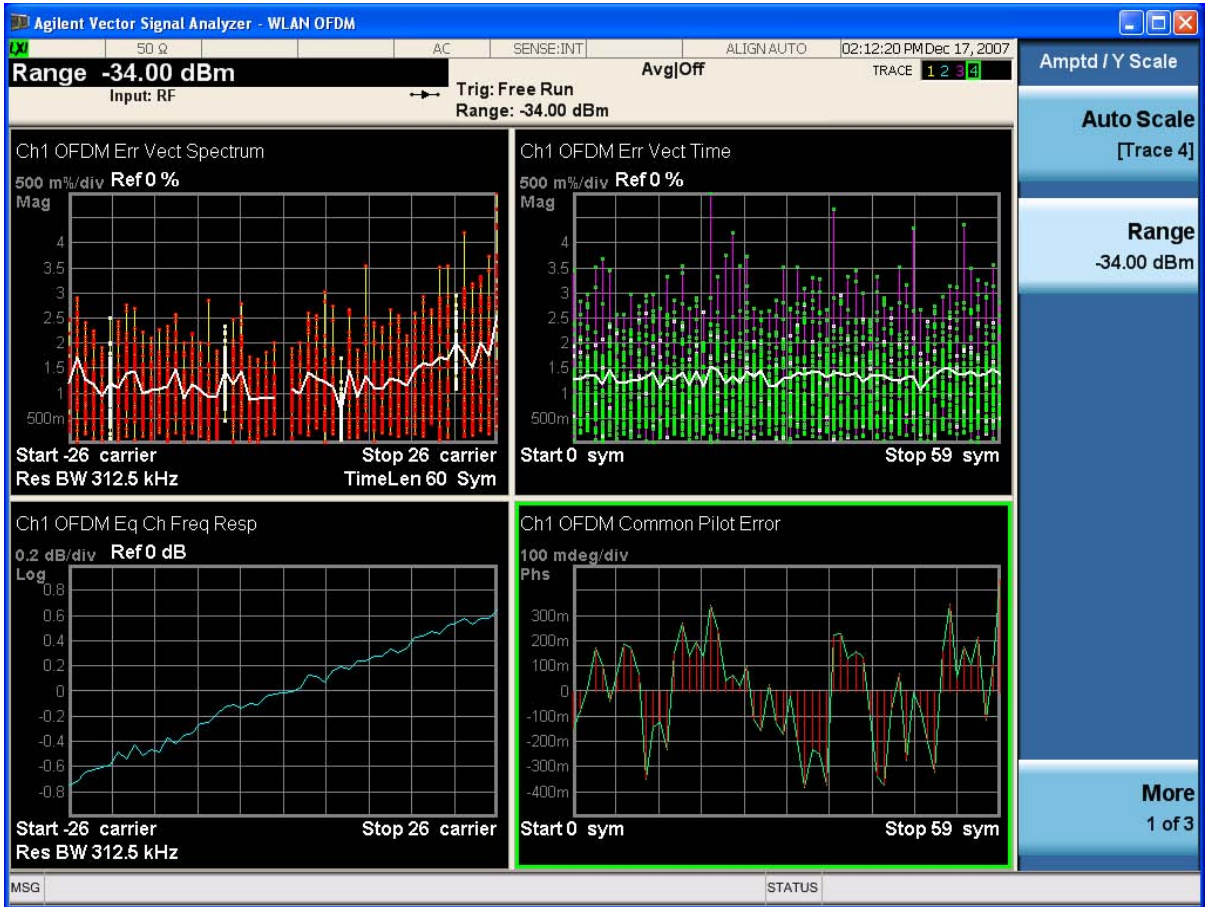
The following graph shows Spectrum in Log Mag (dB) format, Time in Log Mag (dB) format, Search Time in Log Mag (dB) format, and CCDF in Log Mag (Linear Unit) format. See the following figure.

Step

Action

Notes

6



7 Depending on the measurement results you may need to rescale the measurement results.

- a. Press **Amptd/Y Scale, Auto Scale** to automatically optimize the displayed Y Scale results.

If you have a problem, and get an error message, see [“Interpreting Error Codes”](#) on page 131, or [“Troubleshooting OFDM Measurements”](#) on page 102.

Troubleshooting OFDM Measurements

This topic contains information to help you troubleshoot measurements when using OFDM Demodulation. You should also review Setting up an OFDM Demodulation Measurement for additional measurement information.

PROBLEM	POSSIBLE CAUSE	SOLUTIONS
Demodulation fails to lock on signal	Signal not present.	Check Connections.
	Carrier too far from center frequency	Adjust center frequency. The analyzer center frequency must be within $2 * \text{Subcarrier Spacing}$ (625 kHz for 802.11a or HIPERLAN/2) to lock properly.
	Input is over-loaded or under ranged.	Adjust input range. Typically, the best EVM is achieved when the range is as small as possible while avoiding overloads.
	Frequency span is too narrow.	Increase frequency span. A frequency span of at least 18 MHz is typically required for 802.11a and HIPERLAN/2 signals.
	Incorrect subcarrier spacing.	Set correct subcarrier spacing. The normal subcarrier spacing for 802.11a and HIPERLAN/2 signals is 312.5 kHz.
	OFDM signal has inverted frequency spectrum	Check the Mirror Frequency Spectrum setting (MeasSetup > Demod Properties > Advanced tab).
	802.11a signal has incorrect SIGNAL symbol at start of burst	Override the auto detection of modulation type and result length (MeasSetup > Demod Properties > Format tab and Time tab).
	HIPERLAN/2 signal is using 1/8 guard interval length instead of 1/4	If this is the case, the analyzer will get a good Sync Correlation in the Syms/Errs trace, but the IQ Meas constellation and the EVM will be bad. Set the analyzer to use 1/8 guard interval (MeasSetup > Demod Properties > Format tab).
Wrong modulation format	Select correct modulation format	
Signal uses the 802.11g DSSS-OFDM format	Use the Preset-to-Standard button to select IEEE 802.11g DSSS-OFDM format. Because a DSSS-OFDM signal has a much longer preamble than other OFDM signals, it is sometimes helpful to increase the search length.	
SYNC NOT FOUND error message	802.11a signal has incorrect Short Training Sequence (Short Sync) in burst preamble.	Try setting the analyzer to synchronize to the Channel Estimation Sequence (Long Sync) portion of the burst preamble (MeasSetup > Demod Properties > Advanced tab).

PROBLEM	POSSIBLE CAUSE	SOLUTIONS
EVM larger than expected	VSA demodulator set incorrectly. Attempting to demodulate an 802.11b WLAN-DSSS modulated signal.	Set the VSA demodulator to WLAN-DSSS mode. Select (MeasSetup > Demodulator > WLAN-DSSS).
	I/Q misaligned using I+jQ receiver.	The "Error Vector Spectrum" trace will shows as a "V" shape. Click Utilities > Calibration > External Amplitude tab, select the Calibration Constants check box and adjust the delays for each input channel.
	89611 with ESA H70 hardware needs adjusting.	Adjust the Tuner Maximum Mixer Level for the ESA.
	I/Q gain imbalance using I+jQ receiver.	1) Check that impedance is identical for both input channels. 2) Adjust the gains for each input channel (Click Utilities > Calibration > External Amplitude tab > Calibration Constants check box).
	Signal is transmitting incorrect pilot bits.	If the signal is transmitting incorrect pilot bits, the CPE level will be high, both in the Syms/Errs summary and on the Common Pilot Error trace. Turning off Pilot Timing Tracking, and possibly Pilot Phase Tracking, may help (MeasSetup > Demod Properties > Advanced tab).
	Signal has longer than usual transition region between symbols	Change Symbol Timing Adjustment to be more negative (MeasSetup > Demod Properties > Advanced tab).
	Noise or interference from adjacent signals.	Reduce the span to eliminate excess noise and interfering signals.
EVM increasing from beginning of burst to end (visible on Error Vector Time trace)	OFDM signal has inverted frequency spectrum	Try inverting the frequency spectrum (MeasSetup-> Demod Properties-> Advanced tab). It is possible for the analyzer to appear to synchronize to a signal with inverted frequency content, because of symmetry properties of the 802.11a Short Training Sequence. In this case, the Sync Correlation value in the error summary table will be only about 5% less than expected, but the demodulation timing and channel estimation are incorrect and the EVM will be large.
	Signal amplitude varies during the burst.	Turn on Pilot Amplitude Tracking (MeasSetup > Demod Properties > Advanced tab).

Making 802.11 a/b/g WLAN Measurements
Making Option 3FP WLAN OFDM Measurements

PROBLEM	POSSIBLE CAUSE	SOLUTIONS
EVM good at beginning of burst, then gets very large near the end of the burst	802.11a signal has incorrect length portion of SIGNAL symbol at start of burst	Override the auto detection of result length (MeasSetup > Demod Properties > Time tab).
EVM good, but Sync Correlation coefficient not good	Center frequency not close enough to signal carrier frequency	Adjust center frequency.
The trace data constellation symbol location shape, such as dots, is not properly displayed.	The display driver is not functioning correctly.	Contact your PC manufacturer to see if a newer version of the display driver is available. If not, try decreasing the hardware acceleration by clicking (XP Instructions) Start, Control Panel, Display, Settings, Advanced, Troubleshoot, decrease the hardware acceleration value, OK, OK.

Making Option 3FP WLAN DSSS Measurements

Measurement Features

Features specific to the **WLAN DSSS** measurement include:

- Analyze variable-length pulses.
- Demodulate long and short preamble formats.
- Auto-select and manual-override pulse length modes.
- Auto-detect and manual-override payload data modulation format modes.
- Generation of 802.11b reference from either raw chips or de-spread symbols.
- Adjustable chip rate.
- Adjustable chip timing.
- Equalization Filter determined from detected 802.11b preamble information.
- De-spread data results.
- PPDU frame Header information (similar to WLAN-OFDM demodulation).
- Ability to disable the descrambler
- Pulse Search
- IQ Normalization.
- Mirrored (flipped) frequency spectrums used to remove the effects of high-side mixing or complex conjugation mismatches in simulated data.
- Measurement offset and interval (similar to time gating) used to select specific data segments for analysis

Some Digital Demodulation features are not available for WLAN DSSS demodulation:

- No support for IEEE Std 802.11 FHSS (Frequency Hopped Spread Spectrum).
- No support for IEEE Std 802.11b Channel Agility.
- Measurement filter other than None and Root Raised Cosine
- Reference filter other than Rect, Gaussian and Raised Cosine
- Sync search
- Multiple points per Chip/Symbol
- Arbitrary constellation rotation
- Time gating (does offer measurement offset/interval feature)

WLAN DSSS Measurement Results

The following **WLAN DSSS** measurement results are available:

- Demodulation Trace Results
 - Error Vector Time
 - Error Vector Spectrum, averaged and unaveraged
 - IQ Measurement Time
 - IQ Measurement Spectrum, averaged and unaveraged
 - IQ Reference Time
 - IQ Reference Spectrum, averaged and unaveraged
 - IQ Magnitude Error
 - IQ Phase Error
- Demodulation Result Tables:
 - Data Symbols and Errors, including:
 - EVM, both RMS and Peak, including chip location of Peak
 - Magnitude error, both RMS and Peak, including chip location of Peak
 - Phase error, both RMS and Peak, including chip location of Peak
 - Frequency Error and Symbol Clock Error
 - IQ errors, including IQ Offset, Quadrature Error, and IQ Gain Imbalance
 - Synchronization Sequence Cross-correlation
 - PPDU demodulation status, including Preamble, Header, and MAC demodulation status
 - Burst Type
 - Header data, including Bit Rate, number of payload data octets (bytes), and time length of the payload data
 - Header Symbols
 - Preamble Symbols
- Demodulation Equalizer Results
 - Equalizer Impulse Response
 - Channel Frequency Response

- Statistical Results
 - CDF
 - CCDF
 - PDF
- Other results common to the Vector Analysis measurement:
 - Time
 - Spectrum, averaged and unaveraged
 - Search Time
 - Raw Main Time

Measuring WLAN DSSS Signals in 8 Steps

WLAN DSSS Measurement Overview

Making successful N9064A VXA measurements of WLAN DSSS signals is easy when you follow these eight main steps. The procedure overview below provides links in blue to a detailed procedure and description for each step:

[“Set Up the Test Equipment and DUT” on page 80](#)

This step configures the analyzer connections for an RF measurement.

[“Select the Mode and Preset the Analyzer” on page 81](#)

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

[“Select and Configure the Analyzer Input” on page 82](#)

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

[“Acquire and Stabilize the Signal” on page 83](#)

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

[“Demodulate the Signal” on page 84](#)

Demodulation is performed by using a specific N9064A VXA demod option, like Option 3FP for WLAN, if installed, or the Digital Demod measurement. Both contain a number of modulation standard presets that enable rapid measurement of modulation quality for a wide variety of signals.

[“Configure the Display” on page 86](#)

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

[“Optimize your Results” on page 87](#)

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

[“Print or Save Your Measurement Results” on page 89](#)

Your measurement result data can be exported or saved as a trace that can be replayed by the instrument. The graphical results can be printed or saved a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Set Up the Test Equipment and DUT

NOTE

Before you can begin making measurements, make sure you have N9064A Option 3FP installed. In case you have purchased this firmware separately as an optional upgrade, refer to “Installing Application Software” on page 16.

This step configures the analyzer connections for an RF measurement.

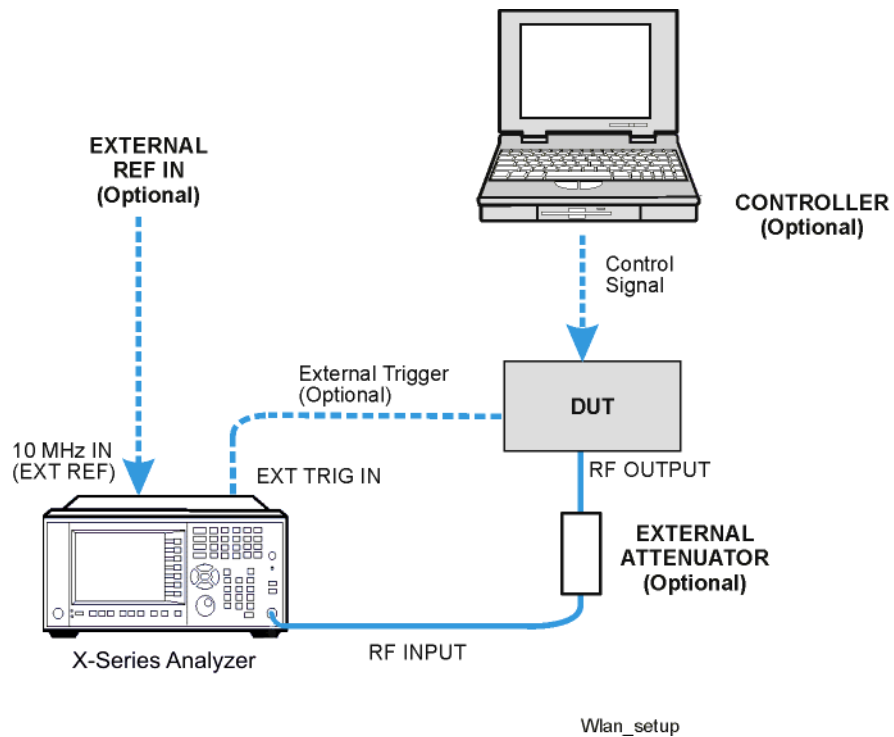
Making the Initial Signal Connection

CAUTION

Before connecting a signal to the instrument, make sure the instrument can safely accept the signal level provided. The signal level limits are marked next to the connectors on the front panel.

Figure 3-3

WLAN DSSS Measurement Setup



The device under test (DUT), which generates WLAN signals, is connected to the RF input port. The DUT may possibly be controlled externally by a computer. External attenuator, external trigger and external reference are optional. Using the appropriate cables, connect the equipment as shown.

Select the Mode and Preset the Analyzer

This step assures the analyzer will be set to a known state, either the factory preset or a user-configured preset.

Step	Action	Notes
1 Select the Vector Signal Analyzer mode.	a. Press MODE, Vector Signal Analyzer .	The default measurement for N9064A VXA is Vector Analysis. Settings made here will be used by Demod measurements later.
2 Preset the analyzer.	a. Press the green Mode Preset button for the factory preset. b. To recall a user-defined Preset: Press User Preset, User Preset to preset the current mode.	

Click to Go Back to [“WLAN DSSS Measurement Overview”](#) on page 108.

Select and Configure the Analyzer Input

This step is where you decide to measure a signal at the analyzer input, or to view a set of stored data. You can recall a stored instrument state, correct for the impedance at the RF input, and make adjustments for external gains and losses. This step is also where you set the analyzer input power range for best results.

Step	Action	Notes
1 Select and configure the analyzer Input settings.	a. Press Input/Output, RF Input, 75 Ohm Input Z , if needed. b. Press AMPTD Y Scale, Range and enter the total signal power at the analyzer input.	The default RF impedance is 50 Ohms. Check: Downrange by step until the overload indicator is displayed as "OV" in the top right corner of the graph. Range back up 1 step.
2 OR If available, you can recall a saved instrument state to establish a group of measurement settings.	a. Press Recall, State . b. Select a Register that contains the state to be retrieved. OR a. Press From File... which opens an Explorer window to browse to your state file location.	Registers 1-6 display the date the last state was saved to help identify which state is saved in each register. TIP Using saved states insure repeatable measurements. See Step 8 for details of saving states.
3 OR If available, you can recall a saved measurement trace for display.	a. Press Recall, Data (Import) b. Press Trace to select the trace that will contain the stored data. c. Press Open... which opens an Explorer window to browse to your state file location.	

Click to Go Back to ["WLAN DSSS Measurement Overview"](#) on page 108.

Acquire and Stabilize the Signal

The Vector measurement is used to view and verify the center frequency of the carrier and set the frequency span. The measurement is also used to view the signal in the time domain and is very useful for determining trigger conditions.

Step	Action	Notes
1	<p>Observe the Spectrum (upper) graph: set the center frequency to your signal's carrier frequency.</p> <ol style="list-style-type: none"> Press FREQUENCY Channel. Use the front-panel keypad to input the center frequency. Press a units key, like GHz, to complete the entry. 	<p>Settings made in the Vector Analysis measurements will be used by Demod measurements later.</p> <p>TIP The center frequencies of the analyzer and input signal must match to within $\pm 3\%$ of the symbol rate ($\pm 1\%$ for 64QAM and $\pm 0.2\%$ for 256QAM).</p>
2	<p>Set the frequency span to view your entire signal. Make sure the entire signal is captured in the Spectrum graph.</p> <ol style="list-style-type: none"> Press SPAN X Scale. Use the front-panel keypad to input the frequency span. Press a units key, like MHz, to complete the entry. You can also use the rotary knob to visually set the span. 	<p>Check: The signal's spectrum should occupy 50-90% of the span, and not extend beyond the edges. It should appear as a distinct, elevated region of noise 20 dB or more above the analyzer noise floor. Broad, glitching sidebands indicate bursts or other transients, which can be handled with triggering or the Burst Search function in Demod settings.</p>
3	<p>Observe the Main Time (lower) graph: set trigger parameters (if used)</p> <ol style="list-style-type: none"> Press Trigger. Select the correct input for the trigger signal. Set levels as required. 	<p>Observe the Time Domain waveform to see if it is stable. You can come back to the Main Time window to see if Demod settings made in later steps have stabilized the waveform.</p> <p>TIP Triggering is unnecessary for most signals. For TDMA and other burst signals, as the Vector Signal Analyzer will readily acquire a "framed" signal.</p>

Click to Go Back to ["WLAN DSSS Measurement Overview"](#) on page 108.

Demodulate the Signal

Demodulation is performed by using the **WLAN DSSS** measurement. It contains a number of DSSS-standard presets that enable rapid measurement of modulation quality.

Step	Action	Notes
1	For signals using digital modulation select and configure the Digital Demod measurement.	For WLAN signals using OFDM modulation select the WLAN OFDM measurement. See “Measuring WLAN OFDM Signals” on page 79.
2	Set the input power range for your signal.	Check: Downrange by 1 step; the overload indicator should be displayed as “OV” in the top right corner of the graph.
3	Configure Demod Setup as needed.	<p>TIP The symbol rate needs to be entered to an accuracy of 10-100 ppm.</p> <p>NOTE Result length is important for bursted signals, as you don’t want to include data symbols taken before or after the burst (i.e. you don’t want to demodulate noise).</p> <p>TIP If the alpha is unknown, estimate it from (60 dB BW/3 dB BW) - 1. EVM peaks between symbols mean an incorrect alpha, but won't usually affect the EVM% readout (except in GSM). In the worst case, start with 0.3 and manually adjust up or down for lowest intersymbol peaks.</p> <p>TIP Burst search length can be longer than a time record; set it to the burst “off” time plus twice the burst “on” time to insure a complete burst in every search.</p>
	a. Press Meas, WLAN DSSS .	
	a. Press AMPTD Y Scale, Range .	
	b. Enter the total signal power at the analyzer input.	
	a. Press Meas Setup, Demod Setup, Symbol Rate and enter a frequency value.	
	b. Press Meas Interval and enter a value to set the number of symbols to be measured.	
	c. Press Points/Symbol and enter a value to set the number of samples per symbol to be measured.	
	d. Set Meas Filter and Alpha/BT parameters.	
	e. If the signal is bursted or has a sync pattern, press Burst/Sync Search and select the Search Length or Sync Pattern to be searched.	

Making 802.11 a/b/g WLAN Measurements
Making Option 3FP WLAN DSSS Measurements

Step	Action	Notes
4 Use Signal Tracking for unstable signals.	a. Press Span X Scale, Signal Track . b. Toggle the setting to On .	Unstable signals will give varying measurement results. This setting will slow down your measurement, but may dramatically improve accuracy.
5 Increase your measurement accuracy by using Equalization.	a. For Digital Demod , press Meas Setup, Adaptive Equalizer and toggle Filter to On . Try using the default settings before making adjustments. b. For other demod measurements, press Mode Setup, Fixed Equalization and select Normal . Try using the default settings before making adjustments	For more information about Adaptive Equalization see “Using Adaptive Equalization” on page 61 and the Adaptive Equalizer section under Measurement Setup. For more information about Fixed Equalization see the Fixed Equalizer section under Analyzer Setup.
6 Final Checks.	a. The EVM% result should be fairly consistent from measurement to measurement. b. EVM vs. symbol trace should be noise-like, but fairly uniform (short peaks are OK). c. Make sure you have selected the correct Range for the signal of interest. Check that the OV1 overload indicator is not displayed. d. If these methods do not improve “noisy” characteristics of your measurement, you may need to supply more signal gain ahead of the RF input to the analyzer. Make sure you use the analyzer’s ability to correct for external gain and attenuation: Press Input/Output, Ext RF Atten and input a value. You may enter a positive number to correct for external attenuation or input a negative number to correct the power measurements for external gain.	Result peaks may indicate faulty triggering or incorrect synchronization. Abrupt changes within the EVM trace signify problems, as do sloping or V-shaped distributions.

Click to Go Back to [“WLAN DSSS Measurement Overview” on page 108.](#)

Configure the Display

Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

Step	Action	Notes
1 Use a Preset View for fast, powerful results displays.	<ul style="list-style-type: none"> a. Press View/Display. b. Select a Preset View from a selection of useful combinations of related data trace displays. 	For details of the Preset Views see Preset View below.
2 OR If desired, choose a custom screen layout.	<ul style="list-style-type: none"> a. Press View/Display, Layout. b. Select a layout that will provide your desired arrangement. 	You can choose up to 4 panes to display your trace data.
3 Customize your layout by assigning a data trace to a measurement display.	<ul style="list-style-type: none"> a. Press Trace/Detector, Select Trace, and select the number of the trace to change. b. Press Data to display a menu of trace groups and select the trace data for assignment to the graph. c. Repeat trace assignment for any other traces in the layout as needed. 	When you press Trace/Detector, Select Trace , the trace numbers are displayed on the screen to help you identify the traces for selection.

Click to Go Back to [“WLAN DSSS Measurement Overview”](#) on page 108.

Optimize your Results

In this step you can finalize the presentation of your data by adjusting various parameters to make your measurement data more useful.

Step	Action	Notes
1 Select a graph for optimization.	a. Use the Next Window key (boxes with arrows) below the display to move the green outline “focus” to activate a graph for customization.	
2 Optimize the X Scale.	a. Press SPAN X Scale, Scale/Div . b. Use the front-panel keypad to input the scale/div. c. Press a units key, like μs , to complete the entry. OR a. Press SPAN X Scale, More, X Scale Auto to enable the instrument to complete the scaling.	
3 Optimize the Y Scale.	a. Press AMPTD YScale, Scale/Div . b. Use the front-panel keypad to input the scale/div. c. Press a units key, like μs , to complete the entry. OR a. Press AMPTD YScale, More, Auto Scale to enable the instrument to complete the scaling.	
4 Use a Marker to indicate and measure signal characteristics.	a. Press Marker, Select Marker , and select the number of the maker desired for your display. b. Press Marker Function, Select Marker to assign a function to the marker. c. Select either Band/Interval Power , or Band/Interval Density , to turn on/off the markers. d. Adjust either the Power Calc settings or Density Calc settings, depending on which function you have selected. e. Press Marker, Delta to turn a Delta marker on/off and adjust its position on the graph.	For more information on Markers see the Markers section under Measurement Setup in Help.

Step	Action	Notes
5 Add titles, or make other changes to the measurement graphs.	<ol style="list-style-type: none">Press View/Display, Display, System, Settings to adjust other parts of the display for all measurement windows.Press View/Display, Display, Annotation, to turn on/off various parts of the display annotation.Press View/Display, Display, Title, Change Title to create a title for the graph.Press View/Display, Display, Graticule to turn graticules on/off.Press View/Display, Display, Display Line to turn a reference line on/off and adjust its position on the graph.	For more information on Display settings see the Display section under Analyzer Setup in Help.

Click to Go Back to [“WLAN DSSS Measurement Overview”](#) on page 108.

Print or Save Your Measurement Results

Your measurement results data can be saved as traces that can be replayed by the instrument, or exported for analysis. The graphical results can be printed or saved as a bitmap file. You can also save the instrument state to preserve the adjustments you have made in previous steps to obtain the exact measurement again, later.

Step	Action	Notes
1 Print your measurement results.	a. Press Page Setup and a Windows dialog box opens that enables you to set print parameters, including printer selection. b. Press Print .	Set up your printer using the Windows Printer control panel. The Print front-panel key is equivalent to performing File, Print, OK in Windows. It immediately performs the currently configured Print to the current printer.
2 Save your measurement results.	a. Press Save , and select Data (Export) to save a data trace, or Screen Image to save the display as a bitmap file. b. Press Save As... a Windows Explorer dialog box opens to enable you to name the file and select the file location. c. Press Quick Save to save repeated measurements in the same format and to the same location as you specified in the last Save procedure. Files saved using Quick Save are numbered sequentially and dated for later reference.	<div data-bbox="959 789 995 816" style="background-color: #f0f0f0; padding: 2px;">TIP</div> <div data-bbox="1084 789 1414 1052"> For repeated measurements, create a directory for your saved files during the initial Save set up. All subsequent Quick Save results will be easier to manage when grouped in the same directory. </div> <div data-bbox="959 1083 1060 1110" style="background-color: #f0f0f0; padding: 2px;">CAUTION</div> <div data-bbox="1149 1083 1414 1346"> Don't save files to the C: or E: drives as they will be overwritten by software upgrades. Use the User Data (D:) drive for file storage or save your results to an external USB drive. </div>
3 If desired, save your measurement state for re-use later.	a. Press Save , and select State to save your current measurement settings for re-use later. b. Select a Register number for storage or press To File... a Windows Explorer dialog box opens to enable you to name the file and select the file location.	When you save a measurement state, only the settings for the current measurement are saved.
4 If desired, save your measurement state as a User Preset .	a. Press User Preset, Save User Preset to save your current measurement settings as a quickly retrievable Mode-level state.	When you save a User Preset the current settings for all measurements in the mode are saved.

Example Measurement - WLAN DSSS

This procedure demonstrates how make a measurement and see different results views available for the WLAN DSSS Demod measurement.

Agilent ESG Series Vector Signal Generator Settings

Figure 3-4 WLAN DSSS Example - Agilent WLAN Signal Studio Setup

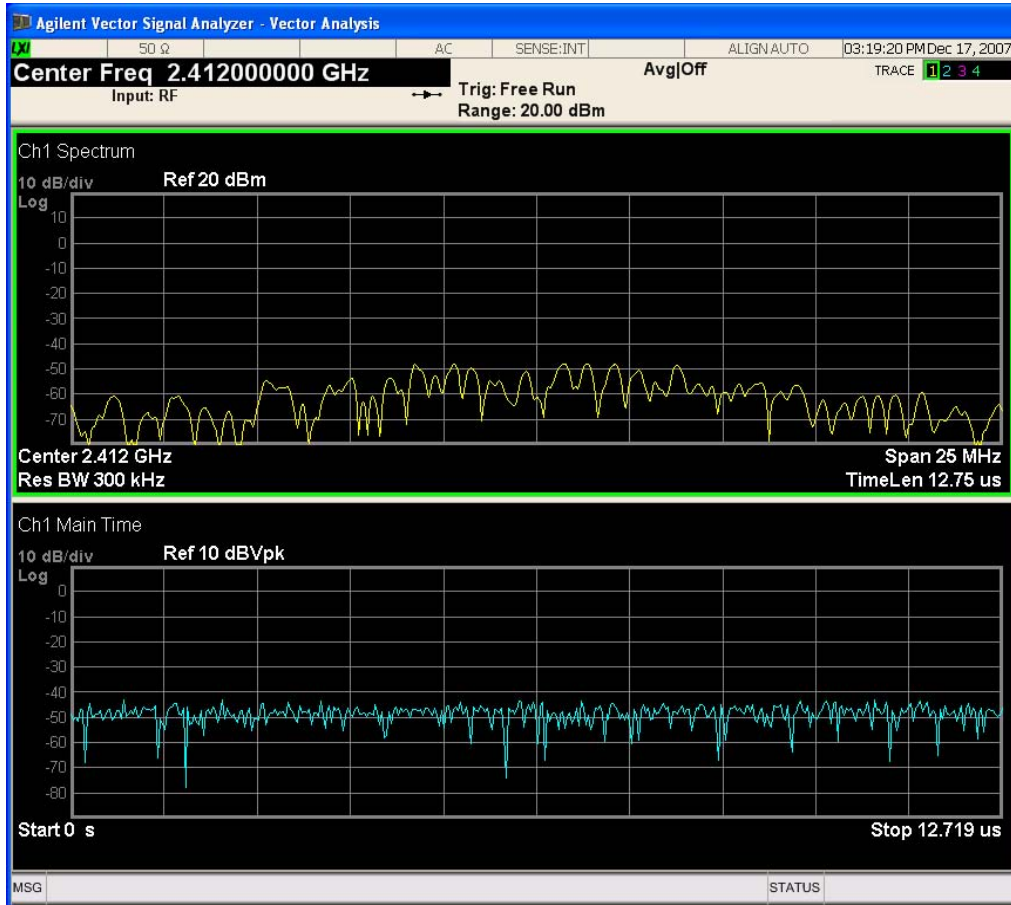
Carrier 0 (Main) - 802.11a Advance	
1. Capability	
Capability	Advanced
State	ON
2. Carrier Basic	
Format	802.11b
Number of Frames	1
Generation Mode	Framed
Idle Interval	100.000 us
Frequency Offset	+0.000000 Hz
Relative Power	0.00 dB
3. Coding and Modulation	
Data Rate	11 Mbps (DSSS)
High Rate Modulation	CCK
DSSS Scrambler	ON
Preamble Type	Long
Power Ramp	
Ramp Type	Linear; 2.000 us
Ramp Time(us)	2.000 us
Clk Locked Flag	Unlocked
4. Payload Configuration	
Payload	PN9; 1024 Bytes Data; MAC Header ON; MAC FCS ON
Total Length per Frame	1058 Byte(s)
Data Type	PN9
Data Length	1024 Byte(s)
MAC Header	General Format
MAC FCS	ON
Increment Sequence Number	ON
Sequence Number Increment by: (Frames)	1
Increment Fragment Number	OFF
5. Spectrum Control	
Filter	
Length(symbol)	Gaussian
BT	6
	0.5

Step	Action	Notes
1	Preset the analyzer.	a. Press Mode Preset .
2	Select the Vector Analysis measurement.	a. Press Meas, Vector Analysis .

Making 802.11 a/b/g WLAN Measurements
 Making Option 3FP WLAN DSSS Measurements

Step	Action	Notes
3	Set the frequency. a. Press Frequency, 2.412 GHz.	View the Vector Analysis measurement default Spectrum and Ch1 Main Time view. See the following figure.

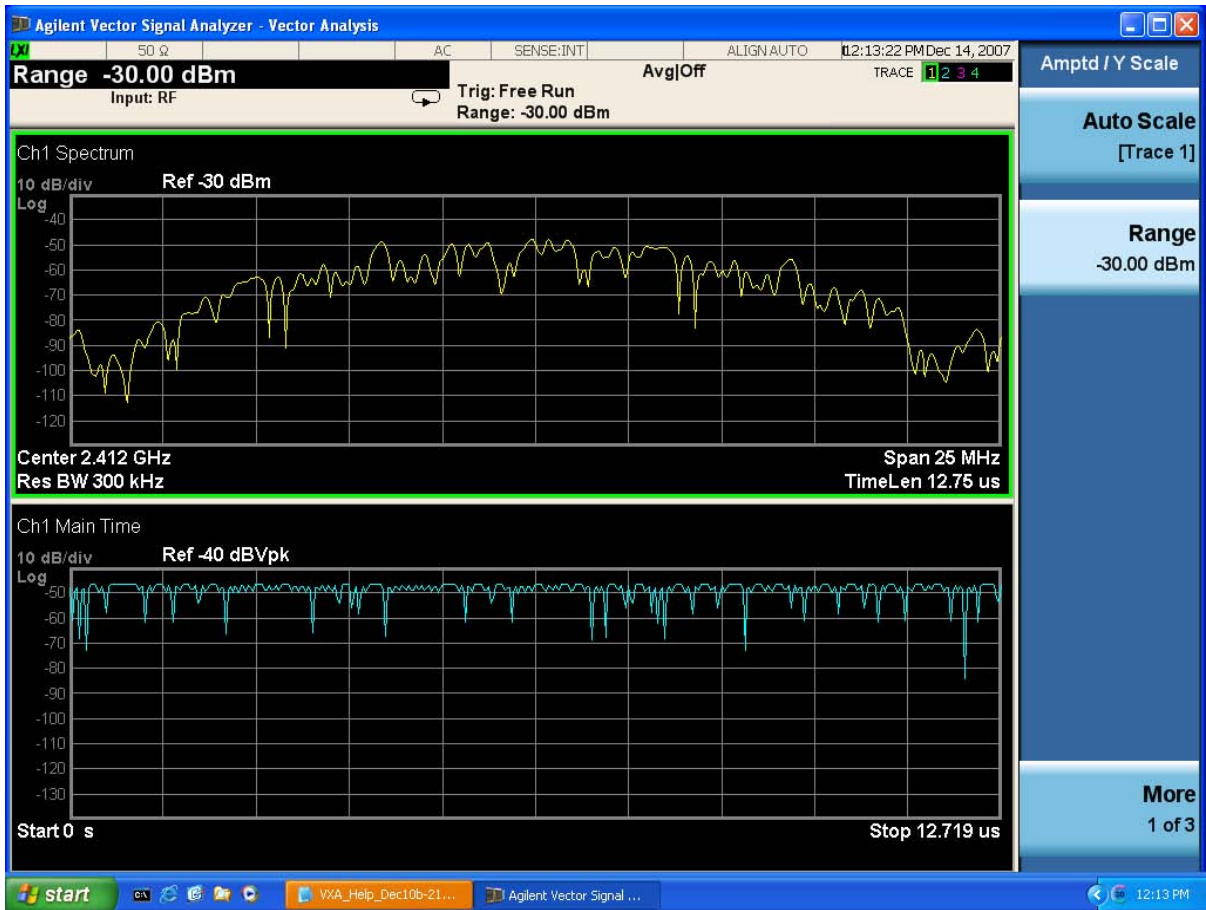
4



5	Adjust the input power range of the analyzer. a. Press Range, -30, dBm.	NOTE A wide carrier is just visible centered around 2.4 GHz with a signal strength of about -50 dBm. The default Ref Level is 30 dBm.
		The noise floor will lower and the signal to noise ratio will increase. See the following figure.
		NOTE The default span (with N9020A-B25) is set at 25 MHz.

Step Action Notes

6

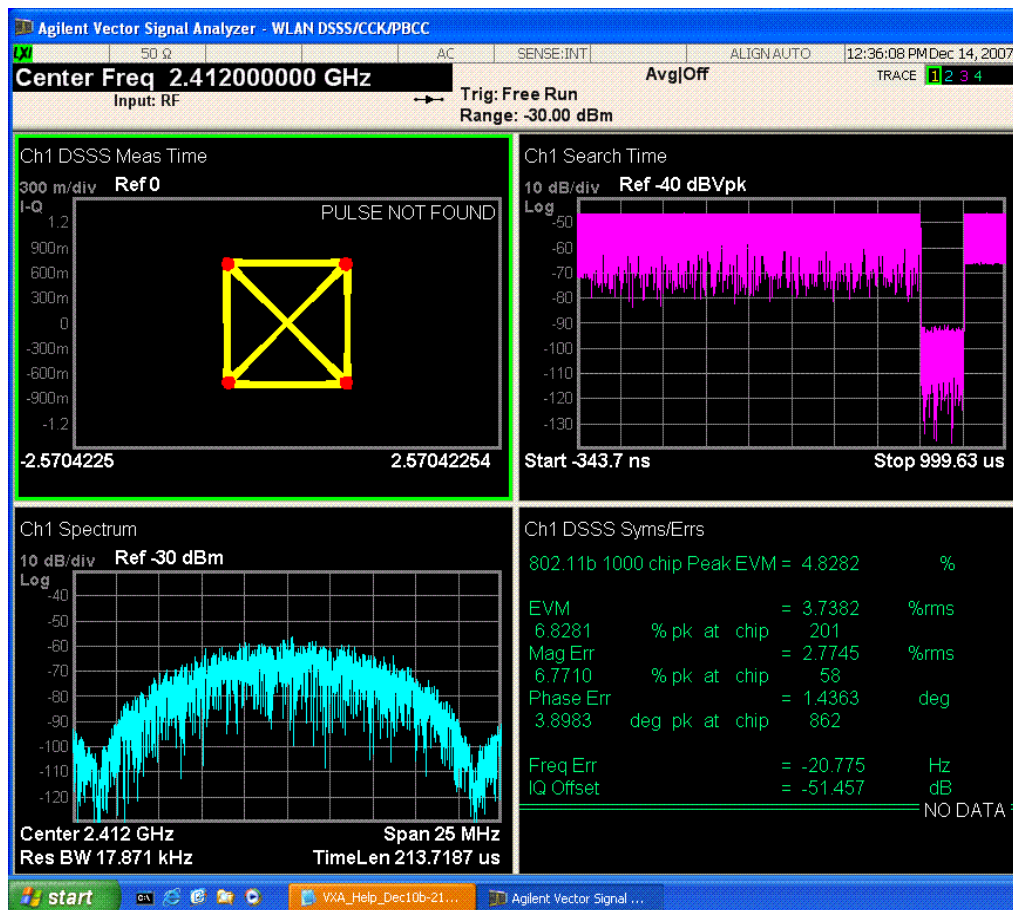


Making 802.11 a/b/g WLAN Measurements
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Step	Action	Notes
7 Initiate the DSSS Demod measurement.	a. Press Meas, WLAN DSSS .	View the default OFDM Demod Basic View which displays IQ Meas Time in I-Q format, Spectrum in Log Mag (dB) format, Search Time in Log Mag (dB) format, and Symbols/Errors in trace 4. See the following figure.
		<hr/> CAUTION PULSE NOT FOUND (or SYNC NOT FOUND) displayed in the upper-right hand corner of the constellation graph indicates that no measurement synchronization with the signal occurred and the results are invalid. Note the poor EVM measurement in the summary in the trace 4 window. <hr/>

Step Action Notes

8



- 9 To correct Search Time of the analyzer.
- a. Press **Meas Setup**, **Meas Time**, **Search Length** and increase the Search Length until the NOT FOUND indication no longer appears.

NOTE In the Search Time graph (trace 3, upper-right), only one “off” period is visible. Search time should always be greater than 2 “on” periods plus one “off” period to insure capture of an entire “on” period.

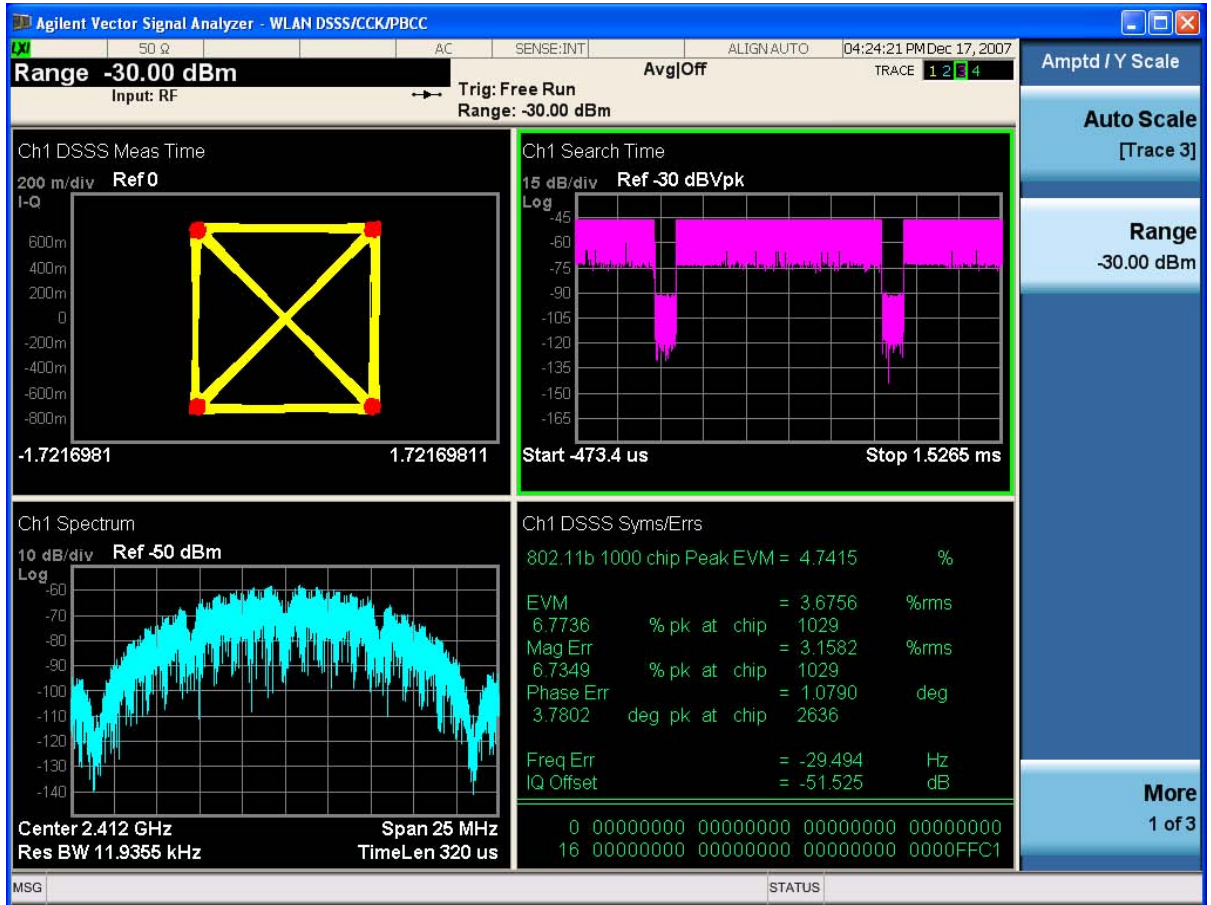
The measured results may improve with a valid measurement.

The graph below shows a OFDM Demod Basic View with the error in the previous step corrected. Note the capture of an entire “on” period in Search Time in trace 3.

Making 802.11 a/b/g WLAN Measurements
 Making Option 3FP WLAN DSSS Measurements

Step Action Notes

10



- 11 Make sure all other signal parameters are correct, including filter selection (default is Rectangular).
- Press **Meas Setup**, **Demod Setup**, **Reference Filter**.
 - Select another filter, like **Gaussian**.

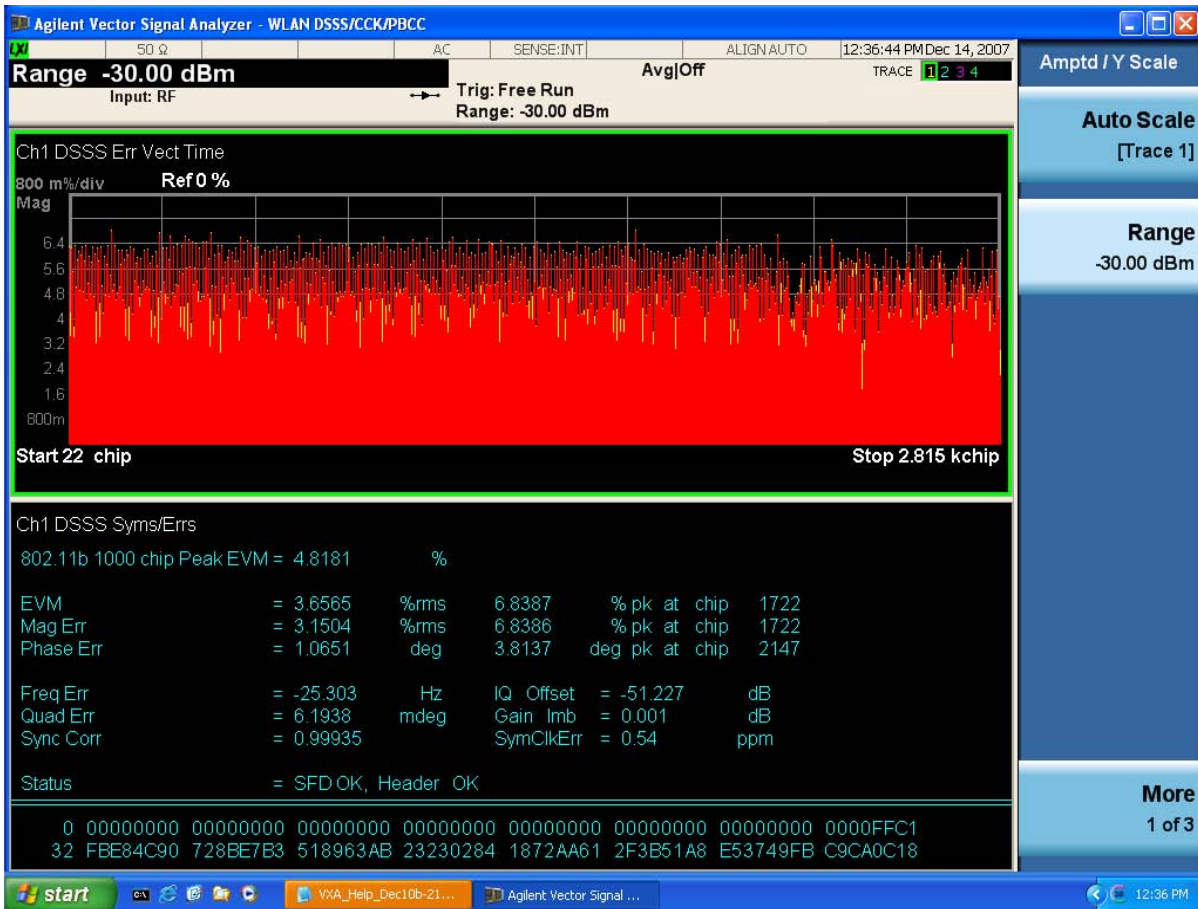
Using DSSS Preset Views

You can use Preset Views to conveniently see other measurement results for DSSS signals:

Step	Action	Notes
1	View a graph of EVM Error Spectrum and a summary results display.	a. Press View/Display, Preset View: EVM

You may need to scale the display. See the following graph.

2

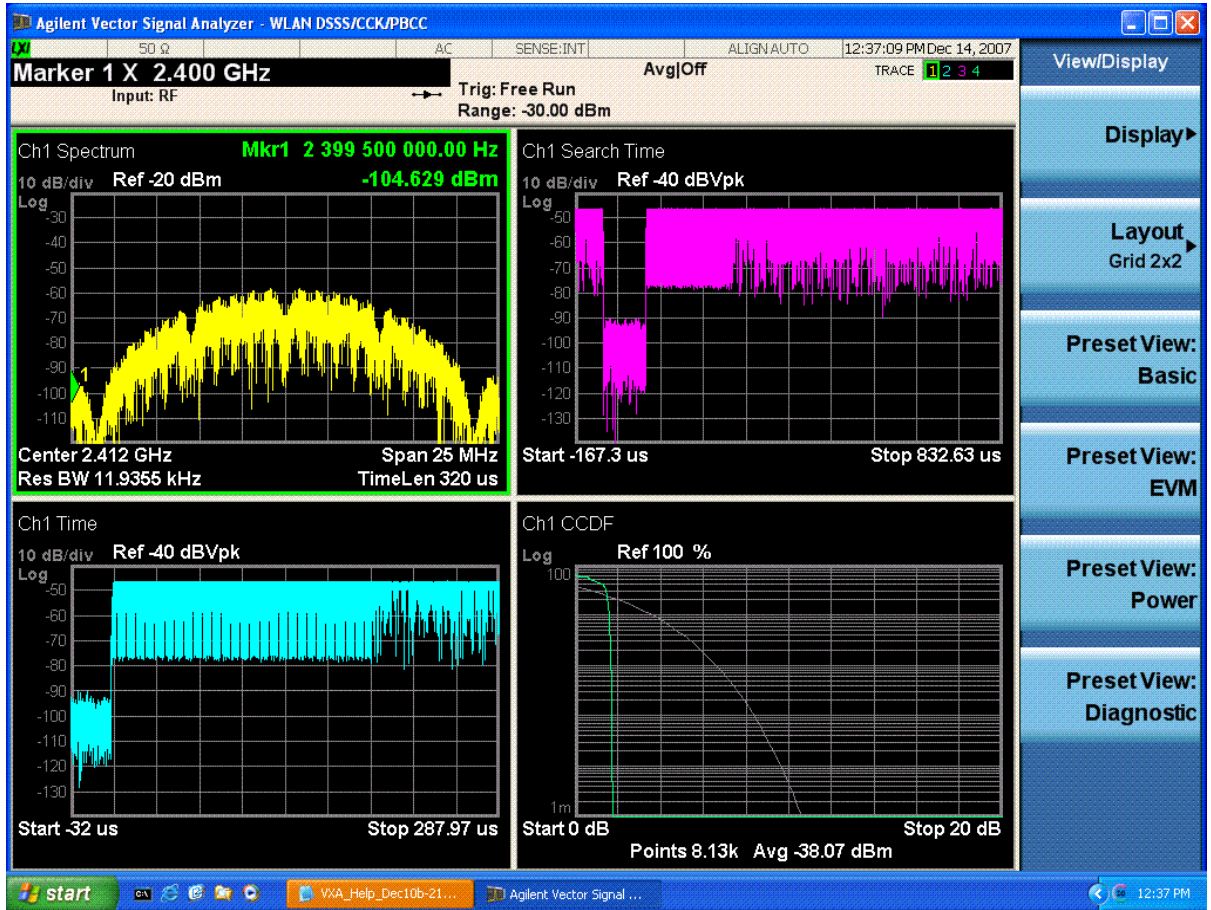


3	Display the Power Preset View.	a. Press View/Display, Preset View: Power.	Graph shows Spectrum in Log Mag (dB) format, Time in Log Mag (dB) format, Search Time in Log Mag (dB) format, and CCDF in Log Mag (Linear Unit) format. See the following figure.
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Making 802.11 a/b/g WLAN Measurements
 Making Option 3FP WLAN DSSS Measurements

Step Action Notes

4



5 Display the Diagnostic Preset View.

a. Press **View/Display, Preset View: Diagnostic.**

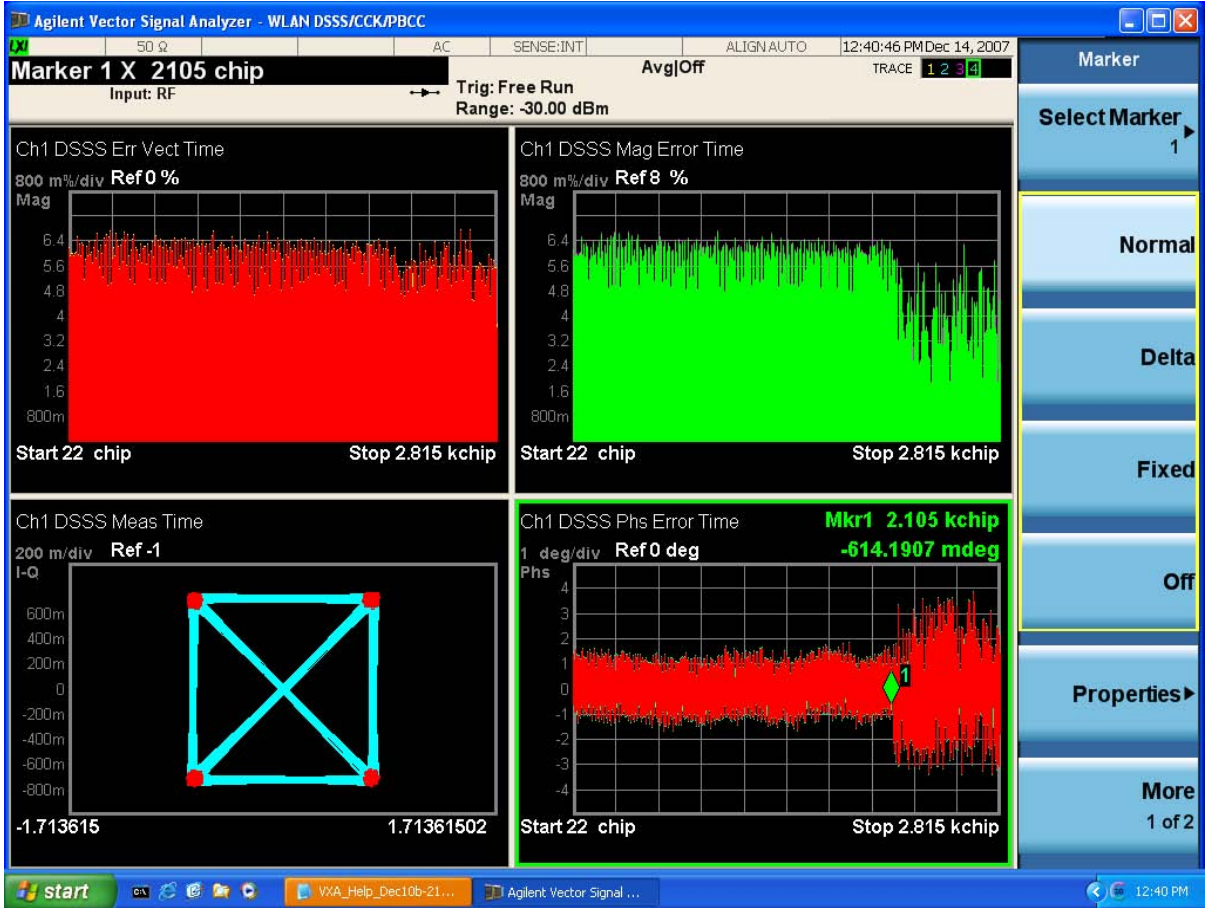
Graph shows Error Vector Spectrum in Linear Mag format, Ch Frequency Response in Log Mag (dB) format, Error Vector Time in Linear Mag format, Common Pilot Error in Wrap Phase format. See the following graph.

Step

Action

Notes

6



7 Automatically optimize the displayed Y Scale results. a. Press **Amptd/Y Scale, Auto Scale**. Depending on the measurement results you may need to rescale the measurement results.

8 Put a Peak Marker in trace 4. a. Press **Marker, Select Marker, 4, then Peak Search**. If you have a problem, and get an error message, see [“Interpreting Error Codes”](#) on page 131, or [“Troubleshooting WLAN-DSSS/CCK/PBCC Measurements”](#) on page 128.

Troubleshooting WLAN-DSSS/CCK/PBCC Measurements

This section contains information to help you troubleshoot measurements when using WLAN-DSSS/CCK/PBCC Demodulation. You should also review Setting up an WLAN-DSSS/CCK/PBCC Demodulation Measurement for additional measurement information.

PROBLEM	POSSIBLE CAUSE	SOLUTIONS
Demodulation fails to lock on signal	Signal not present.	Check Connections.
SYNC NOT FOUND error message	Carrier too far from center frequency	Adjust center frequency. The analyzer center frequency must be within 2.5 MHz to lock-on. For good EVM measurements, set the center frequency to within 550 kHz.
	Input is over-loaded or under ranged.	Adjust input range. Typically, the best EVM is achieved when the range is as small as possible while avoiding overloads.
	Frequency span is too narrow.	Increase frequency span. A frequency span of at least 19.8 MHz is typically required for 802.11b/g DSSS signals.
	Signal has inverted frequency spectrum	Check the Mirror Frequency Spectrum setting (MeasSetup > Demod Properties > Advanced tab).
	Signal has incorrect PLCP Header at start of burst	Override the auto detection of modulation type and result length (MeasSetup > Demod Properties > Format tab and Time tab).
	Wrong modulation format	Select correct modulation format
	Input signal scrambler disabled	Disable the analyzer's descrambler (MeasSetup->Demod Properties->Advanced tab).
	Maximum result length shorter than preamble length	Increase maximum result length (MeasSetup->Demod Properties->Time tab).
Analyzer locks, but data bits incorrect	Signal is a WLAN-OFDM modulated signal	Switch the analyzer to WLAN-OFDM mode.
	Signal has inverted frequency spectrum	Check the Mirror Frequency Spectrum setting (MeasSetup > Demod Properties > Advanced tab). Note that the burst Preamble and Header are usually BPSK modulated, so would be unaffected by an inverted frequency spectrum. But the data portion of the burst is generally QPSK modulated and the detected data bits will be incorrect if the frequency spectrum is inverted.

PROBLEM	POSSIBLE CAUSE	SOLUTIONS
PULSE NOT FOUND error message	Search length too short.	Increase search length, or adjust triggering to ensure that the leading and trailing edges of a pulse are fully within the search length.
	Signal is not pulsed.	WLAN-DSSS/CCK/PBCC is pulsed signals. If the signal is not pulsed, try to use triggering to position the preamble just after the beginning of the search length. In this case, PULSE NOT FOUND will still be displayed, but demodulation may be successful anyway.
	Search length not optimized	Try the following method to determine Search Length when performing a Pulse Search: $SL = (2 * MaxOn) + MaxOff$ Where: SL is search length in seconds. MaxOn is the maximum on time of a pulse in seconds. MaxOff is the maximum off time between pulses in seconds.
EVM larger than expected	I/Q misaligned using I+jQ receiver.	The "Error Vector Spectrum" trace will shows as a "V" shape. Click Utilities > Calibration > Amplitude tab > Calibration Constants check box and adjust the delays for each input channel.
	I/Q gain imbalance using I+jQ receiver.	1) Check that impedance is identical for both input channels. 2) Click Utilities > Calibration > Amplitude tab > Calibration Constants check box and adjust the gains for each input channel.
	89611 with ESA H70 hardware needs adjusting.	Reduce the span to eliminate excess noise and interfering signals.
EVM good at beginning of burst, then gets very large near the end of the burst	Signal has incorrect Length segment of PLCP Header at start of burst	Override the auto detection of result length (MeasSetup > Demod Properties > Time tab).
The trace data constellation symbol location shape, such as dots, is not properly displayed.	The display driver is not functioning correctly.	Contact your PC manufacturer to see if a newer version of the display driver is available. If not, try decreasing the hardware acceleration by clicking (XP Instructions) Start, Control Panel, Display, Settings, Advanced, Troubleshoot, decrease the hardware acceleration value, OK, OK.

Tips When Using Digital Demodulation

- I/Q Reference or FSK Reference: the analyzer does not need an ideal signal to generate the reference signal. The analyzer uses your signal to internally generate the ideal, reference signal.
- Carrier Lock and Detection: the analyzer does not need a sync word to perform carrier locking or detection. See also the next paragraph on “Center Frequency.”
- Center Frequency: the analyzer's center frequency must be close to the transmitted carrier frequency to achieve carrier lock. The required proximity of the center frequency to the carrier frequency varies depending on the signal type, symbol rate, and system noise. If symbol locking appears poor, you may achieve better carrier locking by observing the “Freq Err” value in the symbol table (for QAM, PSK, and MSK formats) of any successfully locked measurement and add that amount to the center frequency. As a general rule, the carrier-frequency-to-center-frequency error should be within 3% of the symbol rate.
- Symbol Clock: the analyzer does not need an external symbol clock; the analyzer internally generates the symbol clock.
- Maximum Symbol Rate: The maximum symbol rate depends on the alpha of your system and on the span (information bandwidth). See the [symbol rate] softkey for details.
- Span: The minimum span (information bandwidth) depends on the alpha of your system and on the symbol rate. The maximum span is limited by the symbol rate. See the [span] softkey for details.
- Time Gating: time gating is not available for digital demodulation.
- Averaging: averaging is not available for any WLAN OFDM or DSSS Demod trace data, but may be applied to numeric error data in the error summary table by turning on averaging. Three types of averaging are available: rms (video), which computes an rms average of each rms error update in the error summary table; rms exponential, which is like rms (video) except that averaging continues past the average count with an exponential weight; and continuous peak hold, which keeps track of the peak rms error of each update in the error summary table.
- Accuracy: To meet specifications, your signal and its modulation must be fully contained in the selected measurement span.



4 Interpreting Error Codes

During the execution of your measurement you may encounter problems which generate error codes. Referring to the following common errors may be helpful.

If **Err** is shown in the annunciator bar, press the **System, Show, Errors** hard and soft keys to read the detailed error information.

- **Error Code 145 “Under Range”**

If the input signal level is too low to make a valid measurement, this error may appear. If you cannot increase the power into the tester, you need to increase the input sensitivity by adjusting the ADC range.

Press **Meas Setup, More (1 of 3), More (2 of 3), Advanced, ADC Range**, and then **Manual** keys. Increase the setting from None (default) to 6 dB, for example. Another option is to use the **Auto** setting (the **Auto** setting is not used as the default to improve measurement speed).

Press **Restart** to make another measurement and observe the results. Re-adjust the ADC as necessary to obtain a valid measurement.

- **Error Code 217 “Burst Not Found”**

This error indicates the burst signal cannot be detected because of inappropriate parameter settings or an incorrect signal.

For CDMA signals this error means that the tester has failed to find any active channels in the input signal as specified. To improve the correlation some critical parameters need to be adjusted, for example, the input signal level or scramble code.

- **Error Code 219 “Signal too noisy”**

This error means that your input signal is too noisy to capture the correct I/Q components. To make a more stable measurement the trigger source may need to be set to **Frame**, for example.

- **Error Code 413 “ADC Input overload”**

This warning means that your measurement has erroneous results due to the excessive input power level. To correct this condition, the input signal level must be reduced by using the internal and/or external attenuator.

Press the **Mode Setup, Input, Input Atten** keys to enter an attenuation value to reduce the transmitted power from the MS. This allowable range is up to 40 dB.

If you want to attenuate more than 40 dB, connect your external attenuator between the **RF INPUT** port and the DUT. Be sure to add its attenuation value to the readings of the measurement result.

To automate this calculation, press the **Mode Setup, Input, Ext Atten** keys to enter the additional attenuation value. The allowable range is up to 100 dB. The power readings of the measurement take into account the external attenuation value.

For more details consult the chapter in this book dedicated to the measurement in question, or see the “Instrument Messages” manual.



5 Concepts

This chapter describes the concepts and theory of basic analog and digital modulation, cellular modulation, and emerging communications formats. Modulation formats that can be demodulated by the N9064A are shown, and how measurements are performed by the instrument. A list of related Agilent documents is provided for further reference.

Introduction

This chapter provides a variety of digital modulation concepts to help you to better understand the features and measurements performed by N9064A.

[“Introduction to Digital Modulation” on page 148](#), explains the difference between analog and digital modulation. The advantages of digital modulation are given as well as the methods by which a digital baseband signal is modulated onto an RF carrier. The following three sections will build on this introduction to digital modulation.

[“Digital Modulation Format Standards” on page 162](#), contains a general description of the modulation format families. These are, phase shift keying (PSK), frequency shift keying (FSK), minimum shift keying (MSK) and quadrature amplitude modulation (QAM). Within each family, examples of typical I/Q patterns, Spectral diagrams and default values are given for the individual formats. Bit state diagrams for FSK, PSK, QAM and DVB QAM are provided at the end of this section.

[“Communication System Formats” on page 193](#) covers the predefined communication systems. These are, GSM, EDGE, W-CDMA, cdma2000, Bluetooth, NADC, PDC, PHS, IS-95, TETRA, APC025 phase1, VDL Mode 3, and ZigBee 2450 MHz. A general description of each communication system is given together with examples of typical I/Q patterns, Spectral diagrams and default values.

[“Measurements of Digital RF Communications Signals” on page 224](#), describes how the N9064A VXA analyzes digital modulation sources. After reviewing digital modulation fundamentals, typical sources of modulation errors are presented. This section ends with a description of measurement displays and what to look for in determining the quality of a digital modulation measurement.

[“References” on page 253](#) are given along with a list of related Agilent documents for further reading.

Analog Modulation Concepts

Modulation Methods

Modulation is the act of translating some low-frequency or baseband signal (voice, music, and data) to a higher frequency. Why do we modulate signals? There are at least two reasons: to enable the simultaneous transmission of two or more baseband signals by translating them to different frequencies, and to take advantage of the greater efficiency and smaller size of higher-frequency antennae.

In the modulation process, some characteristic of a high-frequency sinusoidal carrier is changed in direct proportion to the instantaneous amplitude of the baseband signal. The carrier itself can be described by the equation:

Equation 5-1

$$e = A \cos((\omega t) + \phi)$$

where:

A = peak amplitude of the carrier,

ω = angular frequency of the carrier in radians per second,

t = time, and

ϕ = initial phase of the carrier at time t = 0.

In the expression above, there are two properties of the carrier that can be changed, the amplitude (A) and the angular position (argument of the cosine function). Thus we have amplitude modulation and angle modulation. Angle modulation can be further characterized as either frequency modulation or phase modulation.

Amplitude Modulation

Modulation degree and sideband amplitude

Amplitude modulation of a sine or cosine carrier results in a variation of the carrier amplitude that is proportional to the amplitude of the modulating signal. In the time domain (amplitude versus time), the amplitude modulation of one sinusoidal carrier by another sinusoid resembles [Figure 5-2 on page 136](#). The mathematical expression for this complex wave shows that it is the sum of three sinusoids of different frequencies. One of these sinusoids has the same frequency and amplitude as the unmodulated carrier. The second sinusoid is at a frequency equal to the sum of the carrier frequency and the modulation frequency; this component is the upper sideband.

The third sinusoid is at a frequency equal to the carrier frequency minus the modulation frequency; this component is the lower sideband. The two sideband components have equal amplitudes, which are proportional to the amplitude of the modulating signal. [Figure 5-1 on page 136](#) shows the carrier and sideband components of the amplitude-modulated wave of [Figure 5-2 on page 136](#) as they appear in the frequency domain (amplitude versus frequency).

Concepts
Analog Modulation Concepts

Figure 5-1 Frequency Domain Display

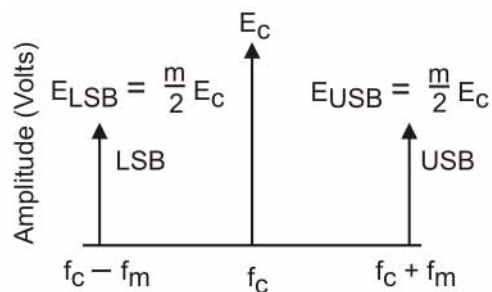
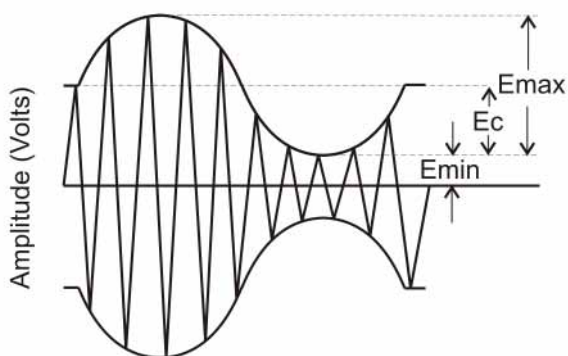


Figure 5-2 Time Domain Display



A measure of the degree of modulation is m , the modulation index. This is usually expressed as a percentage called the percent modulation. In the time domain, the degree of modulation for sinusoidal modulation is calculated as follows, using the variables shown in the figure above:

Equation 5-2
$$m = \frac{E_{max} - E_C}{E_C}$$

Since the modulation is symmetrical,

Equation 5-3
$$E_{max} - E_C = E_C - E_{min}$$

and

Equation 5-4
$$\frac{E_{max} + E_{min}}{2} = E_C$$

From this, it is easy to show that:

Equation 5-5
$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$

for sinusoidal modulation. When all three components of the modulated signal are in phase, they add together linearly and form the maximum signal amplitude E_{max} , shown in [Figure 5-2 on page 136](#).

Equation 5-6
$$E_{max} = E_c + E_{USB} + E_{LSB}$$

Equation 5-7
$$m = \frac{E_{max} - E_c}{E_c} = \frac{E_{USB} + E_{LSB}}{E_c}$$

And, since

Equation 5-8
$$E_{USB} = E_{LSB} = E_{SB}$$

Then:

Equation 5-9
$$m = \frac{2(E_{SB})}{E_c}$$

For 100% modulation ($m = 1.0$), the amplitude of each sideband will be one-half of the carrier amplitude (voltage). Thus, each sideband will be 6 dB less than the carrier, or one-fourth the power of the carrier. Since the carrier component does not change with amplitude modulation, the total power in the 100% modulated wave is 50% higher than in the unmodulated carrier.

Although it is easy to calculate the modulation percentage M from a linear presentation in the frequency or time domain ($M = m \cdot 100\%$), the logarithmic display on a spectrum analyzer offers some advantages, especially at low modulation percentages. The wide dynamic range of a spectrum analyzer (over 70 dB) enables measurement of modulation percentage less than 0.06%. This can easily be seen in the following figure, where $M = 2\%$; that is, where the sideband amplitudes are only 1% of the carrier amplitude. The following figure shows a time domain display of an amplitude-modulated carrier with $M = 2\%$. It is difficult to measure M on this display. [Figure 5-4 on page 138](#) shows the signal displayed logarithmically in the frequency domain. The sideband amplitudes can easily be measured in dB below the carrier and then converted into M . (The vertical scale is 10 dB per division.)

Concepts
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Figure 5-3 Time Domain View of 2% Amplitude Modulation

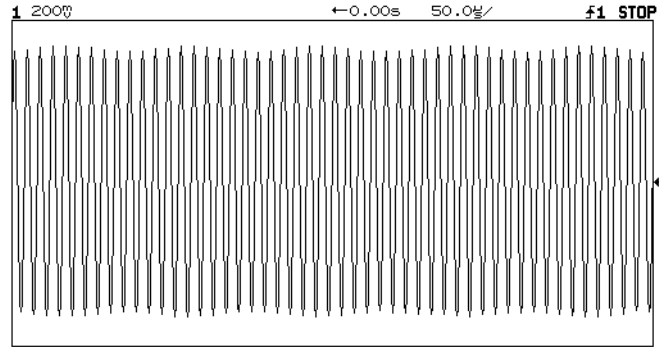


Figure 5-4 Frequency Domain View of 2% Amplitude Modulation

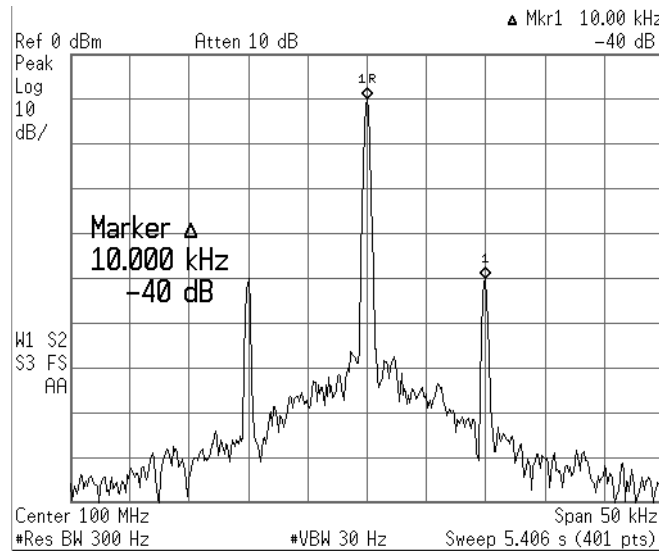
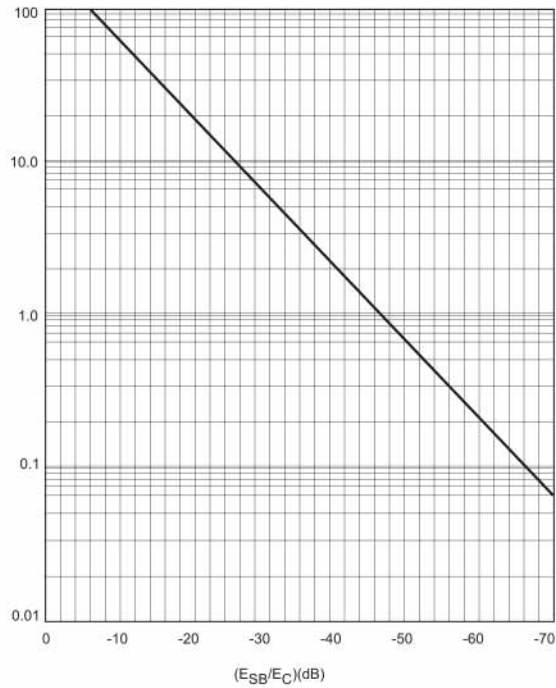


Figure 5-5 Modulation percentage M vs. Sideband Level (log display)



The relationship between m and the logarithmic display can be expressed as:

Equation 5-10
$$(E_{SB}/E_C)(dB) = 20\log\left(\frac{m}{2}\right)$$

or

Equation 5-11
$$(E_{SB}/E_C)(dB) + 6dB(20)\log m$$

The figure above shows modulation percentage M as a function of the difference in dB between a carrier and either sideband.

The following two figures show typical displays of a carrier modulated by a sine wave at different modulation levels in the time and frequency domains.

Figure 5-6 AM Carrier in the Time Domain

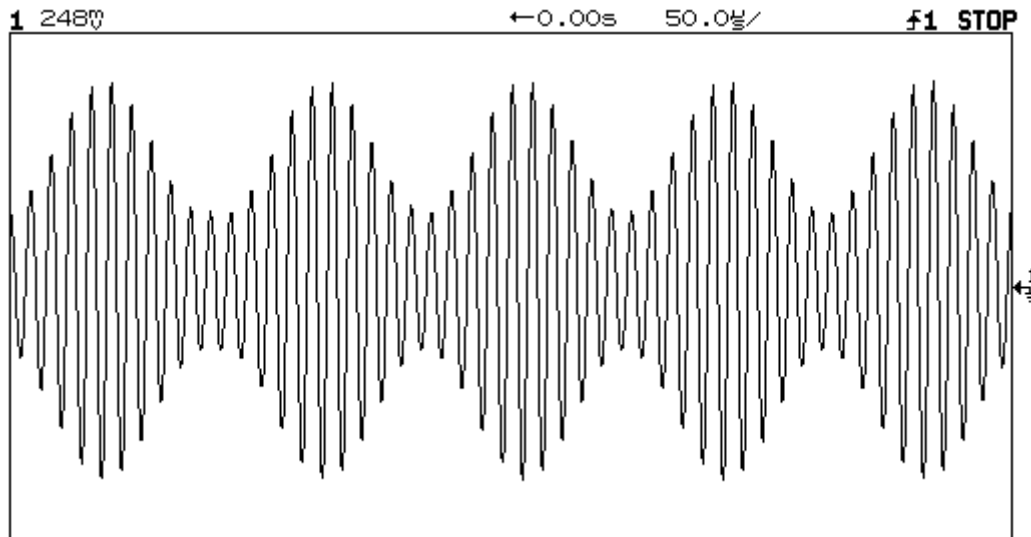


Figure 5-7 AM Carrier in the Frequency Domain

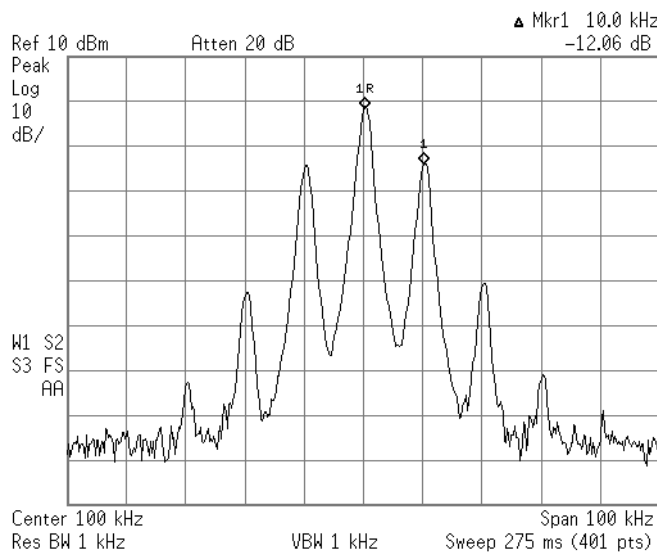
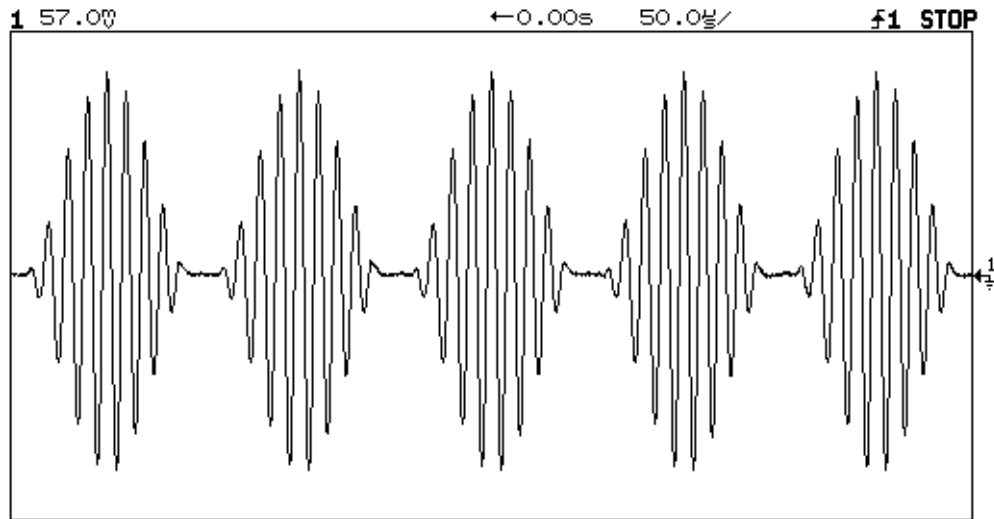


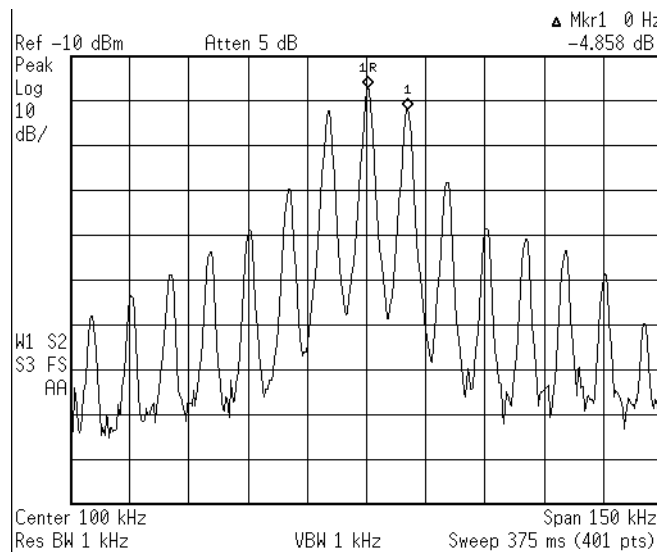
Figure 5-6 on page 140 shows an amplitude-modulated carrier in the time domain. The minimum peak-to-peak value is one third the maximum peak-to-peak value, so $m = 0.5$ and $M = 50\%$. The figure above shows the same waveform measured in the frequency domain. Since the carrier and sidebands differ by 12 dB, $M = 50\%$. You can also measure 2nd and 3rd harmonic distortion on this waveform. Second harmonic sidebands at $f_c \pm 2f_m$ are 40 dB below the carrier. However, distortion is measured relative to the primary sidebands, so the 28 dB difference between the primary and 2nd harmonic sidebands represents 4% distortion.

Figure 5-8 Overmodulated Signal in the Time Domain



The figure above shows an overmodulated ($M > 100\%$) signal in the time domain; $f_m = 10$ kHz. The carrier is cut off at the modulation minima. The figure below is the frequency domain display of the signal. Note that the first sideband pair is less than 6 dB lower than the carrier. Also, the occupied bandwidth is much greater because the modulated signal is severely distorted; that is, the envelope of the modulated signal no longer represents the modulating signal, a pure sine wave (150 kHz span, 10 dB/Div, RBW 1 kHz).

Figure 5-9 Overmodulated Signal in the Frequency Domain



Frequency Modulation and Phase Modulation

Previously we described a carrier with the equation:

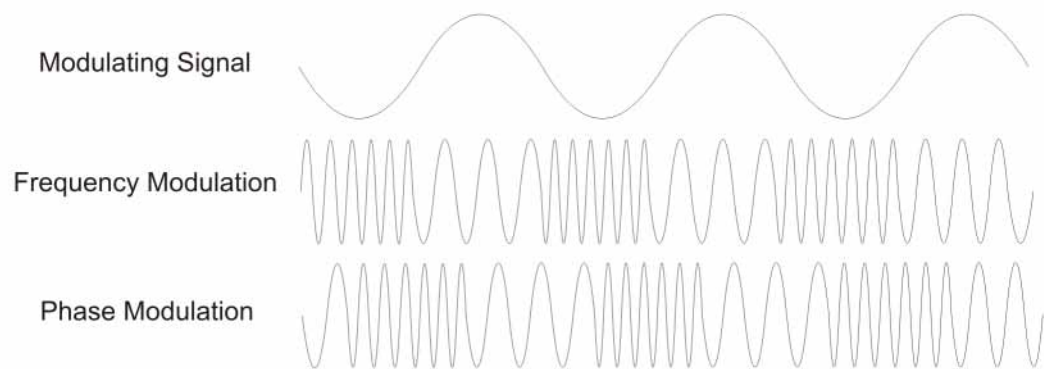
Equation 5-12

$$e = A \cos((\omega t) \div \phi)$$

additionally, we stated that angle modulation can be characterized as either frequency or phase modulation. In either case, we think of a constant carrier plus or minus some incremental change. This change can be implemented as Frequency Modulation or Phase Modulation.

Frequency modulation (FM) conveys information over a carrier wave by varying its frequency. (Unlike amplitude modulation, where the amplitude of the carrier varies while its frequency remains constant). In frequency modulation, the instantaneous frequency deviation of the modulated carrier with respect to the frequency of the unmodulated carrier is directly proportional to the instantaneous amplitude of the modulating signal. This is illustrated in the following figure.

Figure 5-10 Angle Modulation



In phase modulation the instantaneous phase deviation of the modulated carrier with respect to the phase of the unmodulated carrier is directly proportional to the instantaneous amplitude of the modulating signal. This is also illustrated in the previous figure.

For angle modulation, there is no specific limit to the degree of modulation; there is no equivalent of 100% in AM. Modulation index is expressed as:

Equation 5-13

$$\beta = \Delta f_p / f_m = \Delta \phi_p$$

Where:

b = modulation index

Dfp = peak frequency deviation

fm = frequency of the modulating signal

Dfp = peak phase deviation in radians

Equation 6-11 shows that the angle modulation index is really a function of phase deviation, even in the FM case (Dfp/fm = Dfp).Also, note that the definitions for frequency and phase modulation do not include the modulating frequency. In each

case, the modulated property of the carrier, frequency or phase, deviates in proportion to the instantaneous amplitude of the modulating signal, regardless of the rate at which the amplitude changes. However, the frequency of the modulating signal is important in FM and is included in the expression for the modulating index because it is the ratio of peak frequency deviation to modulation frequency that equates to peak phase.

Comparing the basic equation with the two definitions of modulation, we find:

- A carrier sine wave modulated with a single sine wave of constant frequency and amplitude will have the same resultant signal properties (that is, the same spectral display) for frequency and phase modulation. A distinction in this case can be made only by direct comparison of the signal with the modulating wave, as shown in [Figure 5-10 on page 142](#).
- Phase modulation can generally be converted into frequency modulation by choosing the frequency response of the modulator so that its output voltage will be proportional to $1/f_m$ (integration of the modulating signal). The reverse is also true if the modulator output voltage is proportional to f_m (differentiation of the modulating signal).

We can see that the amplitude of the modulated signal always remains constant, regardless of modulation frequency and amplitude. The modulating signal adds no power to the carrier in angle modulation as it does with amplitude modulation.

Mathematical treatment shows that, in contrast to amplitude modulation, angle modulation of a sine-wave carrier with a single sine wave yields an infinite number of sidebands spaced by the modulation frequency, f_m ; in other words, AM is a linear process whereas FM is a nonlinear process. For distortion-free detection of the modulating signal, all sidebands must be transmitted. The spectral components (including the carrier component) change their amplitudes when b is varied. The sum of these components always yields a composite signal with an average power that remains constant and equal to the average power of the unmodulated carrier wave.

Analog Demodulation

Analog Demodulation mode lets you characterize amplitude modulated, frequency modulated, and phase modulated signals in both the frequency domain and the time domain. The analyzer determines the amplitude, phase, or frequency deviation of the modulating signal relative to the carrier.

PM and FM demodulation let you select an automatic carrier-frequency estimation algorithm, [auto carrier]. For PM and FM demodulated traces, you can display the estimated carrier frequency using [demod carrier], under the [Marker Function] hardkey. Averaged measurements also average the estimated carrier frequency for FM, and estimated carrier amplitude for AM.

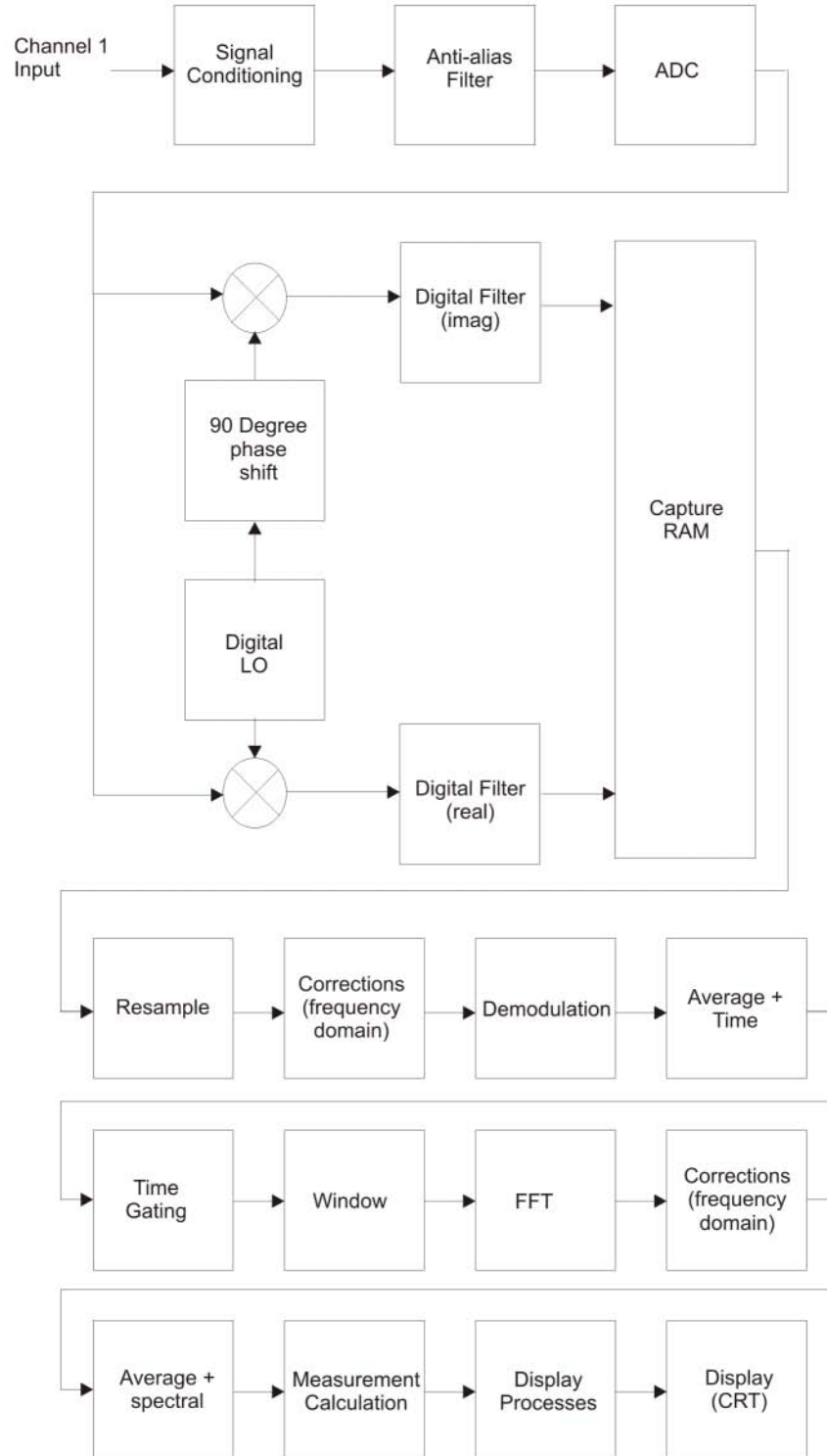
Modulated signals commonly consist of a high frequency carrier-signal modulated by lower frequency audio, video, or data signals. These may also be contaminated with unintentional sources of modulation.

Analog Demodulation recovers the baseband-modulating signal which is contained in the sidebands of the carrier signal.

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Analog Demodulation mode lets you turn demodulation on or off for any input channel or for time-capture data.

Figure 5-11 Analog Demodulation Block Diagram



Bandwidth Concepts for Analog Demodulation

Analog Demodulation produces a baseband result (the start frequency is 0 Hertz), at half the selected frequency span, as shown below.

Figure 5-12

Demodulation Bandwidth

$$\text{BW} = \text{Frequency Span} \rightarrow \boxed{\text{Demod}} \rightarrow \text{BW} = \frac{\text{Frequency Span}}{2}$$

NOTE

The demodulation block produces a start frequency of 0 Hertz.

The input bandwidth to the Analog Demodulation algorithm equals the frequency span. The output bandwidth of the Analog Demodulation algorithm is half the frequency span.

The output bandwidth is half the input bandwidth because Analog Demodulation operates only on double sideband signals. With double sideband signals, the information in one sideband is redundant.

Therefore, the Analog Demodulation algorithm produces a baseband result (start frequency of 0 Hz) to eliminate the need to show the lower sideband on a spectrum display. The result is that the Demodulation algorithm produces a visible span that is half the selected frequency span, and thus contains half as many frequency points.

Analog Demodulation and Time Corrections

Time corrections are automatically enabled when you select Analog Demodulation mode, and are automatically disabled when you return to Vector mode.

Time corrections correct for magnitude and phase errors in the analyzer's input circuitry. Time corrections compensate for these errors prior to the Analog Demodulation process. Left uncorrected, these errors introduce errors in the demodulated signal and also introduce cross modulation products such as PM- to-AM conversions.

Time corrections only correct for distortion over the selected frequency span, which is the bandwidth going into Analog Demodulation. Sidebands or other signals which fall outside of the frequency span, but have not been completely attenuated by the analyzer's digital filter, are subject to distortion and can create errors in the demodulation measurement. Frequencies between the ends of the frequency span $CF \pm (\text{Span}/2)$, and approximately $CF \pm (\text{Span} \times 1.50/2)$ should not contain any signals.

A larger factor, 1.50, is used than the usual 1.28--a factor of 1.28 is used for computing the guard band on spectrum displays. For time displays, 1.50 is used to assure alias protection from signals above $F_s/2$ folding into the guard band as a result of tossing every other point in the last step of decimation.

Spectrum displays avoid showing alias errors by not showing frequencies in the guard band. However, time results are globally affected by any signals with frequencies in the guard band, or frequencies above the guard band not yet fully attenuated by the digital filters aliasing back into the guard band. See the Operator's Guide for additional details.

Triggering Demodulated Measurements

Triggering either coherently with the demodulated waveform, or directly on the demodulated waveform in the case of IF triggering on the envelope, can provide stable waveforms for stationary signals, or synchronization to transient events.

One key benefit to triggering on the demodulated AM, PM, or FM signal is that very high dynamic range measurements can be achieved when using time averaging on stationary modulation signals -- in excess of 30 dB beyond non-triggered demodulation measurements when power-of-2 spans are used.

Triggering on a stationary demodulated signal enables use of time averaging, which is a true, time-domain average. While rms averaging shows the demodulated signal plus noise power, time averaging gradually averages to zero any time components not coherent with the demodulated signal, such as noise.

Time averaging requires that [auto carrier On] be selected. For PM, you can use [PM auto type Phase] or [PM auto type Freq and Phase], but Freq and Phase is best.

Channel triggering is performed prior to digitizing the signal. Demodulation is performed after digitalization, preventing use of Channel triggering on the demodulated signal.

Thus, two options are available for triggering on the demodulated signal:

- IF Triggering provides a stable AM waveform for carriers that are AM modulated with a periodic signal. IF trigger is a digital envelope detection, and hence, can be set to trigger on the AM envelope. Triggering on a pulsed carrier is also possible with IF trigger. Many digital communication signals have a non-constant envelope characteristic. If your signal has envelope fluctuations, you must set the trigger level below the envelope fluctuations to prevent multiple triggers during a pulse.
- External Triggering can acquire stable AM, PM or FM demodulated waveforms for carriers that are modulated with a periodic signal. In this case, the modulating signal must be available, and connected to the external trigger (or to the second input channel, in which case, channel triggering can be used in the same manner as external triggering). If a trigger signal is available that is synchronous to a transient event on the carrier, connecting it to the external trigger will provide demodulation synchronization.

Additional Information

Here's some other things you may need to know when using Analog Demodulation:

- Your signal must be band limited (sidebands must be within the current frequency span).

- Signals within the analyzer's guard bands can interfere with demodulated measurements.
- Analog Demodulation requires a positive start frequency.
- Selecting Analog Demodulation automatically selects zoom mode. Analog Demodulation requires zoom mode to identify the carrier.
- When auto carrier is off, the analyzer's center frequency should be set as close to the carrier frequency as possible. In this case, the center frequency is the carrier frequency used by the Analog Demodulation algorithm. Placement for AM is not an issue, since carrier frequency is not involved in the AM calculation. However, the AM signal must still be contained completely within the displayed span.
- When auto carrier is on, placement of the center frequency with respect to the carrier is not critical. The center frequency is programmed into the digital LO, and represents the initial estimate of the carrier frequency.
- Analog Demodulation alters the time record, resulting in time-domain displays of amplitude versus time (AM), frequency versus time (FM), and phase versus time (PM).
- Analog Demodulation alters the time record, which is the basis for all other measured results. Therefore, all other measured results are computed using the demodulated waveform. For example, the spectrum is the spectrum of the modulating signal.
- When a demodulated measurement is paused, you cannot change the demodulation result. For example, if you pause an AM measurement, you cannot select PM. An invalid trace will result if you do. The measurement must be retaken with the new demodulation result for a valid trace to be generated.
- For additional details, see the analyzer's Operator's Guide and see online help for the [AM], [PM], [FM], and [Baseband] softkeys (under [demodulation setup]).

NOTE

Baseband is an option only for instruments configured with a second channel.

Introduction to Digital Modulation

Why Choose Digital Instead of Analog Modulation?

The RF spectrum must be shared, yet every day there are more users for that spectrum, as demand for communications services increases. Digital modulation schemes have significant advantages over analog modulation schemes.

These are:

- more information capacity
- higher security
- compatibility with digital data services
- better quality communications

What is Digital Modulation?

Digital modulation is a term used in radio, satellite, and terrestrial communications to refer to modulation in which digital states (1's and 0's) are represented by the relative phase and/or amplitude of a carrier. In digital modulation, it is the baseband modulating signal that is in digital form. The original signal may be analog, e.g. voice, so it is converted to a bit stream prior to the modulation process. The amplitude, frequency, or phase of the carrier is modulated in direct proportion to the amplitude of the modulating (baseband) signal, usually just two values, example 0 and 1.

The following figure shows the effect of a digital baseband modulating signal on an RF carrier using four methods of digital modulation. The digital baseband signal seen at the top as a 1010 bit pattern. The upper three waveforms show the effects of this baseband bit pattern modulating the amplitude, frequency and phase of the carrier waveform. These waveforms could also be easily achieved using standard analog modulation techniques.

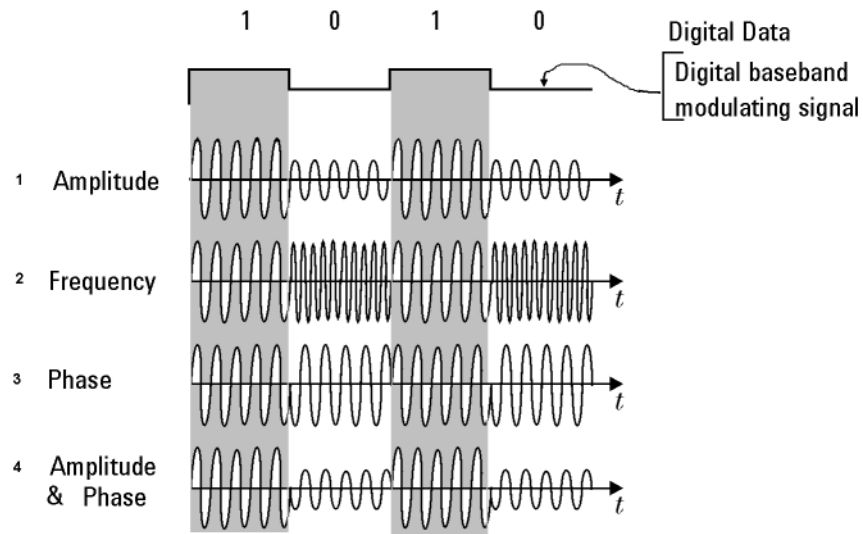
The fourth waveform shows the effects of this baseband bit pattern modulating the amplitude and phase of the carrier at the same time. In theory, by combining waveforms 1 and 3, this waveform could also have been created using analog modulation techniques. However, this type of waveform is difficult to generate, and especially difficult to detect using analog modulation.

In digital modulation, instead of using analog modulation techniques, a fundamentally different modulation technique is used. If a double balanced mixer is used, waveform 4 becomes easy to produce. This form of modulation is referred to as I/Q, Vector or complex modulation. For consistency, the term I/Q modulation will be used throughout this chapter.

In I/Q modulation the baseband modulating signal is separated into two components, an I and a Q component. The fourth waveform in the following figure is easy to generate and detect using the techniques of I/Q modulation. Using the I/Q modulator, the amplitude and the phase of the carrier can be modulated together or independently.

Figure 5-13

Modulation



In digital modulation, the information is contained in the relative phase and amplitude of the carrier signal.

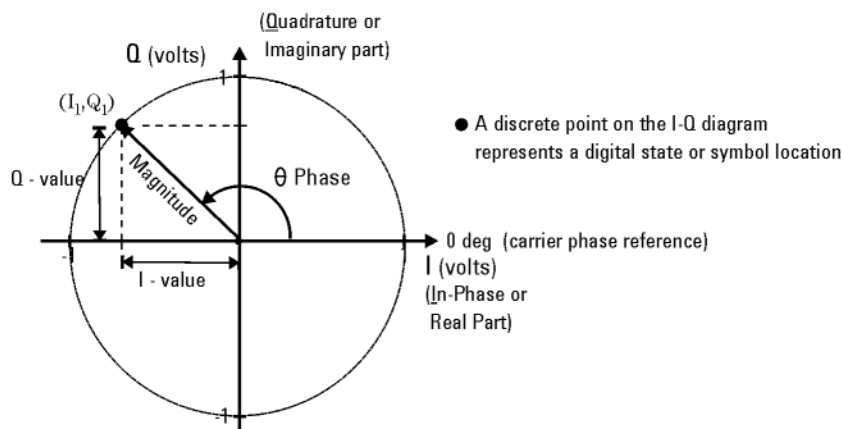
I/Q modulation can best be presented in the I/Q plane or I/Q diagram as shown in the following figure.

In most digital communication systems, the frequency of the carrier is fixed so only phase and magnitude need to be considered.¹ The unmodulated carrier is the phase and frequency reference, and the modulated signal is interpreted relative to the carrier. Notice in the following figure that the unmodulated carrier reference is 0° , along the I axis.

In the following table the phase and magnitude of the modulated carrier can be represented in rectangular or polar coordinates as a discrete point in the I/Q plane. In rectangular coordinates, "I" represents the in-phase (phase reference) component and "Q" represents the quadrature (90° out of phase) component. Using polar coordinates in this example, the phase angle is 135° and the amplitude is 1 as seen by the magnitude vector.

1. The carrier frequency of the GSM digital communication system does change, and GSM is in widespread use.

Figure 5-14 I/Q Plane or I/Q Diagram



Digital modulation refers to modulation in which digital states are represented by relative phase and amplitude of the carrier. The phase and magnitude can be represented in polar or rectangular coordinates as a discrete point in the I-Q plane.

Depending on the particular format or application, digital modulation may modify both amplitude and phase simultaneously. I/Q modulation is a very powerful scheme because it can be used to generate any arbitrary carrier phase and magnitude. Each value of magnitude and phase has a corresponding point in the I/Q plane.

The location of each point is of critical importance as it represents a digital code. Each discrete point is called a symbol as it symbolizes a unique digital code. The symbol points are not random; their exact position on the I/Q plane is specified by the modulation format being used. Fortunately, there are a limited number of digital modulation formats to become familiar with.

In any given digital modulation format, the signal moves between the symbols arriving at a symbol at the decision point on the symbol clock. Each communications format standard (application) uses a particular modulation format. There are four main modulation format categories. All four are variations of the common I/Q Modulation and will be explained in more detail later, "[Digital Modulation Format Standards](#)" on [page 162](#)

- In phase shift keying (PSK), the digital modulating signal changes the carrier at every baseband signal change. By simultaneously changing the carrier phase, symbols can be represented and transmitted. See "[Phase Shift Keying \(PSK\) Concepts](#)" on [page 164](#)
- In Frequency shift keying (FSK), the frequency of the carrier changes slightly for every symbol change. Different frequencies can be used to represent different symbols. See "[Frequency Shift Keying \(FSK\) Concepts](#)" on [page 170](#)
- Minimal shift keying (MSK) is a specific form of FSK. See "[Minimum Shift Keying \(MSK\) Concepts](#)" on [page 173](#)

- Quadrature amplitude modulation (QAM) combines amplitude and phase changes. Each quadrant of the I/Q plane can have several symbols allocated to it. Hence 16QAM, 32QAM etc. See “[Quadrature Amplitude Modulation \(QAM\) Concepts](#)” on page 175.

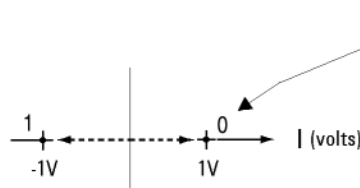
PSK examples

Binary phase shift keying (BPSK) is the most simple form of phase shift keying. The carrier amplitude and frequency remain constant while the phase of the carrier is switched 180 degrees or not depending on the symbol being transmitted.

Figure 5-15

BPSK example

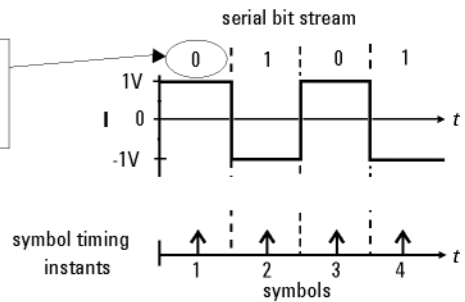
Constellation Diagram



In binary phase shift keying (BPSK) there are two symbols, 0 and 1. Both are on the I axes. There is no Q axes component.

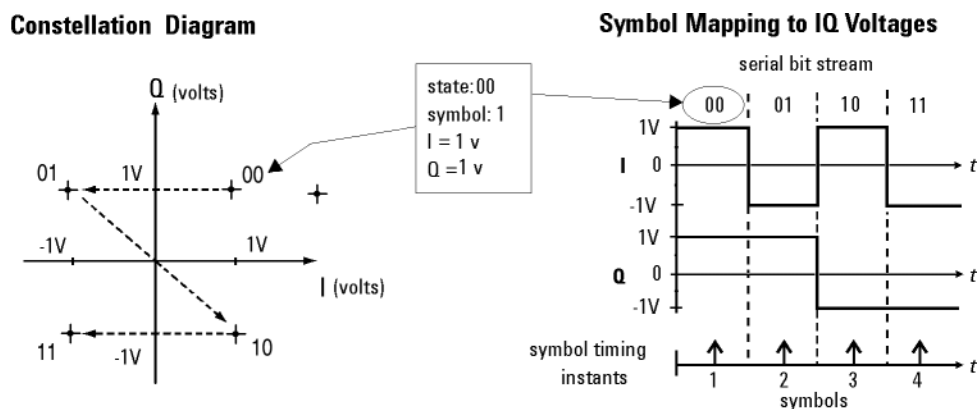
state: 0
symbol: 1
I = 1 v

Symbol Mapping to I Voltages



The next example shows another member of the PSK format, quadrature phase shift keying (QPSK). The following figure shows four symbol states are shown, 00, 01, 10 and 11. There is one symbol in each quadrant. The symbol state shown previously in [Figure 5-14 on page 150](#) would be in the top left quadrant, the 01 symbol in the following figure. All symbols are of equal importance, no individual symbol is more important than any other symbol. The I/Q voltages drive movement around the constellation diagram.

Figure 5-16 Example 1, constellation diagrams and symbols



Each position or state in the constellation diagram represents a specific bit pattern (symbol) and symbol time.

Also, from the QPSK constellation diagram in the figure above, there is a symbol path from any symbol to any of the other three symbols on the I/Q plane. Notice in the constellation diagram there is a probability of one chance in four that the signal trajectory will go through the origin. See [“Effects Of Going Through The Origin” on page 156](#).

NOTE

In this example the voltage ranges of both I and Q axes are plus to minus one volt. These values will vary with individual systems and formats. The origin is at 0 volts for both axes.

QPSK is a four-symbol system, each symbol representing two data bits.

Orthogonality

The baseband digital information is separated into two independent components: the I (in-phase) and Q (quadrature) components.

The most important characteristic of I and Q components is that they are independent components (orthogonal). Orthogonality means at right angles. The Q signal has no I component in it so that any variation in the I signal has no effect on the Q signal and vice versa.

QAM example

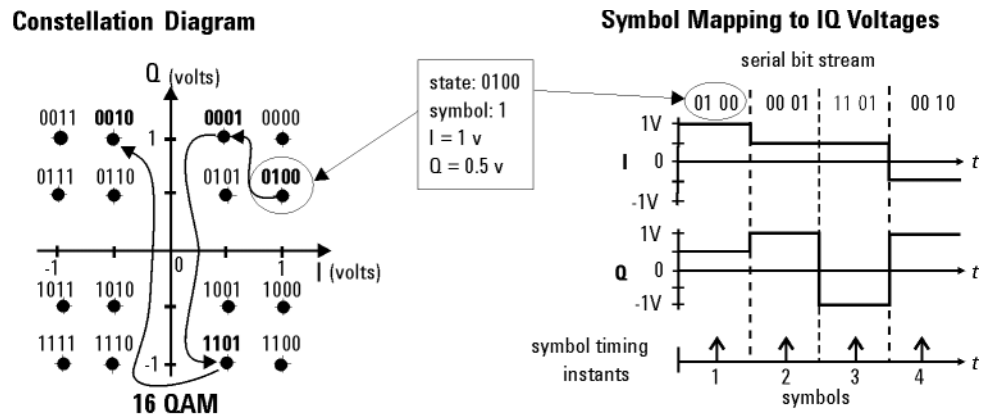
The example in the following figure is a member of the QAM family, 16 QAM. The QPSK example had one symbol per quadrant. In this example, 16 QAM there are four symbols per quadrant, making a total of sixteen possible symbols. The symbol state shown earlier in [Figure 5-14 on page 150](#) would again be in the top left quadrant in the following figure. In this 16 QAM format scheme, it would be the symbol that represents 0011.

The constellation diagram in the following figure shows the path of a four symbol serial bit stream, 0100, 0001, 1101, 0010. The symbol-mapping graphic in the following figure shows the I/Q voltages and timing used to create the four symbols.

Notice that the four symbols per quadrant have been achieved by having four levels of I/Q voltage, +1, +1/2, -1/2 and -1volts. The QAM format can be expanded to 64 symbols per quadrant or more. It is important to understand that, for given I/Q voltages, the more symbols per quadrant, the smaller the changes in I/Q voltage have to be to generate individual symbols.

Figure 5-17

Constellation Diagrams and Symbols



Each position or state in the constellation diagram represents a specific bit pattern (symbol) and symbol time.

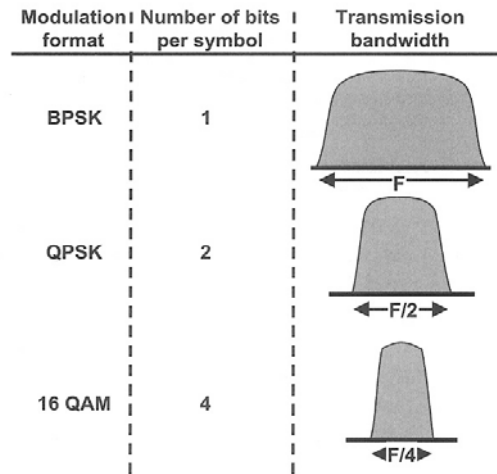
Symbol Rate

The rate at which the carrier moves between points in the constellation is called the symbol rate. The more constellation states that are used, the lower the required symbol rate for a given bit rate. The symbol rate is important because it sets the bandwidth required to transmit the signal.

Bandwidth

The lower the symbol rate, the lower the bandwidth required for transmission. For example, the 16QAM shown in the following figure uses 4 bits/symbol. If the radio transmission rate is 16 Mbps, then the symbol rate = 16 (Mbps) / 4 bits or 4 MHz. This provides a symbol rate that is one-fourth the bit rate and a more spectrally efficient transmission bandwidth (4 MHz vs. 16 MHz). The BPSK modulation format shown in the following figure uses 1 bit per symbol and a transmission bandwidth of 16 MHz.

Figure 5-18



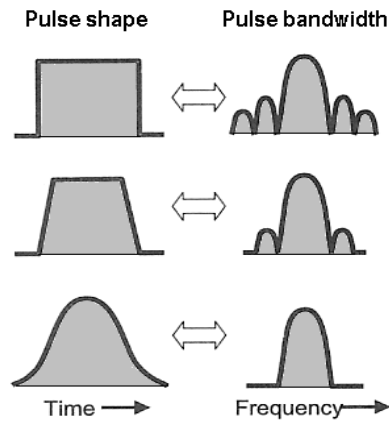
Filtering

Figure 5-13 on page 149 shows rapid changes in the carrier due to the rapid transitions in the modulating bit stream. The result is a spectrum essentially the same as that produced by a pulsed carrier which theoretically is infinitely wide. Too wide a spectrum (bandwidth) cannot be tolerated because of interference with adjacent carriers. To prevent this, filtering is introduced.

Well designed filtering enables the transmitted bandwidth to be significantly reduced, without losing the content of the digital data. This improves the spectral efficiency of the signal.

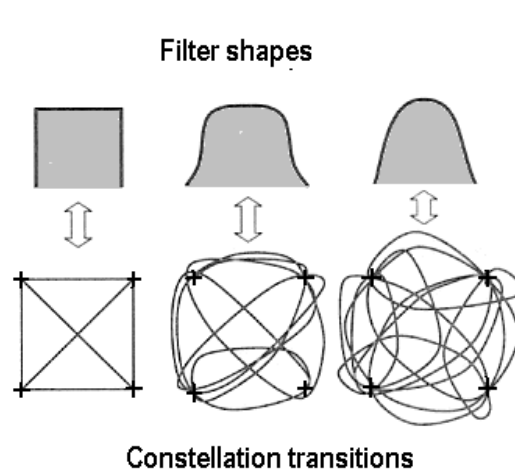
The following figure shows the bandwidth required to successfully reproduce three pulse shapes. The top example is a square pulse that has very fast edges creating the square shape. These fast edges require the presence of high frequencies in order to happen. This can be seen in the pulse bandwidth required to successfully reproduce the square pulse. Notice also, in the other two examples in the following figure that as the edges of the square pulse become slower, the pulse bandwidth required becomes smaller. A filter designed to pass the bandwidth of the bottom example in the following figure would allow the pulse shape corresponding to it. This pulse shape still contains all the information of the original square pulse shape. However, it is important to understand that in the bottom example the I/Q voltage is only at the symbol or decision point for a short time. As opposed to the top example where it is there longer.

Figure 5-19 The Relationship of Pulse Shape and Bandwidth



Again there are trade-offs; filtering reduces the bandwidth occupied for a digital pulse stream. Filtering also reduces interference because it reduces the tendency of one signal or one transmitter to interfere with another, such as in a Frequency-Division-Multiple-Access (FDMA) system. The effect of filtering can be seen on a QPSK signal in the following figure.

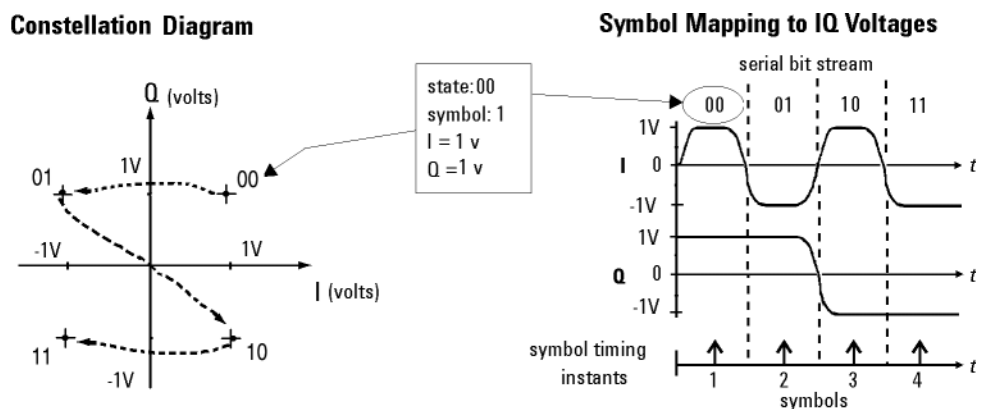
Figure 5-20 The relationship Between Filter Shape and I/Q Transitions



The following figure shows the effects of filtering on the same serial bit stream used in the QPSK example discussed earlier. Compare this to [Figure 5-16 on page 152](#); the serial bit stream transitions are now more rounded, taking longer to change from one state to another. Too much filtering can reduce modulation quality by preventing the signal from reaching the constellation point. See [“Modulation quality measurements” on page 232](#).

Figure 5-21

I/Q diagram with filtering applied



Each position or state in the constellation diagram represents a specific bit pattern (symbol) and symbol time.

On the receiver end, reduced bandwidth brought about by filtering improves sensitivity because more noise and interference are rejected.

There are several different varieties of filters used. The most common are

- Nyquist or raised cosine
- Square-root raised cosine
- Gaussian filters

Effects Of Going Through The Origin

The example shown in the previous figure has three symbol changes. Symbol changes 1 and 3 have only one I/Q bit change, either I or Q. However, in symbol change 2, both I and Q change and the signal trajectory passes through the origin. The origin represents 0V carrier magnitude (I/Q value of 0,0).

Why is it necessary to worry about the signal passing close to the amplifier origin? The problem lies in potential nonlinearities in the amplifier circuits. A signal, which changes amplitude over a very large range, will exercise these nonlinearities to the fullest extent. These nonlinearities will cause distortion products. In continuously modulated systems they will cause "spectral regrowth" or wider modulation sidebands (a phenomenon related to intermodulation distortion). For this reason, other modulation formats have been developed for applications where spectral regrowth is a problem. See ["Differential Modulation Concepts" on page 166](#).

Spectral regrowth does not automatically result from trajectories that pass through or near the origin. If the amplifier and associated circuits are perfectly linear, the spectrum (spectral occupancy or occupied bandwidth) will be unchanged.

Transmitting the Digital Signal

Each digital modulation format has advantages and disadvantages, making it more or less suitable for different communication applications. Applications include satellite, cellular communication, microwave digital radio and deep space telemetry.

Generally for digital modulation, an I/Q modulator is used to mix the digital baseband signal with the RF carrier¹. In the process of modulation - transmission - demodulation errors or impairments can be introduced to the baseband signal, (see “Interpreting Measurement results”)

Using an I/Q demodulator, demodulating the signal is straightforward in principle. The I/Q modulator will be examined next, to understand how the I/Q signals are combined with the RF carrier signal. It is these modulated RF signals that N9064A VXA has been developed to analyze. See “Measurements of Digital RF Communications Signals” on page 224.

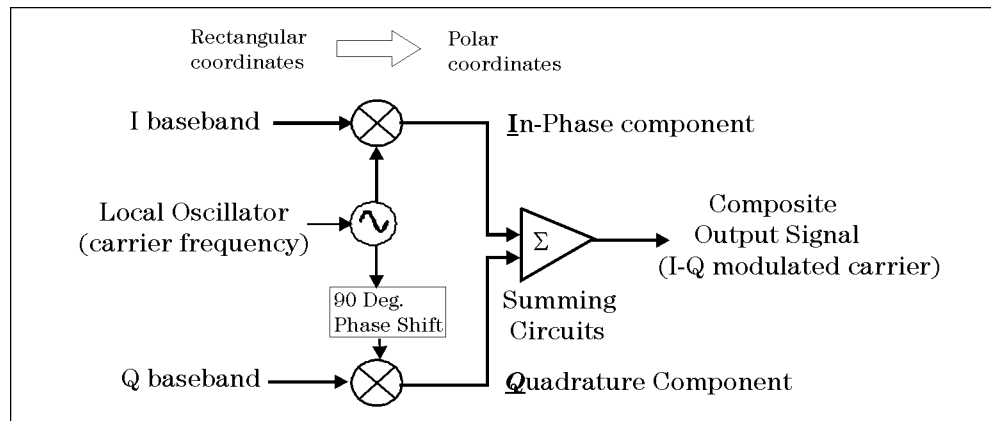
I/Q Modulator

The I/Q modulator is the device used in digital communications to generate I/Q modulation. The I/Q modulator puts the encoded digital I and Q baseband information onto the carrier (the following figure).

The two modulators shown in the following figure are double balance mixers (DBM). The DBM is in effect a continuously variable attenuator. With a DBM in both the I and Q channels, complete control is possible over the magnitude and phase of the combined output of the I/Q modulator.

Figure 5-22

I/Q Modulator



I-Q Modulator

The I/Q modulator receives the I and Q baseband signals as inputs and mixes them with the same local oscillator (LO), which is up converted to the RF carrier frequency. The I information amplitude modulates the carrier producing the In-phase component. The Q information amplitude modulates a 90-degree (orthogonal) phase shifted version of the carrier producing the Quadrature component. These two orthogonal modulated carrier signals are summed together producing the composite I/Q modulated carrier signal. Fundamentally this can be viewed as a hardware (or software) implementation of a rectangular to polar coordinate conversion.

1. BPSK does not have a Q component and GSM uses a different modulator.

The main advantage of I/Q modulation is the ease of combining independent signal components into a single composite signal and later splitting the composite signal into its independent component parts.

System Multiplexing

Analog systems have the limitation of one user per carrier frequency. This limits the number of users able to use any given band of frequencies. However, the number of users can be increased for this same band of frequencies by combining digital modulation with multiplexing.

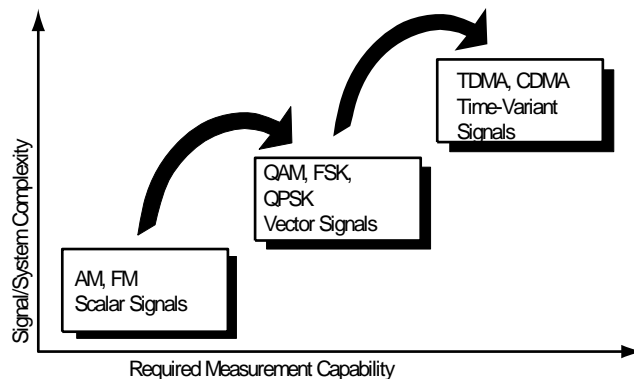
Two principal types of multiplexing (or “multiple access”) are TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access). These are two different ways to add diversity to signals allowing different signals to be separated from one another. The following figure shows how increased capacity can be achieved by multiplexing at the expense of increased complexity. The lowest diagram shows system capacity increasing from analog to digital to digital signal multiplexing. Several TDMA and CDMA systems will be discussed later.

As an example of multiplexing, consider yourself in a crowded room full of people talking to each other in groups. The fact that they are successfully talking shows that communication is possible. What makes it possible for them to communicate when each person’s voice and hearing frequency range is about the same? Individuals maybe “tuning in” their group’s voices because they are familiar, perhaps even speaking in a dialect or language that is closer to their own. The differences in pitch between group members also make it easier to listen. Or a person may use a pause in the general noise level of the room before conversing. Each of these techniques is used in digital signal multiplexing:

- Waiting for quiet time would be analogous to time division multiple access (TDMA).
- Language or dialect differences would be analogous to code division multiple access (CDMA).
- Pitch differences would be analogous to frequency division multiplexing (FDM).

Figure 5-23

The path from analog to digital signal multiplexing

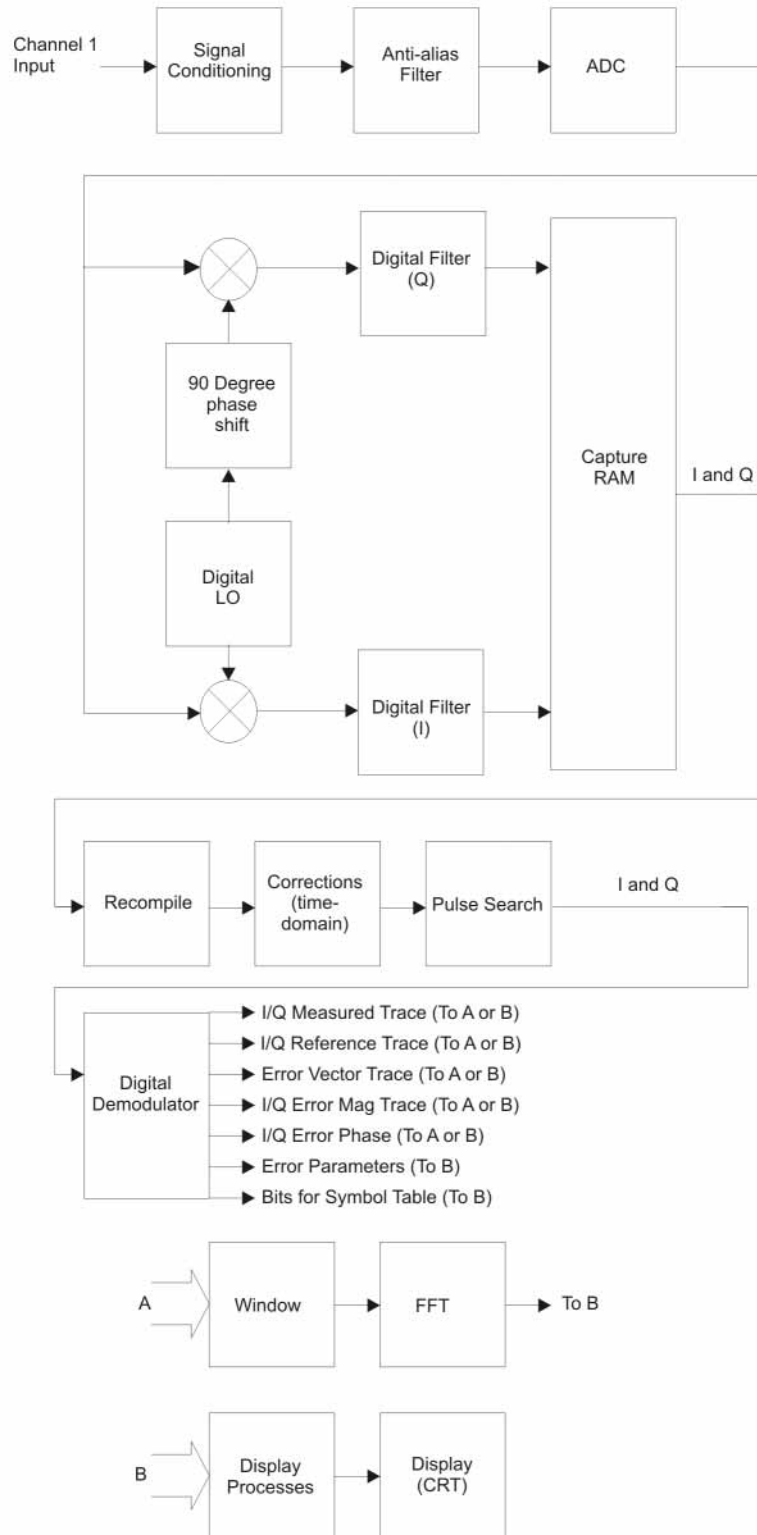


The next three sections will cover practical digital modulation formats, applications and measurement concepts.

Digital Demodulation

The following block diagram shows how the analyzer performs digital, demodulated measurements. This block diagram applies to all demodulation formats. However, note that the output of the “Digital Demodulation” and “Error Computations” blocks is different for FSK--see online help for the [FSK] softkey for details.

Figure 5-24 Digital Demodulation Block Diagram



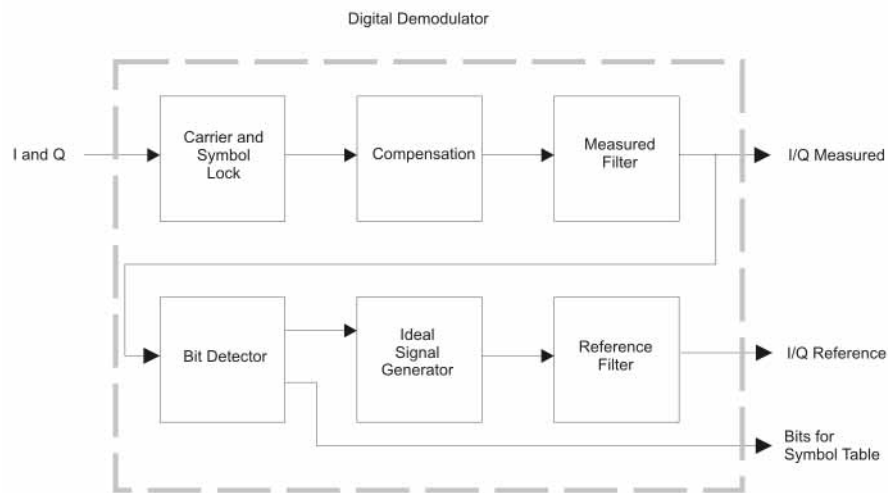
The Digital Demodulation instrument mode lets you perform measurements on digitally modulated signals. Measurements are possible on continuous or pulsed (burst) carriers (such as TDMA). In addition, you can specify a sync pattern and an offset to look at selected portions of demodulated data.

The demodulator used within this analyzer incorporates advanced technology that does not require external filtering, coherent carrier signals, or symbol-clock timing signals. The analyzer has built-in Gaussian, raised-cosine, and user-definable matching filters (with adjustable alpha) and locks to the carrier and to a defined symbol rate.

Furthermore, the demodulator uses your signal to generate an ideal signal (called I/Q reference or FSK reference).

The following block diagram shows the digital demodulator used to demodulate all formats except FSK:

Figure 5-25 *Digital Demodulation Detail*



The I/Q reference signal is the signal that would result after demodulating a signal if that signal were ideal (contained no errors). You can compare the measured signal to the reference signal to quantify and locate errors in the measured signal.

Digital Modulation Format Standards

Introduction

The previous section introduced digital modulation and the concepts behind the individual formats. This section now introduces each format and provides details.

Modulation Formats and Applications

The following table shows modulation formats supported in N9064A VXA, grouped by the modulation format family.

To find out more about an individual format

- See [“Phase Shift Keying \(PSK\) Concepts”](#) on page 164
- See [“Differential Modulation Concepts”](#) on page 166
- See [“Offset QPSK Modulation Concepts”](#) on page 168
- See [“Frequency Shift Keying \(FSK\) Concepts”](#) on page 170
- See [“Minimum Shift Keying \(MSK\) Concepts”](#) on page 173
- See [“Quadrature Amplitude Modulation \(QAM\) Concepts”](#) on page 175

Families of Format and data sheets

Each modulation format has its separate data sheet showing constellation diagram, frequency spectrum occupied and a chart of default settings.

Table 5-1 Families of Digital Modulation Formats

Format Family	Modulation Format
PSK	BPSK
	QPSK
	8PSK
	DQPSK
	Pi/4 DQPSK
	D8PSK
	Offset QPSK
FSK	FSK 2, 4, 8 states
MSK	MSK
QAM	16, 32, 64, 128, 256

Table 5-1 Families of Digital Modulation Formats

Format Family	Modulation Format
DVB QAM	16, 32, 64, 128, 256
EDGE	EDGE

Applications

The following table shows the modulation formats for different applications used in wireless communications.

Table 5-2 Modulation Formats for Different Applications

Modulation Format	Application
MSK, GMSK	GSM, CDPD
BPSK	Deep space telemetry, cable modems
QPSK, Pi/4 DQPSK	Satellite, CDMA, NADC, TETRA, PHS, PDC, LMDS, DVDB-S, cable (return path), cable modems, TFTS, APC025 phase1
OQPSK	CDMA, satellite
8PSK	Satellite, aircraft, telemetry pilots for monitoring broadband video systems
FSK, GFSK	DECT, paging, RAM mobile data, AMPS, CT2, ERMES, land mobile, public safety
2FSK	Bluetooth
16 QAM	Microwave digital radio, modems, DVB-C, DVB-T
32 QAM	Terrestrial microwave, DVB-T
64 QAM	DVB-C, modems, broadband set top boxes, MMDS
256 QAM	Modems, DVB-C (Europe), Digital Video (US)

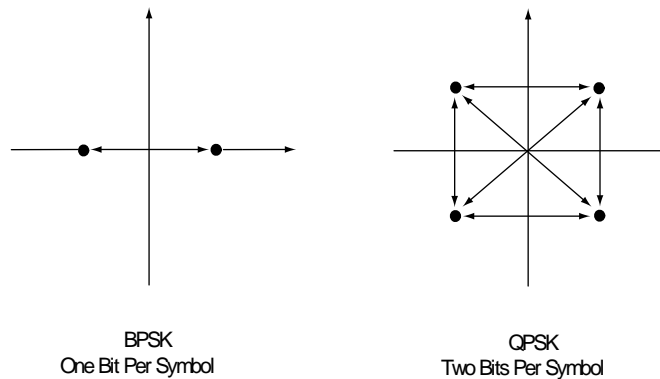
Phase Shift Keying (PSK) Concepts

One of the simplest forms of digital modulation is binary or Bi-Phase Shift Keying (BPSK). One application where this is used is for deep space telemetry. The phase of a constant amplitude carrier signal moves between zero and 180 degrees. On an I/Q diagram, the I state has two different values. There are two possible locations in the constellation diagram, so a binary one or zero can be sent. The bit rate is one bit per symbol.

A more common type of phase modulation is Quadrature Phase Shift Keying (QPSK). It is used extensively in applications including CDMA (Code Division Multiple Access) cellular service, wireless local loop, and DVB-S (Digital Video Broadcasting — Satellite). Quadrature means that the signal shifts between phase states which are separated by 90 degrees. The signal shifts in increments of 90 degrees from 45 to 135, -45, or -135 degrees. These points are chosen as they can be easily implemented using an I/Q modulator. Only two I values and two Q values are needed and this gives two bits per symbol. There are four states because $2^2 = 4$. It is therefore a more bandwidth-efficient type of modulation than BPSK, potentially twice as efficient.

Figure 5-26

Phase Shift Keying (PSK)

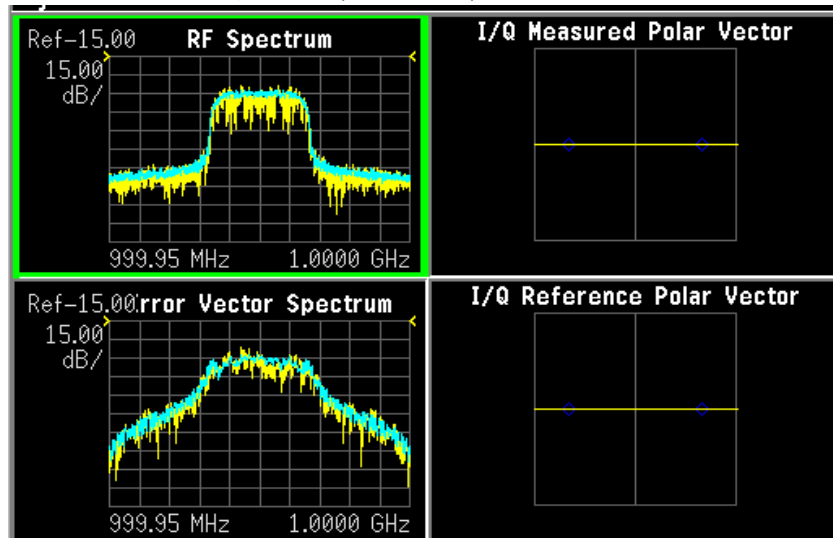


Types of PSK

- [“BPSK Modulation Characteristics” on page 165](#)
- [“QPSK Modulation Characteristics” on page 165](#)
- [“8PSK Modulation Characteristics” on page 166](#)
- [“DQPSK Modulation Characteristics” on page 167](#)
- [“p/4 DQPSK Modulation Characteristics” on page 168](#)
- [“D8PSK Modulation Characteristics” on page 168](#)
- [“Offset QPSK Modulation Characteristics” on page 169](#)

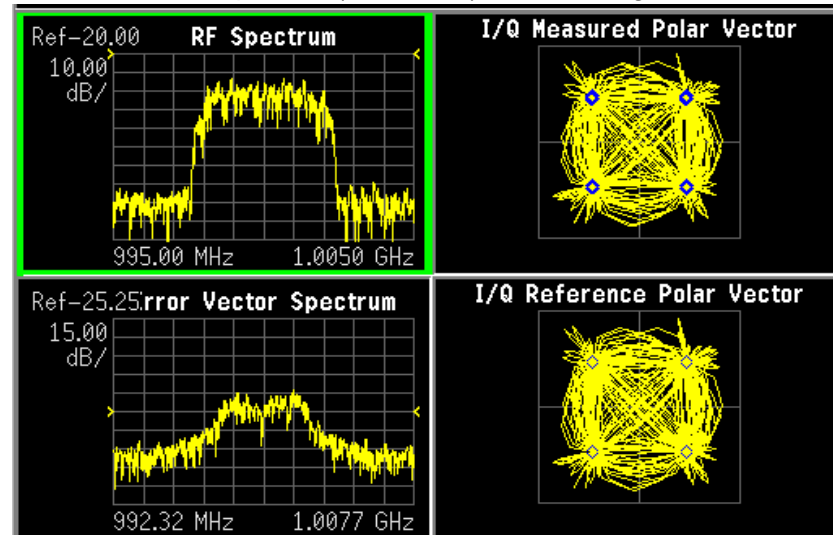
BPSK Modulation Characteristics

Figure 5-27 BPSK Error Vector Spectrum (Quad View)



QPSK Modulation Characteristics

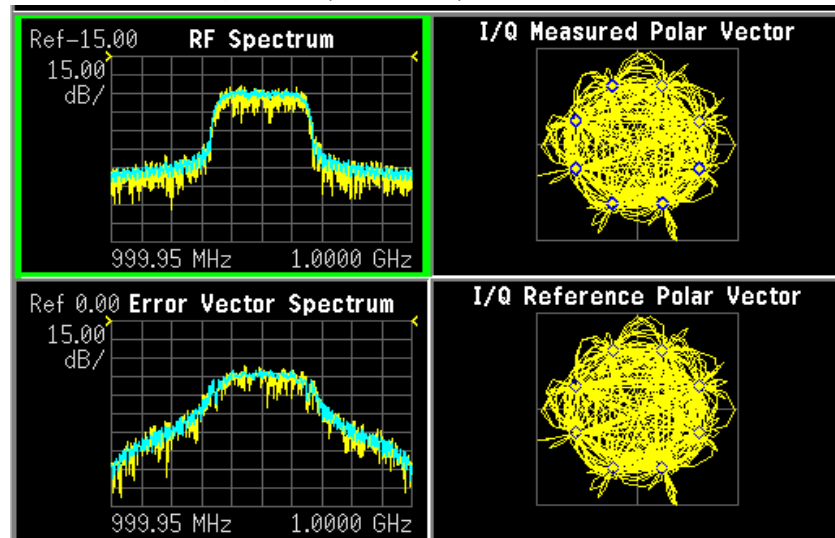
Figure 5-28 QPSK Error Vector Spectrum (Quad View)- W-CDMA Signal



8PSK Modulation Characteristics

Figure 5-29

8PSK Error Vector Spectrum (Quad View)



Differential Modulation Concepts

A variation to standard PSK is differential modulation as used in differential QPSK (DQPSK). Differential means that the information is not carried by the absolute state, it is carried by the transition between states. In some cases there are also restrictions on allowable transitions. This occurs in $\pi/4$ DQPSK where the carrier trajectory does not go through the origin. A DQPSK transmission system can transition from any symbol position to any other symbol position. The $\pi/4$ DQPSK modulation format is widely used in many applications including

CELLULAR

- NADC- IS-54 (North American digital cellular)
- PDC (Pacific Digital Cellular)

CORDLESS

- PHS (personal handyphone system)

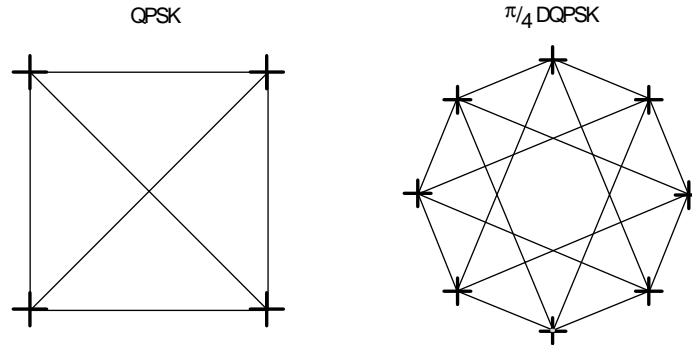
TRUNKED RADIO

- TETRA (Trans European Trunked Radio)

The $\pi/4$ DQPSK modulation format uses two QPSK constellations offset by 45 degrees ($\pi/4$ radians). Transitions must occur from one constellation to the other. This guarantees that there is always a change in phase at each symbol, making clock recovery easier. The data is encoded in the magnitude and direction of the phase shift, not in the absolute position on the constellation. One advantage of $\pi/4$ DQPSK is that the signal trajectory does not pass through the origin, thus simplifying transmitter design. Another is that $\pi/4$ DQPSK, with root raised cosine filtering, has better spectral efficiency than GMSK, the other common cellular modulation type.

Figure 5-30

Differential Modulation

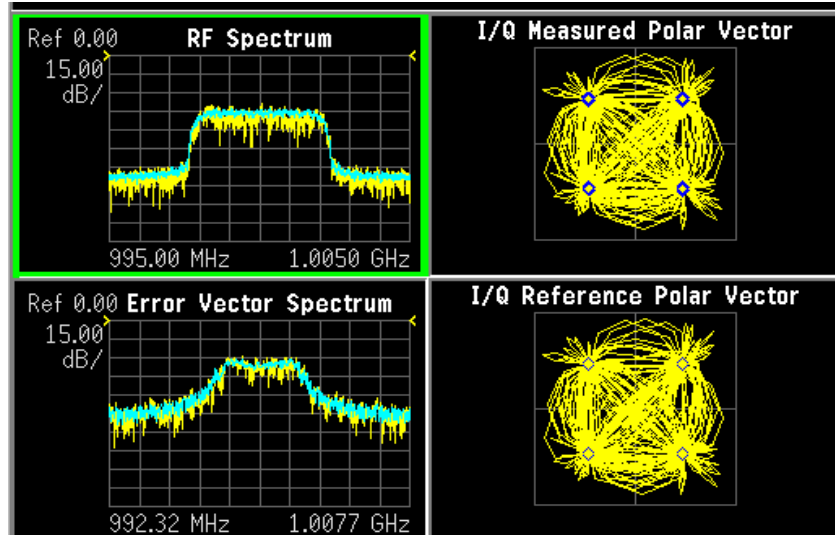


Both formats are 2 bits/symbol

DQPSK Modulation Characteristics

Figure 5-31

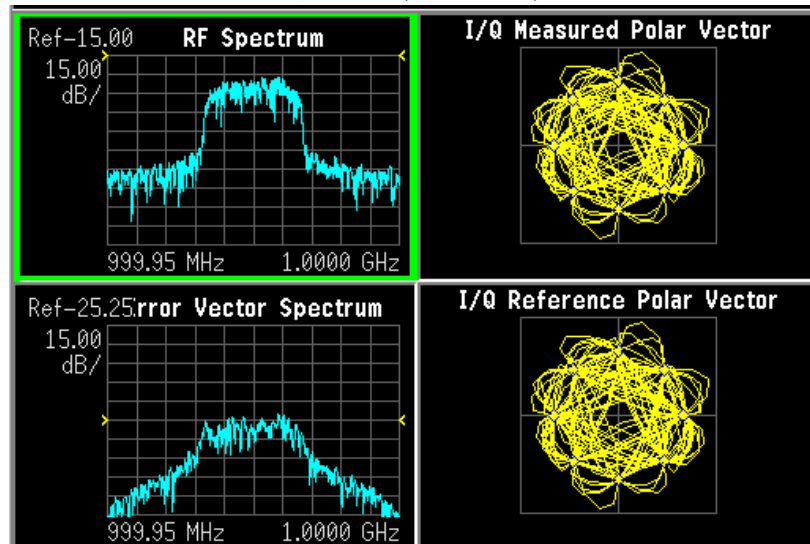
DQPSK Error Vector Spectrum (Quad-View)



$\pi/4$ DQPSK Modulation Characteristics

Figure 5-32

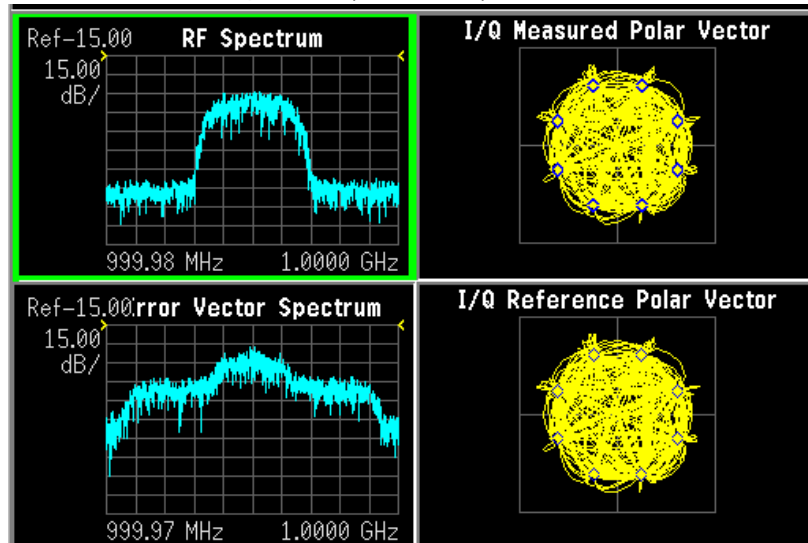
$\pi/4$ DQPSK Error Vector Spectrum (Quad-View)



D8PSK Modulation Characteristics

Figure 5-33

D8PSK Error Vector Spectrum (Quad-View)



Offset QPSK Modulation Concepts

Offset QPSK (OQPSK) is used in the cellular CDMA (code division multiple access) system for the reverse (mobile to base) link.

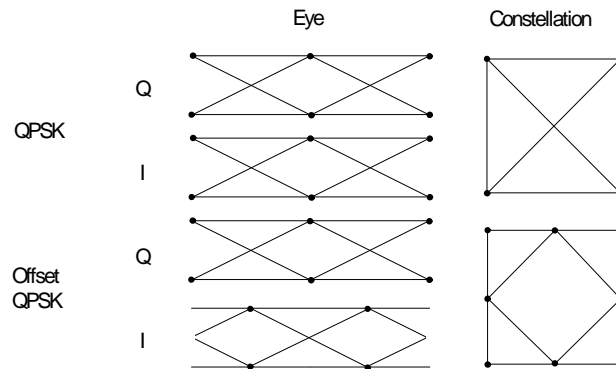
In QPSK, the I and Q bit streams are switched at the same time. The symbol clocks, or the I and Q digital signal clocks, are synchronized. In offset QPSK (OQPSK), the I and Q bit streams are offset in their relative alignment by one half of a symbol period. This is shown in the diagram. Since the transitions of I and Q are offset, at any given time only one of the two bit streams can change values. This creates a dramatically different

constellation, even though there are still just two I/Q values. This has power efficiency advantages. In OQPSK the signal trajectories are modified by the symbol clock offset so that the carrier amplitude does not go through or near zero (the center of the constellation). The spectral efficiency is the same with two I states and two Q states. The reduced amplitude variations (perhaps 3 dB for OQPSK, versus 30 to 40 dB for QPSK) allow a more power-efficient, less linear RF power amplifier to be used.

The following figure shows a comparison of the Eye diagrams of QPSK and Offset QPSK. To learn more, see [“Eye diagrams” on page 240](#).

Figure 5-34

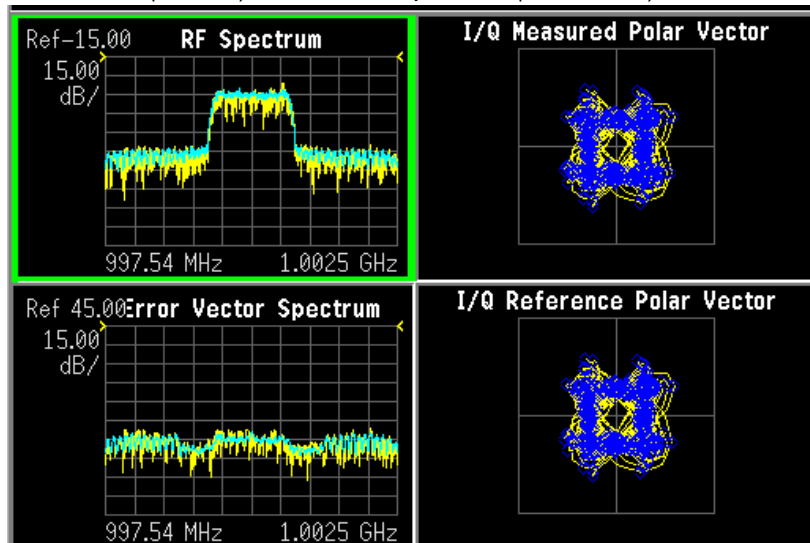
I/Q “Offset” Modulation



Offset QPSK Modulation Characteristics

Figure 5-35

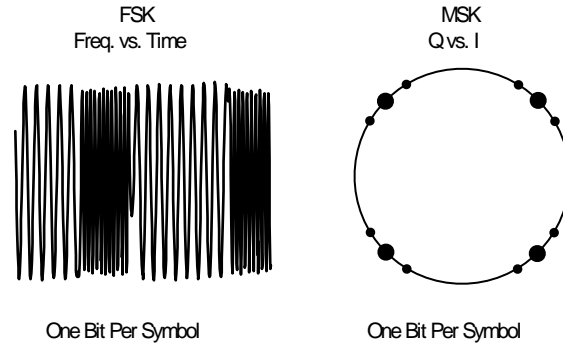
Offset QPSK (OQPSK) Error Vector Spectrum (Quad-View)



Frequency Shift Keying (FSK) Concepts

Figure 5-36

Frequency Shift Keying



Frequency modulation and phase modulation are closely related. A static frequency shift of +1 Hz means that the phase is constantly advancing at the rate of 360 degrees per second (2π rad/sec), relative to the phase of the unshifted signal.

FSK (Frequency Shift Keying) is used in many applications including cordless and paging systems. Some of the cordless systems include DECT (Digital Enhanced Cordless Telephone) and CT2 (Cordless Telephone 2).

In FSK, the frequency of the carrier is changed as a function of the modulating signal (data) being transmitted. Amplitude remains unchanged. In binary FSK (BFSK or 2FSK), a "1" is represented by one frequency and a "0" is represented by another frequency.

FSK Modulation Characteristics

Figure 5-37

FSK Error Vector Spectrum (Quad-View) - 2 FSK Signal

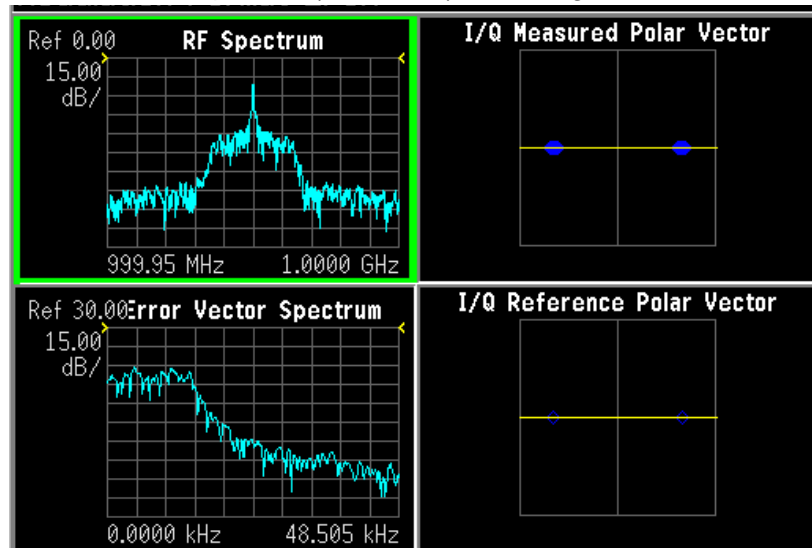
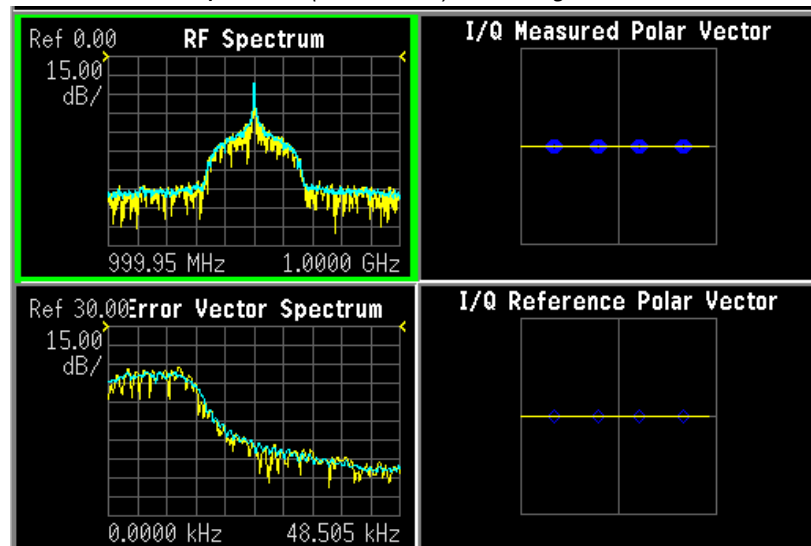


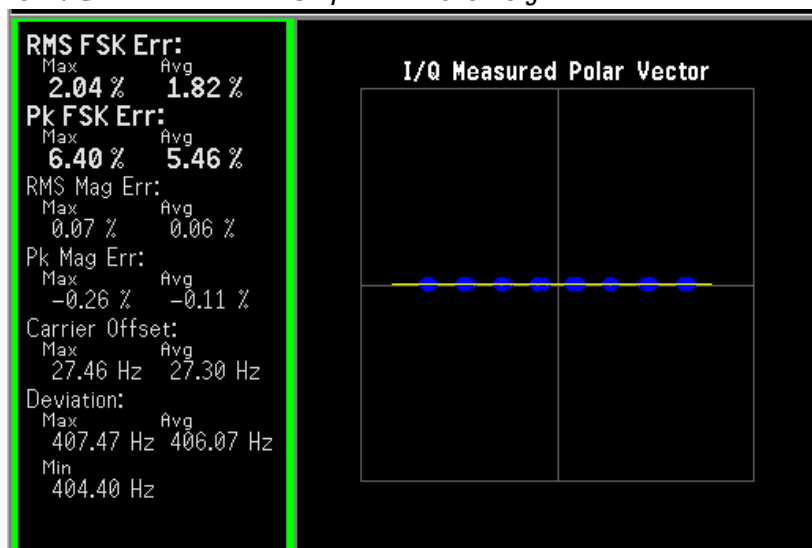
Figure 5-38

FSK Error Vector Spectrum (Quad-View)- 4FSK Signal



Concepts
Digital Modulation Format Standards

Figure 5-39 FSK I/Q Measured Polar Graph View- 8FSK Signal



Minimum Shift Keying (MSK) Concepts

Since a frequency shift produces an advancing or retarding phase, frequency shifts can be detected by sampling phase at each symbol period. Phase shifts of $(2N + 1) \pi/2$ radians are easily detected with an I/Q demodulator. At even numbered symbols, the polarity of the I channel conveys the transmitted data, while at odd numbered symbols the polarity of the Q channel conveys the data. This orthogonality between I and Q simplifies detection algorithms and hence reduces power consumption in a mobile receiver. The minimum frequency shift which yields orthogonality of I and Q is that which results in a phase shift of $\pm \pi/2$ radians per symbol (90 degrees per symbol). FSK with this deviation is called MSK (Minimum Shift Keying). The deviation must be accurate in order to generate repeatable 90 degree phase shifts. MSK is used in the GSM (Global System for Mobile Communications) cellular standard. A phase shift of +90 degrees represents a data bit equal to "1," while -90 degrees represents a "0." The peak-to-peak frequency shift of an MSK signal is equal to one-half of the bit rate.

FSK and MSK produce constant envelope carrier signals, meaning they have no amplitude variations. This is a desirable characteristic for improving the power efficiency of transmitters. Amplitude variations can exercise nonlinearities in an amplifier's amplitude-transfer function, generating spectral regrowth, a component of adjacent channel power. Therefore, more efficient amplifiers (which tend to be less linear) can be used with constant-envelope signals, reducing power consumption. MSK has a narrower spectrum than wider deviation forms of FSK. The width of the spectrum is also influenced by the waveforms causing the frequency shift. If those waveforms have fast transitions or a high slew rate, then the spectrum of the transmitter will be broad. In practice, the waveforms are filtered with a Gaussian filter, resulting in a narrow spectrum. In addition, the Gaussian filter has no time-domain overshoot, which would broaden the spectrum by increasing the peak deviation. MSK with a Gaussian filter is termed GMSK (Gaussian MSK).

Constant Envelope MSK Modulation

GSM uses a variation of constant amplitude modulation format called 0.3 GMSK (Gaussian Minimum Shift Keying).

In constant-envelope modulation the amplitude of the carrier is constant, regardless of the variation in the modulating signal. It is a power-efficient scheme that allows efficient class-C amplifiers to be used without introducing degradation in the spectral occupancy of the transmitted signal. However, constant-envelope modulation techniques occupy a larger bandwidth than schemes which are linear. In linear schemes, the amplitude of the transmitted signal varies with the modulating digital signal as in BPSK or QPSK. In systems where bandwidth efficiency is more important than power efficiency, constant envelope modulation is not as well suited.

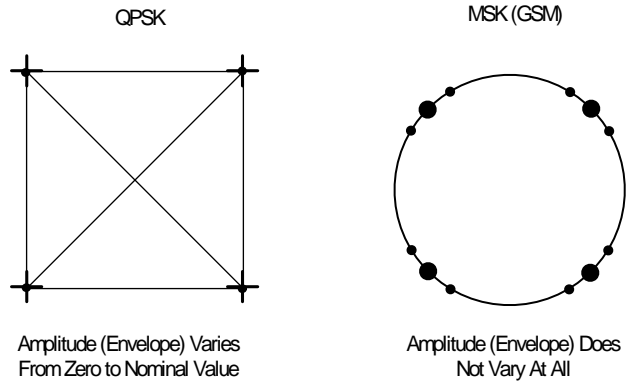
MSK is a special type of FSK where the peak-to-peak frequency deviation is equal to half the bit rate.

GMSK is a derivative of MSK where the bandwidth required is further reduced by passing the modulating waveform through a Gaussian filter. The Gaussian filter minimizes the instantaneous frequency variations over time. GMSK is a spectrally

efficient modulation scheme and is particularly useful in mobile radio systems. It has a constant envelope, spectral efficiency, good BER performance, and is self-synchronizing.

Figure 5-40

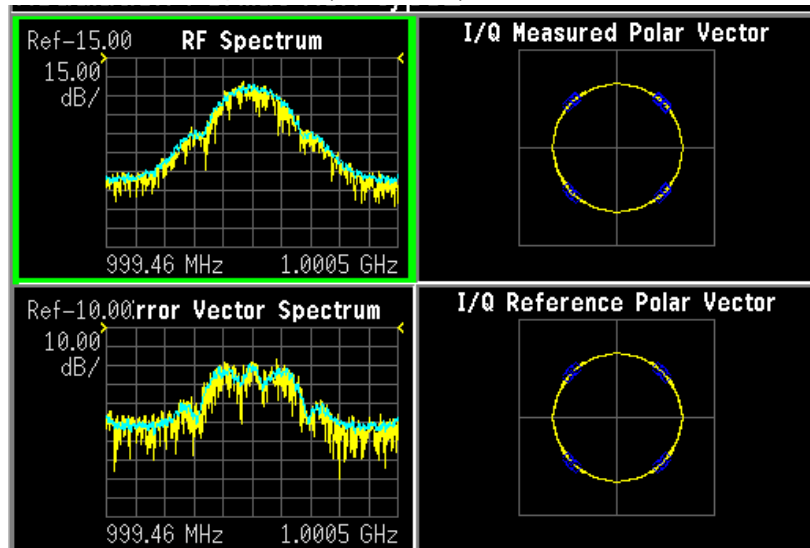
Constant Envelope MSK Modulation



MSK Modulation Characteristics

Figure 5-41

MSK Error Vector Spectrum (Quad-View)



Quadrature Amplitude Modulation (QAM) Concepts

Quadrature amplitude modulation (QAM) is used in applications including microwave digital radio, DVB-C (Digital Video Broadcasting—Cable), and modems.

16 QAM

In 16-state quadrature amplitude modulation (16QAM), there are four I values and four Q values. This results in a total of 16 possible states for the signal. It can transition from any state to any other state at every symbol time. Since $16 = 2^4$ four bits per symbol can be sent. This consists of two bits for I, and two bits for Q. The symbol rate is one fourth of the bit rate. So this modulation format produces a more spectrally efficient transmission. It is more efficient than BPSK, QPSK, or 8PSK.

Note that to a point QPSK is the same as 4QAM.

32 QAM

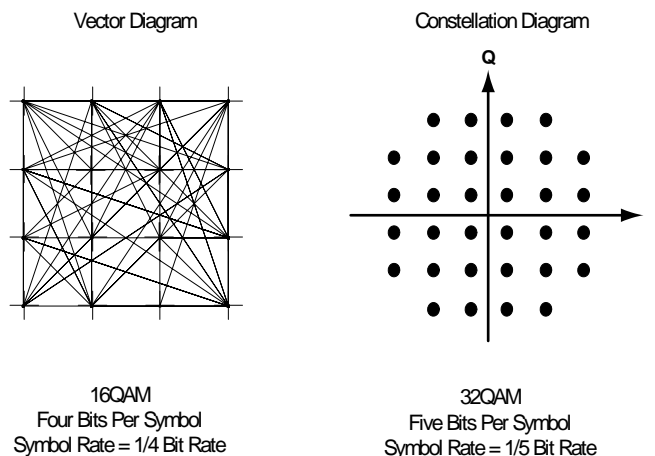
Another variation is 32QAM. In this case there are six I values and six Q values resulting in a total of 36 possible states ($6 \times 6 = 36$). This number is too many states for a power of two (the closest power of two is 32). So the four corner symbol states, which take the most power to transmit, are omitted. This reduces the amount of peak power the transmitter has to generate. Since $2^5 = 32$, there are five bits per symbol and the symbol rate is one fifth of the bit rate.

The current practical limits are approximately 256QAM, though work is underway to extend the limits to 512 or 1024 QAM. High state QAM formats are better suited to cable delivery where the noise is lessened.

A 256QAM system uses 16 I-values and 16 Q-values, giving 256 possible states. Since $2^8 = 256$, each symbol can represent eight bits. A 256QAM signal that can send eight bits per symbol is very spectrally efficient. However, for a given maximum power, the symbols are closer together than lower-valued QAM's and are thus more subject to errors due to noise and distortion. Such a signal may have to be transmitted with extra power (to effectively spread the symbols out more) and this reduces power efficiency as compared to simpler schemes.

Figure 5-42

Quadrature Amplitude Modulation



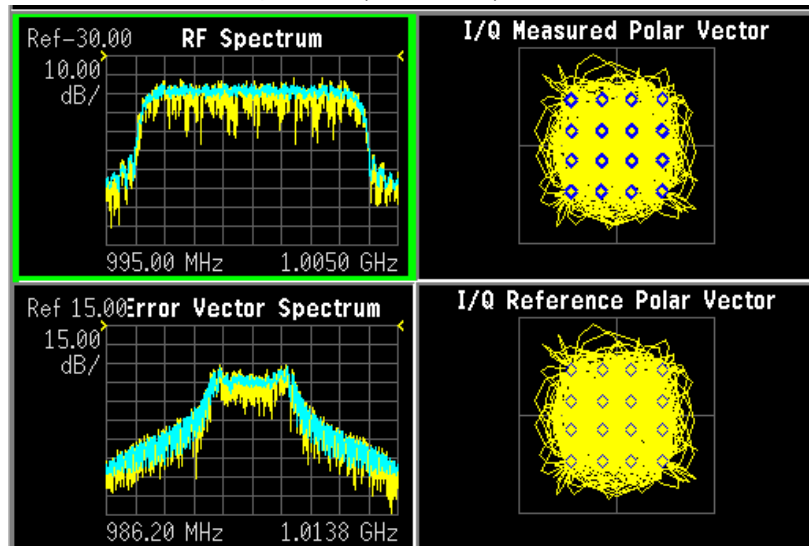
However, bandwidth efficiency is better for higher QAM's. For example, BPSK uses 80 Ksymbols-per-second sending 1 bit per symbol. A system using 256QAM sends eight bits per symbol so the symbol rate would be 10 Ksymbols per second. A 256QAM system enables the same amount of information to be sent as BPSK using only one eighth of the bandwidth. It is eight times more bandwidth efficient. However, there is a trade-off. The radio becomes more complex and is more susceptible to errors caused by noise and distortion. Error rates of higher-order QAM systems such as this degrade more rapidly than QPSK as noise or interference is introduced. A measure of this degradation would be a higher bit error rate (BER).

In any digital modulation system, if the input signal is distorted or severely attenuated the receiver will eventually lose symbol lock completely. If the receiver can no longer recover the symbol clock, it cannot demodulate the signal or recover any information. With less degradation, the symbol clock can be recovered, but it is noisy, and the symbol locations themselves are noisy. In some cases, a symbol will fall far enough away from its intended position that it will cross over to an adjacent position. The I and Q level detectors used in the demodulator would misinterpret such a symbol as being in the wrong location, causing bit errors. QPSK is not as efficient, but the states are much farther apart for a given power and the system can tolerate a lot more noise before suffering symbol errors. QPSK has no intermediate states between the four corner-symbol locations, so there is less opportunity for the demodulator to misinterpret symbols. QPSK requires less transmitter power than QAM to achieve the same bit error rate.

QAM Modulation Characteristics

Figure 5-43

16QAM Error Vector Spectrum (Quad-View)



Modulation Bit State Diagrams

This section shows bit state diagrams for various digital modulation formats that may be demodulated by the Modulation Analysis measurement, including FSK, PSK, QAM, and DVB QAM. Constellation diagrams are used to illustrate most PSK and complex modulation formats, while BPSK and FSK are mapped to a single axis.

Bit State Diagrams by Modulation Family

The bit state diagrams are grouped by modulation family on the following pages:

[“FSK Bit state Diagrams” on page 178](#)

[“PSK Bit State Diagrams” on page 180](#)

[“QAM Bit State Diagrams” on page 184](#)

[“DVB QAM Bit State Diagrams” on page 188](#)

FSK Bit state Diagrams

FSK bit state diagrams are represented as states on a single axis.

Figure 5-44

2FSK Bit State Diagram



Figure 5-45 4FSK Bit State Diagram



Figure 5-46 8FSK Bit State Diagram



PSK Bit State Diagrams

PSK bit state diagrams are mostly represented below in constellation diagrams, except for BPSK, which is shown as states on a single axis.

Figure 5-47

BPSK Bit State Diagram

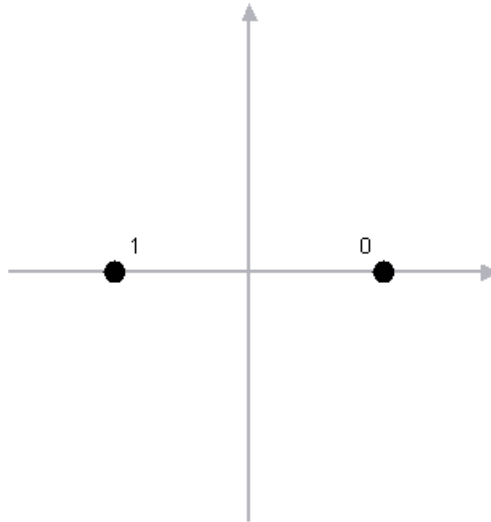


Figure 5-48

QPSK Bit State Diagram

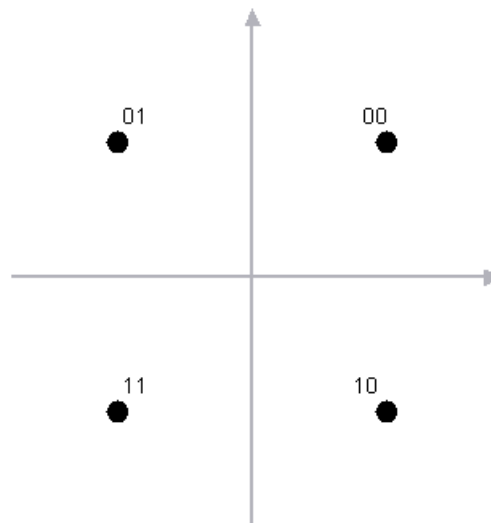


Figure 5-49 OQPSK (Offset QPSK) Bit State Diagram

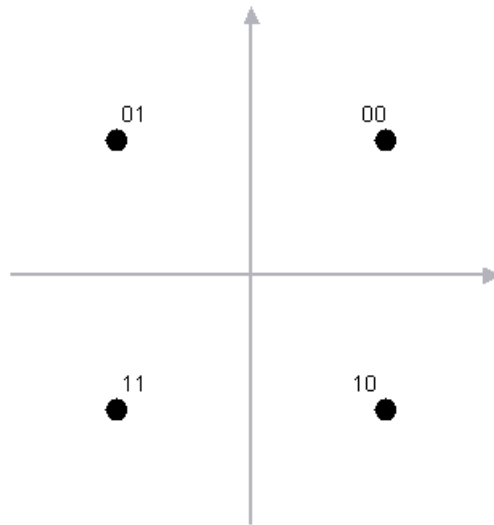
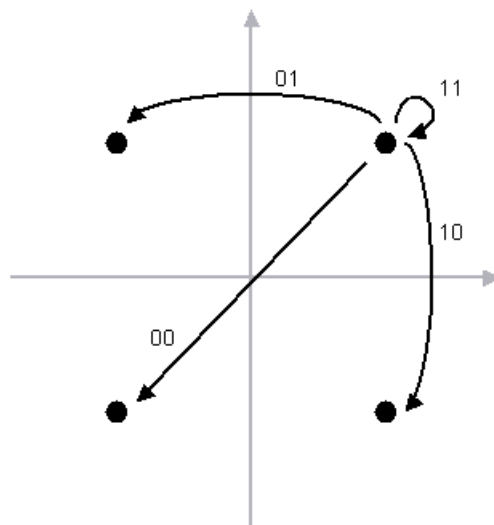


Figure 5-50 DQPSK (Differential QPSK) Bit State Diagram



Concepts
Digital Modulation Format Standards

Figure 5-51 8PSK Bit State Diagram

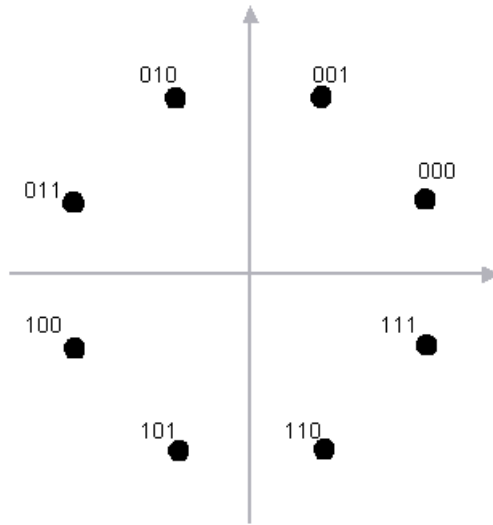


Figure 5-52 D8PSK (Differential 8PSK) Bit State Diagram

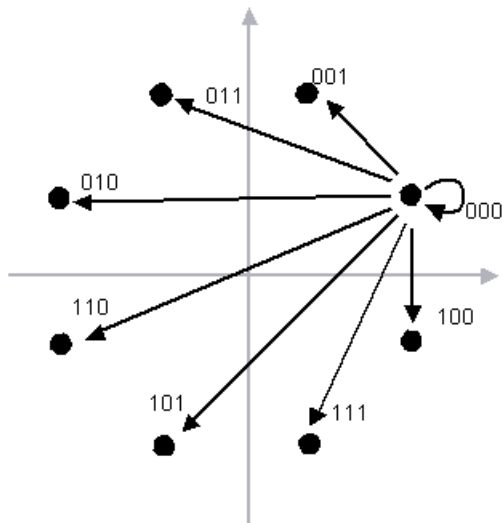
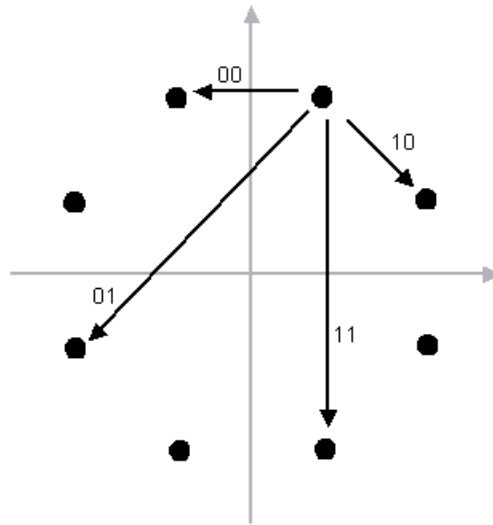


Figure 5-53 $\pi/4$ DQPSK Bit State Diagram



QAM Bit State Diagrams

QAM bit states are represented below in constellation diagrams.

Figure 5-54 16 QAM Bit State Diagram

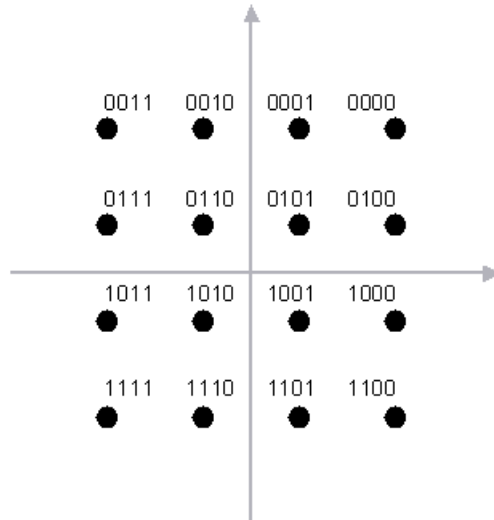


Figure 5-55 32 QAM Bit State Diagram

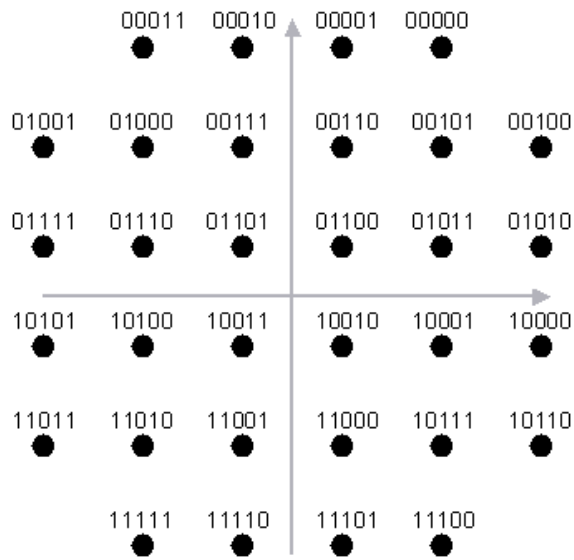


Figure 5-56 64 QAM Bit State Diagram

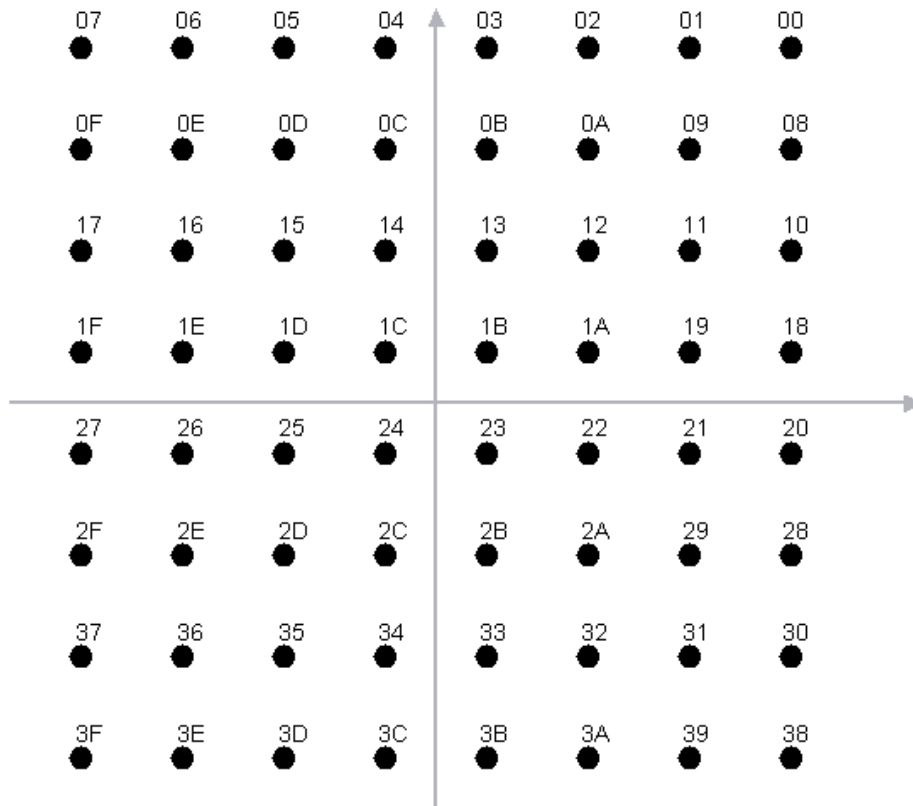


Figure 5-57 128 QAM Bit State Diagram

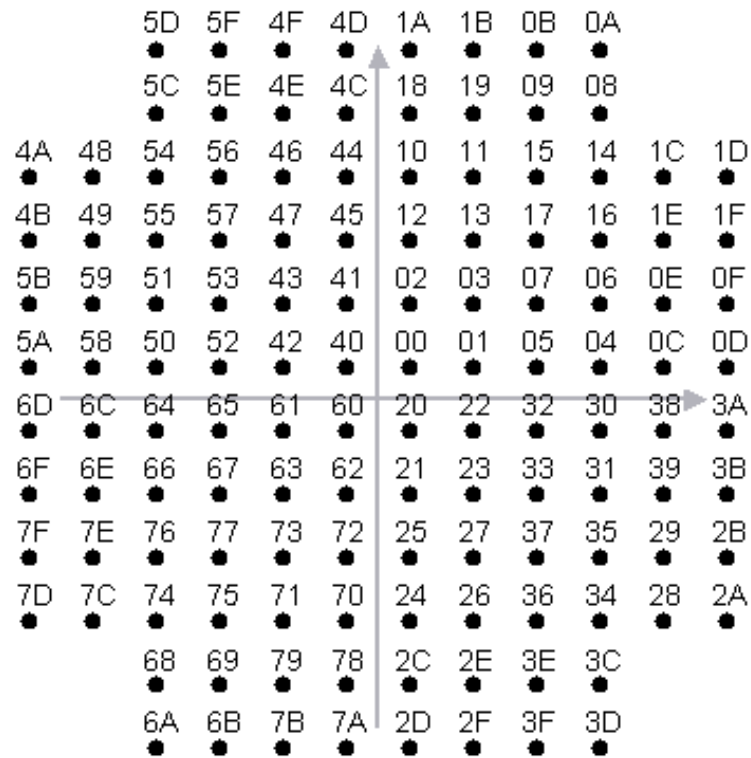
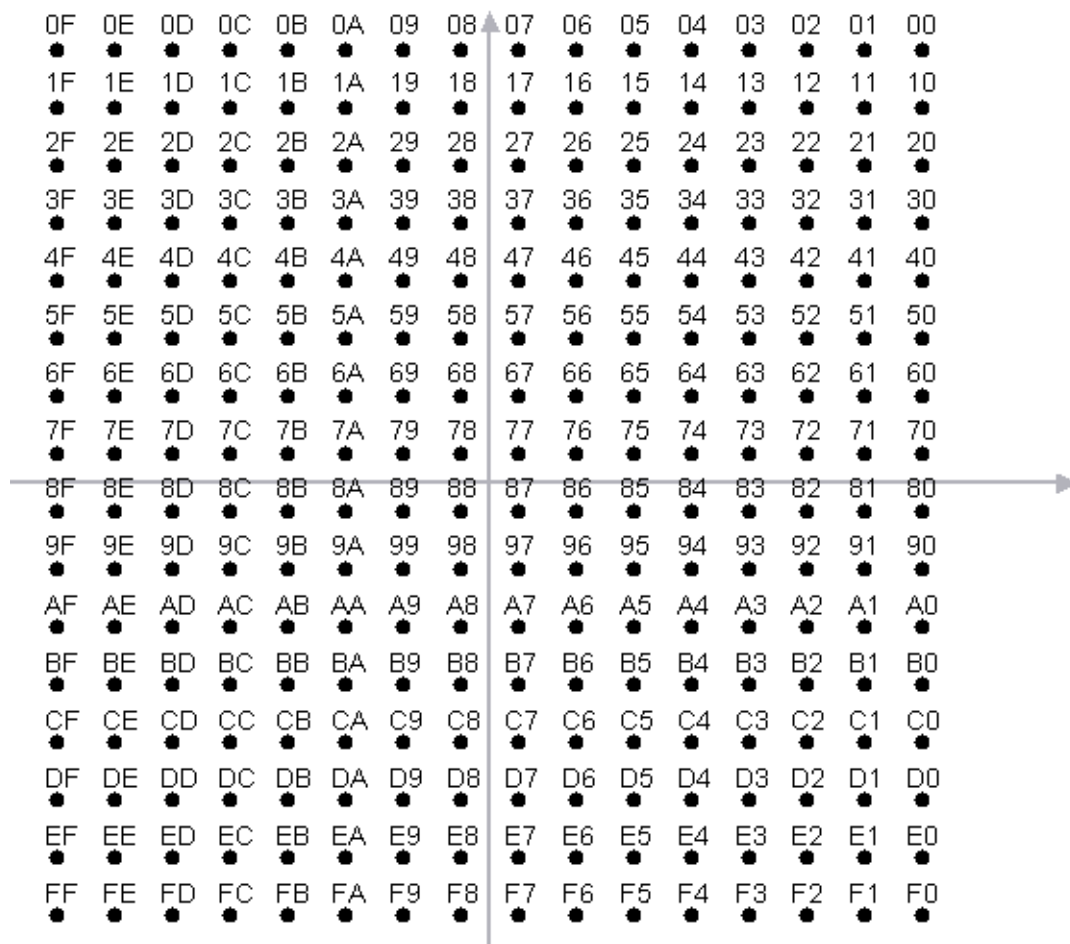


Figure 5-58 256 QAM Bit State Diagram



DVB QAM Bit State Diagrams

DVB QAM bit states are represented below in constellation diagrams.

As shown in [Figure 5-59 on page 188](#), [Figure 5-60 on page 189](#), and [Figure 5-61 on page 190](#), the constellation points in Quadrant 1 are converted to Quadrants 2, 3, and 4 by changing the two MSBs (i.e., I_k and Q_k) and by rotating the q LSBs according to the rule given in the table below.

Table 5-3 DVB 16QAM, 32 QAM, 64QAM Rotation Rules

Quadrant	MSBs	LSBs Rotation
1	00	
2	10	$+\pi/2$
3	11	$+\pi$
4	01	$+3\pi/2$

Figure 5-59

DVB 16QAM Bit State Diagram

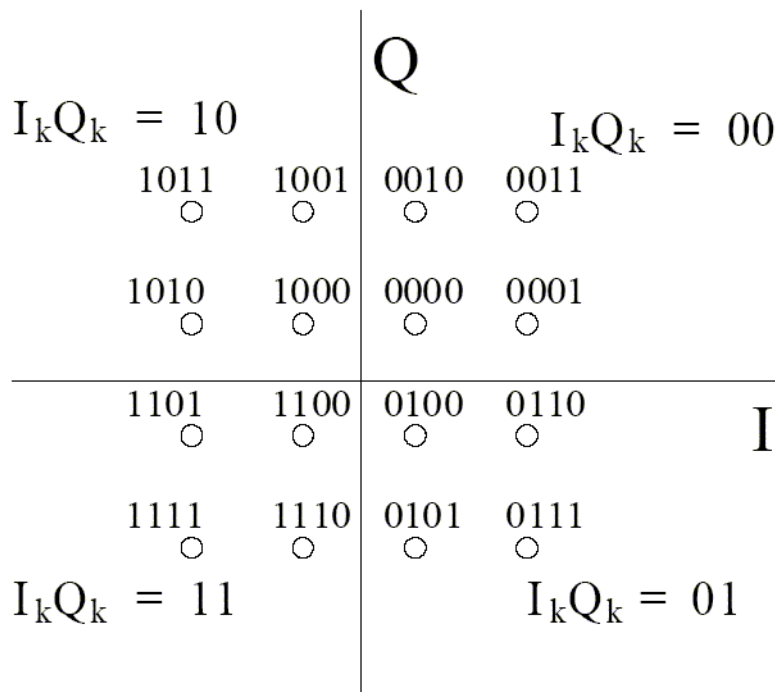


Figure 5-60 DVB 32QAM Bit State Diagram

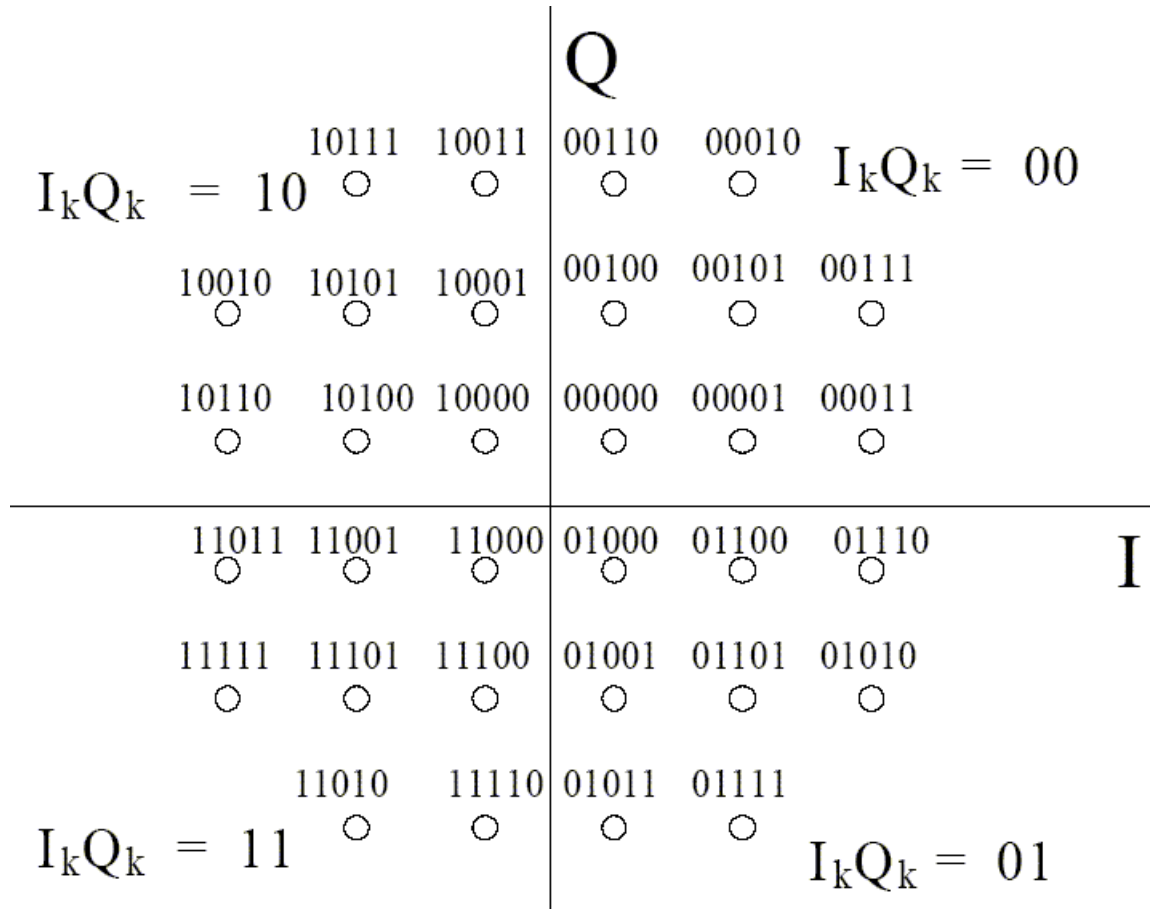


Figure 5-61 DVB 64QAM Bit State Diagram

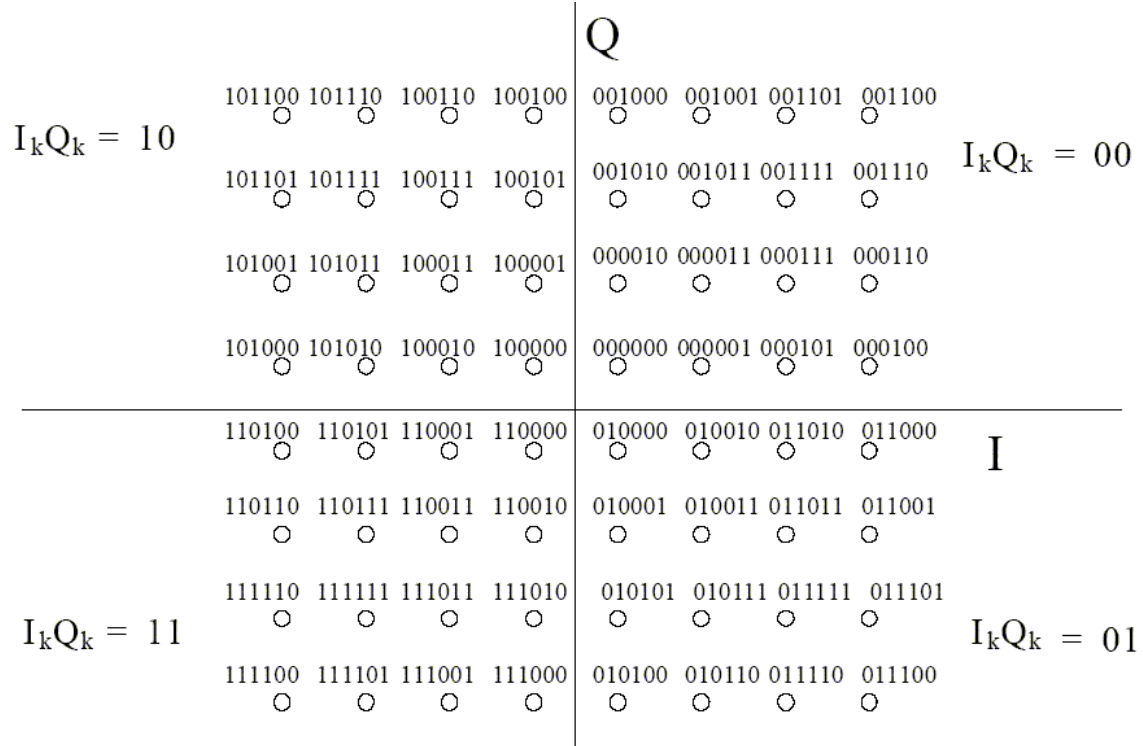


Figure 5-62 DVB 128QAM Bit State Diagram

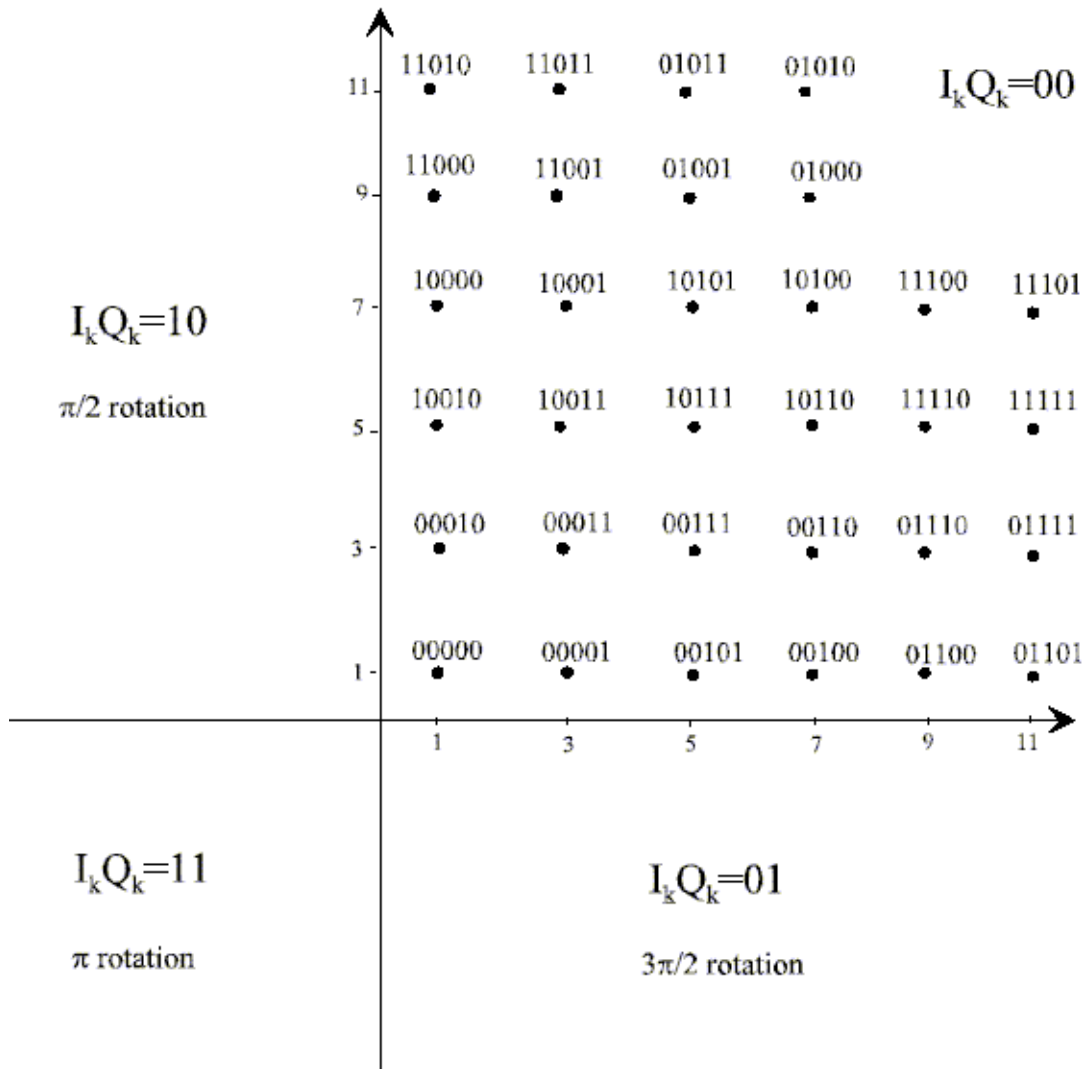
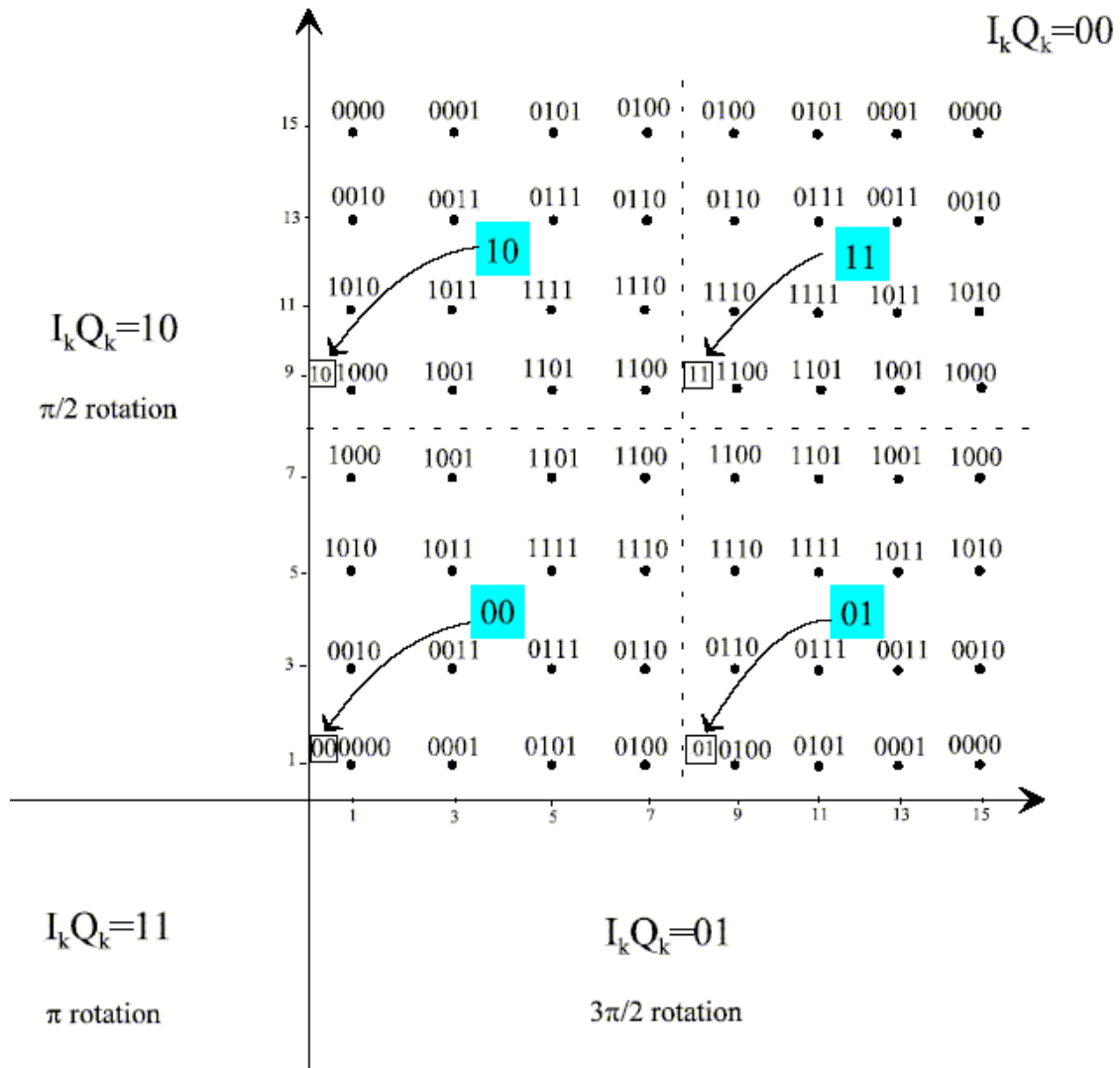


Figure 5-63 DVB 256QAM Bit State Diagram



Communication System Formats

N9064A VXA Supported Communications Format Standards

- IS-95 [page 193](#)
- W-CDMA [page 195](#)
- cdma2000 [page 199](#)
- NADC [page 202](#)
- PDC [page 206](#)
- PHS [page 207](#)
- TETRA [page 209](#)
- Bluetooth [page 210](#)
- GSM [page 215](#)
- EDGE [page 215](#)
- APC025 phase1 [page 215](#)
- VDL Mode 3 [page 222](#)
- ZigBee 2450MHz [page 223](#)

NOTE

N9064A VXA can analyze digital modulation for a single code channel only. If multiple code channels are transmitted, synchronization will fail, and incorrect EVM results will be obtained. For modulation quality measurements of multiple code channels, Modulation Accuracy and Code Domain measurements must be performed by a full-featured standard-based measurement application, like N9073A for W-CDMA.

What is the cdmaOne (IS-95) Communication System?

Code Division Multiple Access (CDMA) is a direct sequence spread-spectrum digital communications technique that was originally designed for military applications. The main advantages of CDMA over other types of communications schemes are:

- greater capacity than with other techniques
- immunity to signal loss and degradation in the presence of high broadband interference
- immunity to signal loss and degradation due to multipath, scatter, and fading
- power consumption of mobile stations is strictly minimized (by base station control)
- supports full 9600 baud capability for voice and data communications
- provides increased security

CDMA uses correlative codes to distinguish one user from another. Frequency division is still used, as is done with Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), but in a much larger bandwidth (1.25 MHz). CDMA uses a direct sequence spread spectrum technique that realizes increased capacity from 1:1 frequency reuse and sectorized cells. The capacity limit is soft. That is, capacity can be increased with some degradation of the error rate or voice quality.

In cdmaOne, a single user's channel consists of a specific frequency combined with a unique code. Correlative codes enable each user to operate in the presence of substantial interference. The interference is the sum of all other users on the same cdmaOne frequency, both from within and without the home cell, and from delayed versions of these signals. It also includes the usual thermal noise and atmospheric disturbances. Delayed signals caused by multipath are separately received and combined in cdmaOne. One of the major differences in access, compared to a non-cdma system, is that any cdmaOne frequency can be used in all sectors of all cells. This is possible because cdmaOne is designed to decode the proper signal in the presence of high interference.

The cdmaOne communication system is defined in the following Electronics Industry Association (EIA) and Telecommunications Industry Association (TIA) documents:

TIA/EIA/ IS-95-A	Mobile Station - Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System
TIA/EIA-97-B	Recommended Minimum Performance Standards for Base Stations Supporting Dual-Mode Wideband Spread Spectrum Cellular Mobile Stations
TIA/EIA-98-B	Recommended Minimum Performance Standards for dual-Mode Wideband Spread Spectrum Cellular Mobile Stations

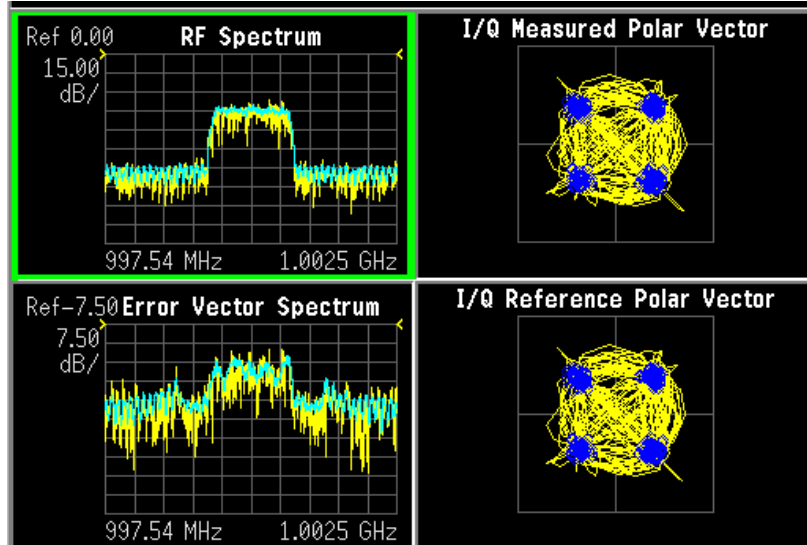
And the following American National Standards Institute (ANSI) documents:

J-STD-008	Personal Station-Base Station Compatibility Requirements for 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) Personal Communications Systems
J-STD-018	Recommended Minimum Performance Requirements for 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) Personal Stations
J-STD-019	Recommended Minimum Performance Requirements for Base Stations Supporting 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) Personal Stations

cdmaOne Communication System

Figure 5-64

cdma One Error Vector Spectrum (Quad-View)



What is the W-CDMA Communications System?

Wideband code division multiple access (W-CDMA) is a popular air interface technology for third generation RF cellular communications systems. In W-CDMA (3GPP), the cells operate asynchronously, which makes the mobile synchronization more complex, but offers the advantage of flexibility in placement of the base stations. Both reverse and forward transmitter power controls are implemented with 0.625 ms intervals. W-CDMA is a direct sequence spread-spectrum digital communications technique that supports wider RF bandwidths, typically from 5 to 20 MHz. The main advantages of W-CDMA over other types of communication schemes are:

- greater capacity
- immunity to signal loss and degradation due to high-level broadband interference, multipath, scattering, and fading
- power consumption of mobile stations or user equipment (UE) is strictly minimized by both base station and mobile controls
- supports variable data rates up to 144 kbits/second for mobile (vehicular) data rate, up to 384 kbits/second for portable (pedestrian) data rate, and up to 2 Mbits/second for fixed installations
- provides increased security

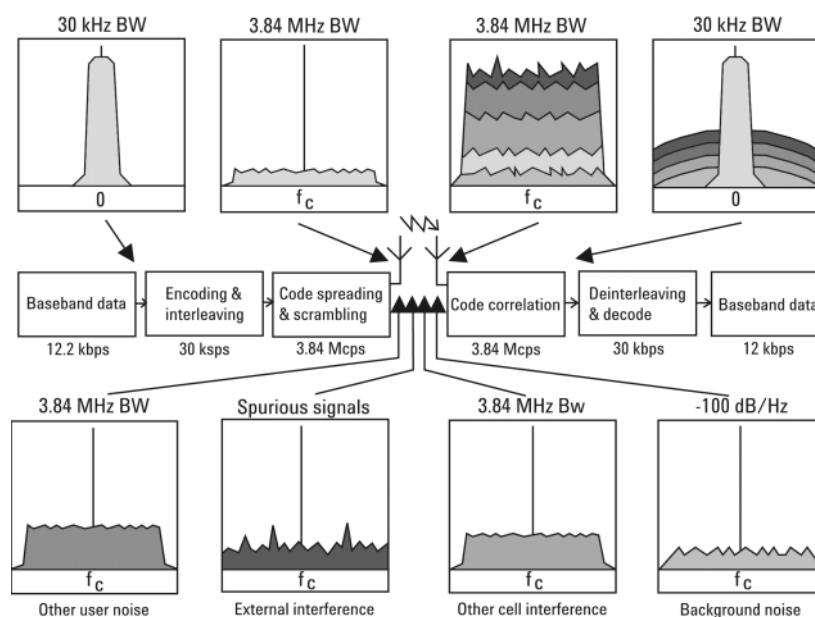
W-CDMA uses correlative codes to distinguish one user from another. Frequency division is still used, as is done with Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), but in a much larger bandwidth such as 5 MHz or greater. An initial baseband data rate is spread to a transmitted bit rate of 3.840 Mcps, which is also called chip rate or spread data rate. W-CDMA realizes increased capacity from 1:1 frequency reuse and sectorized cells. The capacity limit is soft. That is, capacity can be increased with some degradation of the error rate or voice quality.

W-CDMA Code Division Multiple Access

As its name implies, W-CDMA is a code division multiple access (CDMA) system. As opposed to time division multiple access (TDMA), in CDMA, all users transmit at the same time. Frequency divisions are still used, but at a much larger bandwidth. In addition, multiple users share the same frequency carrier. Each user's signal uses a unique code that appears to be noise to all except the correct receiver. Therefore, the term channel describes a combination of carrier frequency and code. Correlation techniques enable a receiver to decode one signal among many that are transmitted on the same carrier at the same time. The following figure shows a simplified version of the transmission and reception processes for a W-CDMA system. One difference between W-CDMA and earlier existing 2G CDMA systems (like IS-95) is that W-CDMA uses a wider bandwidth (3.84 MHz, as opposed to 1.23 MHz for IS-95).

Figure 5-65

W-CDMA Transmission and Reception Processes



In W-CDMA, a single user's channel consists of a specific frequency combined with a unique code. Correlative codes enable each user to operate in the presence of substantial interference. The interference is the sum of all other users on the same W-CDMA frequency, both from within and outside of the home cell, and from delayed versions of these signals. It also includes the usual thermal noise and atmospheric disturbances. Delayed signals caused by multipath are separately received and combined in W-CDMA. Unlike access in non-CDMA systems, any W-CDMA frequency can be used in all sectors of all cells.

The W-CDMA system starts with a narrowband signal at a data rate of 12.2 kbps. In reality, this data rate is variable, up to 2 Mbps. After coding and interleaving, the resulting symbol rate in this example is 30 ksps. This is spread with the use of specialized codes to a bandwidth of 3.84 MHz. The final spread bits are called chips, and the final spread rate is defined in terms of chips per second (3.84 Mcps for

W-CDMA). The ratio of the spread data rate (3.84 Mcps) to the encoded data rate (30 kbps in this case) is called the spreading gain. The ratio of the spread data rate to the initial data rate (12.2 kbps in this case) is called the processing gain (overall coding gain). In CDMA systems the spreading gain is a big contributor to the processing gain. The processing gain allows the receiver's correlator to extract the desired signal from the noise. When transmitted, a CDMA signal experiences high levels of interference, dominated by the signals of other CDMA users. This takes two forms, interference from other users in the same cell and interference from adjacent cells. The total interference also includes background noise and other spurious signals. When the signal is received, the correlator recovers the desired signal and rejects the interference. This is possible because the interference sources are uncorrelated to each channel's unique code. In W-CDMA, the unique code for each channel is a combination of the scrambling code and the orthogonal variable spreading factor (OVSF) code, which are described in the following sections.

Base Station and User Equipment Identification

As in other CDMA systems, in W-CDMA each base transceiver station (BTS) output signal is "scrambled" by multiplying all of its data channels by a unique pseudo noise (PN) code, referred to in the W-CDMA specification as a scrambling code. The UE receiver can distinguish one BTS from another by correlating the received signal spectrum with a scrambling code that is identical to that used in the desired BTS. Similarly, each UE output signal is scrambled with a unique scrambling code that allows the BTS receiver to discern one UE from another. The scrambling codes are applied at a fixed rate of 3.840 Mcps. The scrambling codes are not orthogonal, therefore, some interference can exist between two UEs.

Data Channelization

Besides distinguishing which transmitter is being listened to, a CDMA receiver must further distinguish between the various channels originating from that transmitter. For example, a BTS will transmit unique channels to many mobile users, and each UE receiver must distinguish each of its own channels from all the other channels transmitted by the BTS. In W-CDMA, this function is provided by the channelization codes, also known as OVSF codes.

OVSF codes are orthogonal codes similar to the Walsh codes used in IS-95 and cdma2000. Each channel originating from a W-CDMA BTS or UE is multiplied by a different OVSF codes. In IS-95, Walsh codes are fixed at 64 chips in length; in W-CDMA, the length of these codes, also known as the spreading factor (SF), can be configured from 4 to 512 chips, with the resulting downlink (DL) symbol rate being equal to the system chip rate of 3.84 Mcps divided by the SF. For example a SF of four corresponds to a symbol rate of 960 kbps.

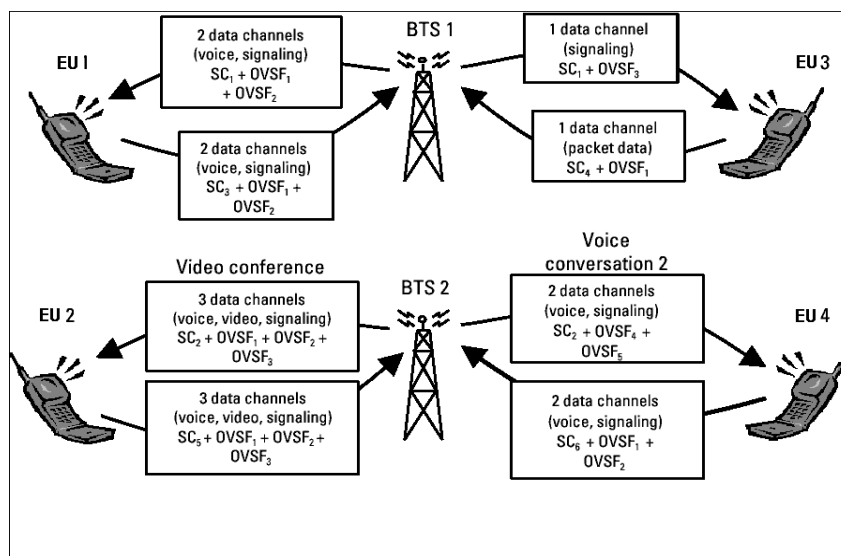
The entire set of OVSF codes is identical for each UE and BTS. The scrambling code allows OVSF code reuse between UE and BTS within the same geographic location. Therefore, it is the combination of OVSF and scrambling codes that provides a unique communication channel between a UE and BTS.

The W-CDMA radio link between the BTS and UE must support multiple simultaneous data channels. For example, a 3G connection may include bi-directional voice, video, packet data, and background signaling messages, each representing a unique data channel within a single frequency carrier.

The following figure illustrates a W-CDMA system with two BTS and four UEs. The scrambling code (SC) provides a unique identity to each UE and each BTS. The OVVSF code allocations provide a unique identity to each channel conveyed by a UE or BTS within one cell. For example SC2 identifies BTS 2, and SC6 identifies UE 4. BTS 2 uses OVVSF4 and OVVSF5 to send voice and signaling information to UE 4. This UE uses OVVSF1 and OVVSF2 to send voice and signaling information back to BTS 2. Note that other BTSs and UEs also use the same OVVSF codes (OVVSF1 and OVVSF2). This is not a problem since the scrambling codes decorrelate the re-used OVVSF codes.

Figure 5-66

W-CDMA Code Allocations

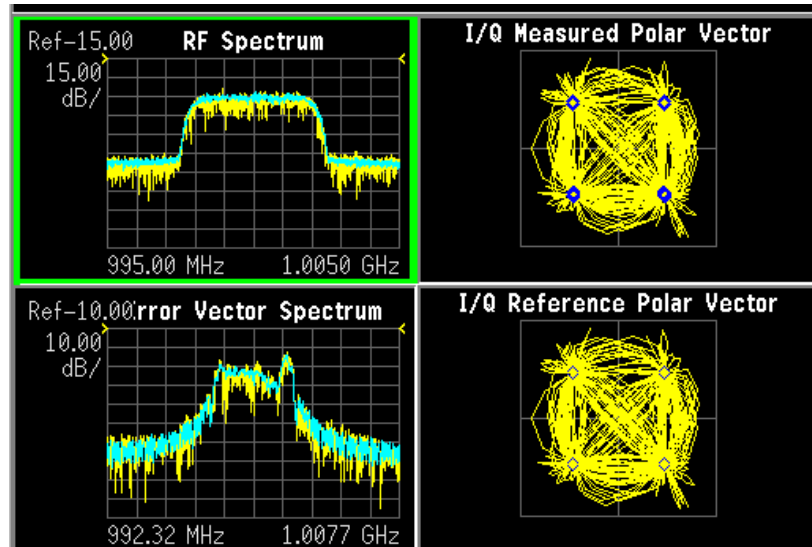


The combination of OVVSF codes and scrambling codes provide the signal spreading, and therefore, the spreading gain needed for the receiver correlators to pull the desired signal out of the noise. The SF determines the degree of spreading gain. For high data rate signals, the SF and spreading gain are lower. For the same level of interference, the amplitude for high data rate channels must be higher, in order for all channels to maintain equal energy-per-bit-to-noise ratio (E_b/N_0).

W-CDMA Communication System

Figure 5-67

W-CDMA Error Vector Spectrum (Quad-View)



What Is the cdma2000 Communication System?

Introduction

Code Division Multiple Access 2000 (cdma2000) is a wideband CDMA standard that has been adopted by 3GPP2. It provides a wideband air interface for third generation global wireless communications systems. cdma2000 is a derivative of the IS-95-B CDMA system, also known as cdmaOne, and provides an upgrade path to support IMT-2000. This section will present the basics of cdma2000 as it differs from IS-95, and will assume the reader has some familiarity with IS-95 technology.

cdma2000 is defined in the following Telecommunications Industry Association (TIA) and Electronics Industry Alliance (EIA) document: TIA/EIA/IS-2000-1 through TIA/EIA/IS-2000-6.

cdma2000 relies on the Global Positioning System (GPS) for intercell synchronization. Both reverse and forward transmitter power controls are implemented with 1.25 ms intervals. cdma2000 is a direct sequence spread-spectrum digital communications technique that supports wider RF bandwidths from 1.25 to 15 MHz. The main advantages of cdma2000 over other types of digital communication schemes are:

- greater capacity
- immunity to signal loss and degradation due to high-level broadband interference, multipath, and fading
- strict minimization of power consumption for mobile stations by both base station and mobile controls
- support for variable data rates; up to 144 kbits/second for mobile (vehicular) data rate, up to 384 kbits/second for portable (pedestrian) data rate, and up to 2 Mbits/second for fixed installations
- increased security

cdma2000 uses correlative codes to distinguish one user from another. Frequency division is still used, as is done with Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), but in a much larger bandwidth such as 1.25 MHz or greater. cdma2000 realizes increased capacity from 1:1 frequency reuse and sectored cells. The capacity limit is soft. That is, capacity can be increased with some degradation of the error rate or voice quality.

In cdma2000, a single user's channel consists of a specific frequency combined with a unique Walsh code channel. Correlative Walsh codes enable each user to operate in the presence of substantial interference. The interference is the sum of all other users on the same cdma2000 frequency, both from within and outside of the home cell, and from delayed versions of these signals. It also includes the usual thermal noise and atmospheric disturbances. Delayed signals caused by multipath are separately received and combined in cdma2000. One of the major differences in access is that any cdma2000 frequency can be used in all sectors of all cells. This is possible because cdma2000 is designed to decode the proper signal in the presence of high interference.

Also, cdma2000 offers a number of RF structures to accommodate almost any conceivable application. These options include direct spreading to support those applications where clear spectrum is available and multi-carrier arrangements using 1.25 MHz wide channels to allow overlays with TIA/EIA-95-B systems.

Spreading Rate

Spreading rate (SR) defines the final spread chip rate in terms of 1.2288 Mcps. The two spreading rates are SR1 and SR3. An SR1 signal has a chip rate of 1.2288 Mcps and occupies the same bandwidth as cdmaOne signals. The SR1 system doubles the system capacity; therefore, it can be considered an improved cdmaOne system.

There are two main differences between cdmaOne and cdma2000. The first is fast power control and quadrature phase shift keying (QPSK) modulation rather than dual binary phase shift keying (BPSK) in the forward link. The second difference is the presence of a pilot signal, to allow coherent demodulation, and hybrid phase shift keying (HPSK) spreading in the reverse link.

An SR3 cdma2000 signal has a rate of 3.6864 Mcps (3×1.2288 Mcps) and occupies three times the bandwidth of cdmaOne. Originally, the SR3 system appeared to be viable. Upon further investigation the SR3 cdma2000 system was determined to not be viable and is no longer receiving any commercial attention at this time. Therefore, we will not be covering SR3 in this section.

Radio Configuration

Radio configuration (RC) defines the physical channel configuration based upon a specific channel data rate. Each RC specifies a set of data rates based on either 9.6 or 14.4 kbps bit streams, the two existing data rates supported for cdmaOne. Each RC also specifies the spreading rate (either SR1 or SR3) and the physical coding. Currently there are nine radio configurations defined in the cdma2000 system for the forward link and six for the reverse link. Examples include:

- RC1 is the backwards-compatible mode of cdmaOne for 9600-bps voice traffic. It includes 9.6, 4.8, 2.4, and 1.2 kbps data rates and operates at SR1. It does not use any of the cdma2000 coding improvements.
- RC3 is a cdma2000-specific configuration based on 9.6 kbps that also supports 4.8, 2.7, and 1.5 kbps for voice, while supporting data at 19.2, 38.4, 76.8, and 153.6 kbps and operates at SR1. Each base transceiver station (BTS) or MS must be capable of transmitting using different RCs at the same SR. Refer to [1] for detailed information on the different RCs.

Differences between cdma2000 and W-CDMA

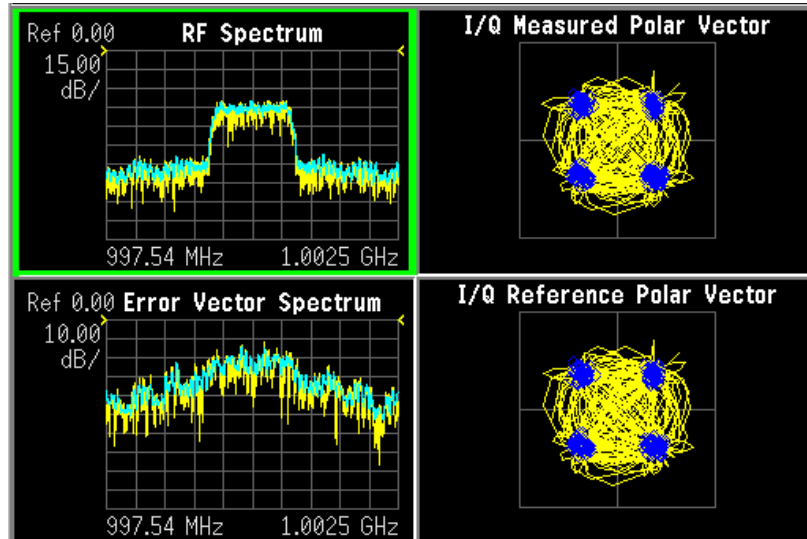
The Third-Generation Partnership Project (3GPP) W-CDMA is the other main wideband CDMA technology competing for the 3G cellular market. There has been much discussion about the need to harmonize W-CDMA and cdma2000 in an attempt to facilitate global use of 3G phones. However, even though both systems are based on a similar CDMA technology, they are significantly different. The main differences are:

- spreading rate - (3.84 Mcps for W-CDMA versus 1.2288 Mcps for cdma2000 SR1)
- synchronization and BTS identification methodology - W-CDMA does not use GPS, or Global Positioning System. For information on-CDMA user equipment (UE)¹ design and test issues, refer to [2].

1. W-CDMA specifications use the term UE to refer to mobile phones or other computing devices that provide wireless access to the W-CDMA system.

cdma2000 Communication System

Figure 5-68 *cdma2000 Error Vector Spectrum (Quad-View)*



What is the NADC Communications System?

The North American Dual-Mode Cellular (NADC) is one of the cellular communications systems. NADC is also referred to as North American Digital Cellular, or American Digital Cellular (ADC). Occasionally it is also referred to as Digital Advanced Mobile Phone Service (D-AMPS) or NADC-TDMA.

The NADC communications system is defined in the Electronics Industry Alliance (EIA) and Telecommunication Industry Association (TIA) standard documents. The following is a list of all relevant and applicable standard documents:

- TIA/EIA IS-136.1
TDMA Cellular/PCS - Radio Interface - Mobile Station - Base Station Compatibility - Digital Control Channel
- TIA/EIA IS-136.2
TDMA Cellular/PCS - Radio Interface - Mobile Station - Base Station Compatibility - Traffic Channels and FSK Control Channel
- TIA/EIA IS-137
TDMA Cellular/PCS - Radio Interface - Minimum Performance Standards for Mobile Stations
- TIA/EIA IS-138
TDMA Cellular/PCS - Radio Interface - Minimum Performance Standards for Base Stations
- TIA/EIA-627

800 MHz Cellular System, TDMA Radio Interface, Dual-Mode Mobile Station - Base Station Compatibility Standard (ANSI/TIA/EIA-627-96), which replaced IS-54-B

- TIA/EIA-628

800 MHz Cellular System, TDMA Radio Interface, Minimum Performance Standards for Dual-Mode Mobile Stations (TIA/EIA-628-96), which replaced IS-55-A

- TIA/EIA-629

800 MHz Cellular System, TDMA Radio Interface, Minimum Performance Standards for Base Stations Supporting Dual-Mode Mobile Stations (ANSI/TIA/EIA-629-96), which replaced IS-56-A

Each base station retains the analog control channels and analog traffic channels of the advanced mobile phone service (AMPS) system. In addition, a base station can have digital traffic channels. The mobile stations are dual mode and access the network via the analog control channel. They are capable of using either analog or digital traffic channel. Digital control channel and digital only mobile stations are also currently being produced.

The AMPS system and the analog part of the NADC IS-54 system employ a frequency division multiple access (FDMA). FDMA means that each traffic channel is assigned to a separate RF frequency. A pair of frequencies with 45 MHz apart (80 MHz apart for 1900 MHz band) is used to provide full duplex operation of the NADC system. The RF channel spacing is 30 kHz. The modulation for the analog portion is frequency modulation (FM).

The digital part of the NADC system employs a combination of FDMA and time division multiple access (TDMA). The NADC time division multiple access structure enables up to six users to share a single carrier frequency. The TDMA frame structure divides time on a carrier into a stream of frames. Each frame is 40 ms long consisting of 6 timeslots; thus, one timeslot is 6.67 ms long. A digital traffic channel is defined by a carrier frequency (or channel number) and a timeslot number. Each user must transmit data only on his carrier frequency, at a time defined by timeslot number. Currently, 2 timeslots per frame are required for each user because more time is required to transmit voice using full-rate speech codecs presently available. When half-rate speech codecs are incorporated into the system, each traffic channel will require just one timeslot per frame.

NADC digital mobile stations transmit a burst of data when their assigned timeslot occurs. This means a mobile station transmits a bursted amplitude modulation signal, ramping transmission power on and off. An NADC digital base station transmits continuously, switching digital modulation on at the appropriate timeslots.

The digital modulation format used in the NADC system is the $\pi/4$ differential quadrature phase shift keying ($\pi/4$ DQPSK). The $\pi/4$ DQPSK modulation causes both phase and amplitude variations on the RF signal. The quadrature nature of this modulation enables 2 bits to be transmitted at the same time on orthogonal carriers. These 2 bits make one NADC symbol. The digital modulation operates at 162 symbols, or 324 bits in each timeslot. Since there are 1944 bits in 6 timeslots and 25 frames in one second, the transmission bit rate is 48,600 bits per second.

The key objectives of the NADC system are to increase the subscriber capacity, provide more secure voice communications, and be backwards compatible with the existing AMPS analog cellular system.

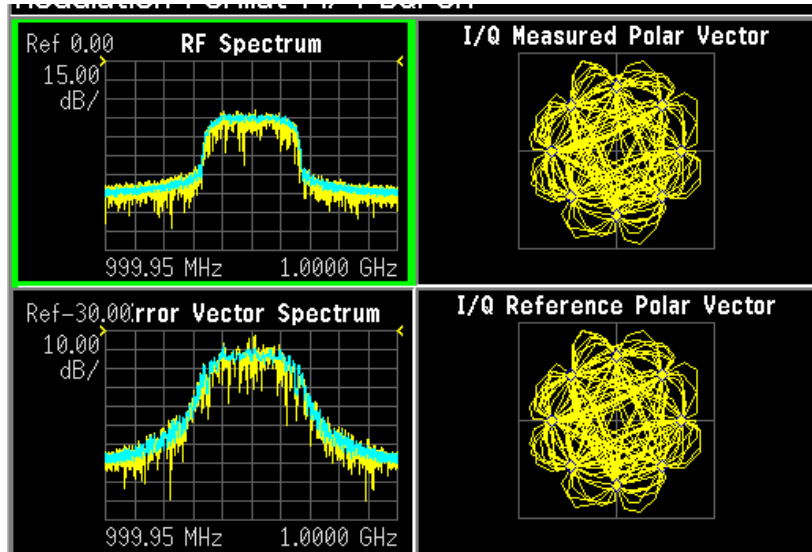
Since the system transmits all information in a digital form, it will be much harder to listen to someone else's cellular phone conversation. This is a key benefit for people using cellular phones that convey confidential information. The NADC is backwards compatible with the existing AMPS system so that analog cellular phones would not be obsolete. Therefore, all NADC mobiles have the capability to operate using the existing analog base stations as well as the digital base stations.

Following is a summary of the NADC air interface. Note that the frequency range is the same as the analog cellular. Since it is a dual-mode system, NADC will use the same frequency band currently assigned to the AMPS cellular. The available channels are divided into analog and digital channels. The channel spacing is 30 kHz each, and the RX/TX frequency difference is 45 MHz as in the AMPS cellular. NADC has a RX/TX time spacing of 1.85 ms. It uses the $\pi/4$ DQPSK modulation and the modulation rate is 24.3 ksymbols/sec. NADC will initially enable 3 users per frequency pair and will enable 6 when implemented with the half-rate voice coder. One frame is 40 ms and consists of 6 timeslots that are each 6.667 ms long. There are 162 symbols per timeslot and the symbol period is 41.16 μ s.

800 MHz	Uplink	825.030 to 848.970 MHz	824.040 to 825.000 MHz
	Downlink	870.030 to 893.970 MHz	869.040 to 870.000 MHz
	Channel Numbers	1 to 799	991 to 1023
1900 MHz	Uplink	1850.040 to 1909.920 MHz	
	Downlink	1930.080 to 1989.990 MHz	
	Channel Numbers	2 to 1998	

NADC Communication System

Figure 5-69 NADC Error Vector Spectrum (Quad-View)



What is the PDC Communications System?

The PDC communications system is defined in the Research and Development Center for Radio Systems document, RCR STD-27, the Personal Digital Cellular Telecommunication System Standard.

The PDC system is a digital communications system that employs a combination of a frequency division multiple access (FDMA) and a time division multiple access (TDMA). A pair of frequencies (130 or 50 MHz apart in the 800 MHz bands and 48 MHz apart in the 1500 MHz band) is used to provide the full duplex operation with RF channels spacing 50 kHz each with interleaving by 25 kHz.

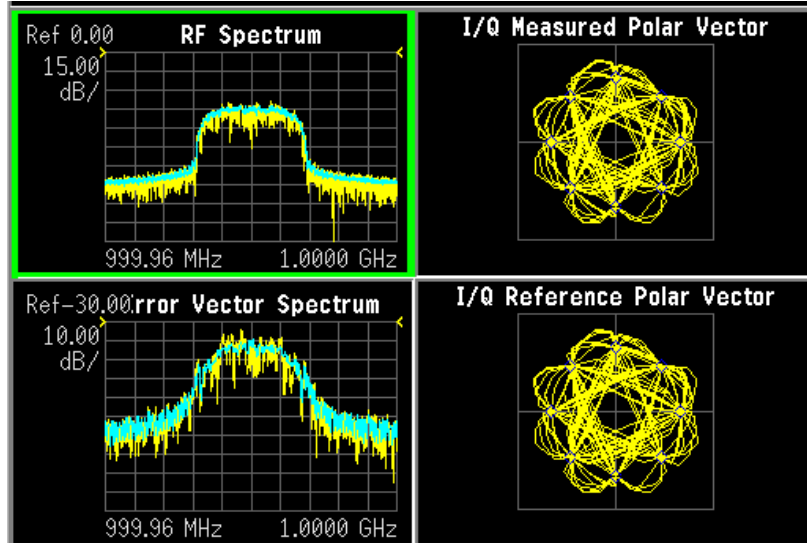
800 MHz	Uplink	940 to 958 MHz	887 to 889 MHz
	Downlink	810 to 828 MHz	832 to 834 MHz
800 MHz	Uplink	898 to 901 MHz	915 to 940MHz
	Downlink	843 to 846 MHz	860 to 885 MHz
1500 MHz	Uplink	1429 to 1453 MHz	
	Downlink	1477 to 1501 MHz	

One TDMA frame is structured with 6 timeslots, so each channel frequency can support up to 6 timeslots. Currently, two timeslots of each frame are used for one traffic channel, which is required for the full-rate speech codec. When half-rate speech codecs are incorporated into the system, each traffic channel will require just one timeslot per frame. One frame is 40 ms long and each timeslot is 6.667 ms long. Thus, the mobile stations have burst carriers that are turned on for two timeslots (full-rate codec) or one timeslot (half-rate codec). When an RF channel is in use by a digital base station, the base station carrier will be turned on for one entire frame. This is true even if only one traffic channel is in use on that RF channel. However, the carrier power can be different at each timeslot.

The digital modulation format used in the PDC system is $\pi/4$ differential quadrature phase shift keying ($\pi/4$ DQPSK). The $\pi/4$ DQPSK modulation causes both phase and amplitude variations on the RF signal. The quadrature nature of this modulation enables 2 bits to be transmitted at the same time on orthogonal carriers. There are 140 symbol periods in each timeslot, and each symbol contains 2 bits of information. Therefore, there are 280 bits in each timeslot. Since there are 1,680 bits in 6 timeslots and 25 frames in one second, the transmission bit rate is 42,000 bits per second.

PDC Communication System

Figure 5-70 PDCError Vector Spectrum (Quad-View)



What is the PHS Communication System

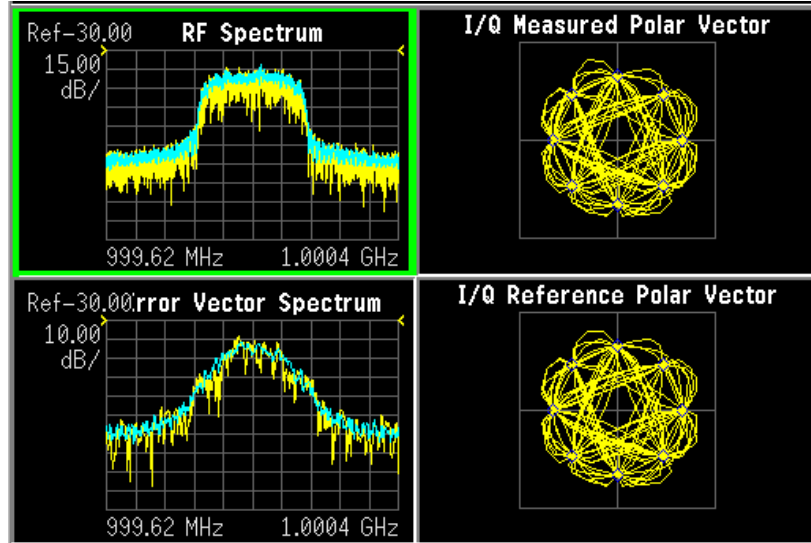
PHS

NTT Personal Communications Network Group and DDI Pocket Telephone Group began operation of PHS (personal handy-phone system) services in Tokyo and Sapporo on July 1, 1995. PHS is an effective data transmission means for mobile computing, and allows terminals to be used in virtually any locations at home, outdoors and in the office.

The PHS standard is a TDD-TDMA based low tier micro cellular wireless communications technology operating in the 1880 to 1930 MHz band, now used by millions of subscribers worldwide in public PHS networks, PHS-WLL networks, corporate indoor PBX applications and in the home environment. The cell installation architecture, which uses dynamic channel allocation, requires reduced cell station installation planning and costs for the operators, and can be cost effectively deployed in environments ranging from urban to rural environments.

PHS Communication System

Figure 5-71 PHS Error Vector Spectrum (Quad-View)



What is the TETRA Communications System

TETRA is a digital trunked radio system that can provide voice or data communications between PMR users.

The trunked radio aspects enable the users to only occupy as much of the spectrum as they need to deliver a message. When the radio channel is not conveying information it is made available to others to use. In addition the TETRA network enables one terminal to efficiently communicate with other terminals in ways which are difficult to achieve with the public cellular networks.

The digital modulation format used is $\pi/4$ DQPSK (45 degree phase offset Differential Quaternary Phase Shift Keying), with a root-raised cosine channel filter with an alpha of 0.35 in both the transmitter and the receiver, giving an overall raised cosine filter response. This modulation scheme ensures a highly efficient use of the radio frequency spectrum.

Each radio frequency (RF) carrier is divided into four time slots, which enables up to four users to key their mobile radios to the same carrier frequencies. The RF carriers are spaced at 25 kHz intervals, resulting in very efficient use of the spectrum since each user effectively occupies just 6.25 kHz of spectrum. The use of digital technology ensures good frequency re-use patterns and simulcast networking if required. The air interface data rate is 36 kbits/s (18 ksymbols/s).

The air interface uses a frequency offset between its transmit and receive frequencies - the frequency duplex - the exact difference being network implementation dependent. For public safety applications in the 380 to 400MHz band the duplex is typically 10 MHz.

The TETRA standard uses a digital voice coder/decoder (codec), proposed by SGS Thomson, which reduces the speech information to a low data rate of 4.567 kbits/s. The codec ensures that the speech data is suitable for transmission over the air interface as well as ensuring that voice transmissions are secure from casual eavesdropping. In addition encryption systems are supported to provide even greater levels of security since the transmissions cannot be decoded by only monitoring the air interface.

The standard also enables two mobile terminals to communicate without the presence of any infrastructure (called Direct Mode Operation or DMO). This means that the range of the TETRA system can be extended outside the normal coverage area - for example aiding the penetration of a building or basement area which would normally have poor coverage. This feature, which is particularly valuable for public safety authorities, is not easily achieved by cellular systems with their fixed infrastructure. Another use of the DMO system is extending the cell coverage by using terminals as repeaters, enabling terminals outside the cell to use terminals, which can communicate with the cell to pass the information on.

Data transmissions are supported by the TETRA standard with both circuit mode data (where the terminal acts as an RF modem) and packet data (based on Internet Protocol). Data can be transmitted in idle slots or even transmitted in more than one

time slot per frame to increase the data rate. This is useful for transmitting graphical information (including maps), scanned images (such as fingerprints) or transmitting low bit rate compressed camera images.

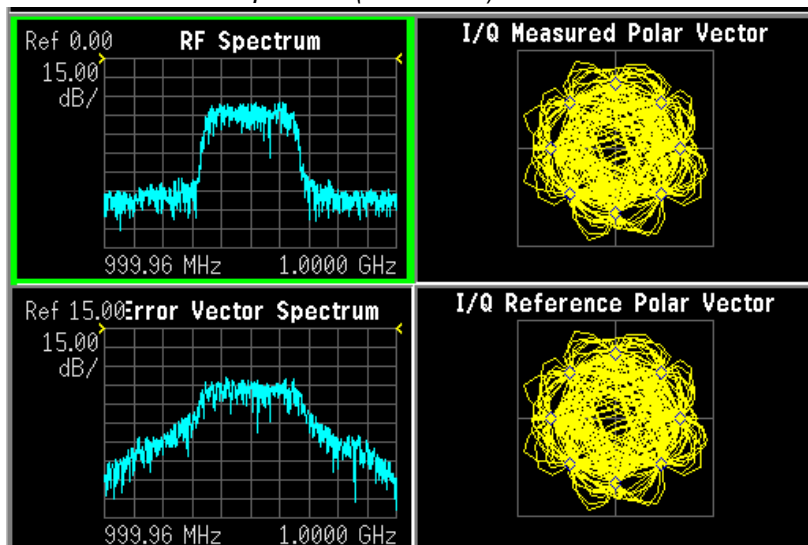
The call set up times (300 ms) is very short compared to cellular systems, which is particularly important in high speed transportation systems and emergency situations. Broadcast transmissions to multiple handsets (point to multipoint) are also allowed - a crucial feature for many PMR applications.

The option of adding a SIM (subscriber interface module) card similar to that used in GSM will provide additional services and security for users, including the easy transfer of user set-ups to a replacement radio for maintenance or roaming purposes.

TETRA Communication System

Figure 5-72

TETRA Error Vector Spectrum (Quad-View)



What is Bluetooth?

Bluetooth is a limited range RF link technology. It is targeted at voice and data transmission between information appliances for home or business environments. The Bluetooth technology eliminates the need for interconnecting cables and enables ad hoc networking among devices.

The Bluetooth system consists of a radio unit, a baseband link control unit, and link management software. It also includes higher-level software utilities that focus on inter operability features and functionality. The following figure is a block diagram for this type of frequency hopping system, showing the baseband controller and the RF transmitter and receiver sections.

Bluetooth devices operate in the 2400 - 2483.5 MHz Industrial, Scientific and Medical (ISM) band. This band is unlicensed and available globally.

The design emphasis is on very low power, extremely low cost, and robust operation in the uncoordinated, interference dominated RF environment of the ISM band.

The range is specified as 10 meters, or 100 meters with an additional 20 dB power amplifier. The maximum data rates for a single link are 432.6/432.6 kbps symmetrical, or 721.0/57.6 kbps asymmetrical. The connection topology is basically a star, with a single master and up to 7 slaves.

The radio unit employs Frequency Hopping Spread Spectrum (FHSS). Frequency hopping is pseudo-random, usually at 1600 hops/sec. The signal is nominally at each hop frequency for one 625 us timeslot. Each pair of time consecutive slots constitutes a time-division duplex (TDD) frame. The first slot contains a master-to-slave burst; the second may contain a slave-to-master burst.

There are 79 Bluetooth channels, each 1 MHz wide. Frequency hopping occurs over all the 79 channels.

Communication is by packet based TDD. Each data packet has a preamble / header / payload format. Various packet types are defined. Various levels of error correction and link security are supported. Circuit and packet modes of operation are supported. Digitized audio and data are supported. Procedures for link control are defined.

Bluetooth Radio Unit

The Bluetooth radio unit is shown in the following figure as the transmitter and receiver sections of the block diagram. The transmitter up converts the baseband information to the frequency-modulated carrier. Frequency hopping and bursting are performed at this level. Conversely, the receiver down converts and demodulates the RF signal. The following table summarizes some of the key RF characteristics of Bluetooth.

Figure 5-73

Bluetooth radio block diagram

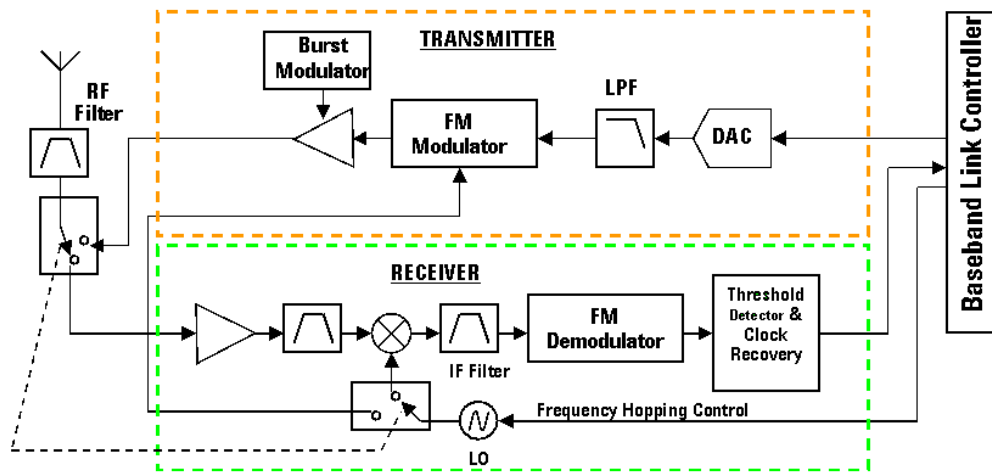


Table 5-4 Bluetooth RF Characteristics

Characteristic	Specification	Notes
Carrier Frequency	2400 to 2483.5 MHz (ISM radio band)	$f=2402+k$ MHz, $k=0,\dots,78$
Modulation	0.5 BT Gaussian-filtered 2FSK at 1 Msymbol/s Modulation index: 0.28 to 0.35 (0.32 nominal)	Digital FM scheme The peak frequency deviation allowed is 175 kHz

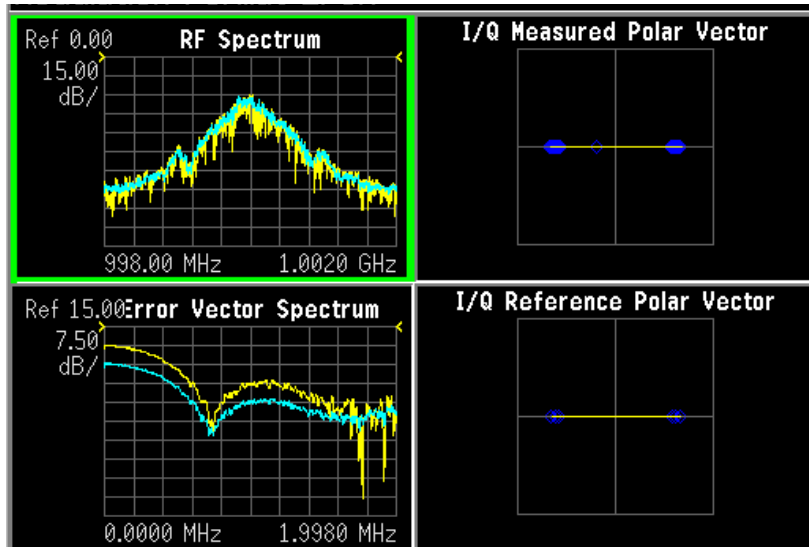
Table 5-4 Bluetooth RF Characteristics

Characteristic	Specification	Notes
Hopping	<p>1600 hops/s (in normal operation)^a</p> <p>1 MHz channel spacing</p> <p>The system has 5 different hopping sequences:</p> <ol style="list-style-type: none"> 1) Page hopping sequence 2) Page response sequence 3) Inquiry sequence 4) Inquiry response sequence 5) Channel hopping sequence <p>The first four are restricted hopping sequences used during connection setup. The normal channel hopping sequence is pseudorandom based on the master clock value and device address.</p>	<p>The channel hopping sequence is designed to visit each frequency regularly and with roughly equal probability. It has a periodicity of 23 hours and 18 minutes.</p>
Transmit Power	<p>Power Class 1: 1 mW (0 dBm) to 100 mW (+20 dBm)</p> <p>Power Class 2: 0.25 mW (−6 dBm) to 2.5 mW (+4 dBm)</p> <p>Power Class 3: 1 mW (0 dBm)</p>	<p>Class 1 power control: +4 to +20 dBm (required) −30 to 0 dBm (optional)</p> <p>Class 2 power control: −30 to 0 dBm (optional)</p> <p>Class 3 power control: −30 to 0 dBm (optional)</p>
Operating Range	<p>10 cm to 10 m (100 m with Power Class 1)</p>	
Maximum Data Throughput	<p>The asynchronous channel can support an asymmetric link of maximally 721 kbps in either direction while permitting 57.6 kb/s in the return direction, or a 432.6 kbps symmetric link.</p>	<p>Data throughput is lower than the 1 Msymbol/s rate as a result of the overhead, which is inherent in the protocol.</p>

a. Hop speed may vary depending on packet length.

Bluetooth Communication System

Figure 5-74 Bluetooth Error Vector Spectrum (Quad-View)



What are GSM and EDGE?

The Global System for Mobile communication (GSM) digital communications standard defines a voice and data over-air interface between a mobile radio and the system infrastructure. This standard was designed as the basis for a radio communications system. A base station control center (BSC) is linked to multiple base transceiver station (BTS) sites that provide the required coverage.

EDGE (Enhanced Data Rates for GSM Evolution) enhances the GSM standard by implementing a new modulation format and filtering designed to provide higher data rates in the same spectrum. EDGE and GSM signals can be transmitted on the same frequency, occupying different timeslots, and both use existing GSM equipment. EDGE has also been adopted as the basis for IS-136HS.

GSM 450, GSM 480, GSM 850, GSM 900, DCS 1800, and PCS 1900 are GSM-defined frequency bands. The term GSM 900 is used for any GSM system operating in the 900 MHz band, which includes P-GSM, E-GSM, and R-GSM. Primary (or standard) GSM 900 band (P-GSM) is the original GSM band. Extended GSM 900 band (E-GSM) includes all the P-GSM band plus an additional 50 channels. Railway GSM 900 band (R-GSM) includes all the E-GSM band plus additional channels. DCS 1800 is an adaptation of GSM 900, created to allow for smaller cell sizes for higher system capacity. PCS 1900 is intended to be identical to DCS 1800 except for frequency allocation and power levels. The term GSM 1800 is sometimes used for DCS 1800, and the term GSM 1900 is sometimes used for PCS 1900. The following documents detail the standards used when testing:

Table 5-5 Documents detailing the GSM/EDGE standards used:

	GSM-450 GSM-480 GSM-850 GSM-900	DCS-1800	PCS-1900
Mobile station	ETS 300 607-1 (11.10)	ETS 300 607-1 (11.10)	J-STD-007
Base station	ETS 300 609-1 (11.21)	ETS 300 609-1 (11.21)	J-STD-007
Radio transmission and reception	ETS 300 910 (5.05)	ETS 300 910 (5.05)	J-STD-007

NOTE

These standards are continually being updated by the communications industry.

The GSM digital communications standard employs an 8:1 Time Division Multiple Access (TDMA) enabling eight channels to use one carrier frequency simultaneously. The 270.833 kbits/second raw bit rate is modulated on the RF carrier using Gaussian Minimum Shift Keying (GMSK).

The standard includes multiple traffic channels, a control channel, and a cell broadcast channel. The GSM specification defines a channel spacing of 200 kHz.

Table 5-6 *EDGE and GSM Band Data*

	P-GSM (GSM 900)	E-GSM (GSM 900)	R-GSM (GSM 900)	DCS 1800 (GSM 1800)	PCS 1900 (GSM 1900)	GSM 450	GSM 480	GSM 700	GSM 850
Uplink (MS Transmit)	890 to 915 MHz	880 to 915 MHz	876 to 915 MHz	1710 to 1785 MHz	1850 to 1910 MHz	450.4 to 457.6 MHz	478.8 to 486 MHz	777 to 792 MHz	824 to 849 MHz
Downlink (BTS Transmit)	935 to 960 MHz	925 to 960 MHz	921 to 960 MHz	1805 to 1880 MHz	1930 to 1990 MHz	460.4 to 467.6 MHz	488.8 to 496 MHz	747 to 762 MHz	869 to 894 MHz
Range (ARFCN)	1 to 124	0 to 124 and 975 to 1023	1 to 124 and 955 to 1023	512 to 885	512 to 810	259 to 293	306 to 340	438 to 511	128 to 251
TX/RX Spacing (Freq.)	45 MHz	45 MHz	45 MHz	95 MHz	80 MHz	45 MHz	45 MHz	30 MHz	45 MHz
TX/RX Spacing (Time)	3 timeslots	3 timeslots	3 timeslots	3 timeslots	3 timeslots	3 timeslots	3 timeslots	3 timeslots	3 timeslots
Modulation Data Rate GMSK (kbits/s) 8PSK (kbits/s):	270.833 812.499	270.833 812.499	270.833 812.499	270.833 812.499	270.833 812.499	270.833 812.499	270.833 812.499	270.833 812.499	270.833 812.499
Frame Period	4.615 ms	4.615 ms	4.615 ms	4.615 ms	4.615 ms	4.615 ms	4.615 ms	4.615 ms	4.615 ms
Timeslot Period	576.9 μ s	576.9 μ s	576.9 μ s	576.9 μ s	576.9 μ s	576.9 μ s	576.9 μ s	576.9 μ s	576.9 μ s
GSM Bit and Symbol Period	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s
EDGE Symbol Period	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s	3.692 μ s
Modulation GSM EDGE	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK	0.3 GMSK 3 π /8 8PSK
Channel Spacing	200 kHz	200 kHz	200 kHz	200 kHz	200 kHz	200 kHz	200 kHz	200 kHz	200 kHz
TDMA Mux	8	8	8	8	8	8	8	8	8

Table 5-6 *EDGE and GSM Band Data*

	P-GSM (GSM 900)	E-GSM (GSM 900)	R-GSM (GSM 900)	DCS 1800 (GSM 1800)	PCS 1900 (GSM 1900)	GSM 450	GSM 480	GSM 700	GSM 850
Voice Coder Bit Rate	13 kbits/s	13 kbits/s, 5.6 kbits/s	13 kbits/s	13 kbits/s	13 kbits/s	13 kbits/s	13 kbits/s	13 kbits/s	13 kbits/s

The framing structure for GSM and EDGE measurements is based on a hierarchical system consisting of timeslots, TDMA frames, multiframes, superframes, and hyperframes. One timeslot consists of 156.25 (157) symbol periods including tail, training sequence, encryption, guard time, and data bits. Eight of these timeslots make up one TDMA frame. Either 26 or 51 TDMA frames make up one multiframe. Frames 13 and 26 in the 26 frame multiframe are dedicated to control channel signaling.

These principles of the GSM systems lead to the need for the fundamental transmitter measurements such as:

- Power vs Time - which verifies that the transmitter output power has the correct amplitude, shape, and timing for the TDMA sequence.
- Phase and Frequency Error - which verifies the accuracy of the transmitters 0.3 GMSK modulation process.
- Output RF Spectrum - which verifies that the RF carrier is contained within the designated 200 kHz channel.

Mobile Stations and Base Transceiver Stations

The cellular system includes the following:

- base transceiver stations, referred to as BTS
(frequency ranges dependent on the standard; refer to)
- mobile stations, referred to as MS
(frequency ranges dependent on the standard; refer to)

Uplink and Downlink

Uplink is defined as the path from the mobile station to the base transceiver station.

Downlink is the path from the base transceiver station to the mobile station.

What is an ARFCN?

An ARFCN is the Absolute Radio Frequency Channel Number used in the GSM system. Each RF channel is shared by up to eight mobile stations using Time Division Multiple Access (TDMA). The ARFCN is an integer (in a range dependent on the chosen standard, refer to) which designates the carrier frequency.

What Is A Timeslot?

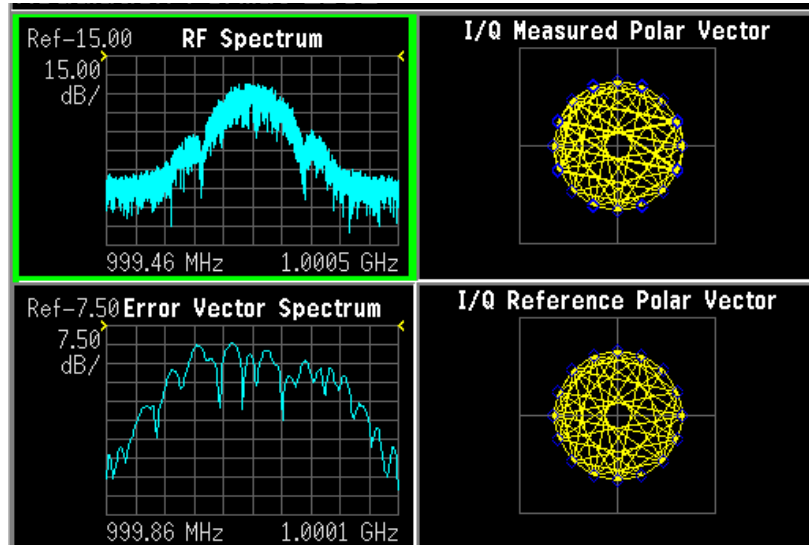
GSM utilizes Time Division Multiple Access (TDMA) with eight time slots per RF channel which enables eight users to use a single carrier frequency simultaneously. Users avoid one another by transmitting in series. The eight users can transmit once every 4.62 ms for 1 timeslot which is 577 μ s long. The eight user timeslots are numbered from 0 to 7.

Typically, each 577 μ s timeslot has a length of 156.25 bit periods, which consists of 148 data bits and 8.25 guard bits. The 4.62 ms required to cycle through eight timeslots is called a frame. In a TDMA system, the shape of each transmitted burst must be controlled carefully to avoid over-lapping bursts in time.

EDGE Communication System

Figure 5-75

EDGE Error Vector Spectrum (Quad-View)



What is APC025 phase 1?

APC025 is Project 25, a joint effort of APCO, the Association of Public-Safety Communications Officials, International, Inc. and the National Association of State Telecommunications Directors. APC025 phase1 is a digital trunked radio system that uses FDMA, Frequency Division Multiple Access modulation. Phase 1 is a modulation format in which individual carriers are modulated using 9600 baud FSK for the forward link and methods known as C4FM (a 4FSK scheme) and CQPSK (a 25QAM scheme) for the reverse link.

FEATURES OF APC025 phase 1

6.25 kHz Bandwidth (CQPSK) Modulation The QPSK, or QPSK-C, modulator consists of a table look-up, the two outputs of which (I and Q) are Nyquist filtered and then amplitude modulated, in phase and quadrature phase, before summing. The information bits are processed by the look-up table to yield a 5-level I signal and a 5-level Q signal. The I and Q signals are filtered with the Nyquist Raised Cosine Filter previously described. The I signal is then multiplied by the carrier and the Q signal is multiplied by the carrier after it has been delayed by 90 degrees. The modulated I and Q carriers are then summed together to yield the modulator output.

The C4FM modulator consists of a Nyquist Raised Cosine Filter, cascaded with a shaping filter, cascaded with a frequency modulator.

Addressing A very large number of radio addresses are provided, both for individual radios and talk-groups.

Aggregate Bit Rate The aggregate bit rate is 9600 bits/s. In the case of data transmission, data packets basically consist of a header, containing overhead information, followed by data. In the case of digitized voice transmission, after the transmission of a header containing error protected overhead information, 2400 bits/s is devoted to periodically repeating the overhead information needed to allow for late entry (or the missed reception of the header).

C4FM Frequency Modulator The deviation is +1.8 kHz for dibit 01, +0.6 kHz for dibit 00, -0.6 kHz for dibit 10, and -1.8 kHz for dibit 11.

C4FM Nyquist Filter The dibits of information (i.e., 4800 symbols) are filtered with a raised cosine filter which satisfies the Nyquist criterion minimizing inter-symbol interference. The group delay of the filter is flat over the pass-band for $|f| < 2880$ Hz. The magnitude response of the filter is approximately 1 for $|f| < 1920$ Hz, $0.5 + 0.5 \cos(2(f/1920))$ for $1920 \text{ Hz} < |f| < 2880$ Hz, and 0 for $|f| > 2880$ Hz.

C4FM Shaping Filter The shaping filter has a flat group delay over the band-pass for $|f| < 2880$ Hz. The magnitude response of the filter for $|f| < 2880$ Hz is $\sin(\pi f/4800)/(\pi f/4800)$.

Data Packet Data Blocks Confirmed Data Blocks contain a 7-bit serial number (to allow for selective transmission), 9 bits of error detection on the entire block, and 14 octets of data. Unconfirmed Data Blocks contain 12 octets of data (note: a 32-bit error detection code is appended to the end of all data packets).

Data Packet Error Correction Header Blocks normally use a rate 1/2 trellis coder for error correction. Unconfirmed data packets normally use a rate 1/2 trellis coder, while confirmed data packets normally use a rate 3/4 trellis coder. Interleaving is applied over Data Blocks.

Data Packet Header The Header Block used for communications between a radio and a packet data node (i.e., switch) contains 10 octets of address and control information, followed by 2 octets of error detection coding. Information contained in the header includes: the identity of the Service Access Point to which the data is being directed, a manufacturers identification (to allow for non-standard functions), a logical link identifier to identify the sending radio of an inbound packet to a node and the receiving radio of a packet outbound from a node, the number of blocks to follow in the packet, the number of pad octets to fill out the last block, the sequence number of the packet, and the Fragment sequence number. For packet data communications directly between two radios, essentially two 12-octet Header Blocks are used at the beginning of each packet in order to convey the necessary address and control information. The header is preceded by 48 bits of synchronization and 64 bits of network identifier (to prevent confusion between radios in different networks).

Data Packet Structure Data messages are divided into Fragments of less than 512 octets. Fragments are, in turn, divided into Blocks of M octets, where $M=12$ for unconfirmed messages and $M=16$ for confirmed messages (except Header Blocks are 12 octets in length). Note: a Fragment, preceded by header information, is defined as a Data Packet.

Demodulator The demodulator is capable of receiving both the C4FM and the CQPSK signals. It consists of a frequency modulation detector, followed by an Integrate and Dump Filter and then a stochastic gradient clock recovery device. The Integrate and Dump Filter has a flat group delay over the band-pass for $|f| < 2880$ Hz. The magnitude response of the Integrate and Dump Filter, for $|f| < 2880$ Hz, is approximately $\sin(\pi f/4800)/(\pi f/4800)$.

Digitized Voice Coder Method After evaluating several candidates, APC025 selected IMBE (Improved MultiBand Excitation) vocoder, operating at 4400 bits/s. An additional 2800 bits/s of forward error correction is added, for error correction of the digitized voice. IMBE has also been selected by INMARSAT, for use in digital voice maritime satellite communications.

Digitized Voice Frame Structure The Header Word, transmitted at the start of every transmission, contains 120 bits of information and 528 bits of error correction. Voice Frames are 180 ms in length and pairs of Voice frames compose a 360 ms Superframe. The first of a pair of voice frames transmits, in addition to digitized voice and its error corrective coding, 72 bits of link control information, 168 bits of error corrective coding on the link control information, and 16 bits of embedded low-speed data signaling with 16 bits of error corrective coding. The second of the pair of voice frames transmits an additional 16 bits of low-speed data signaling with 16 bits of error corrective coding, 96 bits of encipherment information, and 144 bits of error protective coding on the encipherment information.

Digitized Voice Header Word The header is preceded by 48 bits of synchronization signal and a 64-bit network identifier (to prevent confusion between radios in different networks). The 120 bits of information in the Header Word consists of 72 bits for the

encipherment initialization vector, 8 bits for a manufacturer identifier, 8 bits to identify the encipherment algorithm, 16 bits to identify which encipherment key variable is being employed (in systems with multiple encipherment key variables), and 16 bits for the talkgroup address. Including error corrective coding, status symbols (22 bits) not described in this brief contribution, and preceding signaling, the header requires 82.5 ms for transmission.

Digitized Voice Encryption Information The 96 bits of encipherment information consist of the three encipherment-related fields in the header: the 72-bit encipherment initialization vector, the 8-bit encipherment algorithm identifier, and the 16-bit encipherment key variable identifier. The encipherment information is protected by 144 bits of error corrective coding. Note: the encipherment process does not change during a transmission. The repeating of this information every 360 ms is primarily for late-entry by receiving radios.

Digitized Voice Link Control Information As previously stated, 72 bits of link control information is contained in the first of each pair of Voice Frames. If the addressee is a talk-group, the link control information consists of 1 octet describing the type of information (e.g., talk-group type of transmission), 1 octet containing the manufacturer identifier, 1 bit indicating whether or not the transmission is of an emergency nature, 15 bits reserved for future use, 2 octets for the talk-group address, and 3 octets for the transmitting radio's identifier. If the addressee is another radio, the last 7 of the 9 octets consist of: 1 octet reserved for future use, 3 octets for the destination radio's identifier, and 3 octets for the transmitting radio's identifier. This information is protected with 168 bits of error corrective coding.

Encryption Information required for decoding to take place (including the encoding initialization vector) is transmitted at the beginning of all transmissions, and is embedded in the signaling overhead throughout all digitized voice transmissions. This enables using multiple encoding algorithms and "key variables". An adequate number of bits have been assigned to allow for even the highest (i.e., most secure) levels of encoding.

Error Protection To provide for the maximum possible coverage (i.e., range of operation), a high degree of forward error correction and interleaving has been provided for. The mobile environment is subject to severe Raleigh fading and the APCQ25 techniques have been designed to operate in bit error rate environments of up to 7 percent.

Flexible Modulation Method A pair of modulation methods have been selected that utilize a common receiver. The first, which utilizes a constant-envelope 4-level Frequency Modulation (FM) variant, can utilize simple, high-efficiency amplifiers and has emissions that fit within a 12.5 kHz bandwidth. This method will be fielded in most equipment initially. The second, which utilizes a CQPSK variant with amplitude components, requires the use of highly linear or linearized amplifiers and has emissions that fit within a 6.25 kHz bandwidth. (The receiver, common to both, has a 6.25 kHz bandwidth.)

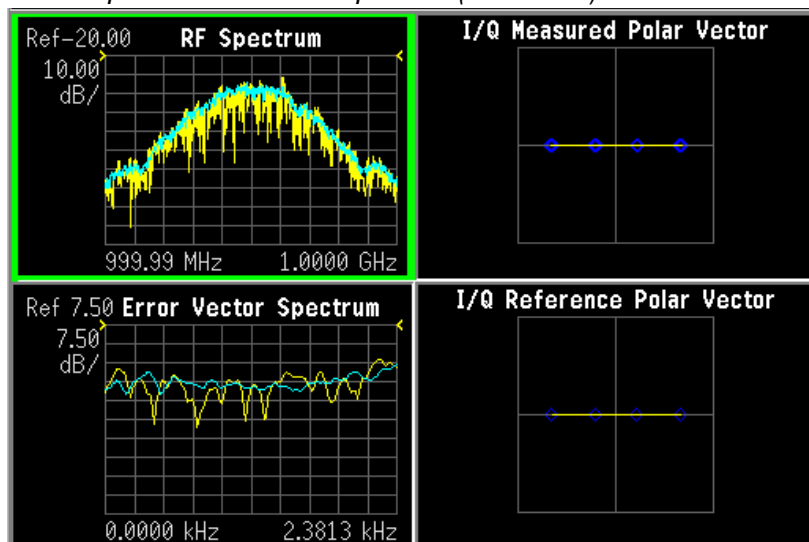
Low-Speed Data With Digitized Voice An 88.9 bit/s low-speed data channel is provided in the digitized voice frame structure. No application is currently defined. One application under discussion is to use the low-speed data channel for the transmission of accurate geographic location information.

Talk-Group Operation Unlike normal telephone operation, all members of a talkgroup can receive the transmissions of all other members of that talk-group. Members of a talk-group do not have to receive the beginning of a digitized voice transmission (i.e., late entry is provided for).

APC025 phase1 Communication System

Figure 5-76

APC025 phase1 Error Vector Spectrum (Quad-View)



What is VDL Mode 3?

VDL mode 3 stands for VHF Digital Link mode 3, and is a radio system used in the Aeronautical AM band to simultaneously transmit voice and data. The system uses TDMA and individual channels are modulated using D8PSK, differential Phase Shift Keying using 8 states or symbols. Data rates of 31,500 baud are accomplished.

Table 5-7 VDL Mode 3 Characteristics

Modulation Scheme	Channel Spacing	Access Scheme	Data Rate (b/s)	User Traffic Type
D8PSK	25 kHz	TDMA	31,500	AVLC& Digital Voice

What is ZigBee (IEEE 802.15.4)

ZigBee is the name given to an implementation of the IEEE 802.15.4 communications standard by the ZigBee Alliance. ZigBee is a wireless networking protocol primarily intended for use in LD-PANs, Low Data [R]ate Personal Area Networks. Many applications are being developed, including monitor and control of home, hospital, and building sensors and utilities as well as security and industrial automation.

ZigBee has 3 RF bands of operation as shown below. N9064A VXA is preset for the 2400-2483.5 (2450) MHz band shown in the first row below.

Table 5-8 *ZigBee Characteristics by Frequency Band*

Frequency	Spreading Parameters		Data Parameters			
	Chip Rate (kchip/s)	Modulation	Data Rate (kb/s)	Symbol Rate (ksymb/s)	Symbols	Data Chan.
2400-2483.5 MHz	2000	O-QPSK	250	62.5	16-ary Orthogonal	16
868-869.6 MHz	300	BPSK	20	20	Binary	1
902-928 MHz	600	BPSK	40	40	Binary	10

Measurements of Digital RF Communications Signals

Introduction

The previous section presented Communication System Format Standards. Each System Format Standard, detailed the operating parameters associated with that Format. When deploying and maintaining a system, it is important to be able to determine if the system is indeed operating as specified by the system format standard.

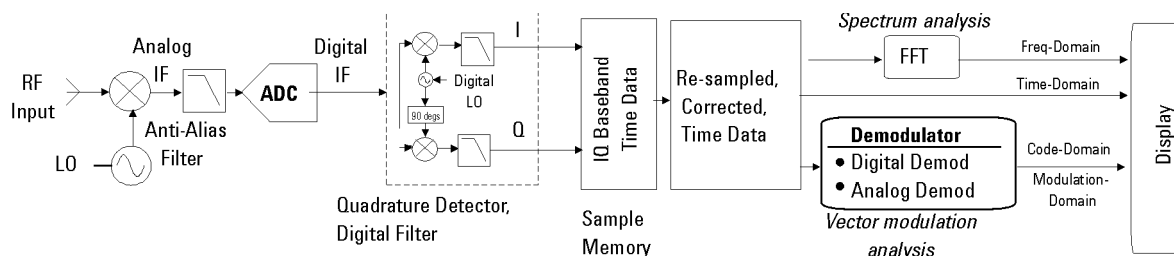
This section gives an overview of how the N9064A VXA demodulates a digitally modulated signal for analysis. A description of the three measurement domains is followed by the modulation quality measurements made on the system formats supported. A review of I/Q, constellation and Eye diagrams is given, in preparation to describing digital modulation errors and signal impairments. The section closes with the displays available to help detect these errors and impairments.

NOTE N9064A VXA can analyze digital modulation for a single code channel only. If multiple code channels are transmitted, synchronization will fail, and incorrect EVM results will be obtained. For modulation quality measurements of multiple code channels, Modulation Accuracy and Code Domain measurements must be performed by a full-featured standard-based measurement application, like N9073A for W-CDMA.

Digital Modulation Analysis

The N9064A VXA can be viewed as a measuring receiver. It is really an I/Q receiver, employing techniques similar to most digital radio receivers for decoding digital modulations. However, the difference is the N9064A VXA is designed for high-accuracy parametric measurement and display of modulation characteristics. Moreover, the N9064A VXA is a measurement tool that can measure and analyze almost every aspect of a digital communications transmitter and receiver system.

Figure 5-77 The N9064A VXA as a Receiver



The figure above shows an Agilent N9064A VXA simplified system block diagram. The RF input signal is down converted through several stages of superheterodyne mixing to an IF that can be accurately digitized by the ADC. This digitized IF is then vector (quadrature) detected and digitally filtered—down converted one last time to an I and Q baseband form (I/Q Time data) and stored in RAM. From here, DSP algorithms

demodulate the signal—recover the carrier and symbol-clock, apply re-constructive filtering and decoding (recover the original bits). With this DSP software implementation almost any modulation format can be demodulated.

The N9064A VXA implementation is different from a radio receiver. The N9064A VXA deals with the sampled signals on a block basis; the radio receiver processes data serially, in real time. When you supply the N9064A VXA with radio receiver parameters, the N9064A VXA in fact synthesizes the receiver via processing in the DSP. It provides all the functions of a receiver down to making analog waveforms. Because the signal has been virtually digitized and placed in memory, it can be post-processed and viewed in any of the time, frequency or modulation domains.

Measurement Domains

The transmitted signal can be viewed in different domains. The time, frequency and modulation domains each provide information about the signal. Time and frequency domain analysis are part of Basic Mode, while digital modulation analysis comes with N9064A VXA.

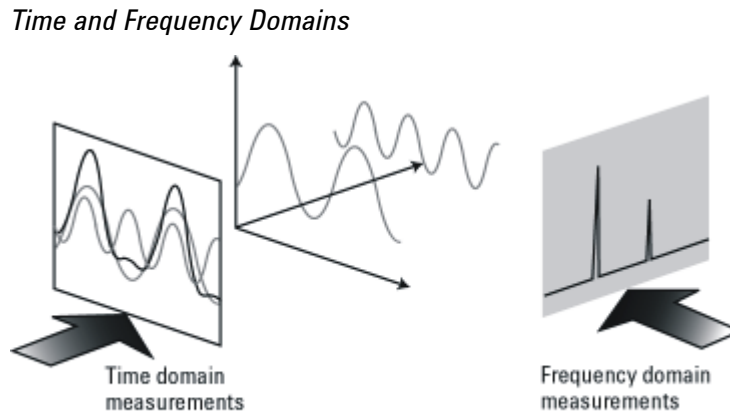
Complex trade-offs in frequency, phase, timing, and modulation are made for interference-free, multiple-user communications systems. It is necessary to accurately measure parameters in digital RF communications systems to make the right trade-offs. Measurements include analyzing the modulator and demodulator, characterizing the transmitted signal quality, locating causes of high Bit-Error-Rate, and investigating new modulation types.

Time Domain

Traditionally, looking at an electrical signal meant using an oscilloscope to view the signal in the time domain. However, oscilloscopes do not band limit the input signal and have limited dynamic range. Vector signal analyzers downconvert the signal to baseband and sample the I and Q components of the signal. They can display the signal in various coordinate systems, such as amplitude versus time, phase versus time, I or Q versus time, and I/Q polar.

Time-domain analysis is especially important in TDMA technologies, where the shape and timing of the burst must be measured.

Figure 5-78



Time Gating

Time-gated spectrum analysis enables you to obtain spectral information about signals occupying the same part of the frequency spectrum that are separated in the time domain. Using an external trigger signal to coordinate the separation of these signals, you can perform the following operations:

- Measure any one of several signals separated in time. For example, you can separate the spectra of two radios time-sharing a single frequency
- Measure the spectrum of a signal in one time slot of a TDMA system
- Exclude the spectrum of interfering signals, such as periodic pulse edge transients that exist for only a limited time

Why time gating is needed:

Traditional frequency-domain spectrum analysis provides only limited information for certain signals. Examples of these difficult-to-analyze signals include the following signal types:

- Pulsed RF
- Time multiplexed
- Time domain multiple access (TDMA)
- Interleaved or intermittent
- Burst modulated

Frequency Domain

Although the time domain provides some information on the RF signal, it does not give us the full picture. The signal can be further analyzed by looking at its frequency components (the previous figure).

Frequency measurements are often more complex in digital systems, since factors other than pure tones must be considered. Occupied bandwidth is an important measurement. It ensures that operators are staying within the bandwidth that they have been allocated. Adjacent channel power (ACP) is also used to detect the effects one user has on other users in nearby channels.

Occupied bandwidth and ACP are available by using the N9064A VXA Vector Analyzer measurement. For more information on these measurements see [“Using Adaptive Equalization” on page 61](#).

Modulation Domain

Modulation accuracy measurements usually involve precision demodulation of a signal and comparison of this demodulated signal with a (mathematically generated) ideal or “reference” signal. The difference between the two is the modulation error, and it can be expressed in a variety of ways. Residual measurements such as this are very powerful for trouble-shooting. Once the reference signal has been subtracted, it is easier to see small errors that may have been swamped or obscured by the modulation itself. The error signal itself can be examined in many ways, in the time domain or (since it is a vector quantity) in terms of its I/Q or magnitude/ phase components. A frequency transformation can also be performed and the spectral composition of the error signal alone can be viewed.

Demodulation involves applying the appropriate filtering before recovering the baseband I and Q signals and sampling these signals at the symbol rate to recover the actual symbols.

Various display formats and capabilities can be used to view the baseband signal characteristics and analyze modulation quality:

- I/Q polar (vector) and constellation diagrams.
- Summary table with I/Q quality metrics, such as Error Vector Magnitude (EVM), magnitude error, phase error, frequency error, rho and I/Q offset.
- Magnitude of the error vector versus time and error vector versus frequency (error vector spectrum).
- Magnitude error and phase error versus time or frequency.
- Eye diagrams.
- Equalization, which enables frequency response and group delay measurements.

Combinations of the display formats and capabilities above can be used to troubleshoot potential problems in the design.

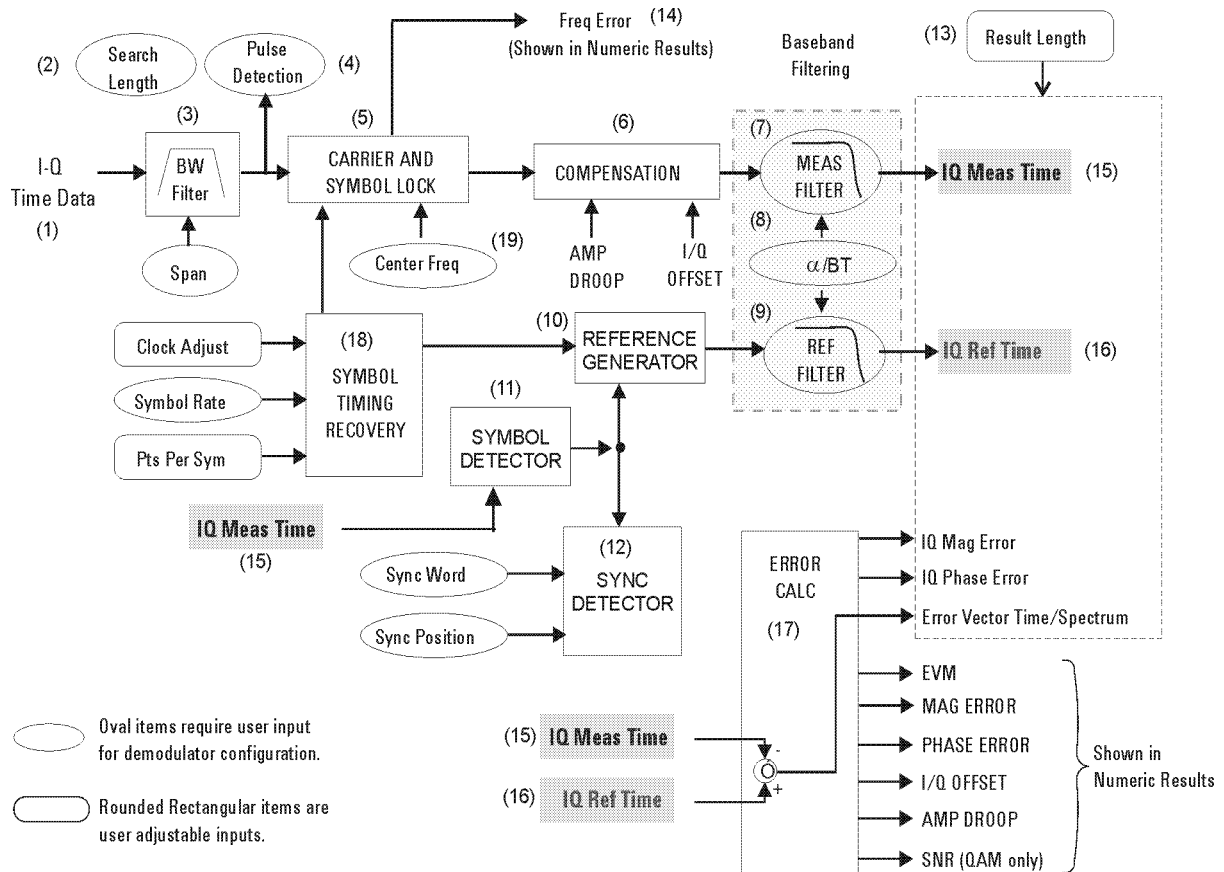
Examples of modulation and frequency domain signals for many modulation formats can be seen in the section.

N9064A VXA Digital Demodulator

The heart of the digital demodulation process in the N9064A VXA is the digital demodulator. The following figure shows a simplified block diagram of the digital demodulator implementation used in the Agilent N9064A VXA. The digital demodulator is a general-purpose demodulator, that requires only a minimum of prior information about the input signal to perform demodulation and can be used on a wide variety of

modulation formats. The demodulator provides carrier lock, symbol clock recovery, and bit recovery (decodes the actual encoded 1's and 0's) and produces the I/Q measured waveforms. The demodulator also produces ideal I/Q waveforms that are synthesized from the actual recovered bits—called I/Q Reference waveforms. The I/Q measured and I/Q Reference waveforms are subtracted to produce I/Q error waveforms. The I/Q error waveforms generate the modulation quality data results, which can be viewed in various data formats and display outputs.

Figure 5-79 Digital Demodulation Block Diagram



The Digital Demodulator Block Diagram by Section

- Input Signals:** the IF signal is digitized and in I/Q format. These samples also go to the Symbol Detector block.
- Search Length:** this user entry tells the demodulator how many symbols to search through in order to find the user specified synchronization word.
- Digital Filter/Decimator:** as seen before in the theory of operation for the vector signal analyzer, based upon your choice of span, excess samples are thrown away or decimated. The digital demodulator has its own separate routine for decimating samples, to ensure that the effective sample rate and timing produce a successful demodulation.

4. **Pulse Detector:** the pulse detector is a handy feature and works as an automatic trigger for burst, I/Q modulated signals. The pulse detector searches for a rise in signal amplitude and then applies the demodulation techniques automatically.
5. **Carrier and Symbol Lock:** when performing an I/Q demodulation without a coherent reference carrier supplied, the receiver must create a phase and timing reference. This block applies inputs of center frequency and symbol rate to recover the carrier and modulation symbol timing from the live modulated carrier.
6. **Compensation:** to further ensure a successful demodulation, this block tests the incoming signal for amplitude droop and IQ offset. Amplitude droop is a measure of the carrier power changing versus time, on a burst carrier. This is compensated for and reported as dB of droop per symbol. IQ offset or origin offset is a function of the amount of carrier feed through. For an ideal modulated signal, the carrier is “nulled” out by the quadrature modulation process making the IQ offset = zero. This value is reported in dB so the ideal case would be minus infinity. Both of these compensated errors are then reported on the Symbol Table/Error Summary.
7. **Measurement Filter:** the filter is specified by type (shape) and bandwidth (alpha or BT). This should be the same filter that would be used by a dedicated receiver, designed to receive and reconstruct the signal under test.
8. **Filter Alpha or BT:** this is a user input to the demodulator setup menu that specifies the required filter bandwidth relative to the symbol rate. Most IQ modulated systems will clearly specify these parameters for the system. The correct filter specification is critical to successful modulation.
9. **Reference Filter:** this filter must be specified, it is the sum of all filtering in the communications system under test. It is the combination of transmitter filtering and receiver filtering. This filter, along with the Reference Generator block will model an ideal reference signal from the signal under test. This reference signal will be the basis for computing the accuracy of the signal under test.
10. **Reference Generator:** this powerful block takes the detected symbols and inputs to the demodulator set up of modulation format, symbol rate and filter specification and computes an ideal model of the incoming signal. This reference will be passed on to the reference filter. The resulting reference signal will be compared to the real signal, to determine the accuracy of modulation.
11. **Symbol Detector:** the symbol detector processes the incoming signal samples and determines what symbols are being transmitted, based upon specifications of modulation format. The resulting symbol stream is passed on to the reference generator for reconstruction into an ideal reference signal.
12. **Sync Detector:** this is a data qualified triggering feature of the digital demodulator. A specific bit pattern (sync word) can be specified with the position of that word relative to the data of interest (trigger delay). The sync detector will then scan the serial bit stream from the symbol detector for that pattern and trigger when it is found.
13. **Result Length:** this user specification determines how many symbols should be demodulated for analysis.

14. **Frequency Error:** this error is the difference between the user-selected center frequency and the actual center frequency measured during the compensation process. The carrier frequency error is reported in the Symbol Table/Error Summary.
15. **IQ Measured Time:** this result is the triggered and synchronized sampled signal under test. It can now be displayed in a number useful ways such as - vector diagrams, constellation diagrams, I and/or Q versus time, etc.
16. **I/Q Reference Time:** this is the idea model of the signal under test. This is what the signal under test would have looked like had it been perfect. It too can be displayed just like a real signal. Its primary use is by the error calc block to compute the error differences between the IQ measured signal and the reference signal.
17. **Error Calculator:** this block takes the two signals, IQ measured time and I/Q reference time and compares them. The result is the comprehensive list of errors shown displayed from here. All of these errors can be displayed and analyzed in a number of useful ways.
18. **Symbol Timing Recovery:** this block looks at your inputs for symbol rate, points per symbol and clock adjust (clock delays) and generates a symbol clock for the demodulator.
19. **Center Frequency:** this is the input for carrier center frequency.

Configuring the Demodulator

The demodulation process begins by configuring the demodulator. The demodulator must be configured to the specific digital modulation format to properly demodulate and analyze the signal. The N9064A provides a set of standard presets (such as GSM, NADC, cdma2000) that automatically configure the demodulator. In those cases, enter the center frequency, select a standard preset, and the analyzer will demodulate the signal. The N9064A VXA has additional capabilities through a general purpose, user-definable demodulator. This enables you to customize the demodulator configuration for non-standard formats or troubleshooting purposes. The demodulator block diagram, shown in [Figure 5-79 on page 228](#), shows the internal demodulator processes (enclosed in rectangular boxes) and the configuration parameters that you can set (enclosed by ovals or rounded rectangular boxes). The items enclosed by an oval identify configuration parameters that are required to define the demodulator for a measurement. The rounded rectangular boxes identify user-adjustable input parameters. At a minimum, the demodulator requires the modulation format (QPSK, FSK, etc.), the symbol rate, the baseband filter type and filter alpha/BT— this set of parameters is generally sufficient for the demodulator to lock to the signal and recover the symbols.

The demodulator uses the configuration inputs and, through DSP, operates on the I/Q Time data received in block format from the analyzers sample memory. The N9064A VXA can also receive I/Q Time data from external hardware such as an Agilent ESA analyzer or from a recorded file. The demodulator uses the supplied center frequency and symbol rate to lock to the carrier and recover the symbol clock from the modulated carrier. Note that the demodulator reference clock does not need to be locked with the source clock. The demodulator automatically provides carrier and symbol lock, you do

not need to supply an external source-clock input. The signal then goes through a compensation process that applies gain and phase correction. The compensation data is stored and can be viewed in the Error Summary table (such as, amplitude droop and I/Q offset error data). Digital baseband filtering is then applied to recover the baseband I-Q waveforms (I-Q Meas Time data). The recovered I-Q waveforms are applied to a symbol detector that attempts to determine what symbols were transmitted based upon the specified modulation format. From this block of symbols, the serial data bits (1's and 0's) are decoded and recovered.

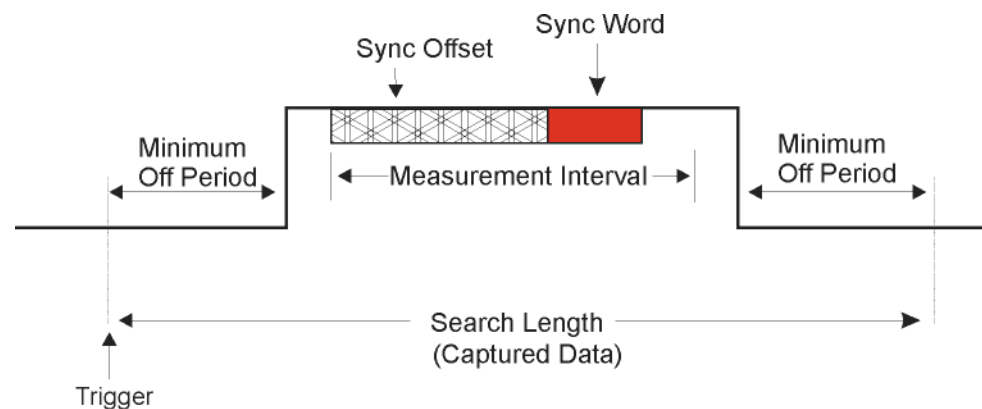
The reference generator uses the detected symbols in conjunction with the modulation format, the symbol rate, and the specified filtering, to synthesize an ideal set of I/Q reference baseband waveforms (I/Q Ref Time data). Finally, the measured I/Q waveforms and reference I-Q waveforms are compared to produce a host of error characteristics (deviation from perfect) such as phase error, magnitude error, and error vector magnitude (EVM).

Synchronization

Synchronization words (or patterns) are often used to resolve carrier phase ambiguity on non-differential modulation formats. It is important to realize that synchronization words are optional and are not necessary in order to achieve carrier locking.

Sync search lets you use a synchronization pattern to isolate a segment of your signal for display and analysis. The analyzer searches through demodulated data to find your sync pattern, and then uses the Result Length to determine how much data to display and the Search Offset to display data relative to the sync pattern.

Understanding Burst/Sync Terms

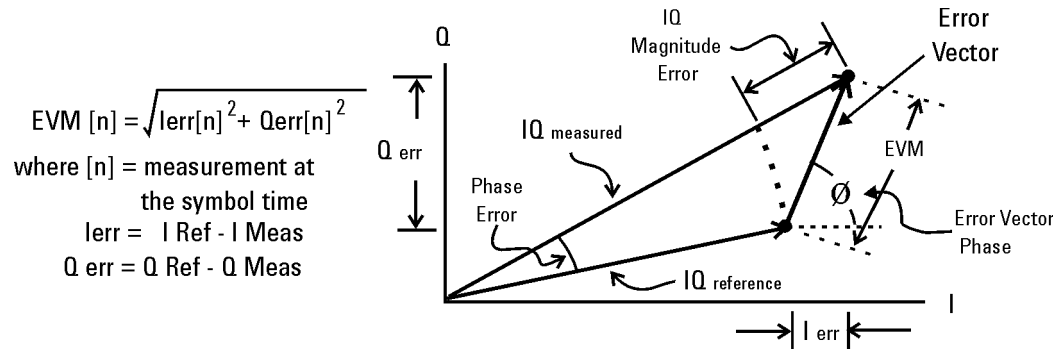


Trigger determines the start of the search length (make sure you include the periods off).

Measurement Interval (Meas Interval key) determines how much data is displayed. The location of the sync word plus the offset determines the position of the measurement interval. This data is used to calculate EVM.

Search Length determines how much data is collected.

Figure 5-80



Error Vector Magnitude (EVM) is the difference between the actual measured signal and an ideal reference signal.

EVM is defined as the root mean square (RMS) of the error vector over time at the instants of the symbol clock transitions. By convention, EVM is usually normalized to either the amplitude of the outermost symbol or the square root of the average symbol power. The EVM measurement and the various related data results are sensitive to any signal impairment that affects the magnitude and phase trajectory of a signal for any digital modulation format. This makes it an ideal measurement tool for troubleshooting communications system problems at baseband, IF, or RF sections of the radio transmitter.

Equalization with EVM

The value of EVM as an indicator of modulation quality can be enhanced by the use of equalization in the measuring instrument. Equalization is commonly used in digital communications receivers. Although its primary function is to reduce the effects of multipath, it also compensates for certain signal imperfections generated in both the transmitter and receiver. For this reason, it is useful to have an equalizer in the measuring instrument.

An instrument with an equalizer will better emulate a receiver; that is, the impairments that the equalizer of the receiver removes are also removed by the measuring instrument. Therefore, the impairments that have little effect on system performance also minimally impact the measured EVM. The following two figures show the magnitude of the error vector versus time without and with equalization. With equalization the constellation looks much better and the magnitude of the error vector versus time is lower. The signal has not changed, only the measurement technique.

Figure 5-81

Without Equalization

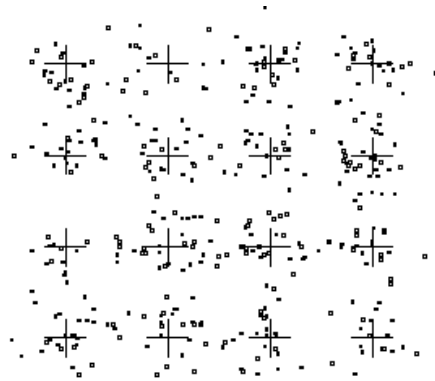
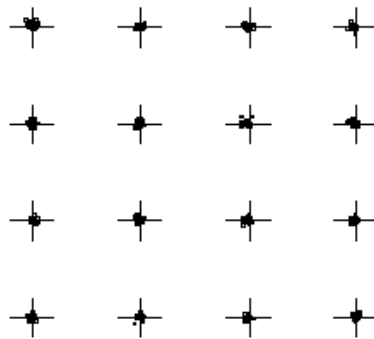


Figure 5-82

With Equalization



What is Adaptive Equalization?

Equalization is the process of applying a filter to a signal to remove or compensate for the effects of linear distortion. This filter can be defined in the frequency domain by frequency response parameters such as gain and phase or group delay. Alternatively it can be defined in the time domain by its impulse response.

Adaptive equalization dynamically creates and applies such a compensating filter, modifying it to more completely compensate for distortion or to track changing signal characteristics.

Equalization is effective at compensating for linear distortion mechanisms including:

- Frequency response errors such as ripple or tilt
- Non-flat group delay or nonlinear phase
- Multipath or delay spread

However equalization is not effective on nonlinear distortion mechanisms such as:

- Noise
- Spectral regrowth or adjacent ch. interference
- Intermodulation
- Spurious
- Harmonic distortion

This lack of effectiveness on nonlinear distortion mechanisms is an unfortunate fact from the standpoint of receiver performance. However if the equalizer capability can be made switchable in the measuring receiver (test equipment), the result is an effective way to distinguish linear from nonlinear distortion. This has considerable implications in the testing of modulators, transmitters and transmission paths. These implications will be covered later in this paper.

Phase and Frequency Errors

For constant-amplitude modulation formats, such as GMSK used in GSM systems, the I/Q phase and frequency errors are more representative measures of the quality of the signal than EVM. As with EVM, the analyzer samples the transmitter output in order to capture the actual phase trajectory. This is then demodulated, and the ideal (or reference) phase trajectory is mathematically derived. Comparing the actual and reference signals determine the phase error. The mean gradient of the phase error signal is the frequency error.

Significant phase errors can indicate problems in the baseband section of the transmitter. The output amplifier in the transmitter can also create distortion that causes unacceptably high phase error for multi carrier signals. Significant phase error at the beginning of a burst can indicate that a synthesizer is failing to settle quickly enough. In a real system, poor phase error reduces the ability of a receiver to correctly demodulate, especially with marginal signal conditions. This ultimately degrades sensitivity.

Frequency error is the difference between the specified carrier frequency and the actual carrier frequency. A stable frequency error simply indicates that a slightly wrong carrier frequency is being used. Unstable frequency errors can indicate short-term instability in the LO, improper filtering, AM-PM conversion in the amplifier, or wrong modulation index if the transmitter is implemented using an analog frequency modulator. See [“References” on page 253](#) for more information on phase and frequency error and other GSM measurements.

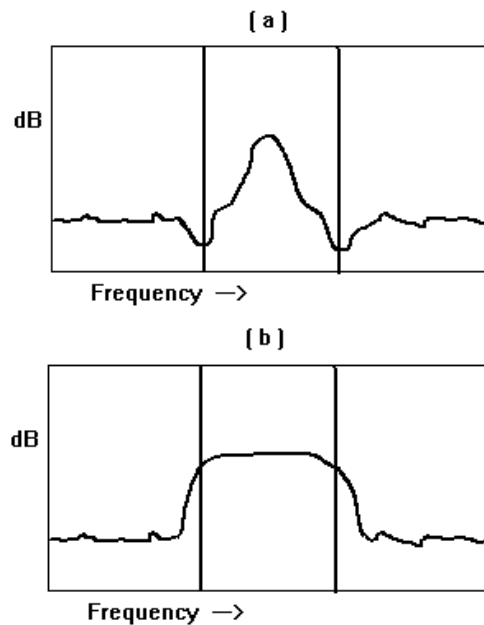
Frequency Response

As noted above, equalization compensates for certain signal imperfections in the transmitter, transmission path or receiver. Equalization removes only linear distortion. Linear distortion occurs when the signal passes through one or more linear devices having transfer functions containing amplitude unflatness (for example, ripple and tilt), and/or group delay variations over the bandwidth of the signal. There can be many sources of linear distortion in a system: bandpass filters in the IF, improper cable terminations, improper baseband filtering, non-compensated $\sin(x)/x$, antenna mismatch, signal combiners and multipath signal effects. From a modeling standpoint, all of the linear distortion mechanisms can be combined and represented by a single transfer function, $H(f)$.

When applying equalization, the measuring instrument must counteract the effects of the linear distortion. To achieve that, an equalizer filter whose transfer function is $1/H(f)$ is applied over the bandwidth of the signal.

Once equalization has been applied, the inverse transfer function of the equalizer, which represents the linear distortion elements of the device under test, can be displayed and measured. If measured directly at the transmitter's output, the inverse transfer function is basically the bits-to-RF frequency response 1 of the transmitter (or the variations from the ideal frequency response caused by non-linear distortions). See "References" on page 253. The actual frequency response can be displayed and measured as magnitude and phase. Ideally, the magnitude of the frequency response should be flat across the frequency band of interest, and its phase should be linear over that same frequency band.

Figure 5-83

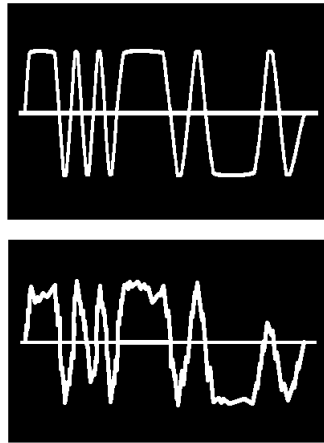


Rho

CDMA systems use $r(\rho)$ as one of the modulation quality metrics. Rho is measured on signals with a single code channel. It is the ratio of correlated power to total power transmitted [Figure 5-84 on page 237](#). The correlated power is computed by removing frequency, phase and time offsets, and performing a cross correlation between the corrected measured signal and the ideal reference. If some of the transmitted energy does not correlate, this excess power appears as added noise that may interfere with other users on the system.

Figure 5-84

Rho



The rho measurement indicates the overall modulation performance level of a CDMA transmitter when transmitting a single channel. Since uncorrelated power appears as interference, poor rho performance affects the capacity of the cell. See [“References” on page 253](#).

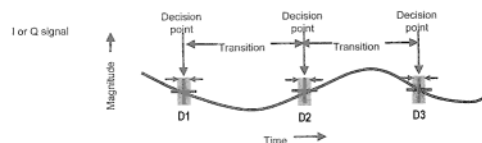
Digital Modulation Errors and Signal Impairments

Recall first the basics of vector modulation: digital bits are transferred onto an RF carrier by varying the carrier’s magnitude and phase. At each symbol-clock transition, the carrier occupies any one of several unique locations on the I versus Q plane. Each location encodes a specific data symbol, which consists of one or more data bits. A constellation diagram shows the valid locations (i.e., the magnitude and phase relative to the carrier) for all permitted symbols of which there must be 2^n , given n bits transmitted per symbol. To demodulate the incoming data, the exact magnitude and phase of the received signal for each clock transition must be accurately determined.

Looking at the I/Q waveform in the time domain, the signal trajectory would look similar to the figure below. The symbol is delivered at the decision point, a small slot in time when the receiver records the I and Q voltages. The digital receiver must know when to read the symbol. The receiver recovering the symbol rate from the signal itself, creating the symbol clock, accomplishes this. This process is called clock recovery.

Figure 5-85

Decision Points



The layout of the constellation diagram and its ideal symbol locations is determined generically by the modulation format chosen (BPSK, 16QAM, $\pi/4$ DQPSK, etc.). The trajectory taken by the signal from one symbol location to another is a function of the specific system implementation, but is readily calculated nonetheless. The trajectories between constellation symbol points are best seen in the I/Q or Eye diagram.

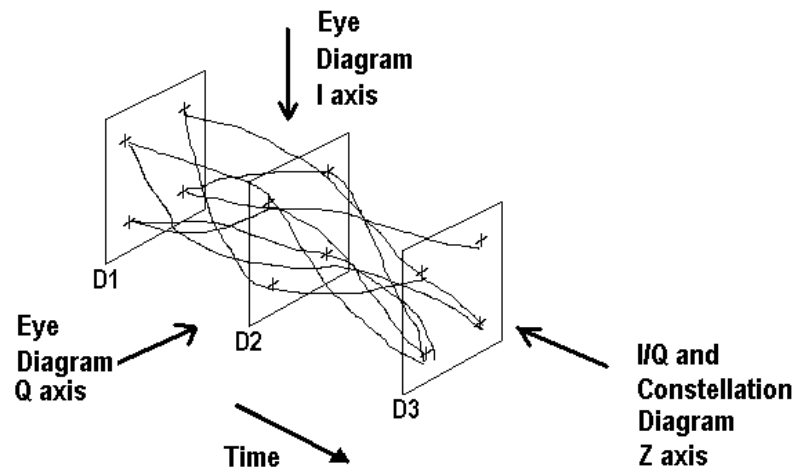
Relationship Between I/Q, Constellation and Eye Diagrams

The following figure shows three decision points in the time domain D1, D2 and D3. Each decision point appears as an I/Q plane for the QPSK format (four symbols). In the QPSK format, the signal trajectories between decision points are not restricted. The trajectory between D1, D2 and D3 vary with the I/Q voltages, similar to those shown in the following figure. The accuracy of the I/Q voltages determines how closely signal passes its symbol on any I/Q plane (decision point). The ideal point is usually indicated by a cross-hair cursor. If the modulation is high quality, the vector should go through one of the symbol point cross hairs.

From the Z-axis in the following figure, the vector path looks as seen in I/Q or Constellation diagrams as shown in [Figure 5-87 on page 239](#).

An observer standing on the I or Q axis looking at the three decision points would observe an Eye diagram, if each trajectory were to persist after the signal had gone. An accumulated record of all the trajectories between these three decision points would appear like [Figure 5-88 on page 240](#).

Figure 5-86

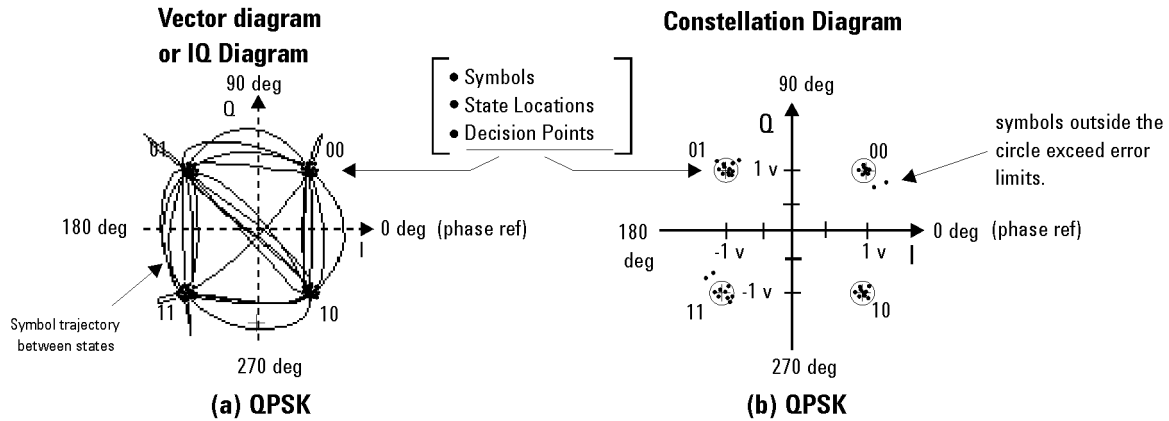


I/Q and Constellation Diagrams

The vector diagram, more commonly called an I/Q diagram in digital modulation, shows the recovered complex, I/Q baseband signal at all moments in time. It shows the states and transitions between them as the signal moves from symbol to symbol in time. A vector drawn from the origin to a point on the vector diagram corresponds to the instantaneous power at that instant in time.

The following figure (a) shows an example I/Q diagram for the “QPSK” modulated signal mentioned earlier. The I/Q diagram shows the 4 ideal state locations (indicated by the crosshairs) positioned at 45, 135, -45, and -135 degrees, the detected symbols, and the transitions between the symbols. The I/Q diagram gives you the peak-to-average power ratios and can be used to determine amplifier compression among other things

Figure 5-87



(a) The Vector or IQ diagram shows the detected symbols and the transitions between them. (b) The Constellation diagram shows the detected symbols versus ideal states, giving you a visual indication of the quality of the measured signal.

Interpreting I/Q Diagrams

When viewing signals in the I/Q plane, keep in mind that you are looking at the signal's amplitude and phase relative to the carrier. The unmodulated carrier is the phase reference (0 deg.). In the previous figure (a), each of the detected symbols modulate the carrier at differing amplitudes and phases relative to the unmodulated carrier, but at the same frequency as the carrier. If the detected symbols were at different frequencies than the unmodulated carrier, they would appear to move as they continuously gain or lose phase relative to the unmodulated carrier. Also, digital modulation is a 3-dimensional measurement, modulation in terms of its I (In-Phase) and Q (Quadrature) components versus time. The I/Q diagram is only a 2-dimensional display, so the time parameter, which cannot be seen, is perpendicular to the I/Q plane (or display screen).

Constellation Diagram

The previous figure (b) shows the constellation diagram for the same QPSK signal. The constellation diagram shows the carrier's magnitude and phase synchronous with the symbol clock. The measurement points are commonly referred to as detection decision-points and represent the detected symbols. It is similar to the I/Q diagram, without showing the transition traces between states.

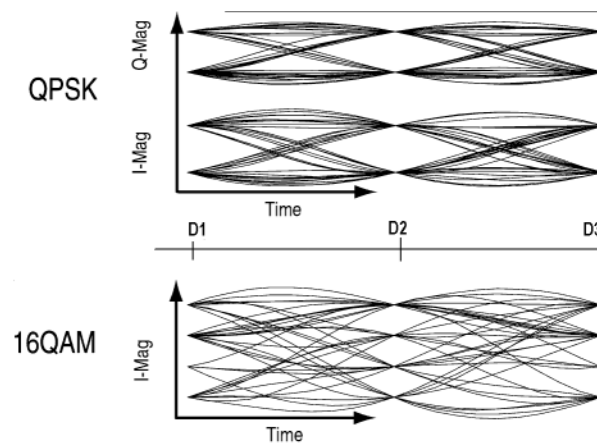
Ideally all symbols should appear as a single point centered at the ideal state location (indicated by the crosshairs). The ideal state is where symbols occur if your signal is without error. However, signal impairments and other modulation errors cause deviations and the symbols will disperse and surround the ideal state location. The N9064A VXA enables you to put definable error-limit circles around the ideal states. Showing the actual detected symbols versus the ideal states, gives you a visual indication of the quality of your signal. Constellation diagrams help identify such signal impairments as amplitude imbalance, quadrature error, or phase noise.

Eye diagrams

The following figure shows another way to view a digitally modulated signal, with an eye diagram. Separate eye diagrams can be generated, one for the I-channel data and another for the Q-channel data. Eye diagrams display I and Q magnitude versus time in an infinite persistence mode, with retraces. The I and Q transitions are shown separately and an “eye” (or eyes) is formed at the symbol decision times. QPSK has four distinct I/Q states, one in each quadrant. There are only two levels for I and two levels for Q. This forms a single eye for each I and Q. Other schemes use more levels and create more nodes in time, through which the traces pass. The lower example is a 16QAM signal which has four levels forming three distinct “eyes.” The eye is open at each symbol. A “good” signal has wide open eyes with compact crossover points.

Figure 5-88

Eye diagram



Impairments

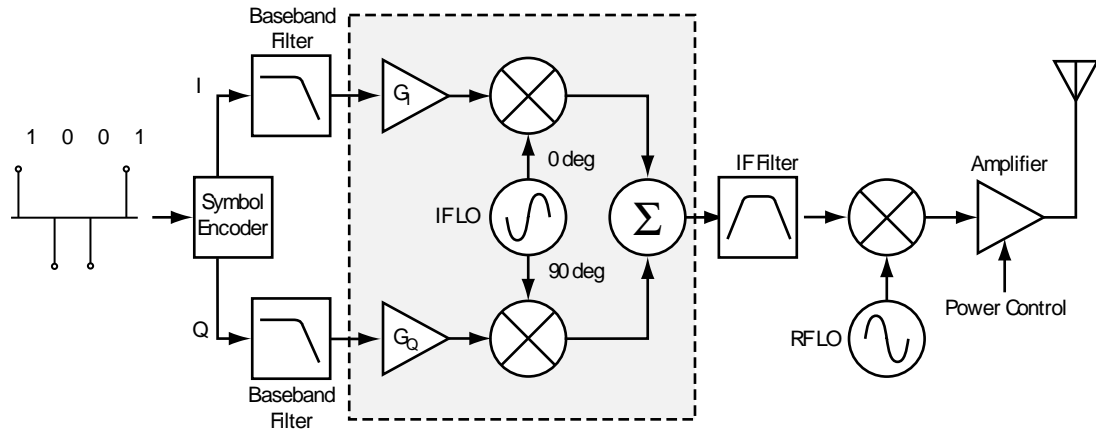
How can you verify the different I/Q impairments? The best way to verify most I/Q impairments is to look at the constellation and EVM metrics.

Matching problems due to component differences between the I side and Q side of a network can cause I/Q impairments. The I/Q modulator in the transmitter is a significant source of I/Q impairments. A diagram of it is shown in the following figure.

For any of these errors, magnifying the scale of the constellation can help detect subtle imbalances visually. Since the constellation is affected, these errors deteriorate EVM.

The most common I/Q impairments are listed below:

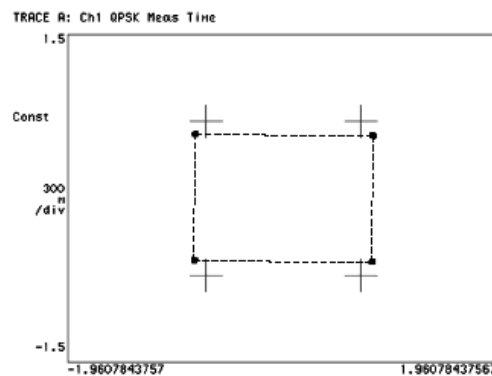
Figure 5-89 I/Q Modulator a source of Impairments



I/Q Gain Imbalance

Since I and Q are two separate signals, each one is created and amplified independently. Inequality of this gain between the I and Q paths results in incorrect positioning of each symbol in the constellation, causing errors in recovering the data. I/Q gain imbalance results in an asymmetric constellation, as seen in the following figure. This problem is rare in systems where the IF is implemented digitally.

Figure 5-90 I/Q Gain Imbalance



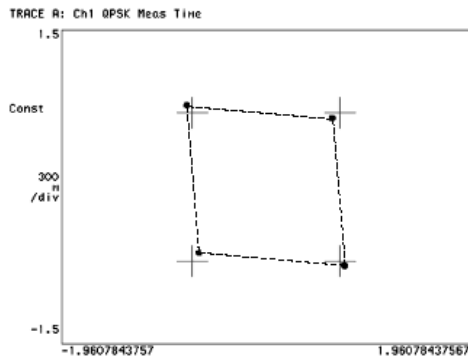
Quadrature errors

Quadrature errors. If the phase shift between the IF (or RF) LO signals that mix with the I and Q baseband signal at the modulator is not 90 degrees, a quadrature error occurs. The constellation of the signal is distorted (see the following figure), which may cause error in the interpretation of the recovered symbols.

Quadrature errors result in a “tipped” or skewed constellation, as seen in the following figure.

Figure 5-91

I/Q Quadrature Errors



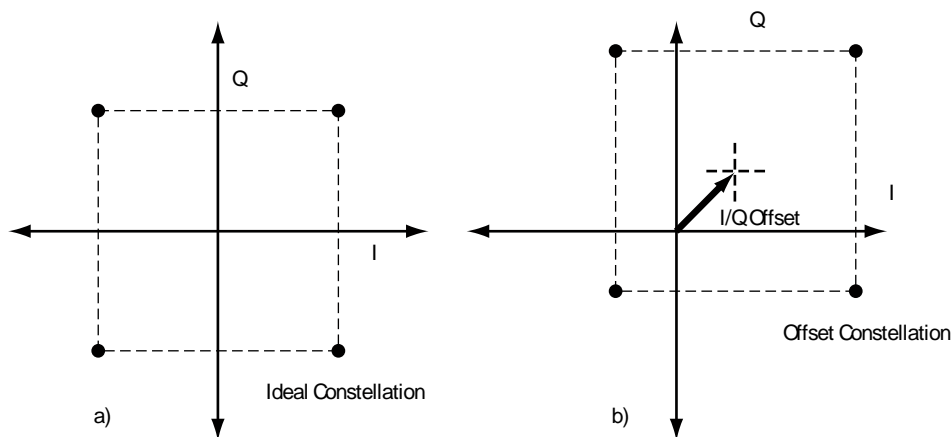
I/Q Offsets

DC offsets may be introduced in the I and Q paths. They may be added in by the amplifiers in the I and Q paths, see the following figure.

For digital IF implementations, offsets may also occur from rounding errors in the DSP. I/Q offsets result in carrier feed through. Some instruments compensate for this error before displaying the constellation or polar diagram and measuring EVM. In that case, I/Q offset is given as a separate error metric.

Figure 5-92

Ideal Versus I/Q Offset Constellation



Delays in I/Q paths

Delays in the I or Q paths also distort the measured constellation.

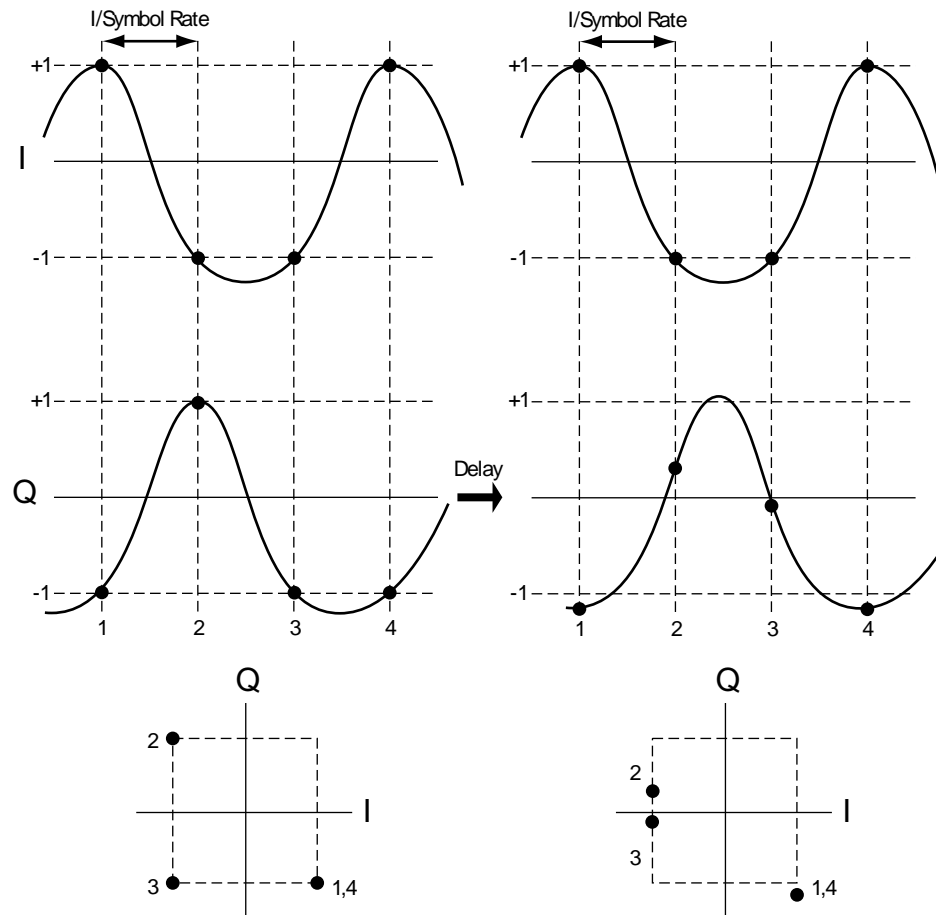
When the serial bit stream is encoded into symbols and the bits are split into parallel paths for creation of the I and Q signals, it is important that these signals are properly aligned. Problems in this process can cause unwanted delays between the I and Q signals. Delays can be caused by the modulator or by the previous components in the I or Q paths (for example, the baseband filter or the DAC). For instance, if the baseband filters are analog, variations in group delay between the filters cause different delays in

the I and Q paths. Different electrical lengths in the I and Q paths may also cause significant delay differences between the two paths, especially for signals with wide bandwidths (high symbol rates). See the following figure.

However, if the delay is an integer number of samples, the final encoded symbols transmitted appear positioned correctly but are incorrect. The error cannot be detected unless a known sequence is measured. Mathematical functions in the measuring instrument can help compensate for delays between I and Q, by enabling you to introduce delays in the I or Q paths. In this way, you can confirm and measure the delay.

Figure 5-93

Delays in I/Q paths



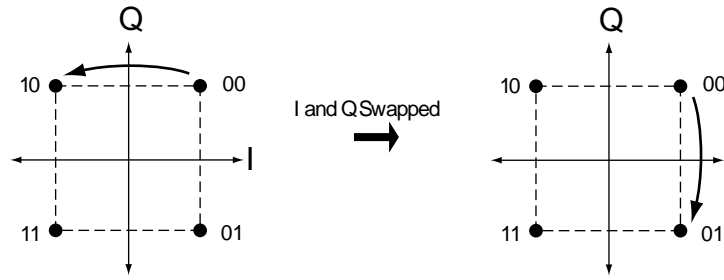
I/Q Signals “Swapped”

“Swapping”, or accidentally exchanging, the I and Q signals reverses the phase trajectory and inverts the spectrum around the carrier. Therefore, swapping the I and Q or changing the sign of the shift (+90 or -90 degrees) makes a difference in the signal transmitted: $\cos(\omega LO t) - j\sin(\omega LO t)$ versus $\cos(\omega LO t) + j\sin(\omega LO t)$. The mapping of the IF I and Q signals is reversed, which causes symbol errors, as seen in the following figure.

Concepts
Measurements of Digital RF Communications Signals

Figure 5-94

I/Q Signals "Swapped"



The condition I/Q swapped, results in an inverted spectrum. However, because of the noise-like shape of digitally modulated signals, the inversion is usually undetectable in the frequency domain.

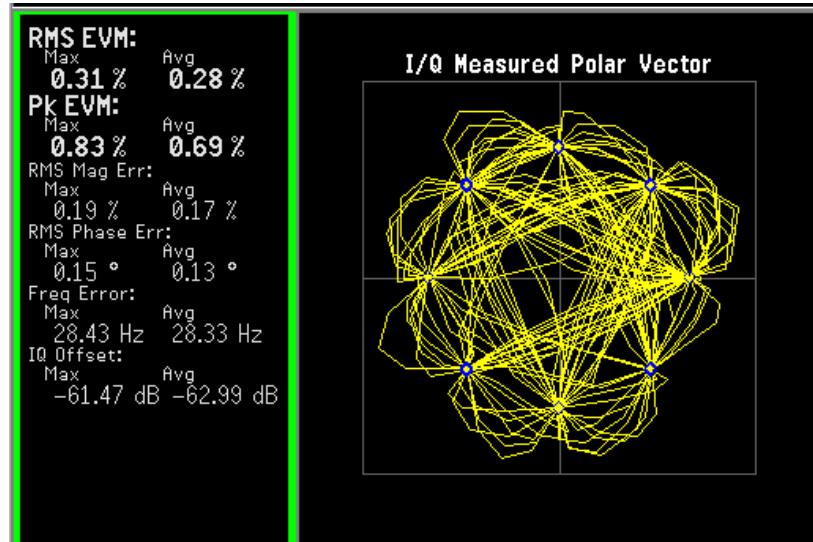
Digital Modulation Displays

NOTE

All the examples in the following section are all views of a single NADC signal measurement, except the FSK Error (Quad-View), which is an APC025 phase1 (FSK) signal. Upon completion of the measurement, the views were selected by pressing **View/Trace**, and selecting the view.

Figure 5-95

I/Q Measured Polar Vector diagram



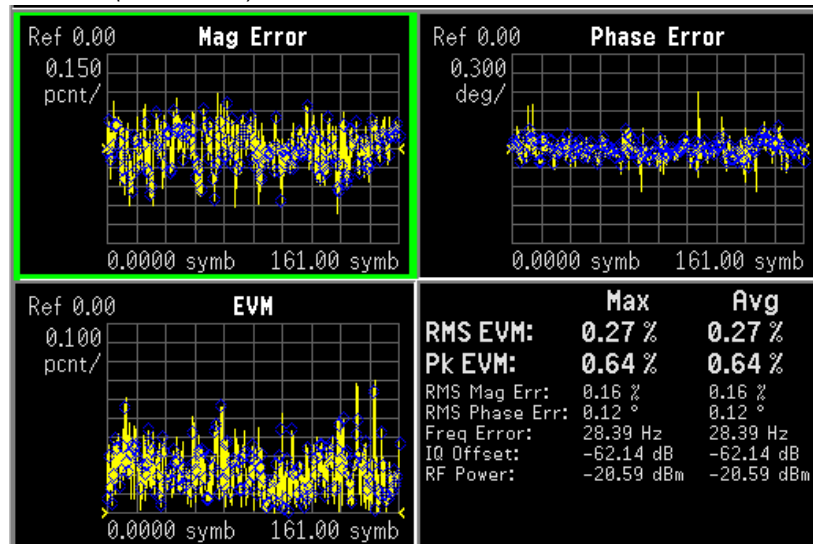
The previous figure shows the “I/Q Measured Polar Graph view”. Individual displays of a large “I/Q Measured Polar Graph” and a summary of the “Numeric Results”.

- A good place to start viewing demodulation results is the I/Q Measured Polar Vector diagram. This tool shows the complex recovered signal at all moments in time with the symbol clock marked with blue dots. The practiced viewing of the vector diagram can see proper modulation format, filtering and other qualitative aspects of the signal.
- The Numeric Results summary shows many important measurement parameters. For a more comprehensive list select the Numeric Results view.

The following figure shows the “I/Q Error (Quad View)”. Individual displays of “I/Q Mag Error”, “I/Q Phase Error”, “EVM” and a summary of “Numeric Results”. These are modulation quality measurements that were defined in.

When modulation errors are observed from the I/Q Measured Polar diagram, the next step might be to determine what is the nature of these errors. EVM can be broken down into its magnitude and phase components.

Figure 5-96 I/Q Error (Quad View)



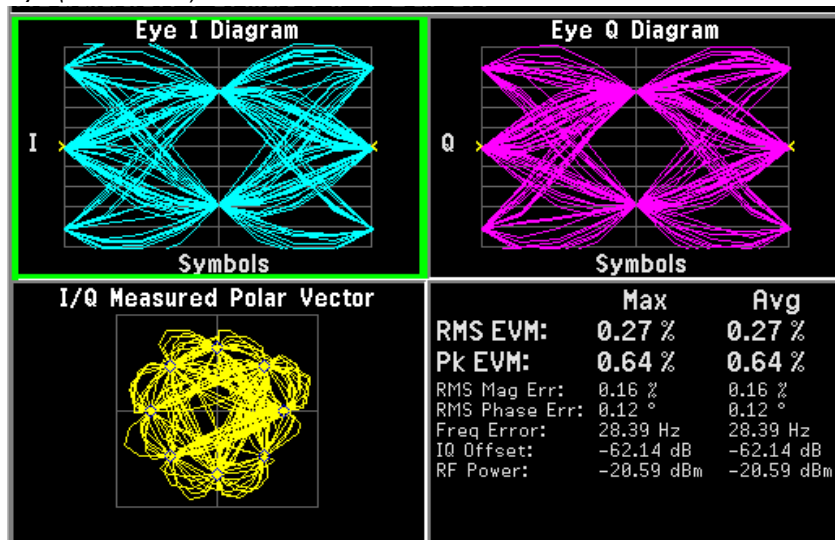
- The “I/Q Mag Error” and “I/Q Phase Error” windows show the error between the I/Q measured and the I/Q reference signals. I/Q Mag Error displays the magnitude error and I/Q Phase Error displays the phase error.
- The EVM vs time windows show the difference between the input signal and the internally generated reference.
- The Numeric Results summary shows many important measurement parameters. For a more comprehensive list select the Numeric Results view.

NOTE

The I/Q Error (Quad View) is the only view that supports markers.

Figure 5-97

Eye (Quad-View)

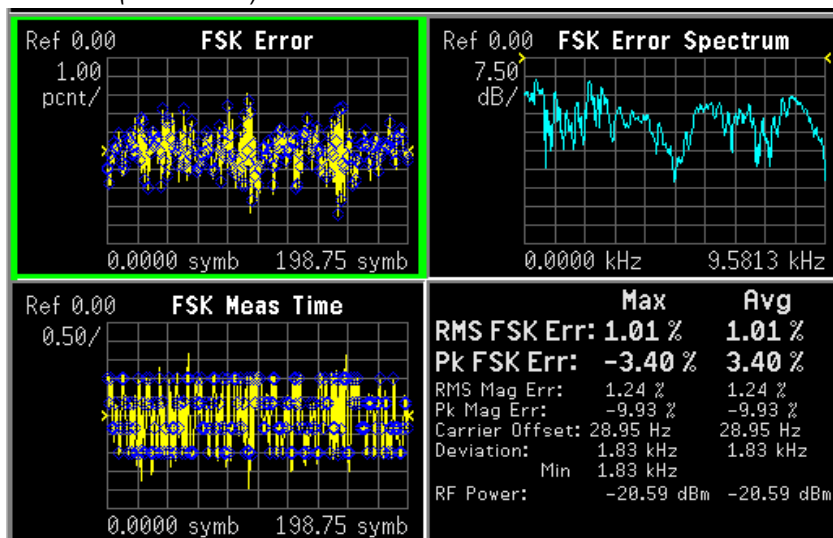


The figure above shows the “Eye (Quad View)”. Individual displays of “Eye I diagram”, “Eye Q diagram” a small “I/Q Measured Polar Graph”, and a summary of “Numeric Results”.

- Eye diagrams are a traditionally tools observed by connecting an oscilloscope to the I/Q test points of a digital radio. Shown are the I and Q voltages versus time. These voltages are retraced every few symbols to show in a statistical way, the repeatability of the signal. The opening of the “eye” shape in the trace is a qualitative indication of noise on the signal. Inconsistencies can be observed when the Eye I and Eye Q diagrams are shown next to each other.
- The I/Q Measured Polar Vector diagram shows the complex recovered signal at all moments in time with the symbol clock marked with red dots. The practiced viewing of the vector diagram can see proper modulation format, filtering and other qualitative aspects of the signal.
- The Numeric Results summary shows many important measurement parameters. For a more comprehensive list select the Numeric Results view.

Figure 5-98

FSK Error (Quad-View)



The figure above shows the “FSK Error”, “FSK Error Spectrum”, “FSK Meas Time”, and a summary of “Numeric Results”.

Numeric Results

The “Numeric Results” view is a powerful digital demodulation tool. For example, reviewing the rms EVM value can quickly help you assess modulation accuracy. Other valuable errors are also reported.

Figure 5-99

Numeric Results

	Max	Avg
RMS FSK Error	1.01 %	1.01 %
Peak FSK Error	-3.40 % at sym 152	3.40 % at sym 152
RMS Mag Error	1.24 %	1.24 %
Peak Mag Error	-9.93 % at sym 93	-9.93 % at sym 93
Carrier Offset	28.95 Hz	28.95 Hz
Deviation	1.83 kHz	1.83 kHz
	Min 1.83 kHz	
RF Power	-20.59 dBm	-20.59 dBm

NOTE

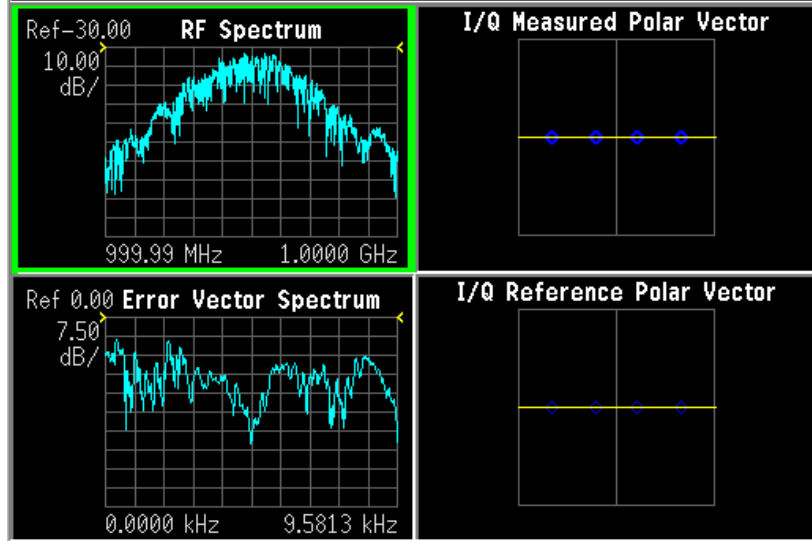
For more information on signal impairments, see the Making Measurements chapter.

Error Vector Spectrum (Quad-View)

The Error Vector Spectrum quad-view is a powerful digital demodulation tool. For example, the Error Vector Spectrum can help you to diagnose clock errors. Seeing the reference vector diagram can quickly help you assess modulation accuracy.

Figure 5-100

Error Vector Spectrum (Quad-View)

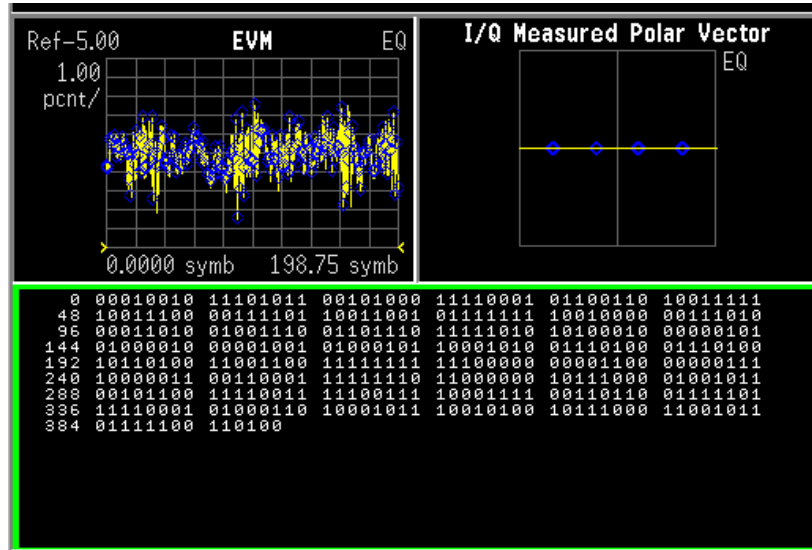


Demod Bits

The Demod Bits view can help you assess modulation accuracy. The same EVM vs. Symbol display is shown, along with the demodulated bits. You may find a correlation between the bit errors and the EVM that indicates time-grouped errors or magnitude errors. You can select the EVM graph and use markers to explore the various data points.

Figure 5-101

Demod Bits View



Equalizer (Quad-View)

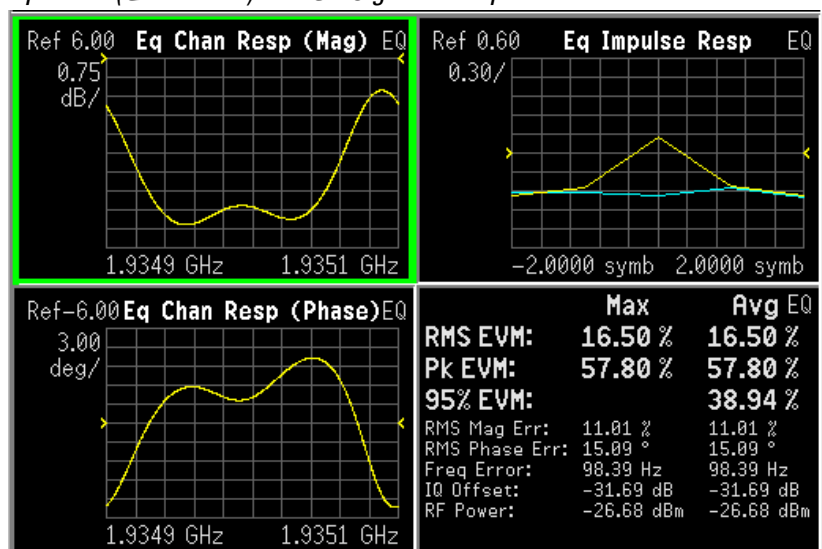
Press **Trace/View, Equalizer (Quad View)**. The Ch Frequency Response trace shows the frequency response channel for which the equalizer is correcting. Ch Frequency Response is computed as the inverse of the equalization filter's frequency response. The data is complex and is normally displayed in units of magnitude and phase.

The Eq Impulse Response trace shows the impulse response of the equalization filter. The example shown in the following figure is an EDGE signal.

The degree of equalization required to correct the measured signal is a direct indication of the linear distortion of the transmitter. For more information on equalization see "Using Adaptive Equalization" on page 61.

Figure 5-102

Equalizer (Quad-View) - EDGE Signal Example



References

- [1] Ken Thompson, "Concepts of cdma2000," Wireless Symposium, 999.
- [2] Designing and Testing 3GPP W-CDMA Base Transceiver Stations, Application Note 1355. Literature number 5980-1239E.
- [3] Understanding GSM/EDGE Transmitter and Receiver Measurements for Base Transceiver Stations and their Components, Agilent Application Note 1312, literature number 5968-2320E
- [4] Understanding CDMA Measurements for Base Stations and Their Components, Agilent Application Note 1311, literature number 5968-0953E

Other Sources of Digital Modulation Information

- Application Note 1298
Digital Modulation in Communications Systems - An Introduction
Agilent part number 5965-7160E
- Application Note 150
Spectrum Analysis
Agilent part number 35952-0292
- Application Note 1313
Test and Troubleshooting Digital RF Comm Transmitters
Agilent part number 5968-3578E
- Application Note 1314
Designing and Testing W-CDMA User Equipment
Agilent part number 5968-3579E
- Application Product Note 89400-14A
10 Steps to a Perfect Digital Demod Measurement
Agilent part number 75996-0444E
- Application Note 1311
Understanding CDMA Measurements for Base Stations and Their Components
Agilent part number 5968-0953E



6 802.11 a/b/g Wireless LAN (WLAN) Concepts

This Chapter describes concepts and theory of WLAN signals and explains how various measurements are performed by the instrument. Suggestions for optimizing and troubleshooting your setup are provided, along with a list of related Agilent documents that are referenced for further information.

Introduction

This chapter introduces concepts of WLAN to better relate the features and attributes of PSA Series Spectrum Analyzer (PSA) option 217, to measurements.

- [“What Is the WLAN Communication System?” on page 257](#) briefly explains the WLAN system, some devices involved in the system and two topologies to build up the system.
- [“What is a WLAN device?” on page 259](#) shows a diagram of the typical WLAN transceiver and some WLAN products.
- [“Digital Modulation Format Standards” on page 261](#) contains a general description of the modulation format families, including basic formats and WLAN specific formats.
- [“Spread Spectrum Concepts” on page 268](#) explains the DSSS concepts and theories.
- [“Orthogonal Frequency Division Multiplexing \(OFDM\) Concepts” on page 270](#) explains the OFDM concepts and theories.
- [“WLAN Standards” on page 271](#) introduces the popular WLAN standards, IEEE 802.11 standard family and gives a summary table of IEEE 802.11 standards.
- [“Other Sources of Measurement Information” on page 278](#) are given along with a list of related Agilent documents for further reading.
- [“References” on page 279](#) are given along with a list of reference documents for further reading.

What Is the WLAN Communication System?

Wireless Local Area Network (WLAN) is a high bandwidth, two-way data communications network that operates over a limited geographic area using radio as the medium of transmission, rather than optical fibre or copper cable.

WLAN is basically an extension of the functionality of wired LAN. WLAN enables mobile computer users to connect to a network and access resources while on the move, or without being physically connected to the network.

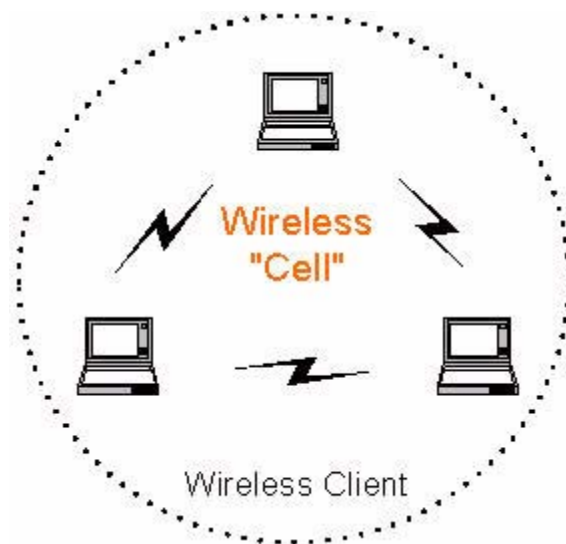
The most widely used WLAN systems involve Network Interface Cards (NICs), also referred to as Stations (STA), and Access Points (APs). The NIC is an expansion board, like a PC (PCMCIA) card, that you can insert into a mobile terminal (MT) so the MT can be connected to the WLAN. The AP acts not only to transfer data between wired and wireless devices, but is also responsible for allocation of the radio channel to the clients it serves.

WLAN can be built with either of two topologies: peer-to-peer or access point-based.

In a peer-to-peer topology, WLAN devices within the wireless "cell" communicate directly to each other as shown in [Figure 6-1 on page 257](#).

Figure 6-1

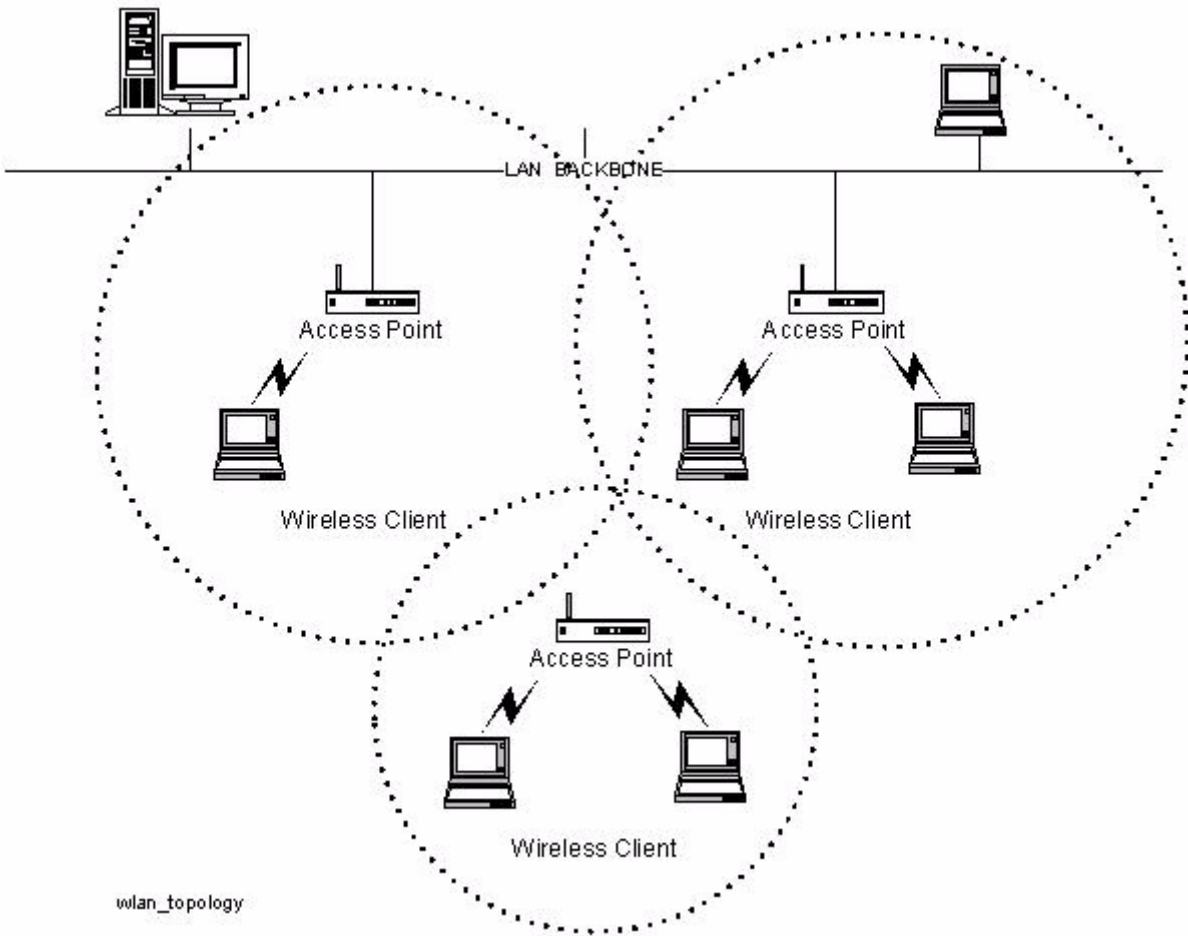
Peer to Peer Topology



An access point is a bridge that connects a wireless client device to the wired network. An access point-based topology uses access points to bridge traffic onto a wired (Ethernet or Token Ring) or wireless backbone as shown in [Figure 6-2 on page 258](#). The access point enables a wireless client device to communicate with any other wired or wireless device on the network. The access point topology is more commonly used, demonstrating that WLANs do not replace wired LANs, they extend connectivity to mobile devices.

802.11 a/b/g Wireless LAN (WLAN) Concepts
What Is the WLAN Communication System?

Figure 6-2 Access Point-Based Topology

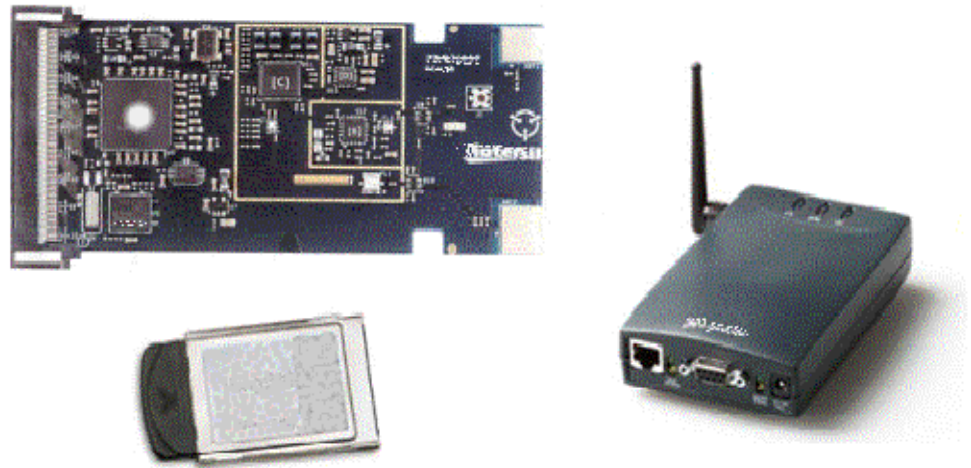


What is a WLAN device?

Besides stand-alone laptop PC cards WLAN chipsets are now being integrated into many other devices, for example, monitor displays, cell phones, Personal Data Assistants (PDA) devices. Follow figure shows some WLAN products.

Figure 6-3

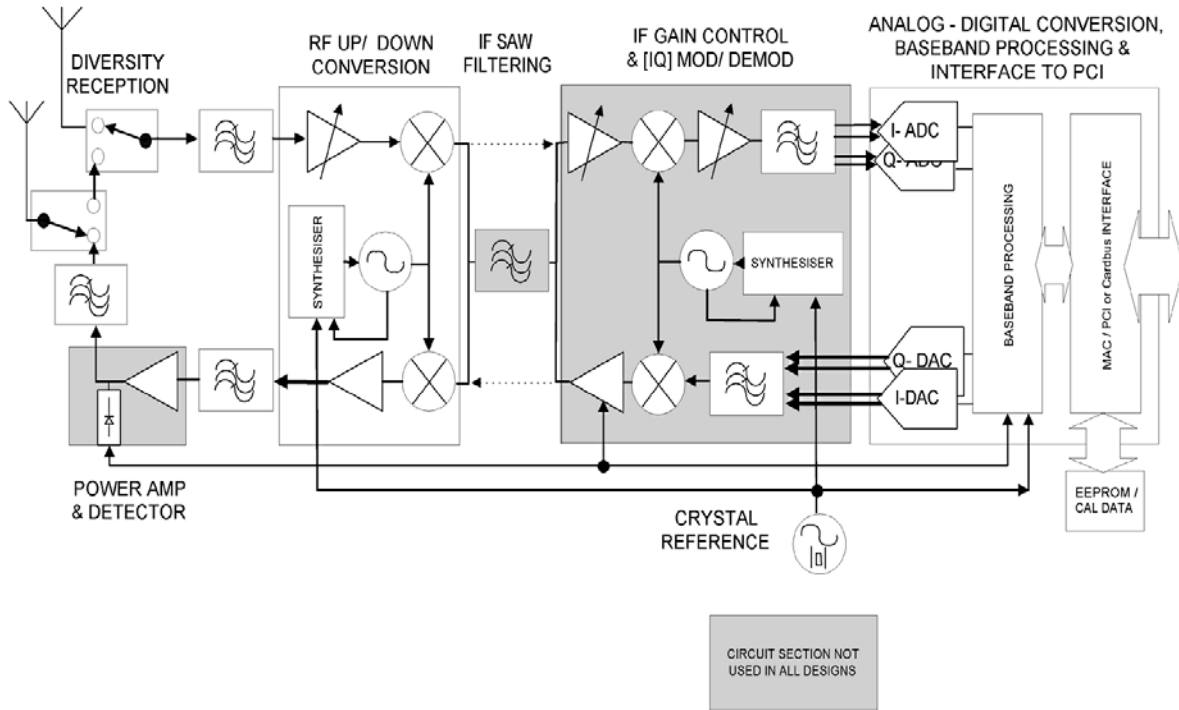
WLAN product examples



The most common format of a WLAN device is a PC (PCMCIA) card suitable for direct connection to a laptop computer. Electrically, the WLAN card is split into two major sections: the analog RF (PHY layer) and the digital baseband (MAC) processing. In many cases the baseband transceiver and processing is on a separate chip from the IF and RF transceiver chain, although newer designs may have higher levels of integration. The diagram below illustrates a block diagram of a typical WLAN transceiver.

802.11 a/b/g Wireless LAN (WLAN) Concepts
What is a WLAN device?

Figure 6-4 Block diagram of a typical WLAN transceiver



Digital Modulation Format Standards

Introduction

This section introduces digital modulation formats supported by WLAN standards and the concepts behind the individual formats.

The RF carrier(s) must be modulated. All the WLAN systems described in this book use a form of phase-shift keying for the preamble. More complex schemes, such as 64QAM (Quadrature Amplitude Modulation) give faster bit rates for user data, but require better radio performance and less noise to work to their full potential. BPSK (Phase Shift Keying), QPSK, and QAM are described in standard RF texts. Often the modulation format changes during the transmission. This is because the early part of the burst contains important information about the burst, including analog characteristics such as frequency, and digital information such as burst length. Simpler modulation formats are less prone to bit errors, and thus are more suitable to use early in a burst.

Modulation Formats and WLAN standards

The following table shows modulation formats supported in PSA Option 217, grouped by the WLAN standards.

Table 6-1 Families of Digital Modulation Formats

WLAN Standard	Carrier Type	Modulation Format
802.11a	OFDM	BPSK
		QPSK
		16 QAM
		64 QAM
802.11b	DSSS	DSSS 1 Mbps
		DSSS 2 Mbps
		CCK 5.5 Mbps
		CCK 11 Mbps
		PBCC 5 Mbps
		PBCC 11 Mbps

Table 6-1 Families of Digital Modulation Formats

WLAN Standard	Carrier Type	Modulation Format
802.11g	DSSS	DSSS 1 Mbps
		DSSS 2 Mbps
		CCK 5.5 Mbps
		CCK 11 Mbps
		PBCC 5 Mbps
		PBCC 11 Mbps
		PBCC 22Mbps
		PBCC 33Mbps
	OFDM	BPSK
		QPSK
		16 QAM
		64 QAM

To find out more about an individual format, see:

- [“Phase Shift Keying \(PSK\) Concepts” on page 262](#)
- [“Quadrature Amplitude Modulation \(QAM\) Concepts” on page 265](#)

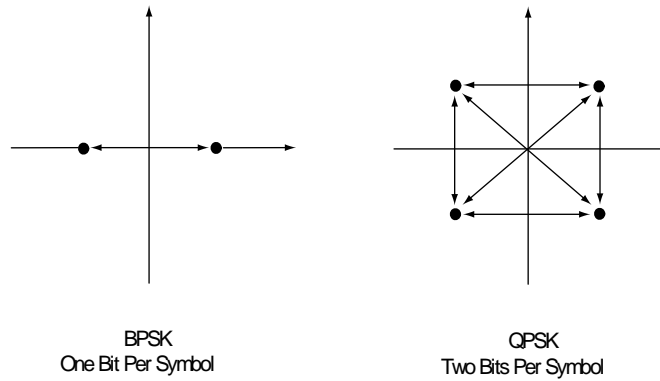
Phase Shift Keying (PSK) Concepts

One of the simplest forms of digital modulation is Binary or Bi-Phase Shift Keying (BPSK). One application where this is used is for deep space telemetry. The phase of a constant amplitude carrier signal moves between zero and 180 degrees. On an I/Q diagram, the I state has two different values. There are two possible locations in the constellation diagram, so a binary one or zero can be sent. The bit rate is one bit per symbol.

A more common type of phase modulation is Quadrature Phase Shift Keying (QPSK). It is used extensively in applications including CDMA (Code Division Multiple Access) cellular service, wireless local loop, and DVB-S (Digital Video Broadcasting — Satellite). Quadrature means that the signal shifts between phase states which are separated by 90 degrees. The signal shifts in increments of 90 degrees from 45 to 135, -45, or -135 degrees. These points are chosen as they can be easily implemented using an I/Q modulator. Only two I values and two Q values are needed and this gives two bits per symbol. There are four states because $2^2 = 4$. It is therefore a more bandwidth-efficient type of modulation than BPSK, potentially twice as efficient.

Figure 6-5

Phase Shift Keying (PSK)



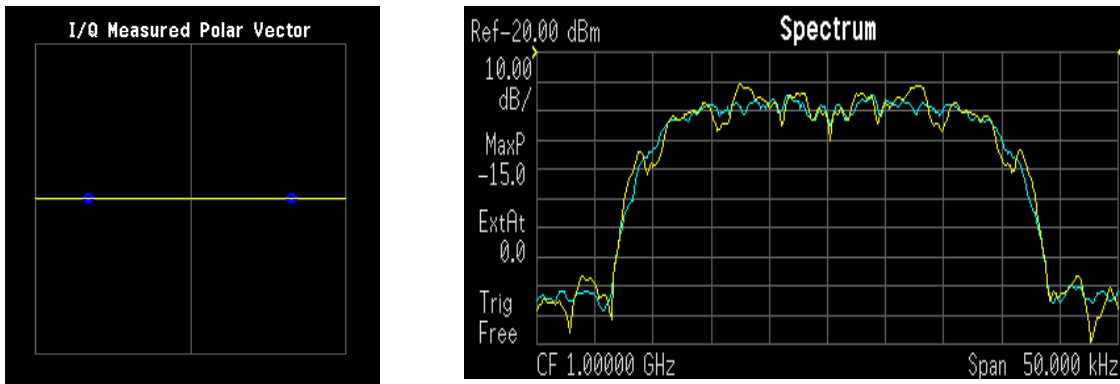
For more information on other types of PSK, see

- “BPSK Modulation Characteristics” on page 263
- “QPSK Modulation Characteristics” on page 264
- “DQPSK Modulation Characteristics” on page 265

BPSK Modulation Characteristics

Figure 6-6

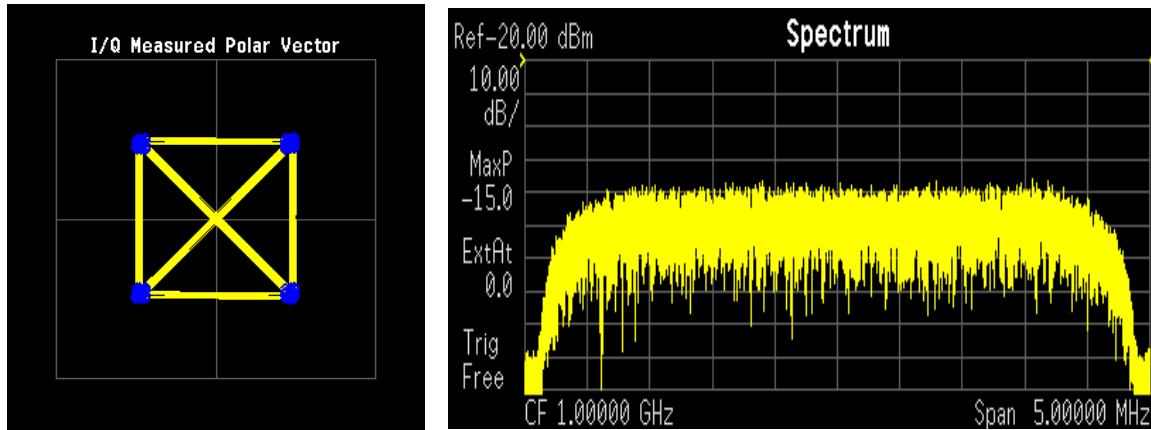
BPSK Constellation and Spectrum View



LEFT: BPSK constellation
RIGHT: BPSK spectrum center freq 1 GHz

QPSK Modulation Characteristics

Figure 6-7 QPSK Constellation and Spectrum View



LEFT: QPSK constellation
RIGHT: QPSK spectrum center freq 1 GHz

Differential Modulation Concepts

A variation of standard PSK is differential modulation as used in differential QPSK (DQPSK). Differential means that the information is not carried by the absolute state, it is carried by the transition between states. In some cases there are also restrictions on allowable transitions. This occurs in $\pi/4$ DQPSK where the carrier trajectory does not go through the origin. A DQPSK transmission system can transition from any symbol position to any other symbol position. The $\pi/4$ DQPSK modulation format is widely used in many applications including

CELLULAR

- NADC- IS-54 (North American digital cellular)
- PDC (Pacific Digital Cellular)

CORDLESS

- PHS (personal handyphone system)

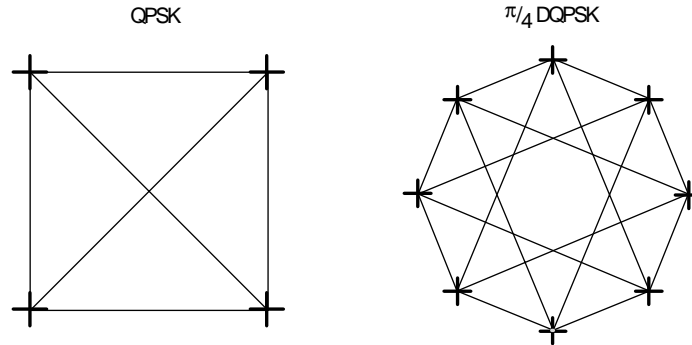
TRUNKED RADIO

- TETRA (Trans European Trunked Radio)

The $\pi/4$ DQPSK modulation format uses two QPSK constellations offset by 45 degrees ($\pi/4$ radians). Transitions must occur from one constellation to the other. This guarantees that there is always a change in phase at each symbol, making clock recovery easier. The data is encoded in the magnitude and direction of the phase shift, not in the absolute position on the constellation. One advantage of $\pi/4$ DQPSK is that the signal trajectory does not pass through the origin, thus simplifying transmitter design. Another is that $\pi/4$ DQPSK, with root raised cosine filtering, has better spectral efficiency than GMSK, the other common cellular modulation type.

Figure 6-8

Differential Modulation

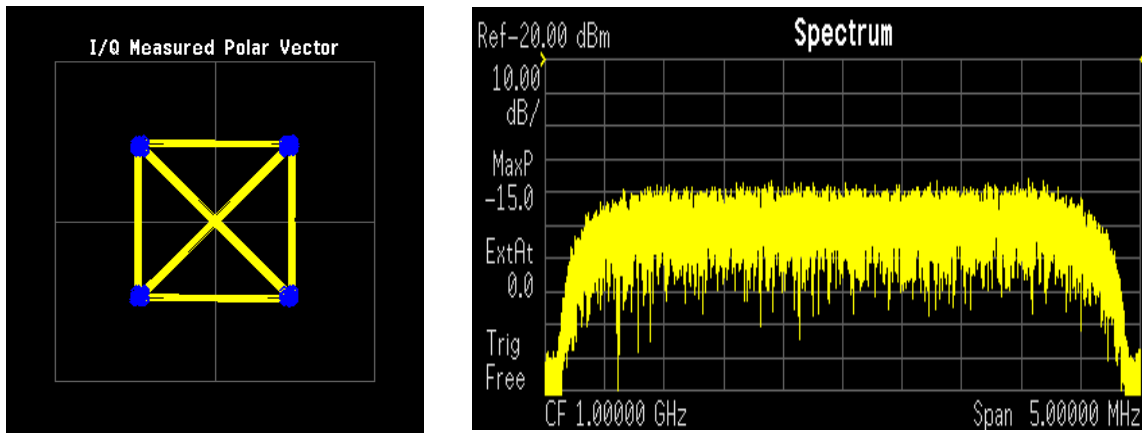


Both formats are 2 bits/symbol

DQPSK Modulation Characteristics

Figure 6-9

DQPSK Constellation and Spectrum View



LEFT: DQPSK constellation
 RIGHT: DQPSK spectrum center freq 1 GHz

Quadrature Amplitude Modulation (QAM) Concepts

Quadrature amplitude modulation (QAM) is used in applications including microwave digital radio, DVB-C (Digital Video Broadcasting—Cable), and modems.

16 QAM

In 16-state quadrature amplitude modulation (16QAM), there are four I values and four Q values. This results in a total of 16 possible states for the signal. It can transition from any state to any other state at every symbol time. Since $16 = 2^4$ four bits per

symbol can be sent. This consists of two bits for I, and two bits for Q. The symbol rate is one fourth of the bit rate. So this modulation format produces a more spectrally efficient transmission. It is more efficient than BPSK, QPSK, or 8PSK.

QPSK is practically the same as 4QAM.

32 QAM

Another variation of QAM is 32QAM. In this case there are six I values and six Q values resulting in a total of 36 possible states ($6 \times 6 = 36$). This number is too many states for a power of two (the closest power of two is 32). So the four corner symbol states, which take the most power to transmit, are omitted. This reduces the amount of peak power the transmitter has to generate. Since $2^5 = 32$, there are five bits per symbol and the symbol rate is one fifth of the bit rate.

The current practical limits for broadcast transmission of QAM signals are approximately 256QAM, though work is underway to extend the limits to 512 or 1024 QAM. High state QAM formats are better suited to cable delivery where the noise is lessened.

A 256QAM system uses 16 I-values and 16 Q-values, giving 256 possible states. Since $2^8 = 256$, each symbol can represent eight bits. A 256QAM signal that can send eight bits per symbol is very spectrally efficient. However, for a given maximum power, the symbols are closer together than lower-valued QAM's and are thus more subject to errors due to noise and distortion. Such a signal may have to be transmitted with extra power (to effectively spread the symbols out more) and this reduces power efficiency as compared to simpler schemes.

Figure 6-10

Quadrature Amplitude Modulation

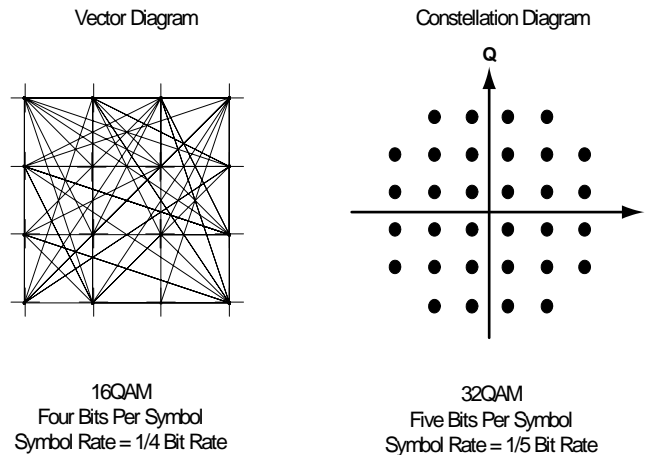


Fig. 14

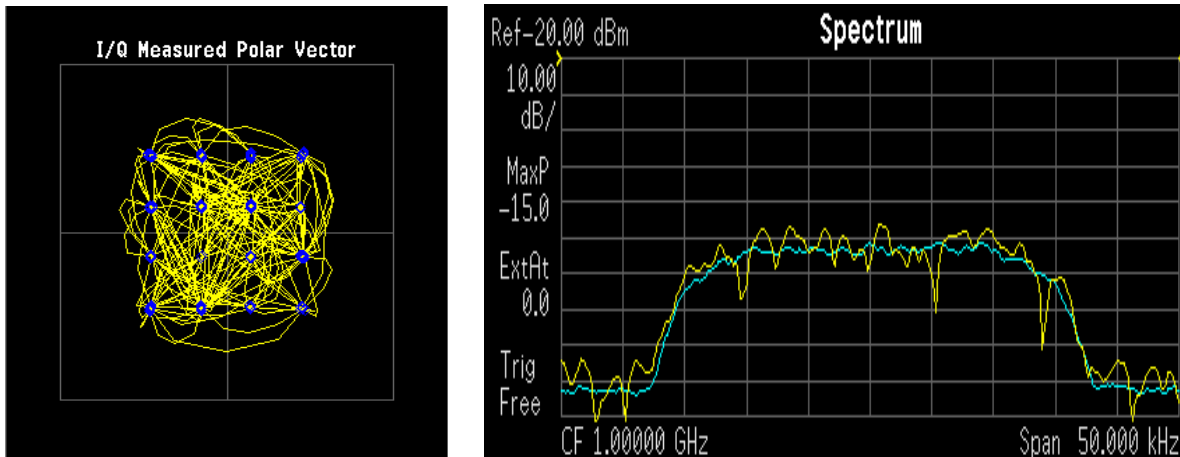
However, bandwidth efficiency is better for higher QAM's. For example, BPSK uses 80 Ksymbols-per-second sending 1 bit per symbol. A system using 256QAM sends eight bits per symbol so the symbol rate would be 10 Ksymbols per second. A 256QAM system enables the same amount of information to be sent as BPSK using only one

eighth of the bandwidth. It is eight times more bandwidth efficient. However, there is a trade-off. The radio becomes more complex and is more susceptible to errors caused by noise and distortion. Error rates of higher-order QAM systems such as this degrade more rapidly than QPSK as noise or interference is introduced. A measure of this degradation would be a higher bit error rate (BER).

In any digital modulation system, if the input signal is distorted or severely attenuated the receiver will eventually lose symbol lock completely. If the receiver can no longer recover the symbol clock, it cannot demodulate the signal or recover any information. With less degradation, the symbol clock can be recovered, but it is noisy, and the symbol locations themselves are noisy. In some cases, a symbol will fall far enough away from its intended position that it will cross over to an adjacent position. The I and Q level detectors used in the demodulator would misinterpret such a symbol as being in the wrong location, causing bit errors. QPSK is not as efficient, but the states are much farther apart for a given power and the system can tolerate a lot more noise before suffering symbol errors. QPSK has no intermediate states between the four corner-symbol locations, so there is less opportunity for the demodulator to misinterpret symbols. QPSK requires less transmitter power than QAM to achieve the same bit error rate.

QAM Modulation Characteristics

Figure 6-11 16 QAM Constellation and Spectrum View



LEFT: 16 QAM constellation
RIGHT: 16 QAM spectrum center freq 1 GHz

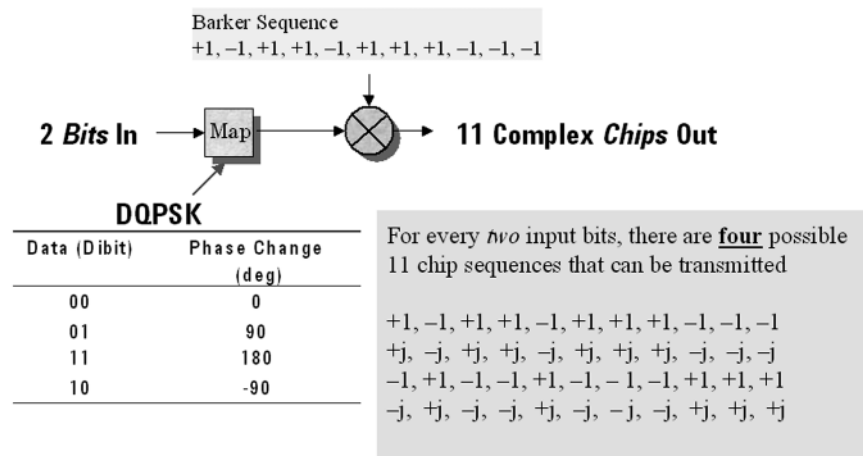
Spread Spectrum Concepts

Direct Sequence Spread Spectrum (DSSS) Concepts

DSSS (Direct Sequence Spread Spectrum) - The energy in a single carrier is spread over a wider spectrum by multiplying data bit(s) with a special 11-bit pattern, called a Barker key. This is done at a chip rate of 11 MHz. This technique can help reduce interference from narrow-band sources. The IEEE 802.11 b uses an 8-bit key. As shown in <Figure 2.1.1 from 1380-1 Page 10>, to create a DSSS signal, a lower rate signal is multiplied by a higher rate signal. For 1 Mbps, the 1 MHz (D)BPSK signal is multiplied by an 11 MHz BPSK signal. Although not generally true of DSSS signals, for this particular signal it can be said that the input bits determine the phase rotation of the spreading code or that it is a (D)BPSK data signal spread by a BPSK spreading sequence, producing a BPSK constellation.

Figure 6-12

DSSS signal spreading for 2 Mbps data rate

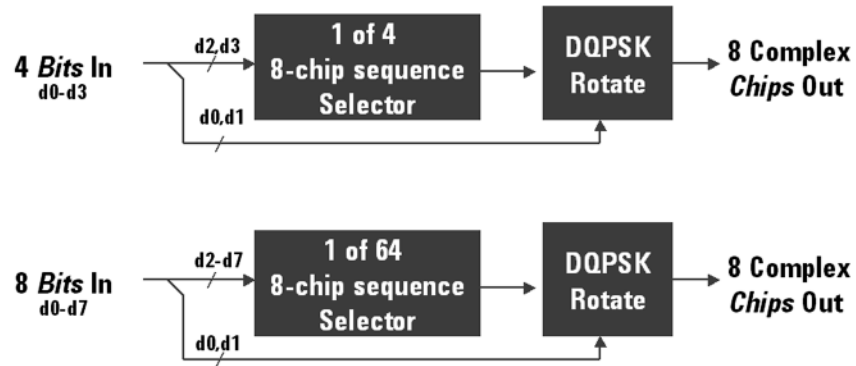


Complementary Code Keying (CCK) Concepts

CCK (Complementary Code Keying) - Changing both the spreading factor and/or the modulation format varies the bit rate. CCK is used to increase IEEE 802.11 b's peak data rate from 2 to 11 Mbps, while still using QPSK (Quadrature Phase Shift Keying) modulation. To achieve 5.5 and 11 Mbps rates, the spreading length is first reduced from 11 to 8. This increase the symbol rate from 1 Msps to 1.375 Msps, then taking data in 4-bit blocks ($4 \times 1.375 = 5.5$) or 8-bit blocks ($8 \times 1.375 = 11$), i.e. 4 bits/symbol or 8 bits/symbol. Six of the 8 bits are used to choose 1 of 64 complementary codes, which are 8 chips long and clocked out at 11 MHz. Thus all 8 chips are "used up" in $(1/1.375)$ us - the time before another byte is ready. The other 2 bits are combined with the code in the QPSK modulator.

Figure 6-13

CCK Modulation



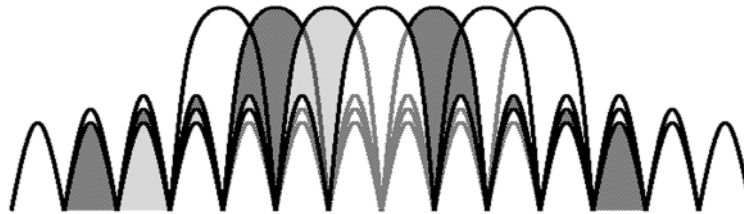
Packet Binary Convolutional Coding (PBCC) Concepts

PBCC (Packet Binary Convolutional Coding) - This scheme is optional for IEEE 802.11 b and g. It is basically a more complex version of CCK, enabling twice as much data to be encoded for a given bandwidth. Normally, a doubling of the data rate within a given bandwidth requires the signal-to-noise ratio of the channel to increase by 3 dB. By using PBCC, only a 0.5 dB increase is required for this data rate increase. In PBCC, the real data rate increase comes from moving from QPSK to 8PSK as the modulation technique, while the reduction in required signal-to-noise ratio comes from using PBCC over CCK. It makes use of Forward Error Correction to improve the link performance when noise is the limitation. Scrambled data is fed into a convolutional encoder. The encoder consists of a 6-stage memory, with specific taps combined to give two outputs. The four possible output states (00, 01, 10, 11) are mapped into two possible QPSK states (11 Mbps). A codeword controls how the chosen state alternates over time. The RF modulator is driven from this point.

Orthogonal Frequency Division Multiplexing (OFDM) Concepts

OFDM (Orthogonal Frequency Division Multiplexing) - OFDM uses multiple carriers, of which there are 52, spaced 312.5 kHz apart. Data is sent on 48 carriers simultaneously, with 4 used as pilots. The time to transmit each bit increases in proportion to the number of carriers. This makes the system less sensitive to multipath interference, a major source of distortion.

Figure 6-14 OFDM Carriers Separation

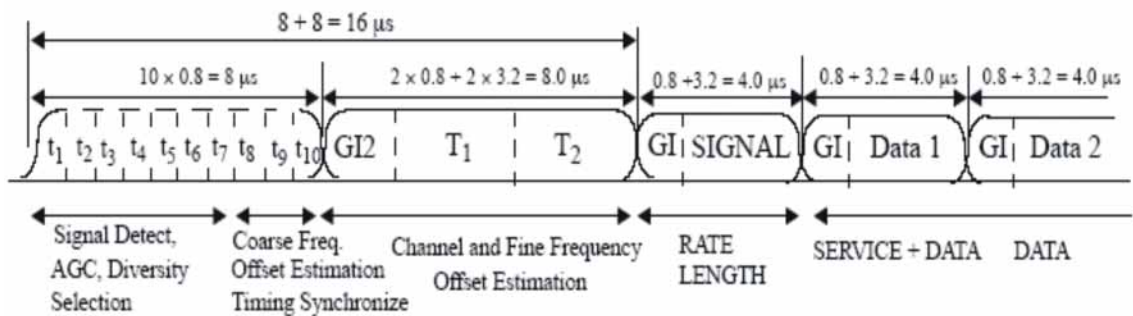


802.11a uses OFDM as its transmission scheme. For 802.11a there are 52 carriers in all, 48 of which are used to carry data and 4 which are used as pilots.

Orthogonal Frequency Division Multiplexing (OFDM) has been formally accepted as the method to achieve high data rates, better than 20 Mbps in the WLAN systems. OFDM provides multiple frequency channels at regular spacing, each modulated by M-ary QAM. An OFDM signal consists of the sum of a number of sub-carriers that are modulated using some form of PSK or QAM. Data interleavers “spread” the information throughout the carriers.

As shown in Figure 6-15, “OFDM training structure,” an OFDM burst actually has four distinct regions. The first is the *Short training sequence*, followed by a *Long training sequence* and finally by the *Signal and Data symbols*. From a RF standpoint, the Signal symbol and the rest of the OFDM symbols are similar.

Figure 6-15 OFDM training structure



WLAN Standards

Overview

Over the past few years, several different WLAN technologies and standards have been developed. This section concentrates on the IEEE 802.11 standards: 802.11b, 802.11a and 802.11g.

There are various modulation schemes, data rates, and frequency ranges contained in the IEEE 802.11 standards family, as summarized in the table below.

Table 6-2 IEEE 802.11 Standards Family

	Wireless LAN Standards			
	802.11b	802.11a	802.11g	
Frequency band	2.4 GHz	5 GHz	2.4 GHz	
Channel separation	25 MHz	20 MHz	25 MHz	
Maximum raw data rate	11 Mbps	54 Mbps	54 Mbps	
Carrier Type	DSSS	OFDM	DSSS	OFDM
Modulation	DSSS, CCK, PBCC	BPSK, QPSK, 16 QAM, 64 QAM	DSSS, CCK, PBCC	BPSK, QPSK, 16 QAM, 64 QAM

The progression of technology in the IEEE 802.11 standard family is 802.11 to 802.11b to 802.11a, and eventually to 802.11g. These IEEE 802.11 systems use either direct sequence spread spectrum (DSSS) techniques or orthogonal frequency division multiplexing (OFDM) schemes.

802.11b

The 802.11b operates in the 2.4 GHz and uses DSSS techniques to spread the energy in a single carrier over a wider spectrum. See [“Direct Sequence Spread Spectrum \(DSSS\) Concepts” on page 268](#). Two coding schemes are used in the 802.11b to spread the spectrum of a single carrier. Complementary code keying (CCK) is mandatory, while packet binary convolutional coding (PBCC) is optional. CCK is used to increase the 802.11b peak data rate to 11 Mbps using QPSK modulation. See [“Complementary Code Keying \(CCK\) Concepts” on page 268](#). PBCC makes use of forward error correction to improve the link performance when noise is the limitation. See [“Packet Binary Convolutional Coding \(PBCC\) Concepts” on page 269](#).

The 802.11b enables 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps operation using various modulation schemes. The 1 and 2 Mbps rates use DBPSK and DQPSK modulation schemes. For 5.5 and 11 Mbps operation, CCK modulation is used.

802.11 a/b/g Wireless LAN (WLAN) Concepts
WLAN Standards

To achieve 5.5 and 11 Mbps rates, the spreading length is first reduced from 11 to 8. This increases the symbol rate from 1 Msps to 1.375 Msps. So, for 5.5 Mbps bit rates one needs to transmit $5.5/1.375$ or 4 bits/symbol and for 11 Mbps, 8 bits/symbol.

Table 6-3 802.11b Rate-dependent parameters

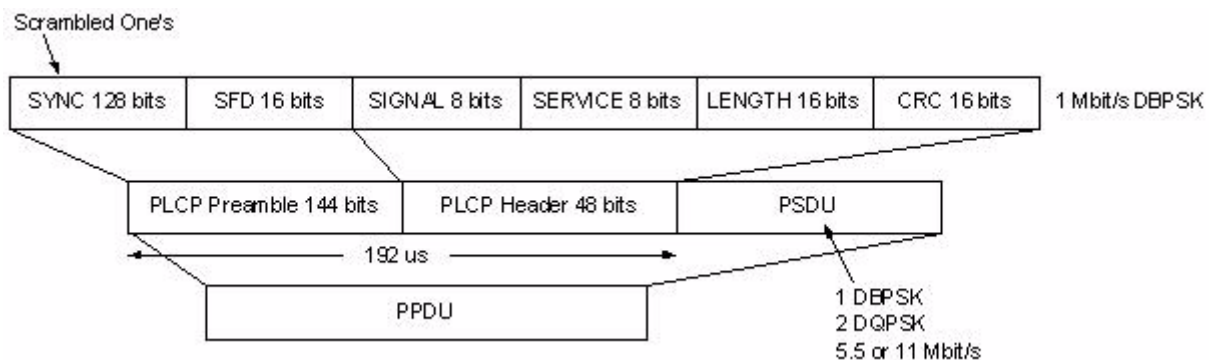
Data rate (Mbps)	Modulation	Symbol rate (MSps)
1	DBPSK	
2	DQPSK	
5.5	CCK	1.375
	PBCC	
11	CCK	1.375
	PBCC	

The approach taken for 802.11b, which keeps the QPSK spread spectrum signal and still provides the required number of bits/symbol, uses all but two of the bits to select from a set of spreading sequences. It uses the remaining two bits to rotate the sequence.

An important difference between the sets of spreading sequences used here and the single Barker code sequence used for the 1 and 2 Mbps rates is that these sequences are complex. In other words, the signal is a (D)QPSK signal with QPSK spreading.

Figure 6-16, "802.11b signal," shows a plot of 802.11b signal burst. For all 802.11b bit rates, the preamble and header are sent at the 1 Mbps rate. The header is 192 usec long (192 bits). This translates to a total of 2112 chips. The payload data is then appended using one of the four modulation rates.

Figure 6-16 802.11b signal



802.11a

802.11a operates in the 5 GHz band and uses OFDM as its transmission scheme.

The 802.11a offers 6, 12 and 24 Mbps and optionally 9, 18, 36, 48 and 54 Mbps bit-rates. The OFDM physical layer uses 52 sub-carriers with 0.3125 MHz spacing, of which 48 are used to carry data and 4 are used as pilots. The occupied bandwidth is 16.6 MHz. Forward error correction coding (convolutional coding) is used with a coding rate of 1/2, 2/3, or 3/4.

The modulation of the individual carriers in the OFDM depends on the data rates. For 6 and 9 Mbps BPSK is used, 12 and 18 Mbps uses QPSK, 24 and 36 Mbps uses 16 QAM, and 48 and 54 Mbps operation uses 64 QAM. [Table 6-4 on page 273](#) provides a summary of the different modulation formats used in OFDM systems and their associated rate-dependent parameters.

Table 6-4

802.11a Rate-dependent parameters

Data rate (Mbps)	Modulation	Coding rate (R)	Coded bits per subcarrier (NBPSK)	Coded bits per OFDM symbol (NCBPS)	Data bits per OFDM symbol (NDBPS)
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

OFDM systems use fixed modulation formats for the preamble. Varying data rates are achieved by changing the modulation for the data transmission portion of a packet. In some cases, the modulation format changes during the data transmission. Simpler modulation formats (such as BPSK) are often used in the early part of the burst, which contains important information such as frequency and burst length, because these formats are less prone to bit errors.

[Figure 6-17, "802.11a Signal,"](#) shows the format for the PPDU including the OFDM preamble, header, PSDU, tail bits, and pad bits. The header contains the following fields: LENGTH, RATE, a reserved bit, an even parity bit, and the SERVICE field. In terms of modulation, the LENGTH, RATE, reserved bit, and parity bit (with 6 "zero" tail bits appended) constitute a separate single OFDM symbol, denoted SIGNAL, which is transmitted with the most robust combination of BPSK modulation and a coding rate of $R = 1/2$. The SERVICE field of the header and the PSDU (with 6 "zero" tail bits and pad bits appended), denoted as DATA, are transmitted at the data rate described in the RATE field and may constitute multiple OFDM symbols.

802.11 a/b/g Wireless LAN (WLAN) Concepts
WLAN Standards

Figure 6-17 802.11a Signal

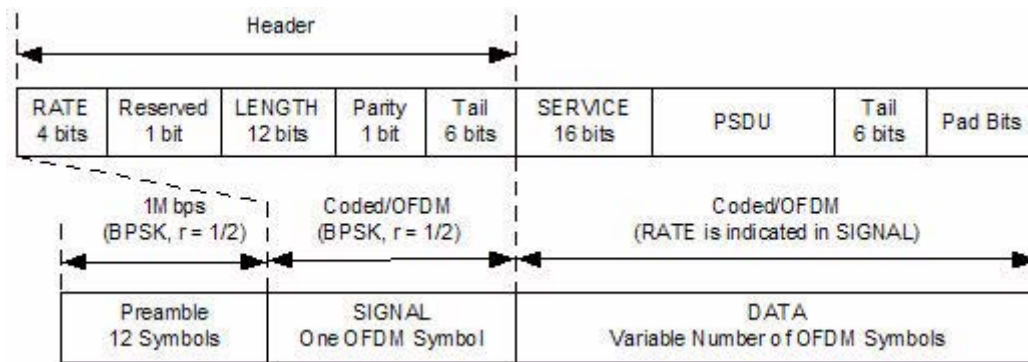
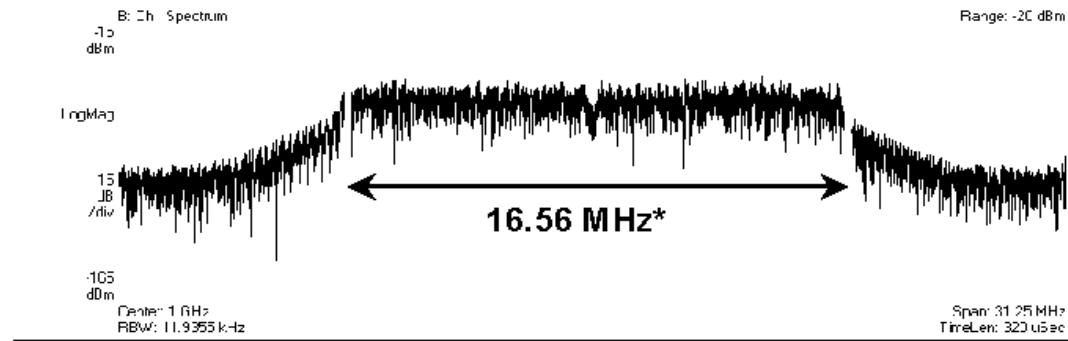
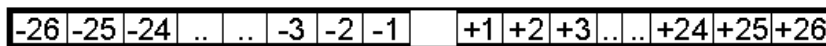


Figure 6-18, “802.11a Spectrum View,” shows an 802.11 a signal burst. The spectrum is not very uniform. This is caused in part by the preambles, but mostly by the data being transmitted.

Figure 6-18 802.11a Spectrum View



Carrier numbering convention



Data carriers:
Pilot carriers:
Carrier 0:

The 802.11a uses 5.15–5.25, 5.25–5.35 and 5.725–5.825 GHz unlicensed national information infrastructure (UNII) bands, each having restrictions imposed on the maximum allowed output power. Table defines the maximum allowable output power for the United States.

Table 6-5 Transmit power level for the United States

Frequency band (GHz)	Maximum output power with up to 6 dBi antenna gain (mW)
5.15-5.25	40 (2.5 mW/MHz)
5.25-5.35	200 (12.5 mW/MHz)
5.725-5.825	800 (50 mW/MHz)

Channel center frequencies are defined at every integral multiple of 5 MHz above 5 GHz. The relationship between center frequency and channel number is given by the following equation:

$$\text{Channel center frequency} = 5000 + 5 \times \text{nch (MHz)} \dots\dots\dots (27)$$

where

$$\text{nch} = 0,1,\dots,200$$

This definition provides a unique numbering system for all channels with 5 MHz spacing from 5 GHz to 6 GHz, as well as the flexibility to define channelization sets for all current and future regulatory domains. The set of valid operating channel numbers by regulatory domain is defined in [Table 6-6](#).

Table 6-6

Valid operating channel numbers by regulatory domain and band

Regulatory domain	Band (GHz)	Operating channel numbers	Channel center frequencies (MHz)
United States	U-NII lower band (5.15 - 5.25)	36 40 44 48	5180 5200 5220 5240
United States	U-NII middle band (5.25 - 5.35)	52 56 60 64	5260 5280 5300 5320
United States	U-NII upper band (5.725 - 5.825)	149 153 157 161	5745 5765 5785 5805

802.11g

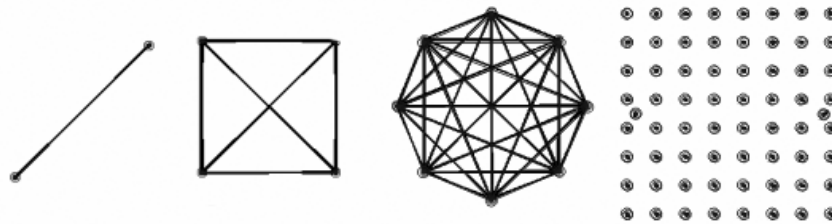
IEEE 802.11g is an extension of the 802.11b standard. So the 802.11g system can interoperate with the 802.11b system. The 802.11g standard adds 802.11a OFDM transmission modes to the 802.11b standard. This provides the 802.11a throughput improvement in the 2.4 GHz band. In addition to the 802.11a OFDM modes, 802.11g also defines optional modes of increased throughput PBCC utilizing 8PSK, and an optional CCK-OFDM mode, which combines the 802.11b preamble with an OFDM packet.

In addition to data rates the 802.11b supports, the 802.11g also enables various data rates using various modulation schemes, such as 11 Mbps using PBCC-11, 22 Mbps using PBCC-22 or CCK-PBCC, 33 Mbps operation using PBCC-33, respectively. For 54 Mbps operation, CCK-OFDM modulation is used.

Similar to the 802.11a, 802.11g OFDM modes map data symbols using BPSK and QPSK for lower data rates and QAM for faster bit rates.

Figure 6-19

Example 802.11g (OFDM) modulation types (left to right: BPSK, QPSK, 8PSK, and 64QAM)



802.11g Specific Modes of Carrier Operation

There are several modes of carrier operation:

- ERP (Extended Rate PHYs) - Shown as Figure 11g_Page15_F7.3.2.13, ERP information element defines the rate extension of the PHY for the Direct Sequence Spread Spectrum (DSSS) system. The ERP builds on the payload data rates of 1 and 2 Mbit/s that use DSSS modulation and builds on the payload data rates of 1, 2, 5.5 and 11 Mbit/s that use DSSS, CCK and optional PBCC modulations. The ERP draws, to provide additional payload data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s. Of these rates, transmission and reception capability for 1, 2, 5.5, 6, 12, and 24 Mbit/s data rates is mandatory. Two additional optional ERP-PBCC modulation modes with payload data rates of 22 and 33 Mbit/s are defined. An ERP-PBCC station may implement 22 Mbit/s alone or 22 and 33 Mbit/s. An optional modulation mode known as DSSS-OFDM is also incorporated with payload data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s.
- ERP (Extended Rate PHYs) - Shown as Figure 11g_Page15_F7.3.2.13, ERP information element defines the rate extension of the PHY for the Direct Sequence Spread Spectrum (DSSS) system. The ERP builds on the payload data rates of 1 and 2 Mbit/s that use DSSS modulation and builds on the payload data rates of 1, 2, 5.5 and 11 Mbit/s that use DSSS, CCK and optional PBCC modulations. The ERP draws, to provide additional payload data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbit/s. Of these rates, transmission and reception capability for 1, 2, 5.5, 6, 12, and 24 Mbit/s data rates is mandatory. Two additional optional ERP-PBCC modulation modes with payload data rates of 22 and 33 Mbit/s are defined. An ERP-PBCC station may implement 22 Mbit/s alone or 22 and 33 Mbit/s. An optional modulation mode known as DSSS-OFDM is also incorporated with payload data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s. The ERP modulations (ERP-OFDM, ERP-PBCC, and DSSS-OFDM) have been designed to coexist with existing.
- ERP-DSSS/CCK -- The PHY uses the capabilities with the following exceptions: Support of the short PLCP PPDU header format capability is mandatory; Clear Channel Assessment has a mechanism that will detect all mandatory sync

symbols; the maximum input signal level (ref 18.4.8.2) is 20 dBm; Locking the transmit center frequency and the symbol clock frequency to the same reference oscillator is mandatory.

- ERP-OFDM -- The PHY uses the capabilities of clause 17 with the following exceptions: The frequency plan is in accordance with sub clauses 18.4.6.1 and 18.4.6.2 instead of 17.3.8.3; CCA has a mechanism that will detect all mandatory clause 19 sync symbols; The frequency accuracy (ref 17.3.9.4 and 17.3.9.5) is ± 25 PPM; The maximum input signal level (ref 17.3.10.4) is -20 dBm; The slot time is 20 μ s in accordance with 18.3.3 except that an optional 9 μ s slot time may be used when the BSS consists of only ERP STAs; SIFS time is 10 μ s in accordance with 18.3.3. See 19.3.2.3 for more detail.
- ERP-PBCC (Optional) -- This is a single carrier modulation scheme that encodes the payload using a 256-state packet binary convolutional code. These are extensions to the PBCC modulation in clause 18. ERP-PBCC modes with payload data rates of 22 and 33 Mbit/s are defined in 19.6.
- DSSS-OFDM (Optional) -- This is a hybrid modulation combining a DSSS preamble and header with an OFDM payload transmission. DSSS-OFDM modes with payload data rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s are defined in 19.7; If the optional DSSS-OFDM mode is used, the supported rates in that mode are the same as the ERP-OFDM supported rates.

Other Sources of Measurement Information

Additional measurement application information is available through your local Agilent Technologies sales and service office. The following application notes treat digital communications measurements in much greater detail than discussed in this measurement guide.

- Application Note 1298
Digital Modulation in Communications Systems - An Introduction
Agilent part number 5965-7160E
- Application Note 1311
Understanding CDMA Measurements for Base Stations and Their Components
Agilent part number 5968-0953E
- Application Note 1486
WLAN RF and Baseband Transmitter Analysis Using Agilent Infiniium Oscilloscopes and 89600 Software, literature number 5989-0327EN.
- Application Note 1380-1
RF Testing of Wireless LAN Products, literature number 5988-3762EN.
- Application Note 1380-2
IEEE 802.11 Wireless LAN PHY Layer (RF) Operation and Measurement, literature number 5988-5411EN.
- Application Note 1380-4
Making 802.11G Transmitter Measurements, literature number 5988-7813EN.
- Application Note
Characterizing Digitally Modulated Signals with CCDF Curves
Agilent part number 5968-5858E
- Application Note
Characterizing Digitally Modulated Signals with CCDF Curves
Agilent part number 5968-5858E

Instrument Updates at www.agilent.com

This web location can be used to access the latest information about the instrument, including the latest firmware version.

<http://www.agilent.com/find/psa>

References

1. Supplement to IEEE Standard for Information Technology, IEEE Std 802.11a-1999 (Supplement to ANSI/IEEE Std 802.11, 1999 Edition)
2. Higher Speed Physical Layer in the 2.4 GHz Band, IEEE Std 802.11b-1999 (Supplement to ANSI/IEEE Std 802.11, 1999 Edition)
3. Higher Speed Physical Layer in the 2.4 GHz Band, IEEE Std 802.11g/D8.2, Apr. 2003 (Supplement to ANSI/IEEE Std 802.11, 1999 (Reaff 2003))



7 Programming Examples

- The programming examples were written for use on an IBM compatible PC.
- The programming examples use C, Visual Basic, or VEE programming languages.
- The programming examples use VISA interfaces (GPIB, LAN, or USB).
- Some of the examples use the IVI-COM drivers.

Interchangeable Virtual Instruments COM (IVI-COM) drivers: Develop system automation software easily and quickly. IVI-COM drivers take full advantage of application development environments such as Visual Studio using Visual Basic, C# or Visual C++ as well as Agilent's Test and Measurement Toolkit. You can now develop application programs that are portable across computer platforms and I/O interfaces. With IVI-COM drivers you do not need to have in depth test instrument knowledge to develop sophisticated measurement software. IVI-COM drivers provide a compatible interface to all. COM environments. The IVI-COM software drivers can be found at the URL:

<http://www.agilent.com/find/ivi-com>

- Most of the examples are written in C, Visual Basic, VEE, or LabView using the Agilent VISA transition library.

The Agilent I/O Libraries Suite must be installed and the GPIB card, USB to GPIB interface, or Lan interface USB interface configured. The latest Agilent I/O Libraries Suite is available: www.agilent.com/find/iolib

- The STATUS subsystem of commands is used to monitor and query hardware status. These hardware registers monitor various events and conditions in the instrument. Details about the use of these commands and registers can be found in the manual/help in the Utility Functions section on the STATUS subsystem.

Visual Basic is a registered trademark of Microsoft Corporation.

X-Series Spectrum Analyzer Mode Programming Examples

The following examples work with Spectrum Analyzer mode. These examples use one of the following programming languages: Visual Basic[®] 6, Visual Basic.NET[®], MS Excel[®], C++, ANSI C, C#.NET, and Agilent VEE Pro.

These examples are available in either the “progexamples” directory on the Agilent Technologies Spectrum Analyzer documentation CD-ROM or the “progexamples” directory in the analyzer. The file names for each example is listed at the end of the example description. The examples can also be found on the Agilent Technologies, Inc. web site at URL:

http://www.agilent.com/find/sa_programming

NOTE

These examples have all been tested and validated as functional in the Spectrum Analyzer mode. They have not been tested in all other modes. However, they should work in all other modes except where exceptions are noted.

Programming using Visual Basic[®] 6, Visual Basic.NET[®] and MS Excel[®]:

- **Transfer Screen Images** from your Spectrum Analyzer using Visual Basic 6

This example program stores the current screen image on the instrument flash memory as “D:\PICTURE.PNG”. It then transfers the image over GPIB or LAN and stores the image on your PC in the current directory as “PICTURE.PNG”. The file “D:\PICTURE.PNG” is then deleted on the instrument flash memory.

File name: _screen.bas

- **Binary Block Trace** data transfer from your Spectrum Analyzer using Visual Basic 6

This example program queries the IDN string from the instrument and then reads the trace data in Spectrum Analysis mode in binary format (Real,32 or Real,64 or Int,32). The data is then stored to a file “bintrace.txt”. This data transfer method is faster than the default ASCII transfer mode, because less data is sent over the bus.

File name: bintrace.bas

Programming using C++, ANSI C and C#.NET:

- **Serial Poll for Sweep Complete** using C++

This example demonstrates how to:

1. Perform an instrument sweep.
2. Poll the instrument to determine when the operation is complete.
3. Perform an instrument sweep.

File name: _Sweep.c

- **Service Request Method (SRQ)** determines when a measurement is done by waiting for SRQ and reading Status Register using C++.

This example demonstrates how:

1. Set the service request mask to assert SRQ when either a measurement is uncalibrated or an error message has occurred,
2. Initiate a sweep and wait for the SRQ interrupt,
3. Poll all instruments and report the nature of the * interrupt on the spectrum analyzer.

The STATUS subsystem of commands is used to monitor and query hardware status. These hardware registers monitor various events and conditions in the instrument. Details about the use of these commands and registers can be found in the manual/help in the Utility Functions section on the STATUS subsystem.

File name: _SRQ.C

- **Relative Band Power Markers** using C++

This example demonstrates how to set markers as Band Power Markers and obtain their band power relative to another specified marker.

File name: _BPM.c

- **Trace Detector/Couple Markers** using C++

This example demonstrates how to:

1. Set different types of traces (max hold, clear and write, min hold)
2. Set markers to specified traces
3. Couple markers

Note: The Spectrum Analyzer is capable of multiple simultaneous detectors (i.e. peak detector for max hold, sample for clear and write, and negative peak for min hold).

File name: _tracecouple.c

- **Phase Noise** using C++

This example demonstrates how to:

1. Remove instrument noise from the phase noise
2. Calculate the power difference between 2 traces

File name: _phasenoise.c

Programming using Agilent VEE Pro:

- **Transfer Screen Images** from my Spectrum Analyzer using Agilent VEE Pro

This example program stores the current screen image on the instrument flash memory as "D:\scr.png". It then transfers the image over GPIB and stores the image on your PC in the desired directory as "capture.gif". The file "D:\scr.png" is then deleted on the instrument flash memory.

File name: _ScreenCapture.vee

- **Transfer Trace Data** data transfer using Agilent VEE Pro

This example program transfers the trace data from your Spectrum Analyzer. The program queries the IDN string from the instrument and supports Integer 32, real 32, real 64 and ASCII data. The program returns 1001 trace points for the signal analyzer.

File name: transfertrace.vee

N9064A VXA Signal Analyzer Programming Examples

The following examples work with N9064A VXA Signal Analyzer Mode. These examples use one of the following programming languages: Visual Basic[®] 6, Visual Studio 2003 .NET[®], and Agilent VEE Pro.

These examples are available in either the “progexamples” directory on the Agilent Technologies N9064A VXA documentation CD-ROM or the “progexamples” directory in the analyzer. The file names for each example is listed at the end of the example description. The examples can also be found on the Agilent Technologies, Inc. web site at URL:

http://www.agilent.com/find/sa_programming

NOTE

These examples have all been tested and validated as functional in N9064A VXA Signal Analyzer Mode.

Programming using Visual Basic[®] 6 and Visual Basic.NET[®]:

- Setting up a Vector Measurement on your N9064A VXA using Visual Basic 6.

This example program:

- Sets up the VSA Mode.
- Sets the Vector Measurement.
- Configures the Vector Measurement.
- Starts the Vector Measurement.
- Reads the trace data in Real 64 data format

File name: VXA-MeasDemo.vbs

- Setting up a Digital Demod Measurement on your N9064A VXA using Visual Basic 6.

This example program:

- Sets up the VSA Mode.
- Sets the Digital Demod Measurement.
- Configures the Digital Demod Measurement.
- Starts the Digital Measurement.
- Reads the trace data, EVM, and demodulated bits.

File name: VXA-DigDemodDemo.vbs

Programming using Agilent VEE Pro:

- Setting up a VSA Measurement on your N9064A VXA using VEE.

This example program:

- Sets up the VSA Mode.
- Sets the Vector Measurement.
- Configures the Vector Measurement.
- Starts the Vector Measurement.
- Reads the trace data in Real 32, Real 64 and ASCII data format

File name: VXA-MeasDemo.vee

- Setting up a Digital Demod Measurement on your N9064A VXA VEE.

This example program:

- Sets up the VSA Mode.
- Sets the Digital Demod Measurement.
- Configures the Digital Demod Measurement.
- Starts the Digital Measurement.
- Reads the trace data, EVM, and demodulated bits.

File name: VXA-DigDemodDemo.vee

Programming using Visual Studio® 2003 .NET:

- Setting up a VSA Measurement on your N9064A VXA using Visual Basic 6.

This example program:

- Sets up the VSA Mode.
- Sets the Vector Measurement.
- Configures the Vector Measurement.
- Starts the Vector Measurement.
- Reads the trace data in Real 64 data format

File name: VXA-MeasDemo.sln

- Setting up a Digital Demod Measurement on your N9064A VXA using Visual Basic 6.

This example program:

- Sets up the VSA Mode.
- Sets the Digital Demod Measurement.
- Configures the Digital Demod Measurement.
- Starts the Digital Measurement.
- Reads the trace data, EVM, and demodulated bits.

File name: VXA-DigDemodDemo.sln