Keysight X-Series Signal Analyzers

This manual provides documentation for the following Analyzers:

PXA Signal Analyzer N9030A
EXA Signal Analyzer N9010A
MXA Signal Analyzer N9020A
CXA Signal Analyzer N9000A

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KEYSIGHT TECHNOLOGIES

N9064A & W9064A VXA Signal Analyzer Measurement Application Measurement Guide

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Table of Contents

1 Introduction

What Does the Keysight N9064A VXA Signal Analyzer Measurement Application Do? 12

2 Making N9064A VXA Measurements

Introduction 16

Measuring Analog Signals 17

- Analog Demod Measurement Overview 17
- Set Up the Test Equipment and DUT 18
  - Making the Initial Signal Connection 18
- Select the Mode and Preset the Analyzer 19
- Select and Configure the Analyzer Input 20
- Acquire and Stabilize the Signal 21
- Demodulate the Signal 22
- Configure the Display 23
  - Analog Demod Preset Views 23
- Optimize your Results 26
- Print or Save Your Measurement Results 27
- Viewing Other Analog Demod Measurement Results 29
- Example Measurement - Analog Demod 30
  - Keysight ESG Series Vector Signal Generator Settings 30

Measuring Digital Signals 40

- Digital Demod Measurement (Option 2FP) Overview 40
- Set Up the Test Equipment and DUT 41
  - Making the Initial Signal Connection 41
- Select the Mode and Preset the Analyzer 42
- Select and Configure the Analyzer Input 43
- Acquire and Stabilize the Signal 44
- Demodulate the Signal 45

Configure the Display 48
Digital Demod Preset View 48
Optimize your Results 50
Print or Save Your Measurement Results 51
Tips When Using Digital Demodulation 53
Using Burst/Sync Search 53
Using Adaptive Equalization 55
Viewing Other Digital Demod Measurement Results 59
Example Measurement - Digital Demod 60
Keysight ESG Series Vector Signal Generator Settings 60
Troubleshooting N9064A VXA Measurements 66

3 Interpreting Error Codes

4 Concepts

Introduction 70
Analog Modulation Concepts 71
Amplitude Modulation 71
Modulation Degree and Sideband Amplitude 71
Frequency Modulation and Phase Modulation 77
Analog Demodulation 79
Bandwidth Concepts for Analog Demodulation 81
Analog Demodulation and Time Corrections 81
Triggering Demodulated Measurements 82
Additional Information 83
Digital Modulation Concepts 84
Why Choose Digital Instead of Analog Modulation? 84
What is Digital Modulation? 84
QAM example 87
PSK Examples 88
Orthogonality 89
Symbol Rate 89

Symbol Rate and Frequency Span 90
Signal-to-Noise Ratio 91
VSB modulated signals 91
Bandwidth 91
Filtering 92
Effects Of Going Through The Origin 94
Transmitting the Digital Signal 94
I/Q Modulator 95
System Multiplexing 96
Digital Demodulation Block Diagram 97
Digital Modulation Format Standards 100
Introduction 100
Modulation Formats and Applications 100
Families of Format and Data Sheets 101
Quadrature Amplitude Modulation (QAM) Concepts 102
16 QAM 102
32 QAM 102
QAM Modulation Characteristics 103
Phase Shift Keying (PSK) Concepts 104
BPSK Modulation Characteristics 105
QPSK Modulation Characteristics 105
8PSK Modulation Characteristics 106
DQPSK Modulation Concepts 106
π/4 DQPSK Modulation Characteristics 108
D8PSK Modulation Characteristics 108
π/8 D8PSK Concepts 108
Offset QPSK Modulation Concepts 109
Minimum Shift Keying (MSK) Concepts 111
Constant Envelope MSK Modulation 111
MSK Modulation Characteristics 112
Frequency Shift Keying (FSK) Concepts 113
FSK Modulation Characteristics 113

Digital Video Broadcast QAM (DVB QAM) Concepts 115
I/Q Origin Offset Compensation 115
Reliable Carrier Lock 115
Vestigial Side Band (VSB) Concepts 117
Carrier locking and pilot search (VSB) 117
Amplitude Phase-Shift Keying (APSK) Concepts 119
Enhanced Data for Global Evolution (EDGE) Concepts 121
Continuous Phase Modulation (CPM) Concepts 122
Modulation Bit State Diagrams 123
Bit State Diagrams by Modulation Family 123
FSK Bit state Diagrams 123
PSK Bit State Diagrams 125
QAM Bit State Diagrams 128
DVB QAM Bit State Diagrams 132
Communication System Formats 137
N9064A VXA Supported Communications Format Standards 137
What is the CDMA Communication System? 146
CDMA Communication System 147
What is the W-CDMA Communications System? 148
W-CDMA Code Division Multiple Access 148
Base Station and User Equipment Identification 150
Data Channelization 150
W-CDMA Communication System 151
What is the NADC Communications System? 152
NADC Communication System 154
What is the PDC Communications System? 155
PDC Communication System 156
What is the PHS Communication System 157
PHS Communication System 157
What is the TETRA Communications System 158
TETRA Communication System 159
What is Bluetooth? 160

Bluetooth Radio Unit 160
Bluetooth Communication System 163
What are GSM and EDGE? 164
Mobile Stations and Base Transceiver Stations 166
Uplink and Downlink 166
What is an ARFCN? 166
What Is A Timeslot? 167
EDGE Communication System 167
What is APCO25 phase 1? 168
FEATURES OF APCO25 phase 1 168
APCO25 phase1 Communication System 171
What is VDL Mode 3? 171
What is ZigBee (IEEE 802.15.4) 172
Measurements of Digital RF Communications Signals 173
Introduction 173
Digital Modulation Analysis 173
Measurement Domains 174
Time Domain 174
Frequency Domain 175
Modulation Domain 176
N9064A VXA Digital Demodulator 177
The Digital Demodulator Block Diagram by Section 177
Configuring the Demodulator 179
Synchronization 180
Understanding Burst/Sync Terms 181
Modulation quality measurements 181
Error Vector Magnitude (EVM) 182
Equalization with EVM 182
What is Adaptive Equalization? 183
Phase and Frequency Errors 184
Frequency Response 184
Rho 185

Digital Modulation Errors and Signal Impairments 186
Relationship Between I/Q, Constellation and Eye Diagrams 187
I/Q and Constellation Diagrams 187
Interpreting I/Q Diagrams 188
Constellation Diagram 188
Eye diagrams 189
Impairments 189
I/Q Gain Imbalance 190
Quadrature errors 190
I/Q Offsets 191
Delays in I/Q paths 191
I/Q Signals “Swapped” 192
Digital Modulation Displays 194
Numeric Results 196
Error Vector Spectrum (Quad-View) 198
Demod Bits 199
Equalizer (Quad-View) 199
References 201

5 Programming Examples

X-Series Spectrum Analyzer Mode Programing Examples 204
N9064A VXA Signal Analyzer Programming Examples 207

1 Introduction

This chapter provides overall information on the Keysight N9064A 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 chapter, in case you purchased this option separately.

What Does the Keysight 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 (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 (also 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
  - — π/4 DQPSK
  - — DQPSK
  - — EDGE
  - — π/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/DVB, 32 w/DVB
  - — CPM

— Standard communications formats provided by Option 2FP include:

- Cellular: CDMA Base and Mobile, GSM, EDGE, CDPD, NADC, PDC, PHP, W-CDMA
- Wireless Networking: WLAN (802.11b), HIPERLAN/1 (HBR and LBR), *Bluetooth*, ZigBee (802.15.4, 868/915/2450 MHz), WiSUN
- Digital Video: DTV8, DTV16, DVB16, DVB32, DVB64, DVB128, DVB256, DVB 16APSK with code rates 2/3 to 9/10, DVB 32APSK with code rates 3/4 to 9/10.
- Other: APCO 25, DECT, TETRA, VDL Mode 3, HCPM, HDQPSK, MIL-STD CPM.

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.

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 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

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.

Three fundamental measurements are available in this mode: **Vector Analysis**, **Analog Demod** (standard with N9064A option 1FP), and **Digital Demod** (available separately as N9064A Option 2FP).

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. With the Vector Signal Analyzer mode selected, 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.

If you purchased this firmware separately as an optional upgrade, refer to the *X-Series Getting Started and Troubleshooting Guide* for information on installing your license.

The following main subjects are presented in this chapter:

- "Measuring Analog Signals" on page 17

  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 29

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

- "Measuring Digital Signals" on page 40

  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 59

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

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 18

This step configures the analyzer connections for an RF measurement.

"Select the Mode and Preset the Analyzer" on page 42

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 43

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 44

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 45

Demodulation is performed by using a specific N9064A VXA demod option, like 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.

"Configure the Display" on page 48

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 50

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 51

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 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.

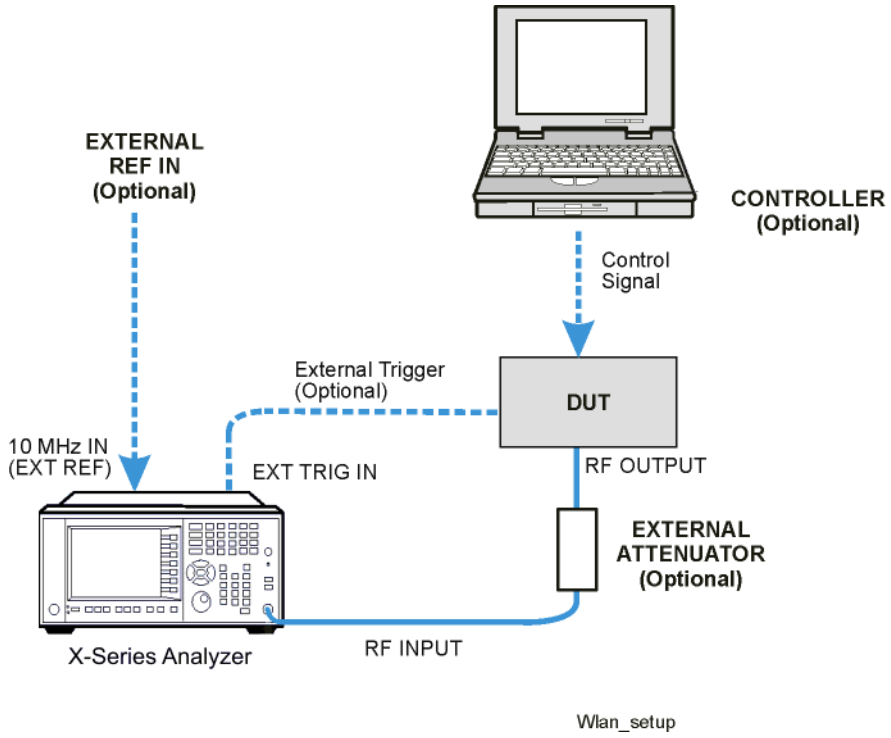
Set Up the Test Equipment and DUT

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*



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 17.

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 (VXA).**	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 the **User Preset** button.	

Click to Go Back to "Measuring Analog Signals" on page 17.

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.
OR **2** 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 27 for details of saving states.
OR **3** If available, you can recall a saved measurement trace for display.	a. Press **Recall**, **Data (Import)** b. Press **Trace** to select the trace that contains 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 17.

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 Observe the Spectrum (upper) graph: set the center frequency to your signal's carrier frequency.	a. Press **FREQ Channel.** b. Use the front-panel keypad to input the center frequency. c. Press a units key, like **GHz**, to complete the entry.	Settings made in the Vector Analysis measurements will be used by Demod measurements later. **TIP** The center frequencies of the analyzer and input signal must match to within ±5%.
2 Set the input power range for your signal.	a. Press **AMPTD Y Scale**, **Range**. b. Enter the total signal power at the analyzer input. c. Press **dBm** to complete the entry.	**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.
3 Set the frequency span to view your entire signal. Make sure the entire signal is captured in the Spectrum graph.	a. Press **SPAN X Scale**. b. Use the front-panel keypad to input the frequency span. c. Press a units key, like **MHz**, to complete the entry. You can also use the rotary knob to visually set the span.	**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.
4 Observe the Main Time (lower) graph: set trigger parameters (if used)	a. Press **Trigger**. b. Select the correct input for the trigger signal. c. Set levels as required.	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. **TIP** Triggering is unnecessary for most signals.

Click to Go Back to "Measuring Analog Signals" on page 17

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.	a. Press **Meas, Analog Demod**.	For signals using digital modulation, select the Digital Demod measurement. See "Measuring Digital Signals" on page 40.
2 Set the input power range for your signal.	a. Press **AMPTD Y Scale**, **Range**. b. Enter the total signal power at the analyzer input. c. Press **dBm** to complete the entry.	**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.	a. Press **Meas Setup**, **Demod Setup, Demod Type.** b. Select from **AM, FM**, or **PM**.	
4 Use signal tracking for unstable signals	a. For FM and PM signals, press **Auto Carrier Freq, On**. b. For PM signals, press **Auto Carrier Phase, On**.	

Click to Go Back to "Measuring Analog Signals" on page 17.

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 Views below.
OR **2** 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**. 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

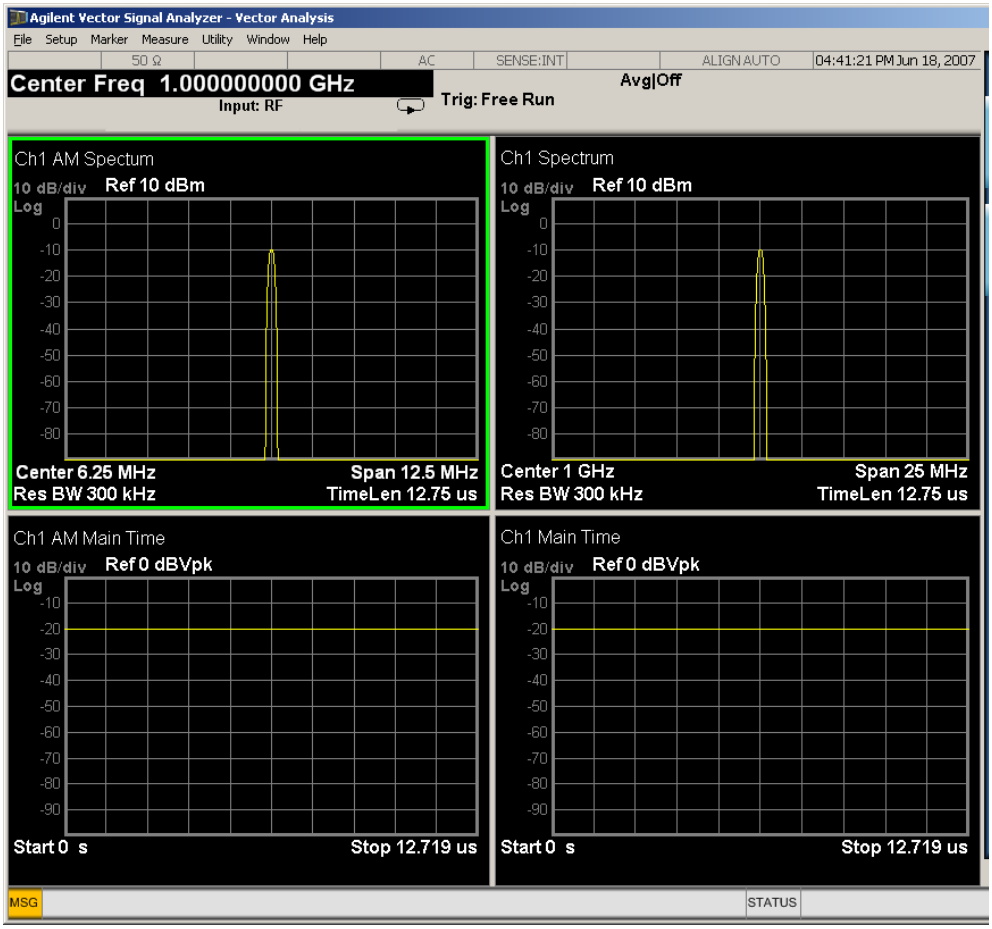
Analog Demod preset displays include Demod Spectrum/Time and Statistics views.

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.

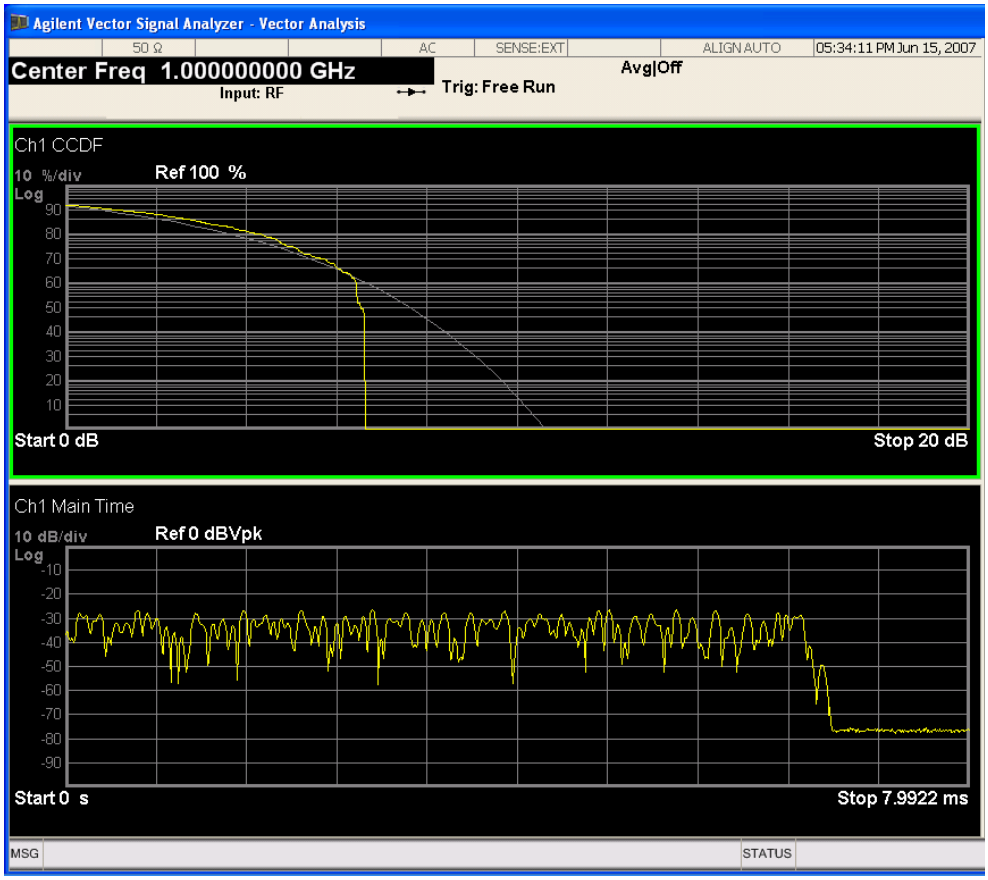
Figure 2-2 *Demod Spectrum/Time Preset View*



Statistics Preset View

This preset shows a stack 2 layout with CCDF in trace 1 and Main Time in trace 2.

Figure 2-3 *Statistics Preset View*



Click to Go Back to "Measuring Analog Signals" on page 17.

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**, **More, X Scale Auto** to enable the instrument to complete the scaling.	
3 Optimize the Y Scale.	a. Press **AMPTD Y Scale, 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**. 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 in Help.
5 Add titles or make other changes to the measurement graphs.	a. Press **View/Display**, **Display**, **System Display 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.	For more information on Display settings, see the Display section under View/Display in Help.

Click to Go Back to "Measuring Analog Signals" on page 17.

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 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 **File, 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.	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. 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
3 If desired, save your measurement state for reuse later.	a. Press **Save**, and select **State** to save your current measurement settings for reuse 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 “Measuring Analog Signals” on page 17.

Viewing Other Analog Demod Measurement Results

This section provides some examples of Analog Demod measurement results of an 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 23.

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, and so on.

Analog Demod Measurement Data Include:

1. Instantaneous Main Time
2. Main Time
3. Gate 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 Reference or Help on Trace/Detector, Data.

Click to Go Back to "Measuring Analog Signals" on page 17.

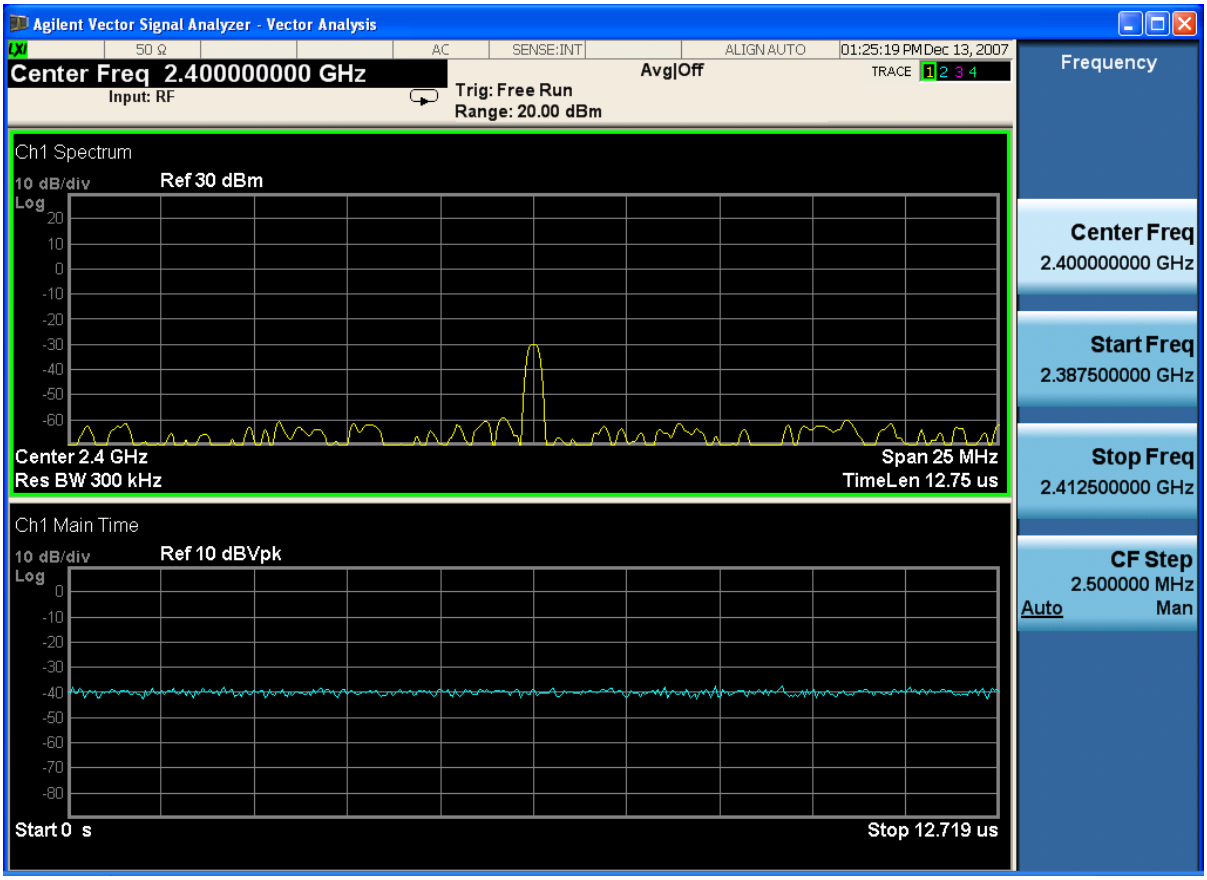
Example Measurement - Analog Demod

Keysight ESG Series Vector Signal Generator Settings

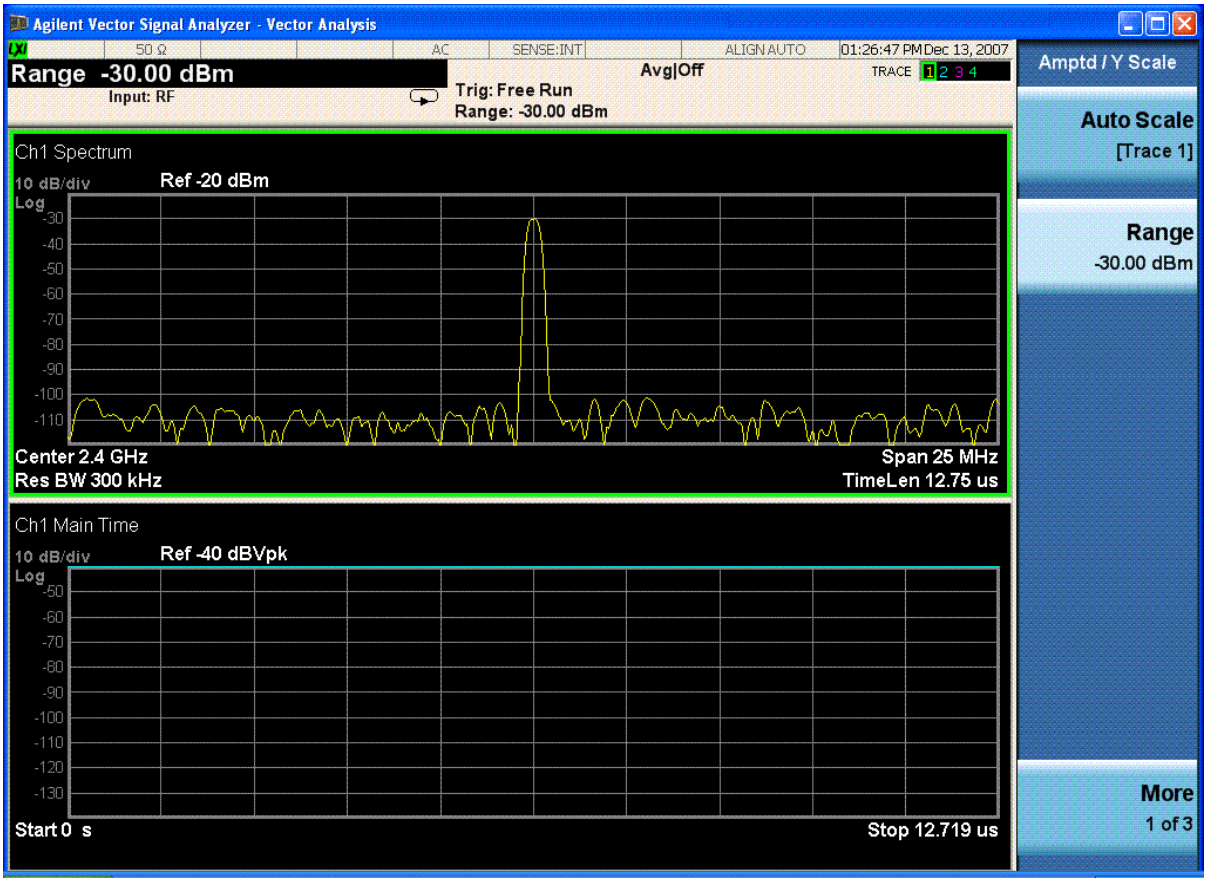
Frequency: 2.4 GHz
Power (Signal Amplitude): -30 dBm
Modulation: FM
FM Rate: 100 kHz
3.2 kHz deviation

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

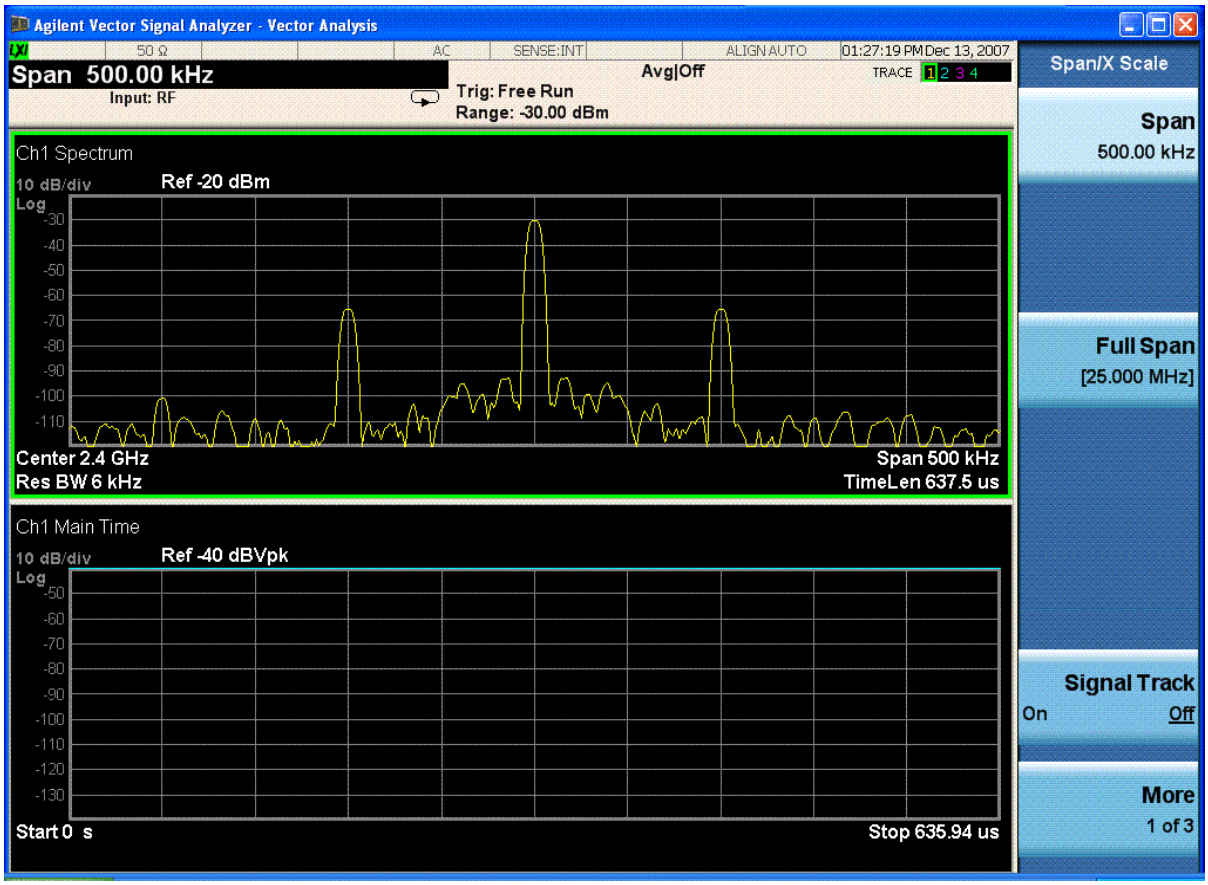
Step	Action	Notes
1 Preset the analyzer.	a. Press **Mode Preset**.	
2 Select the Vector Analysis measurement.	a. Press **Meas, Vector Analysis**.	
3 Set the frequency.	a. Press **FREQ Channel, 2.4 GHz**.	
4 View the measurement.	a. View the Vector Analysis measurement default Spectrum and Ch1 Main Time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

Step	Action	Notes
		
5 Adjust the input power range of the analyzer.	a. Press **AMPTD Y Scale, 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).

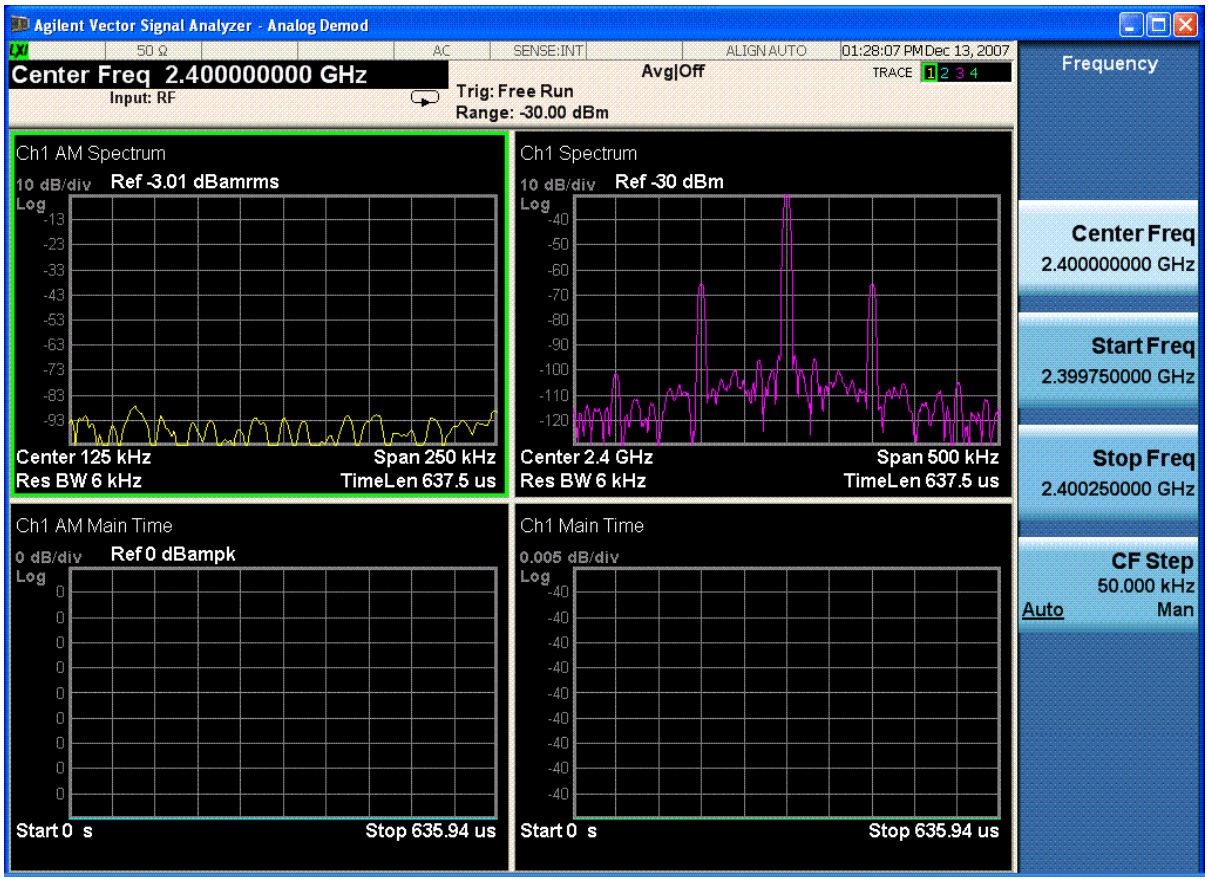
Step	Action	Notes



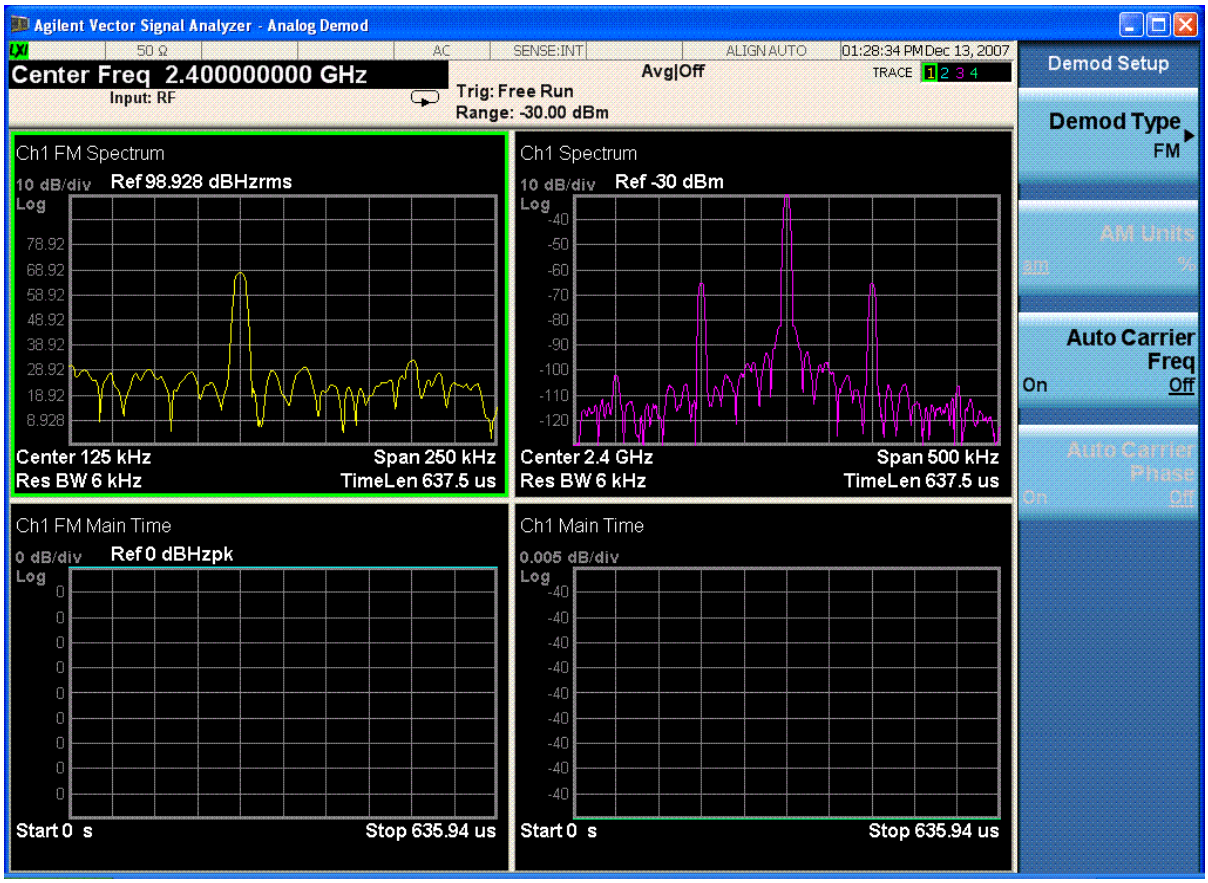
6	Adjust the span.	a. Press **Span X Scale** and the down arrow until the entire signal spectrum is visible in the Spectrum view.	Note the default span (with N9020A-B25) is set at 25 MHz. No sidebands are visible at the span. 500 kHz per division seems to fit nicely. (See the following figure). Now at least 2 sidebands are visible, and Analog Demod can proceed.

Step	Action	Notes
		
7 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).

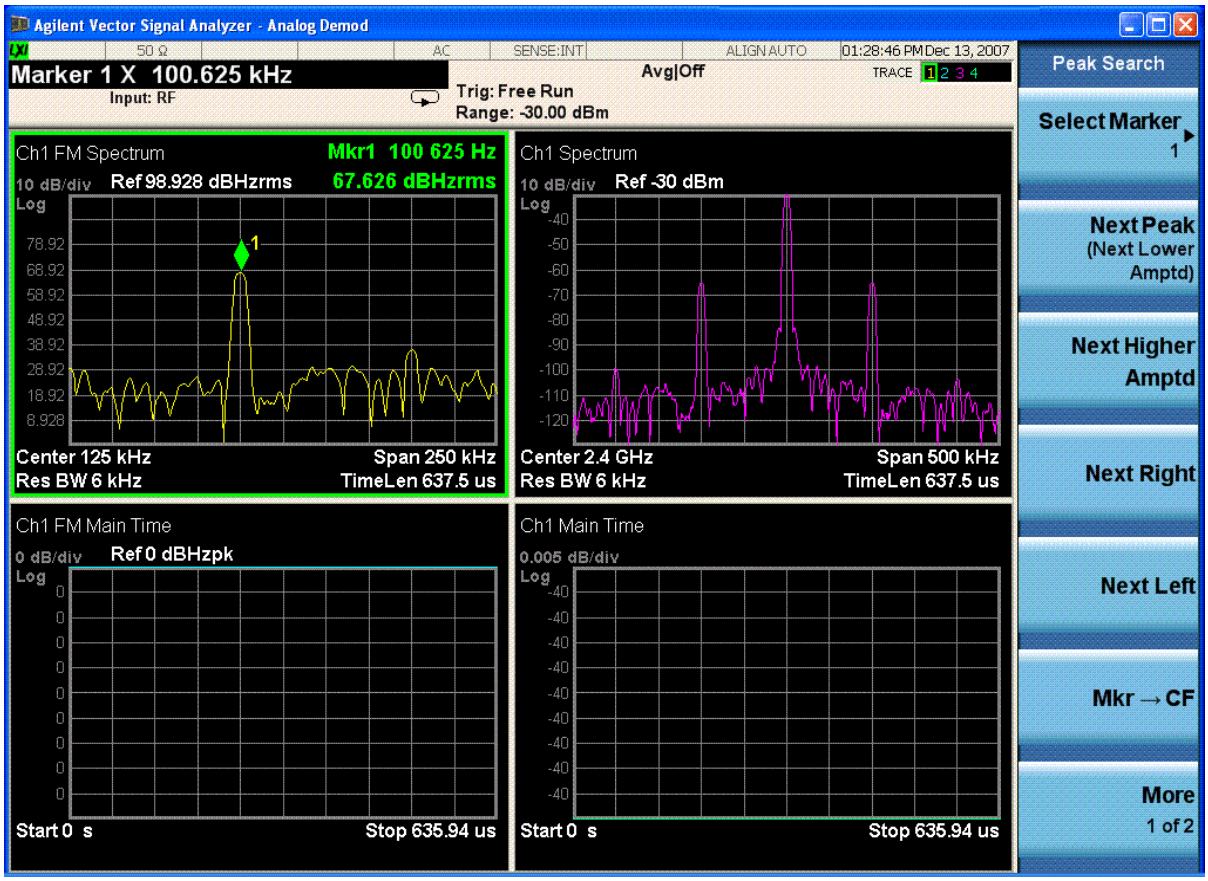
Step	Action	Notes



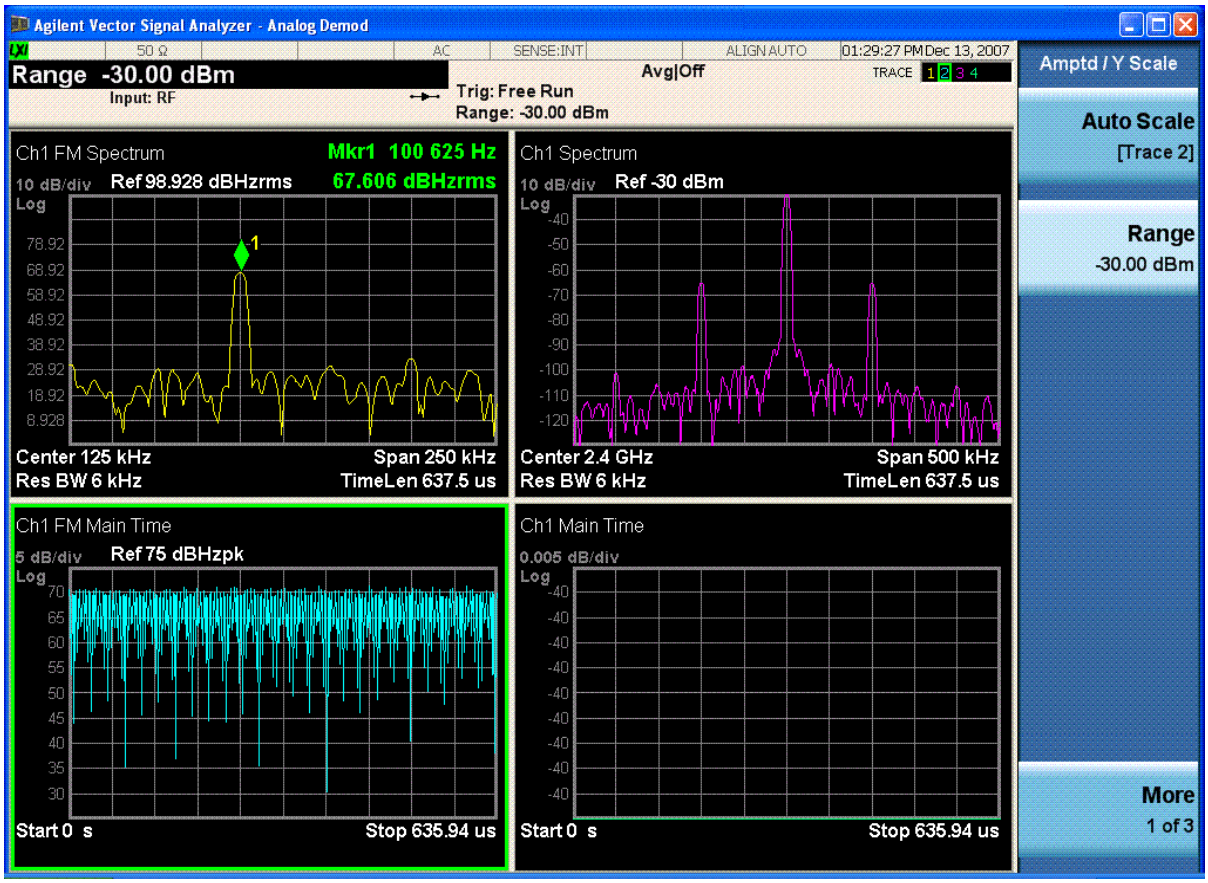
8	Select FM demodulation setup.	a. Press **Meas Setup, Demod Setup, Demod Type**. b. Select **FM** from the menu of available choices.	
9	View the Demod FM Spectrum.	a. View the Demod FM Spectrum in trace 1.	Shows a strong carrier signal. See the following figure.

Step	Action	Notes
		
10 Put a marker on trace 1 that measures the FM modulating frequency.	a. Press **Peak Search**.	Trace 2 displays FM Main Time, the time record of the demodulated signal, but it needs adjustment, as does trace 4.

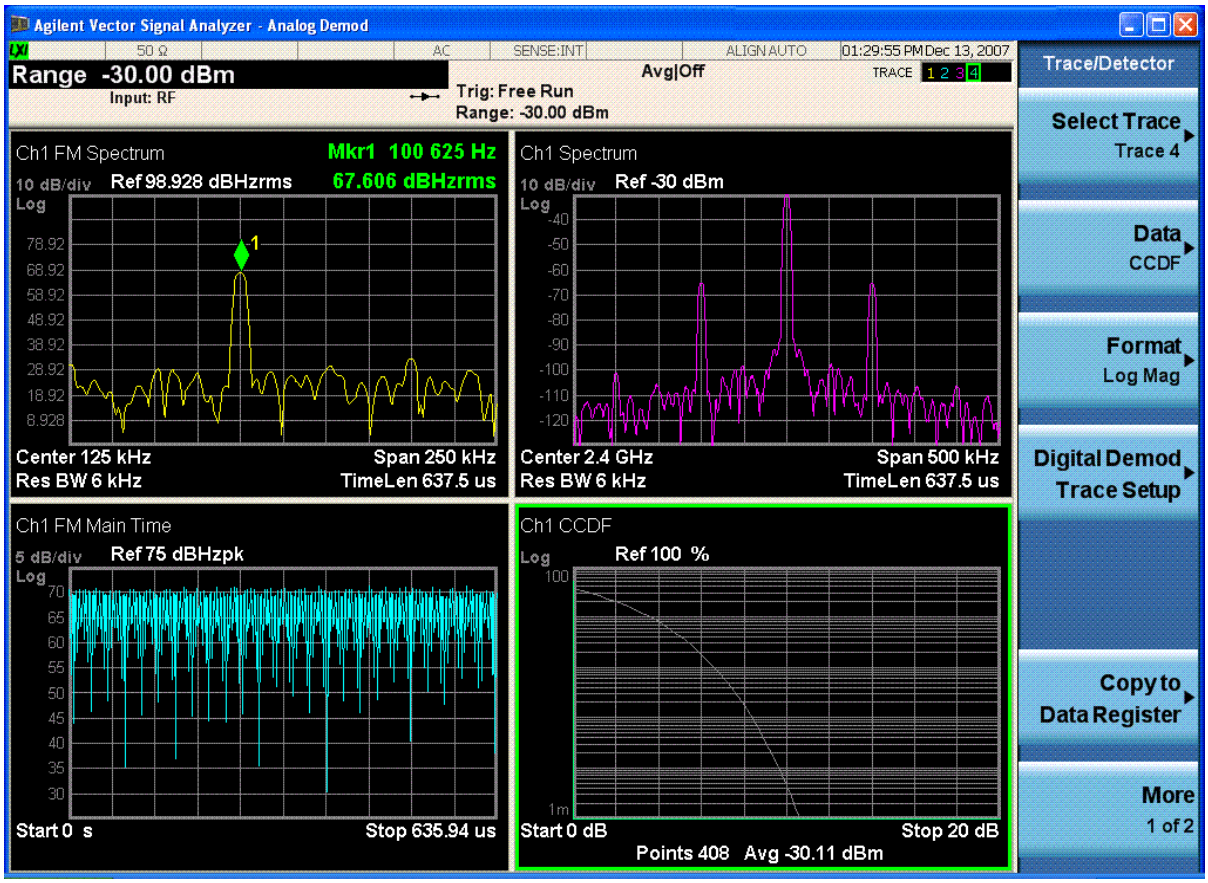
Step	Action	Notes



11 Move the focus (green outline) to trace 3.	a. Press the **Next Window** key or press **Trace/Detector**, **Select Trace**, **Trace 3**.	
12 Optimize the scaling.	a. Press **AMPTD Y Scale**, **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
		
13 Select trace 4.	a. Press **Trace/Detector**, **Select Trace**, **Trace 4.**	Trace numbers are shown to help identify which graphs display traces.
14 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 Meas Setup, Demod Setup, Demod Type.

Step	Action	Notes



If you have a problem and get an error message, see “Interpreting Error Codes” on page 67.

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 41

This step configures the analyzer connections for an RF measurement.

"Select the Mode and Preset the Analyzer" on page 42

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 43

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 44

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 45

Demodulation is performed 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 48

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 50

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 51

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 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.

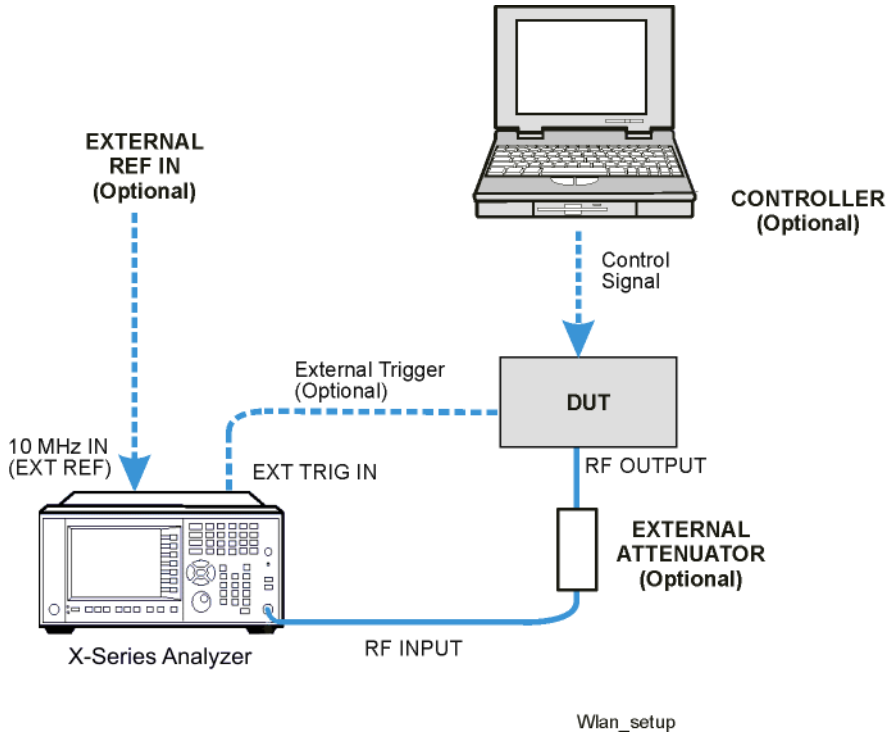
Set Up the Test Equipment and DUT

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 Digital Signals" on page 40.

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 (VXA)**.	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 the **User Preset** button.	

Click to Go Back to "Measuring Digital Signals" on page 40.

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.
OR **2** 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.
OR **3** If available, you can recall a saved measurement trace for display.	a. Press **Recall**, **Data (Import)** b. Press **Trace** to select the trace that contains the stored data. c. Press **Open...**, which opens an Explorer window to browse to your state file location.	

Click to Go Back to "Measuring Digital Signals" on page 40.

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 Observe the Spectrum (upper) graph: set the center frequency to your signal's carrier frequency.	a. Press **FREQ Channel.** b. Use the front-panel keypad to input the center frequency. c. Press a units key, like **GHz**, to complete the entry.	Most settings made in the Vector Analysis measurements will be used by Demod measurements later. **TIP** The center frequencies of the analyzer and input signal must match to within ±3% of the symbol rate (±1% for 64QAM and ±0.2% for 256QAM).
2 Set the input power range for your signal.	a. Press **AMPTD Y Scale**, **Range**. b. Enter the total signal power at the analyzer input.	**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.
3 Set the frequency span to view your entire signal. Make sure the entire signal is captured in the Spectrum graph.	a. Press **SPAN X Scale**. b. Use the front-panel keypad to input the frequency span. c. Press a units key, like **MHz**, to complete the entry. You can also use the rotary knob to visually set the span.	**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.
4 Observe the Main Time (lower) graph: set trigger parameters (if used).	a. Press **Trigger**. b. Select the correct input for the trigger signal. c. Set levels as required.	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. **TIP** Triggering is unnecessary for most signals. For TDMA and other burst signals, as the Vector Signal Analyzer will readily acquire a "framed" signal.

Click to Go Back to "Measuring Digital Signals" on page 40.

Demodulate the Signal

Demodulation is performed by using a specific N9064A VXA demod option, like 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 17.
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 standard presets provided.	If installed, use your standard-specific N9064A VXA option for your signal of interest: See "Making N9064A VXA Measurements" on page 15.
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 **Meas Setup, 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, EDGE, and CPM. Submenus enable you to specify a variety of formats for your signal of interest.

Step	Action	Notes
4 For signals that don't conform to an established format, configure Demod Setup as needed.	a. Press **Meas, Digital Demod**. b. Press **Meas Setup, 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.	**TIP** The symbol rate needs to be entered to an accuracy of 10-100 ppm. **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) **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. **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.
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**, **Fixed EQ Mode**, and select **Normal**. Try using the default settings before making adjustments	For more information about Adaptive Equalization see "Using Adaptive Equalization" on page 55 and the Adaptive Equalizer section under Meas Setup in Help. For more information about Fixed Equalization, see the Fixed Equalization section under Mode Setup in Help.

Step	Action	Notes
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, External Gain, Ext Preamp** 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 "Measuring Digital Signals" on page 40.

Configure the Display

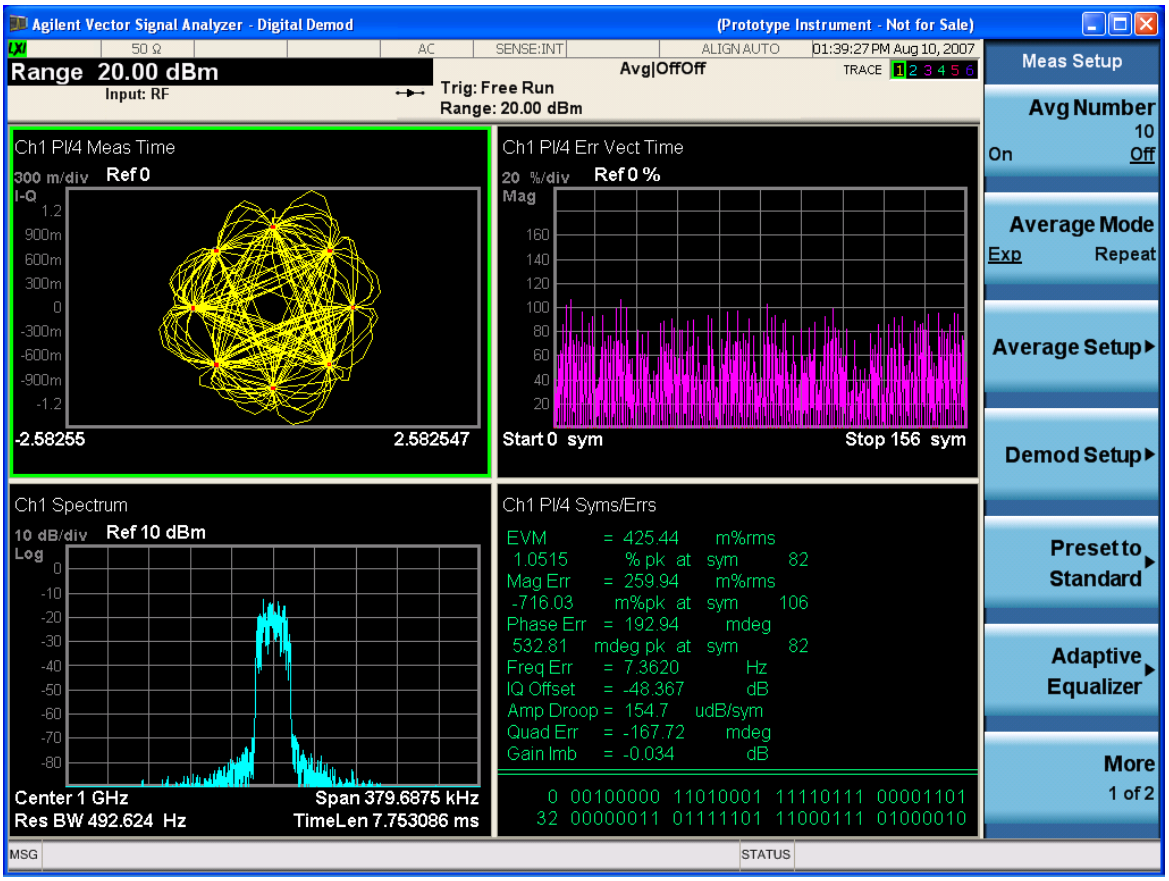
Measurement results are available in graphical displays that can be presented in preset groups or adjusted to suit your specific application. Most results are also available in tabular format.

Step	Action	Notes
1 Use Preset View for fast, powerful result displays.	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.
OR **2** 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**. 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.

Figure 2-5 Digital Demod Preset View- Demod Quad



Click to Go Back to "Measuring Digital Signals" on page 40.

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**, **More, X Scale Auto** to enable the instrument to complete the scaling.	
3 Optimize the Y Scale.	a. Press **AMPTD Y Scale**, **More, 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 Y Scale**, **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**. e. Select **Band Adjust** and adjust the settings as needed. 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 in Help.
5 Add titles, or make other changes to the measurement graphs.	a. Press **View/Display**, **Display**, **System Display 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.	For more information on Display settings, see the Display section under View/Display in Help.

Click to Go Back to "Measuring Digital Signals" on page 40.

Print or Save Your Measurement Results

Your measurement results 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 **File, 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.

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 Digital Signals" on page 40.

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 satisfy 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 67.

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.

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 **Meas** menu:

Step	Action	Notes
1 Access the synchronization menu.	a. Press **Meas Setup**, **Demod Setup**, **More, 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 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 181.

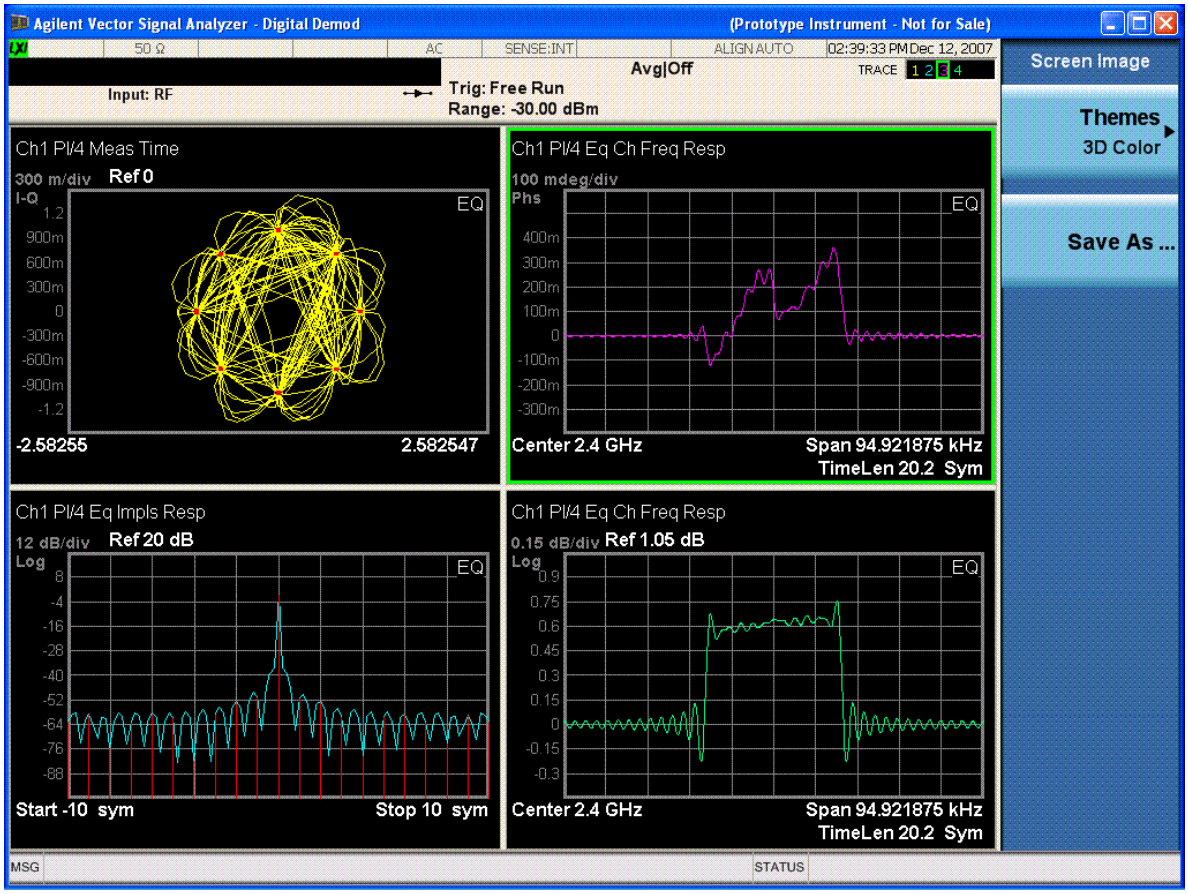
This procedure demonstrates how to setup the equalizer. This procedure assumes you are already in the **Vector Signal Analyzer** mode and you have selected **Digital Demod** under the **Meas** menu.

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 Equalizer**.	
2 Set the equalization filter length.	a. Press **Filter Length**. b. Enter a numeric value. 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 satisfies 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**.	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. The equalization filter has a unit response when you: ▪ 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 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.
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.
6 Hold the filter coefficient values.	a. Press **Hold** and toggle to **On**.	When Hold is On, the analyzer does not update the filter coefficients. Instead, the analyzer uses the last updated coefficients before selecting hold. 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.

Step	Action	Notes
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**.	The example shown in the following figure is an NADC signal. 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. The Eq Impulse Response (trace 2) shows the impulse response of the equalization filter. The Eq Ch Frequency Response (trace 3) shows the phase response of the equalization filter.



Step	Action	Notes
8 You can select other result formats to display the equalizer data for a selected trace:	a. Press **Trace/Detector**, **Format**. b. Select a graphic display format appropriate for the type of trace data assigned to the trace.	

Click to Go Back to "Measuring Digital Signals" on page 40.

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 48.

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, and so on.

Digital Demod Measurement Data Include:

1. Spectrum
2. Instantaneous Spectrum
3. Search Time
4. Time
5. Raw Main Time
6. Meas Time
7. Meas Spectrum
8. Ref Time
9. Ref Spectrum
10. Error Vector Time
11. Error Vector Spectrum
12. Inst Error Vector Spectrum
13. Mag Error
14. Phase Error
15. Symbols/Error Table
16. Ch Frequency Response
17. EQ Impulse Response
18. Occupied BW Summary
19. ACP Summary

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

Click to Go Back to "Measuring Digital Signals" on page 40.

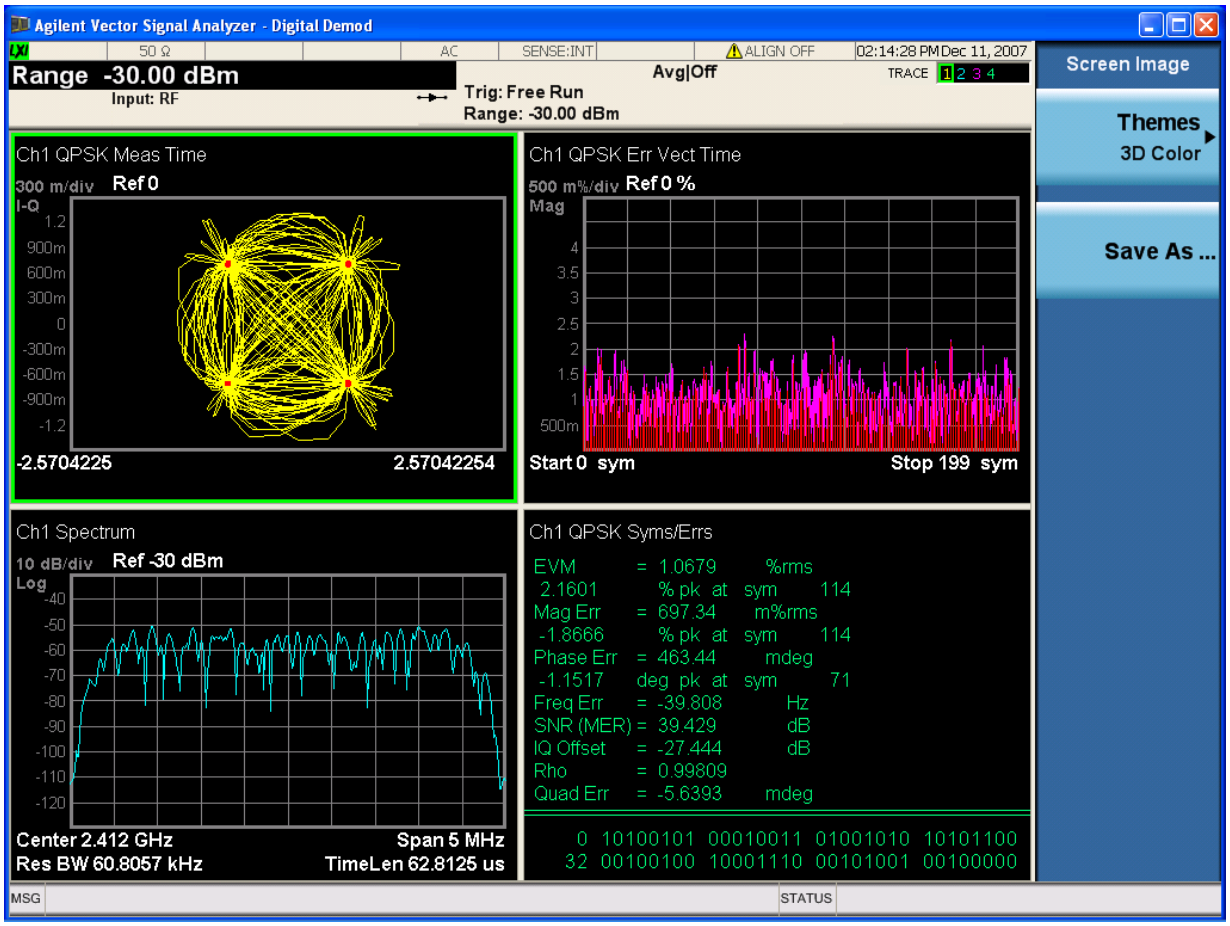
Example Measurement - Digital Demod

Keysight ESG Series Vector Signal Generator Settings

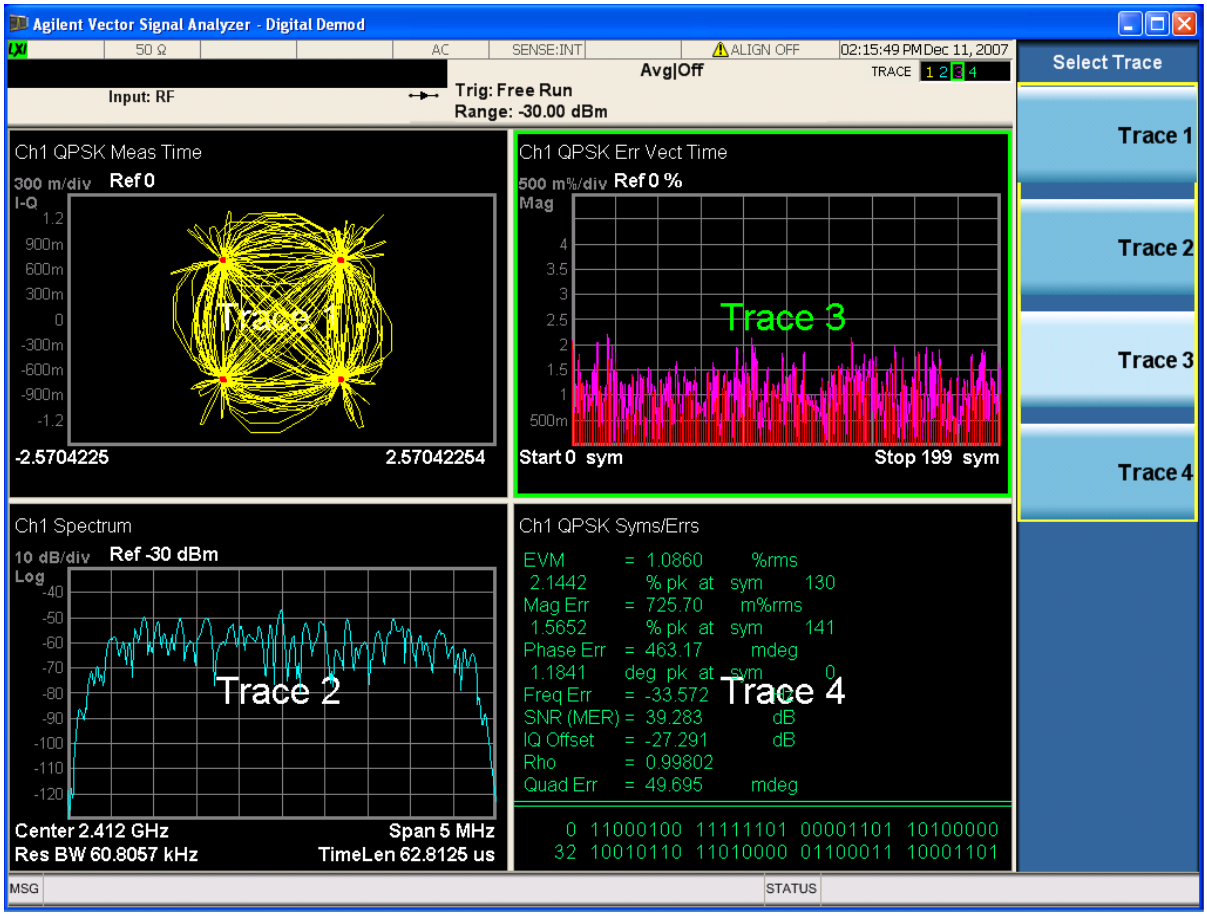
Radio Standard: W-CDMA (3GPP)
Link: Forward
Active channel: 1 DPCH (data channel)
Frequency: 2.412 GHz
Power (Signal Amplitude): -30 dBm
Modulation: QPSK
Symbol rate: 3.84 Msps

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

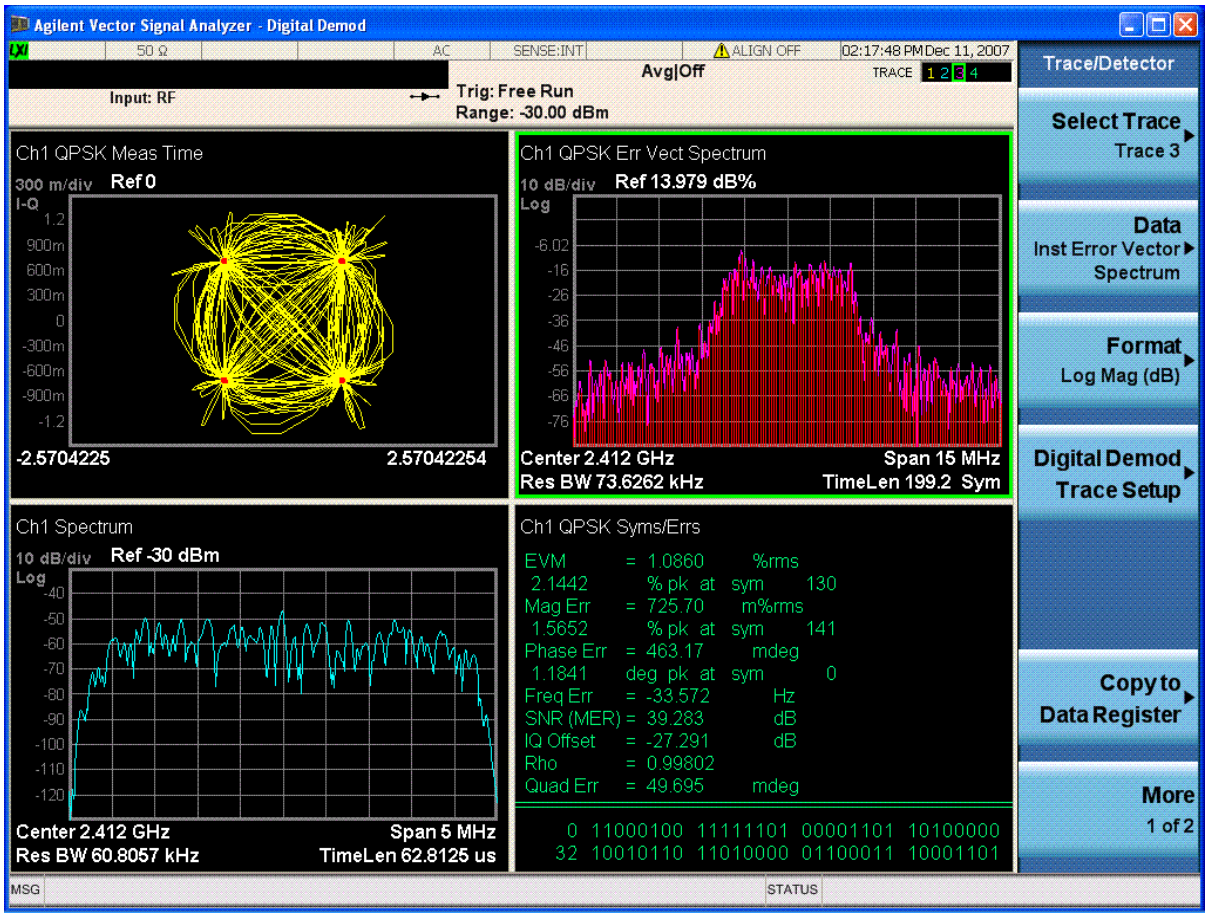
Step	Action	Notes
1 Follow the Measuring Digital Signals procedure.	a. Follow the procedure "Measuring Digital Signals" on page 40 before continuing.	
2 View the default Demod Quad Preset View.	a. View a quad layout with the IQ Meas Time in trace 1, Spectrum in trace 2, Error Vector Time in trace 3, and the Symbol/Error table in trace 4.	See the following figure.

Step	Action	Notes
		
3 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.

Step	Action	Notes



4	Select Error Vector Spectrum data.	a. Press **Data, Demod Error.** b. 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
		
5 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.

Step	Action	Notes



If you have a problem, and get an error message, see "Interpreting Error Codes" on page 67.

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 67.

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 Interpreting Error Codes

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

To view the error messages, press the **System**, **Show, Errors**.

- **141 "Input Overload; ADC over range"**

  To clear this error, reduce the input signal strength or press **AMPTD Y Scale**, **Range** and choose a higher range.

- **503 "Frequency Reference Unlocked"** or 521 "External Ref missing or out of range"

  If you receive either of these errors, it is usually because the Frequency reference input (press **Input/Output**, **More**, **Freq Ref In**) is set to External.

  Make sure a cable is connected between an external reference source and Ext Ref In on the rear panel. Make sure the reference frequency and the External Ref Freq setting match, and the external reference signal level is sufficiently high (around 0 dBm). You should not get either of these errors if the Freq Ref In is set to Sense or Internal.

- **Various calibration errors**

  For calibration errors, please contact Keysight Technical Support.

For more details, see Chapter 2, "Making N9064A VXA Measurements", on page 15 or see the *Instrument Messages* manual.

4 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 as well as how measurements are performed by the instrument. A list of related Keysight documents is provided for further reference.

Introduction

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

"Analog Modulation Concepts" on page 71 describes the analog modulation methods: amplitude modulation, frequency modulation and phase modulation. This section also contains a description of the analog demodulation mode.

"Digital Modulation Concepts" on page 84 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 100 contains a general description of the modulation format families. These are vestigial sideband (VSB), phase shift keying (PSK), frequency shift keying (FSK), minimum shift keying (MSK), quadrature amplitude modulation (QAM), digital video broadcast for QAM (DVB QAM), amplitude phase-shift keying (APSK), enhanced data for global evolution (EDGE), and continuous phase modulation (CPM).

"Communication System Formats" on page 137 covers the predefined communication systems. These are CDMA, CDPD, EDGE, GSM, NADC, PDC, PHS, W-CDMA, *Bluetooth*, HIPERLAN, WLAN(802.11b), ZigBee, DTV, DVB, APCO 25, DECT, TETRA, VDL Mode 3, HCPM, HDQPSK, and MIL-STD CPM.

"Measurements of Digital RF Communications Signals" on page 173 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 201 are given along with a list of related Keysight documents for further reading.

Analog Modulation Concepts

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 4-1

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

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 4-2 on page 72. 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 4-1 on page 72 shows the carrier and sideband components of the amplitude-modulated wave of Figure 4-2 on page 72 as they appear in the frequency domain (amplitude versus frequency).

Figure 4-1 *Frequency Domain Display*

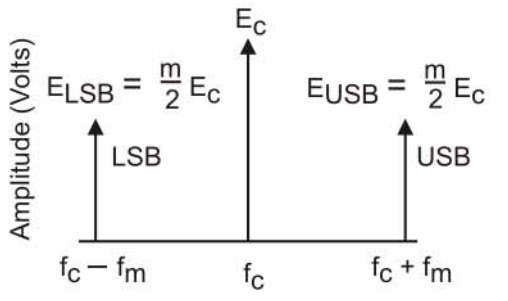
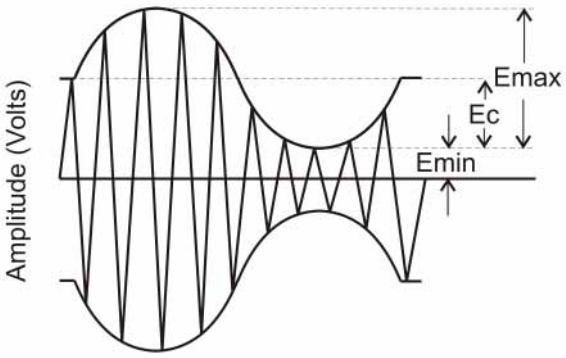


Figure 4-2 *Time Domain Display*



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 4-2

$$m = \frac{E_{max} - E_c}{E_c}$$

Since the modulation is symmetrical,

Equation 4-3

$$E_{max} - E_c = E_c - E_{min}$$

and

Equation 4-4

$$\frac{E_{max} + E_{min}}{2} = E_c$$

From this, it is easy to show that:

Equation 4-5

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

for sinusoidal modulation. When all three components of the modulated signal are in phase, they add together linearly and form the maximum signal amplitude Emax, shown in Figure 4-2 on page 72.

Equation 4-6

$$E_{max} = E_C + E_{USB} + E_{LSB}$$

Equation 4-7

$$m = \frac{E_{max} - E_C}{E_C} = \frac{E_{USB} + E_{LSB}}{E_C}$$

And, since

Equation 4-8

$$E_{USB} = E_{LSB} = E_{SB}$$

Then:

Equation 4-9

$$m = \frac{\mathbf{2}(E_{SB})}{E_C}$$

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 • 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 4-4 on page 74 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.)

Figure 4-3 *Time Domain View of 2% Amplitude Modulation*

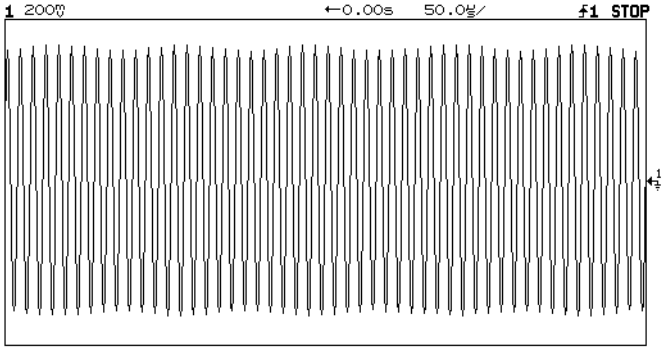


Figure 4-4 *Frequency Domain View of 2% Amplitude Modulation*

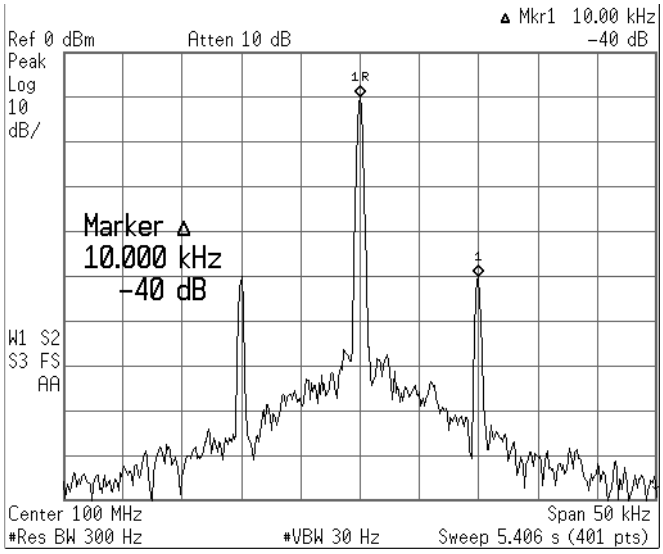
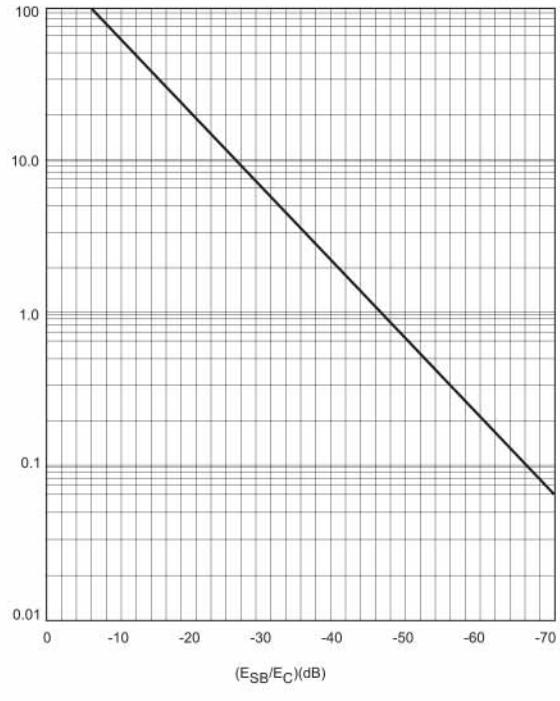


Figure 4-5 *Modulation percentage M vs. Sideband Level (log display)*



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

Equation 4-10

$$(E_{SB}/E_C)(dB) = \mathbf{20log}\left(\frac{m}{2}\right)$$

or

Equation 4-11

$$(E_{SB}/E_C)(dB) + \mathbf{6}dB(\mathbf{20})\mathbf{log}\,m$$

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 4-6 *AM Carrier in the Time Domain*

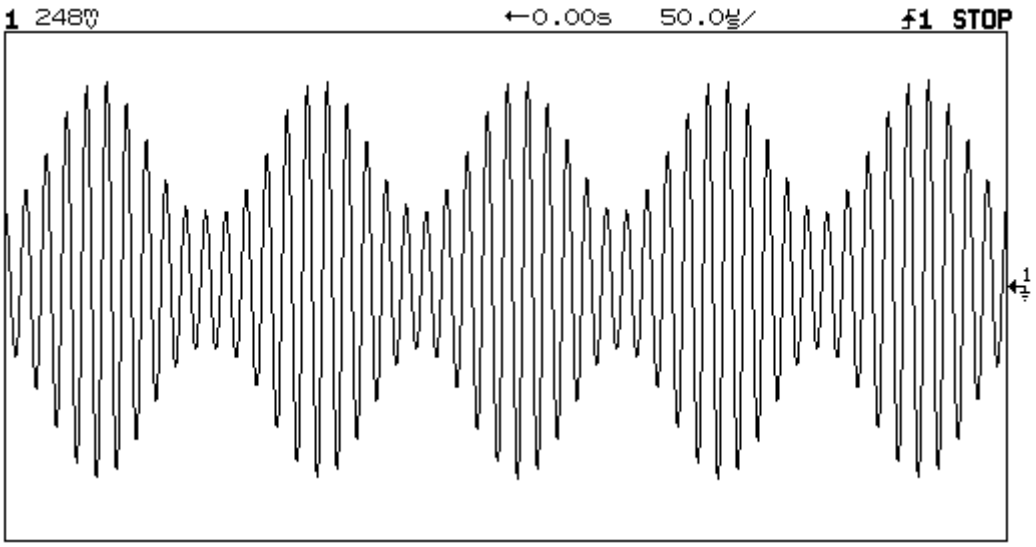


Figure 4-7 *AM Carrier in the Frequency Domain*

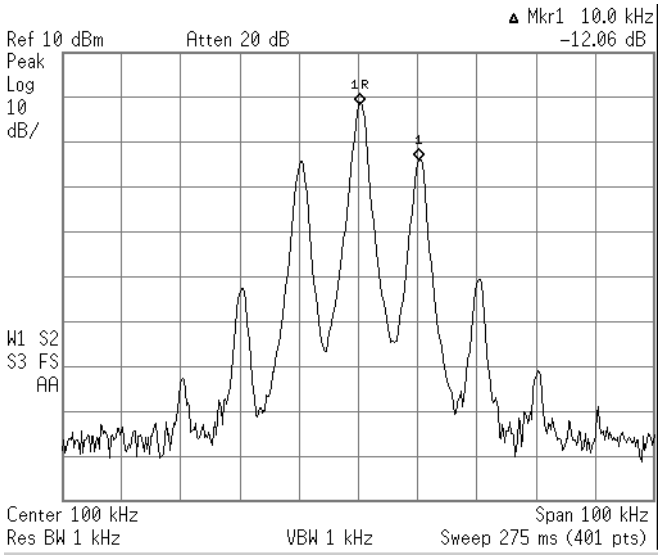
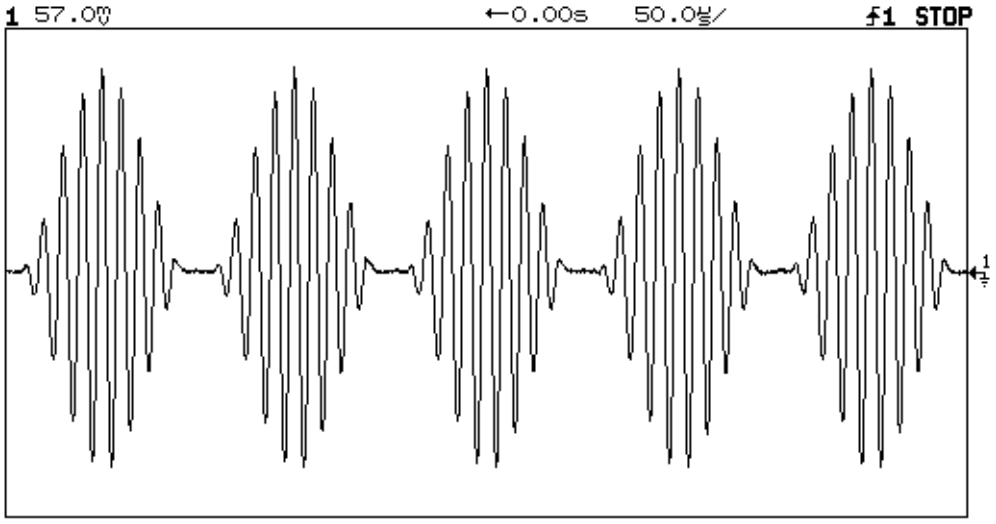


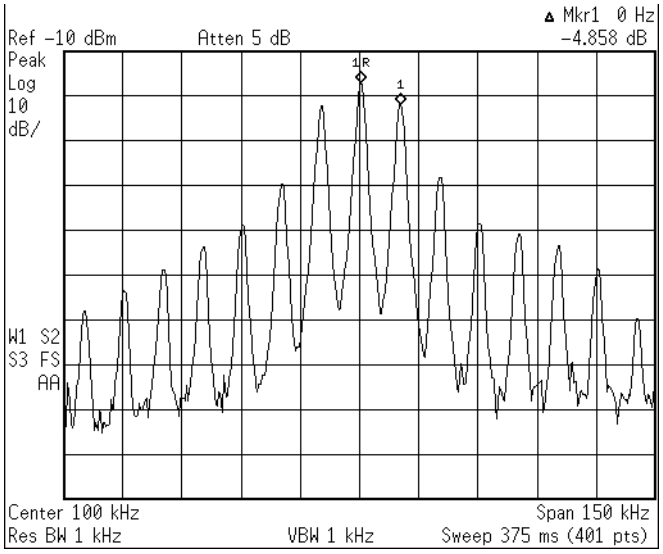
Figure 4-6 on page 76 shows an amplitude-modulated carrier in the time domain. The minimum peak-to-peak value is one third the maximum peak-to-peak value, so m = 0.5 and M = 50%. The figure above shows the same waveform measured in the frequency domain. Since the carrier and sidebands differ by 12 dB, M= 50%. You can also measure 2nd and 3rd harmonic distortion on this waveform. Second harmonic sidebands at fc ± 2fm 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 4-8 *Overmodulated Signal in the Time Domain*



The figure above shows an overmodulated (M>100%) signal in the time domain; fm = 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 4-9 *Overmodulated Signal in the Frequency Domain*



Frequency Modulation and Phase Modulation

Previously we described a carrier with the equation:

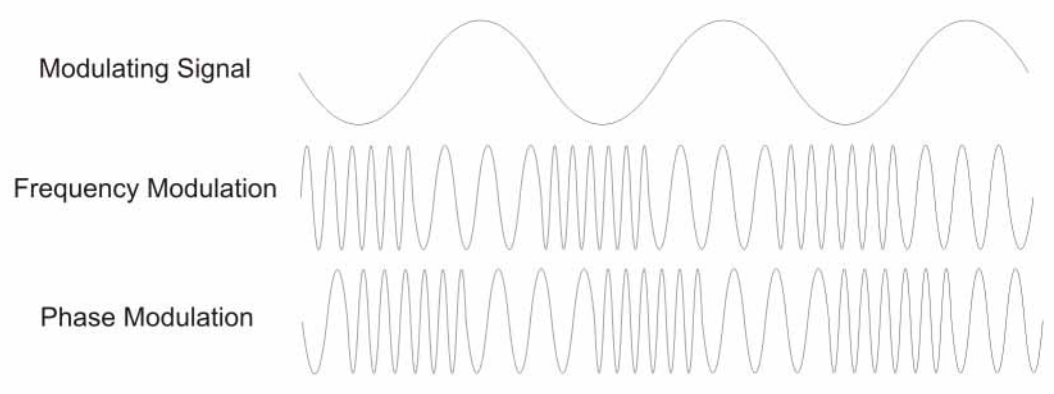
Equation 4-12

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

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 4-10 *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 4-13 $\beta = \Delta f_p / f_m = \Delta\phi_p$

Where:

b = modulation index

Dfp = peak frequency deviation

fm = frequency of the modulating signal

Dfp = peak phase deviation in radians

Equation 4-13 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 4-10 on page 78.
- 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/fm (integration of the modulating signal). The reverse is also true if the modulator output voltage is proportional to fm (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, fm. 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.

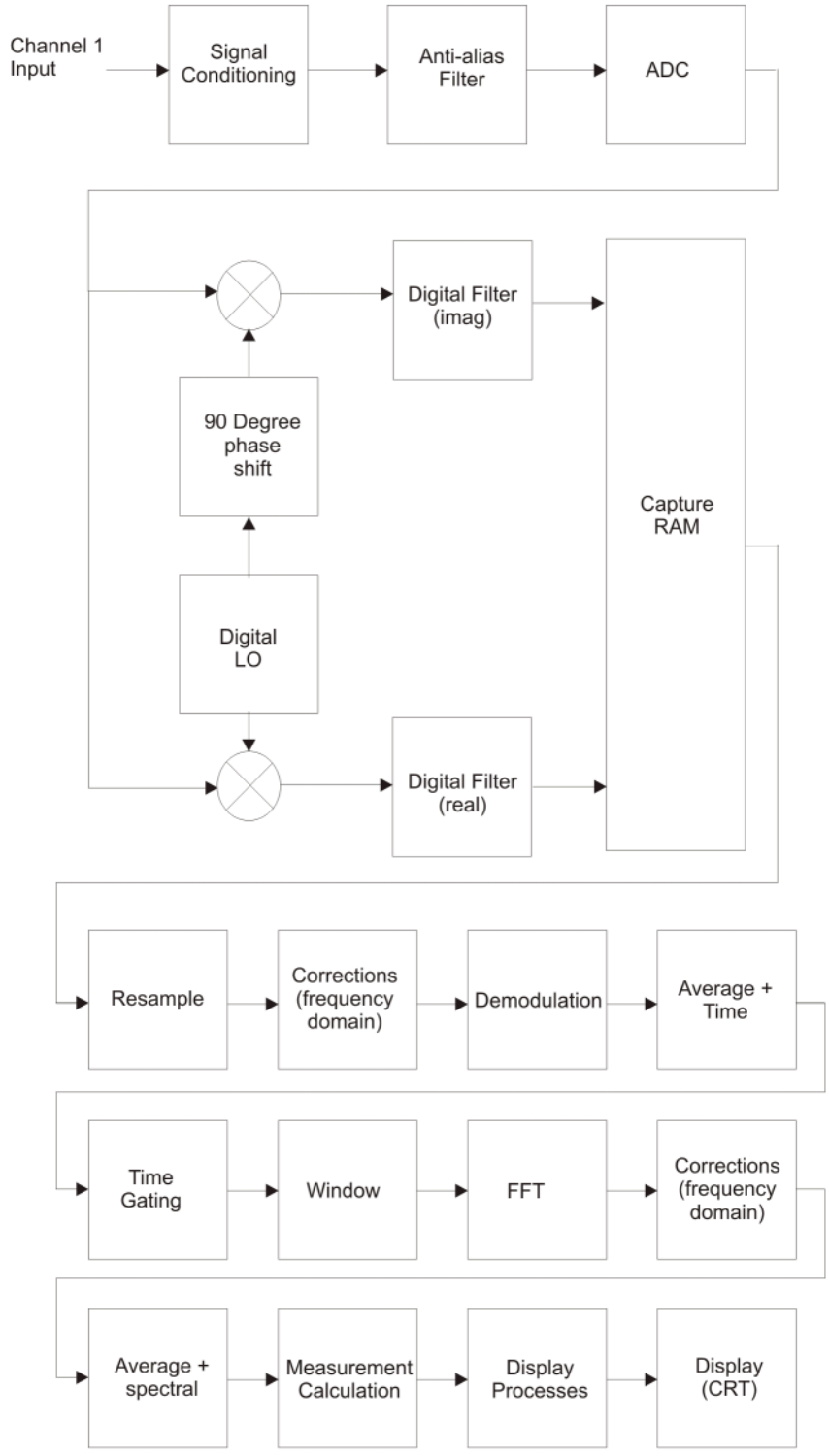
PM and FM demodulation let you select an automatic carrier-frequency estimation algorithm, Auto Carrier. For PM and FM demodulated traces, you can display the estimated carrier frequency using **Demod Setup**, under the **Meas Setup** hardkey. Averaged measurements also average the estimated carrier 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 that is contained in the sidebands of the carrier signal.

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

Figure 4-11 Analog Demodulation Block Diagram



Bandwidth Concepts for Analog Demodulation

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

Figure 4-12 *Demodulation Bandwidth*



NOTE The demodulation block produces a start frequency of 0 Hz.

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 $CF \pm (Span/\mathbf{2})$ and approximately $CF \pm (Span \times \mathbf{1.50}/\mathbf{2})$ should not contain any signals.

A larger factor, 1.50, is used rather 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 Fs/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.

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 Freq On be selected. For PM, you can set Auto Carrier Freq On and/or Auto Carrier Phase On. However, it is best to set both Freq and Phase to On.

Channel triggering is performed prior to digitizing the signal. Demodulation is performed after digitalization, preventing the 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 Auto Carrier softkeys (under Meas Setup, Demod Setup).

Digital Modulation Concepts

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, for example 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, for example 0 and 1.

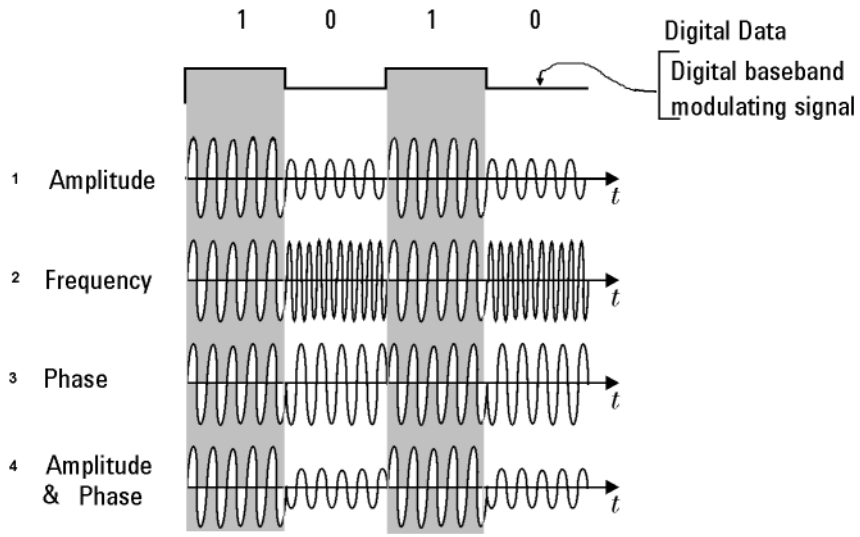
The following figure shows the effect of a digital baseband modulating signal on an RF carrier using four methods of digital modulation. The digital baseband signal seen at the top as a 1010 bit pattern. The upper three waveforms show the effects of this baseband bit pattern modulating the amplitude, 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 4-13 Modulation



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

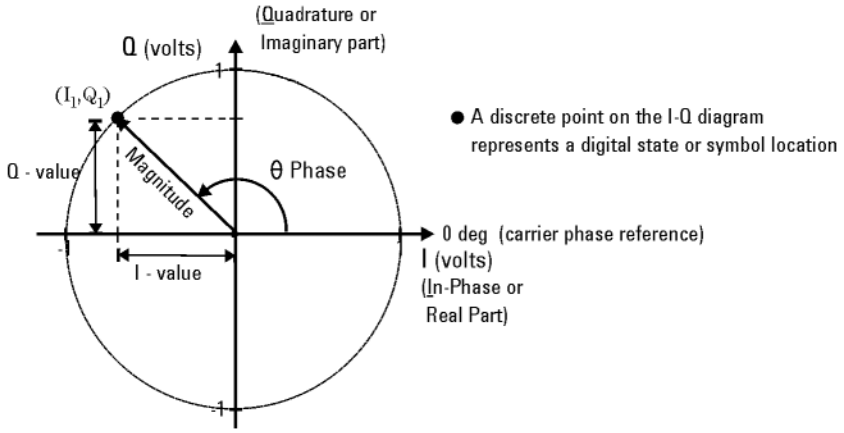
I/Q modulation can best be presented in the I/Q plane or I/Q diagram as shown in the following figure.

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 4-14 *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, which are variations of the common I/Q Modulation and will be explained in more detail in "Digital Modulation Format Standards" on page 100.

- 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 and so on. See "Quadrature Amplitude Modulation (QAM) Concepts" on page 102.
- 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 104.
- 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 113.
- Minimal shift keying (MSK) is a specific form of FSK. See"Minimum Shift Keying (MSK) Concepts" on page 111.

- Digital Video Broadcast for QAM (DVB QAM) is similar to QAM but does not compensate for I/Q origin offset. See “Digital Video Broadcast QAM (DVB QAM) Concepts” on page 115.
- Vestigial Side Band (VSB) shifts the center frequency of the time data by Symbol Rate/4 in order to align the constellation points in vertical lines. See “Vestigial Side Band (VSB) Concepts” on page 117.
- In Amplitude Phase-Shift Keying (APSK), the modulation constellation is composed of concentric rings of uniformly spaced PSK points. See “Amplitude Phase-Shift Keying (APSK) Concepts” on page 119.
- Enhanced Data for Global Evolution (EDGE) was developed to enable the transmission of large amounts of data at a high speed, 384 kilobytes per second. See “Enhanced Data for Global Evolution (EDGE) Concepts” on page 121.
- Continuous Phase Modulation (CPM) signals send data using the change of the carrier phase. The amplitude of the carrier stays constant. “Continuous Phase Modulation (CPM) Concepts” on page 122.

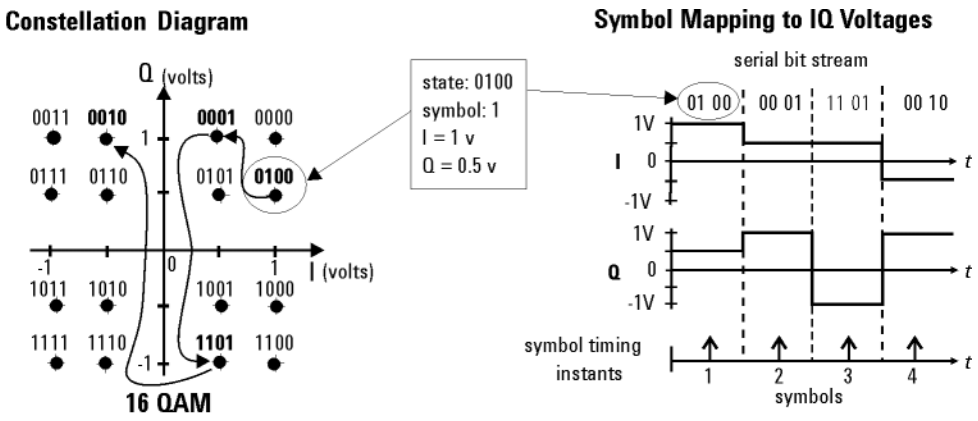
QAM example

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 4-14 on page 86 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 -1 volts. 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.

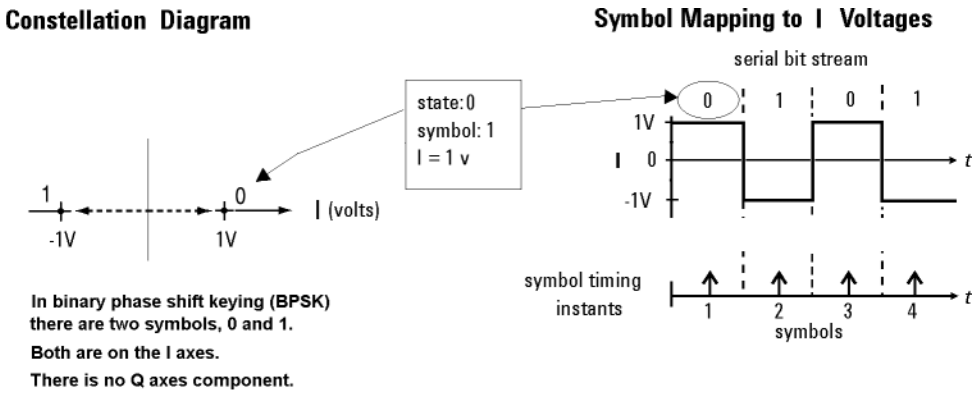
Figure 4-15 *Constellation Diagrams and Symbols*



PSK Examples

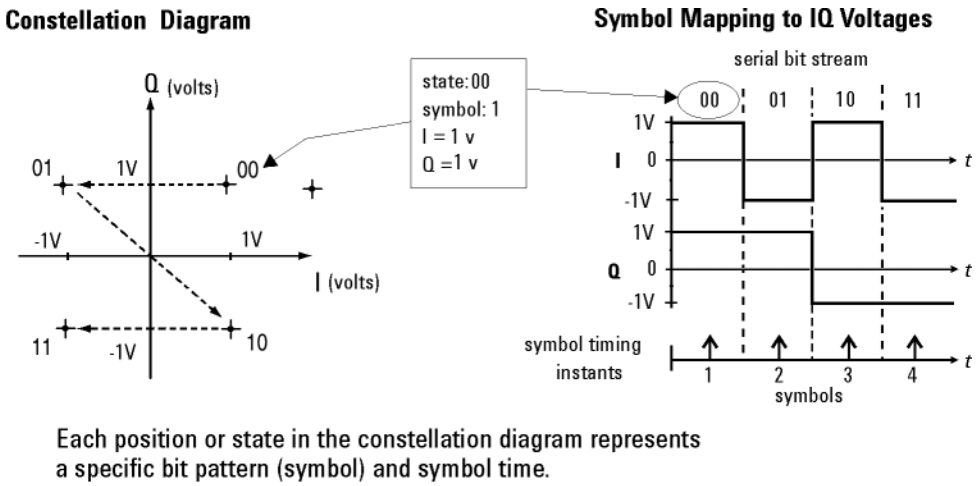
Binary phase shift keying (BPSK) is the most simple form of phase shift keying. The carrier amplitude and frequency remain constant while the phase of the carrier is switched 180 degrees or not depending on the symbol being transmitted.

Figure 4-16 *BPSK example*



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 4-14 on page 86 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 4-17 *Example 1, constellation diagrams and symbols*



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 94.

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.

Symbol Rate

In digital modulation, the Symbol Rate determines the rate (frequency) at which symbols occur. A symbol may consist of one or more bits as determined by the modulation format. For example, in a BPSK (Binary phase shift keying) system, each symbol represents 1 bit; in a QPSK (Quadrature phase shift keying) system, each symbol represents 2 bits.

Symbols are valid only at the timing instant when the receiver interprets the signal. This timing instant is called the detection-decision point.

The VXA's demodulator uses the Symbol Rate to determine the frequency of the detection-decision points. It is important that the Symbol Rate is set to match exactly the symbol rate of the system because the symbol clock frequency is not estimated.

NOTE The more complex the modulation format, the more critical it is that the Symbol Rate be exact. Specifying an incorrect symbol rate introduces errors into the demodulation process.

Symbol Rate and Frequency Span

The Symbol Rate determines the maximum Frequency Span (information bandwidth) that can be measured. For QAM (Quadrature Amplitude Modulation) and PSK (Phase Shift Keying) signals, the Symbol Rate also determines the minimum Frequency Span that satisfies published specifications.

The following formulas show how the symbol rate determines the maximum frequency span that can be measured:

$$\text{Maximum Span (FSK)} = 100 \times \text{(symbol rate)}$$

$$\text{Maximum Span (all others)} = \frac{20 \times \text{(symbol rate)}}{k}$$

$$k = 1.28 \text{ for all formats}$$

The next formulas show, for some signals, how the Symbol Rate can be used to determine the minimum Frequency Span that satisfies published specifications. The first formula is valid only for QAM and PSK signals that use the Raised Cosine or Root Raised Cosine filters at the transmitter. The second formula is valid only for VSB signals.

$$\text{Minimum Span (VSB)} = \text{(symbol rate)} \times \frac{1 + \text{alpha}}{2}$$

$$\text{Minimum Span (QAM, PSK)} = \text{(symbol rate)} \times (1 + \text{alpha})$$

where: alpha is the roll-off factor set with Alpha/BT

For all other signals, there is no “easy” formula to help determine the minimum span that satisfies published specifications. However, you can ensure that the measurement satisfies published specifications by selecting a Frequency Span that contains all energy of the transmitted signal.

To see if your signal falls within the current frequency span, view the spectrum of the signal. If necessary, modify the Frequency Span until it includes all of the signal's energy.

To satisfy published specifications, all of the signal's energy must fall within the span. If a Frequency Span or Symbol Rate is selected that causes the Frequency Span to be narrower than (Symbol Rate) ´ (1 + alpha), the VXA displays DATA?.

Signal-to-Noise Ratio

Signal-to-Noise Ratio (SNR), also known as Modulation Error Ratio (MER), is reported for QAM, DVB QAM, QPSK, APSK, and VSB demodulation formats. It is the ratio of the average symbol power of the transmitted waveform and the noise power, which includes any term that causes the symbol to deviate from its ideal state position, such as additive noise, distortion, and ISI (inter-symbol-interference). The following formula shows how SNR is computed:

$$10 \log \frac{\text{sum N (IQ Reference vector at symbols)}^2}{\text{sum N (error vector at symbols)}^2}$$

where: sum N is the summation of symbols 1 to N, and N is the result length in symbols

VSB modulated signals

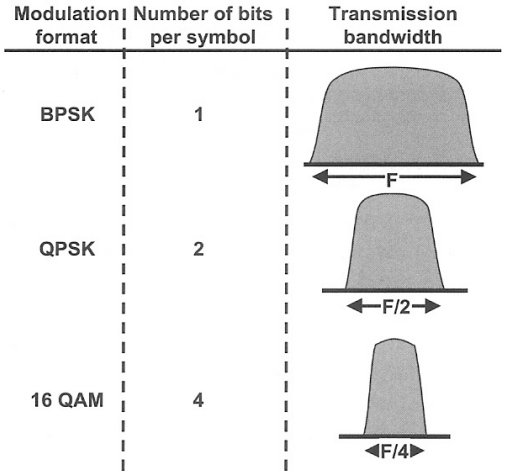
VSB uses only REAL data to compute SNR, as shown in the equation below.

$$10 \log \frac{\text{sum N (Real \{IQ Reference vector at symbols\})}^2}{\text{sum N (Real \{error vector at symbols\})}^2}$$

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 4-18



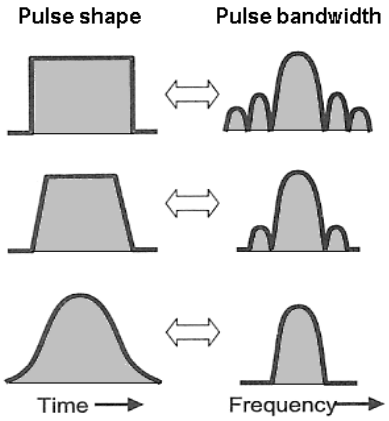
Filtering

Figure 4-13 on page 85 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.

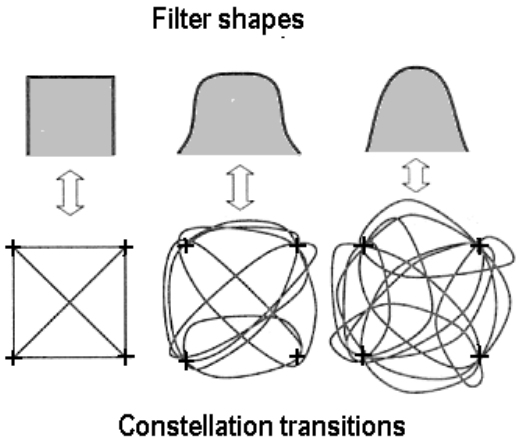
The following figure shows the bandwidth required to successfully reproduce three pulse shapes. The top example is a square pulse that has very fast edges creating the square shape. These fast edges require the presence of high frequencies in order to happen. This can be seen in the pulse bandwidth required 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 4-19 *The Relationship of Pulse Shape and Bandwidth*



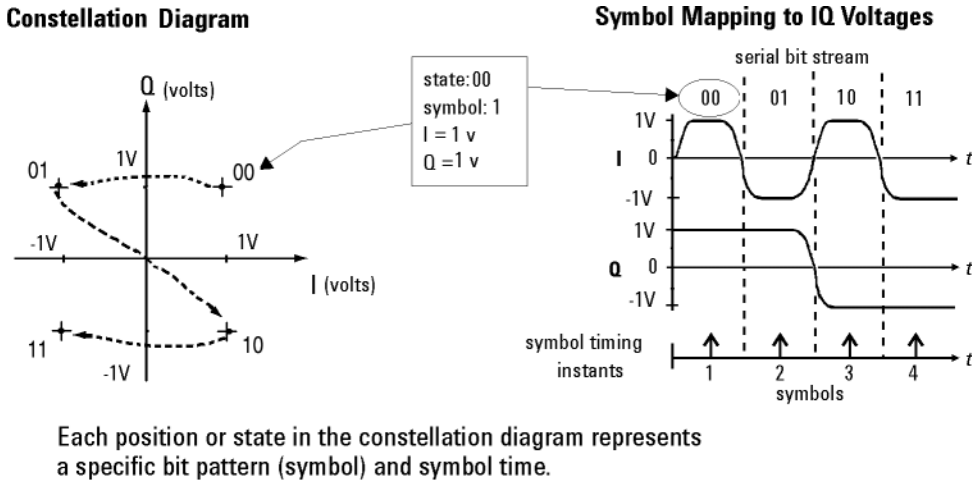
Again there are trade-offs. Filtering reduces the bandwidth occupied for a digital pulse stream. Filtering also reduces interference because it reduces the tendency of one signal or one transmitter to interfere with another, such as in a Frequency-Division-Multiple-Access (FDMA) system. The effect of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

Figure 4-20 *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 4-17 on page 89; 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 181.

Figure 4-21 *I/Q diagram with filtering applied*



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 “DQPSK Modulation Concepts” on page 106.

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 carrier[1]. In the process of modulation - transmission - demodulation errors or impairments can be introduced to the baseband signal.

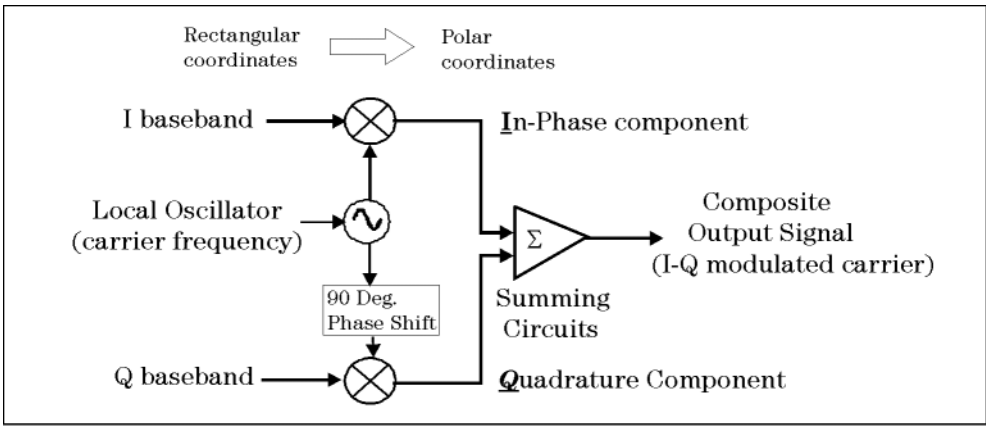
Using an I/Q demodulator, demodulating the signal is straightforward in principle. The I/Q modulator will be examined next, to understand how the I/Q signals are combined with the RF carrier signal. It is these modulated RF signals that N9064A VXA has been developed to analyze. See "Measurements of Digital RF Communications Signals" on page 173.

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 BDM 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 4-22 *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

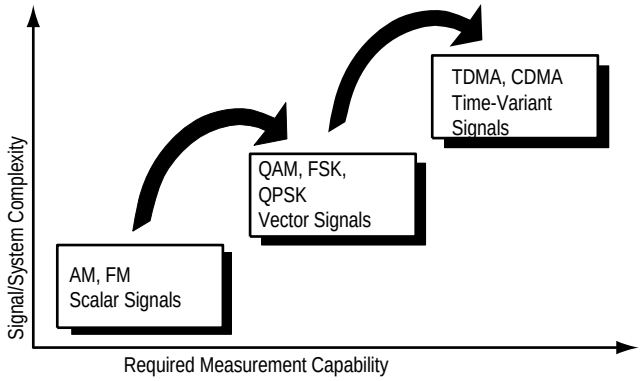
Analog systems have the limitation of one user per carrier frequency. This limits the number of users able to use any given band of frequencies. However, the number of users can be increased for this same band of frequencies by combining digital modulation with multiplexing.

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).

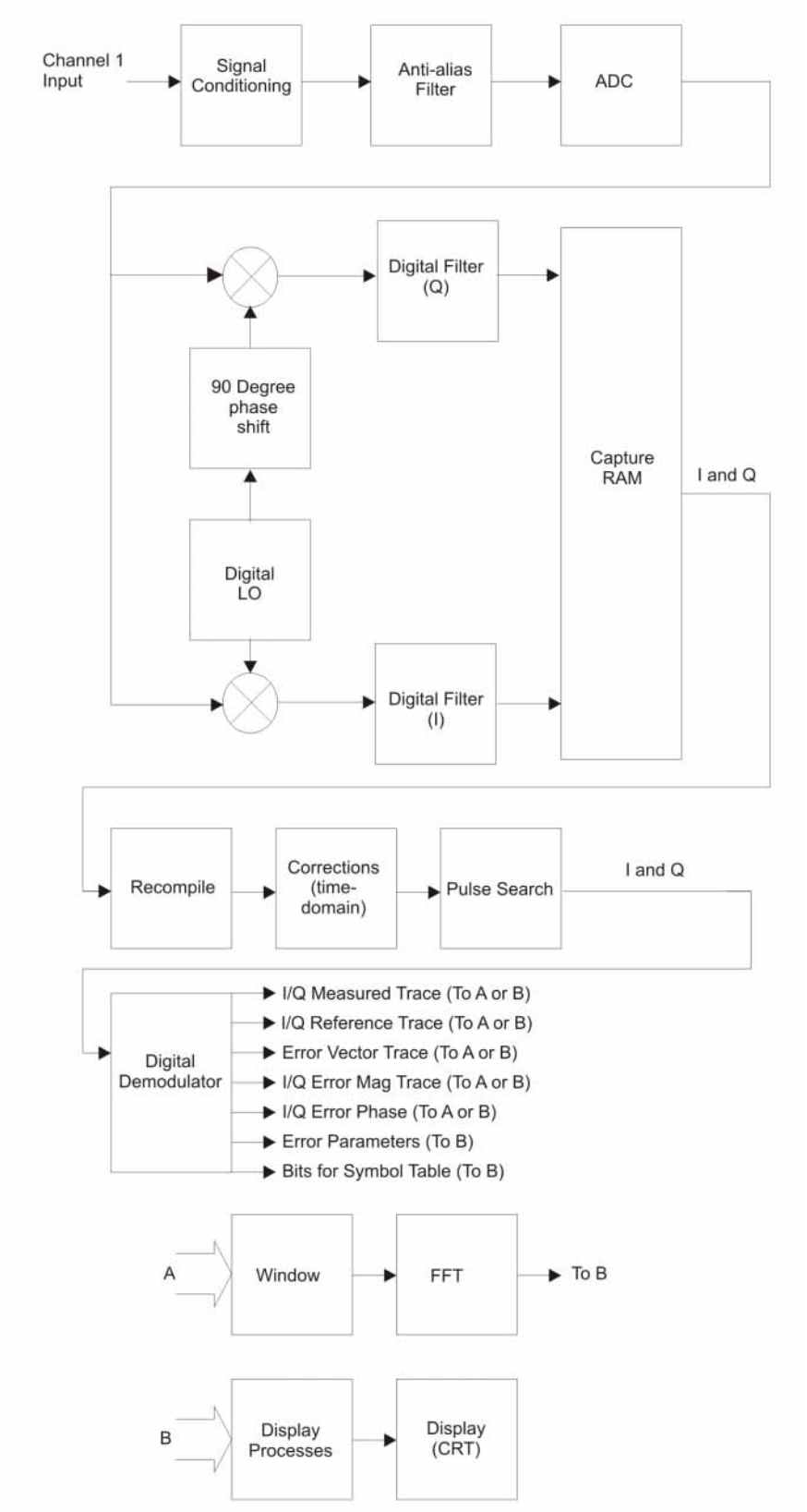
Figure 4-23 *The path from analog to digital signal multiplexing*



Digital Demodulation Block Diagram

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 4-24 Digital Demodulation Block Diagram



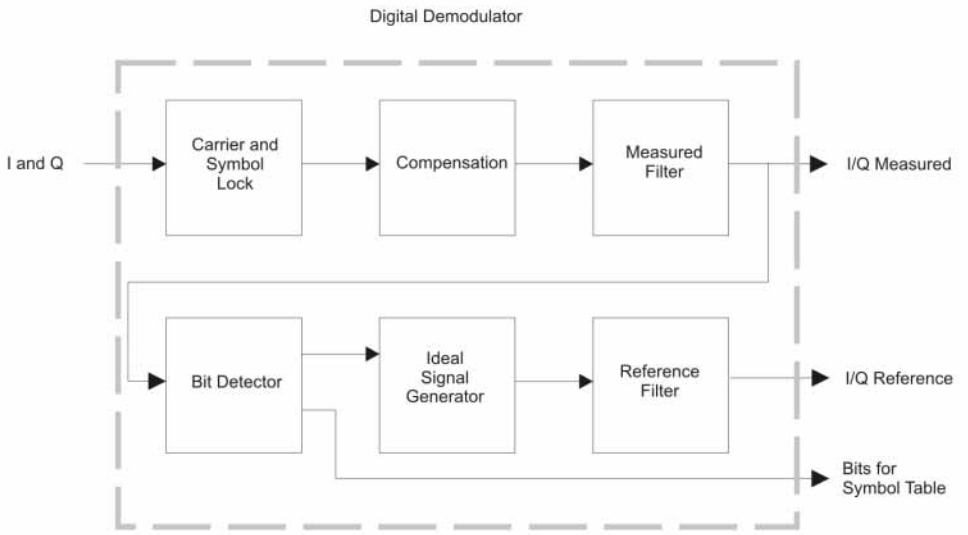
The Digital Demodulation instrument mode lets you perform measurements on digitally modulated signals. Measurements are possible on continuous or pulsed (burst) carriers (such as TDMA). In addition, you can specify a sync pattern and an offset to look at selected portions of demodulated data.

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 4-25 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 "Quadrature Amplitude Modulation (QAM) Concepts" on page 102
- See "Phase Shift Keying (PSK) Concepts" on page 104
- See "DQPSK Modulation Concepts" on page 106
- See "Offset QPSK Modulation Concepts" on page 109
- See "Minimum Shift Keying (MSK) Concepts" on page 111
- See "Frequency Shift Keying (FSK) Concepts" on page 113
- See "Digital Video Broadcast QAM (DVB QAM) Concepts" on page 115
- See "Vestigial Side Band (VSB) Concepts" on page 117
- See "Amplitude Phase-Shift Keying (APSK) Concepts" on page 119
- See "Enhanced Data for Global Evolution (EDGE) Concepts" on page 121
- See "Continuous Phase Modulation (CPM) Concepts" on page 122

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 4-1 Families of Digital Modulation Formats

Format Family	Modulation Format
QAM	QAM16, 32, 64, 128, 256, 512, 1024
PSK	BPSK
	QPSK
	Offset QPSK
	π/4 DQPSK
	DQPSK
	8PSK
	π/8 D8PSK
	D8PSK
MSK	MSK Type 1, 2
FSK	FSK 2, 4, 8, 16
DVB QAM	DVB QAM 16, 32, 64, 128, 256
VSB	VSB 8, 16
APSK	APSK 16, 32, 16 w/DVB, 32 w/DVB
EDGE	EDGE
CPM	CPM

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.

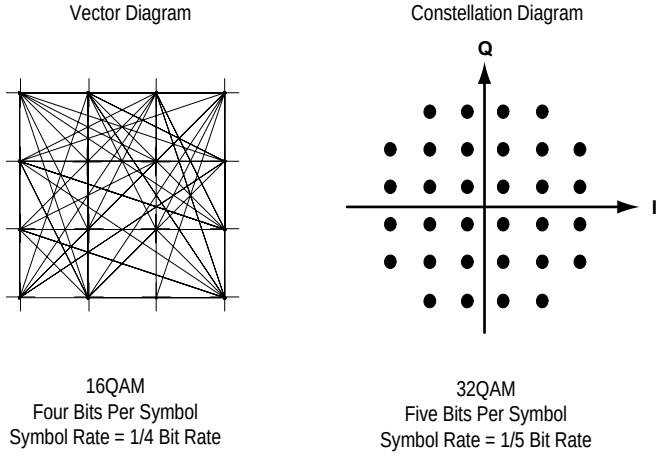
Note that to a point QPSK is the same as 4QAM.

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 (6x6=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.

A 1024QAM system uses 32 I-values and 32 Q-values, giving 1024 possible states. Since $2^{10} = 1024$, each symbol can represent ten bits. A 1024QAM signal that can send ten 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 4-26 *Quadrature Amplitude Modulation*

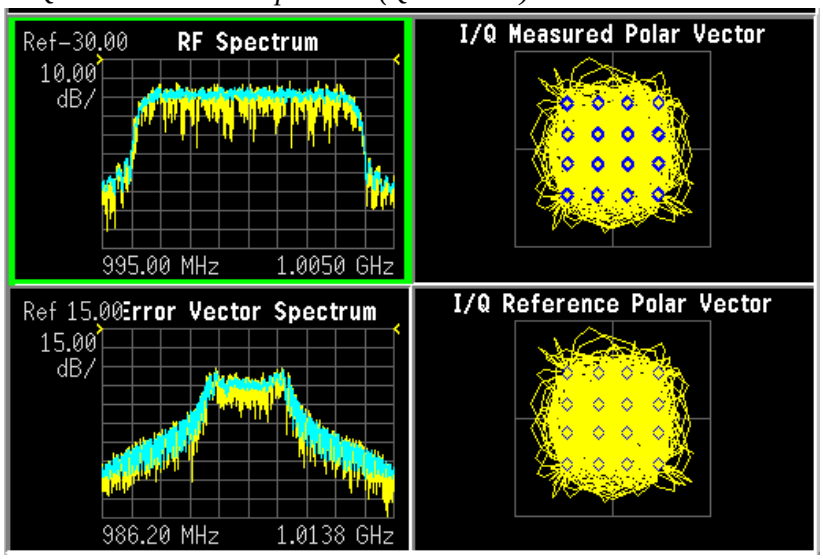


However, bandwidth efficiency is better for higher QAM's. For example, BPSK uses 80 Ksymbols-per-second sending 1 bit per symbol. A system using 256QAM sends eight bits per symbol so the symbol rate would be 10 Ksymbols per second. A 256QAM system enables the same amount of information to be sent as 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 4-27 *16QAM Error Vector Spectrum (Quad-View)*

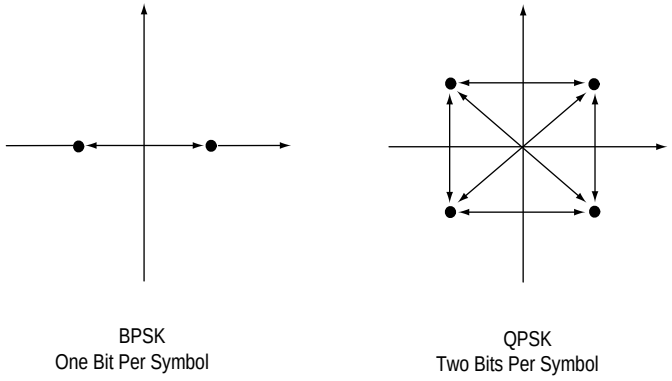


Phase Shift Keying (PSK) Concepts

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 4-28 *Phase Shift Keying (PSK)*

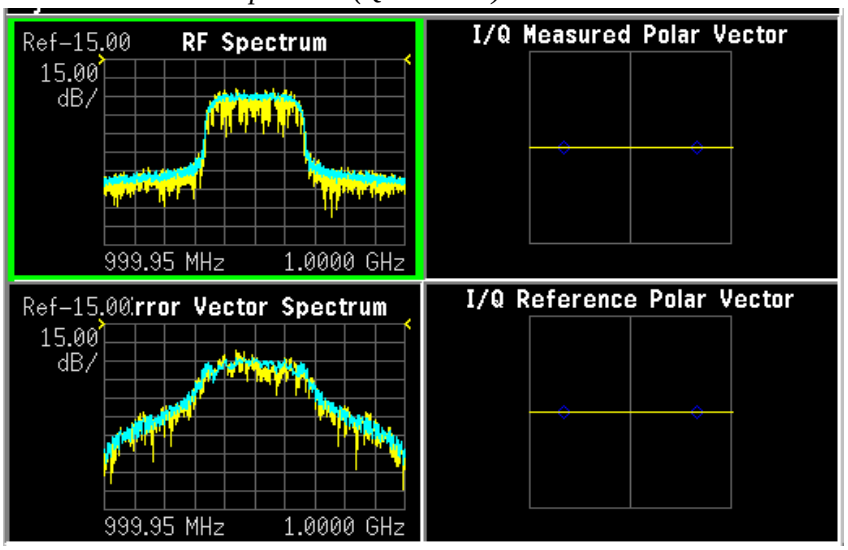


Types of PSK

- "BPSK Modulation Characteristics" on page 105
- "QPSK Modulation Characteristics" on page 105
- "8PSK Modulation Characteristics" on page 106
- "DQPSK Modulation Concepts" on page 106
- "p/4 DQPSK Modulation Characteristics" on page 108
- "D8PSK Modulation Characteristics" on page 108
- "p/8 D8PSK Concepts" on page 108
- "Offset QPSK Modulation Concepts" on page 109

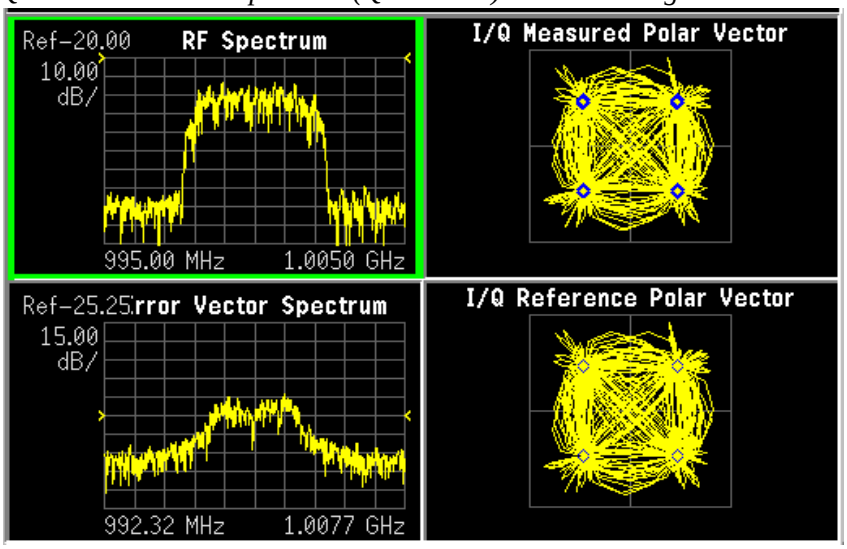
BPSK Modulation Characteristics

Figure 4-29 *BPSK Error Vector Spectrum (Quad View)*



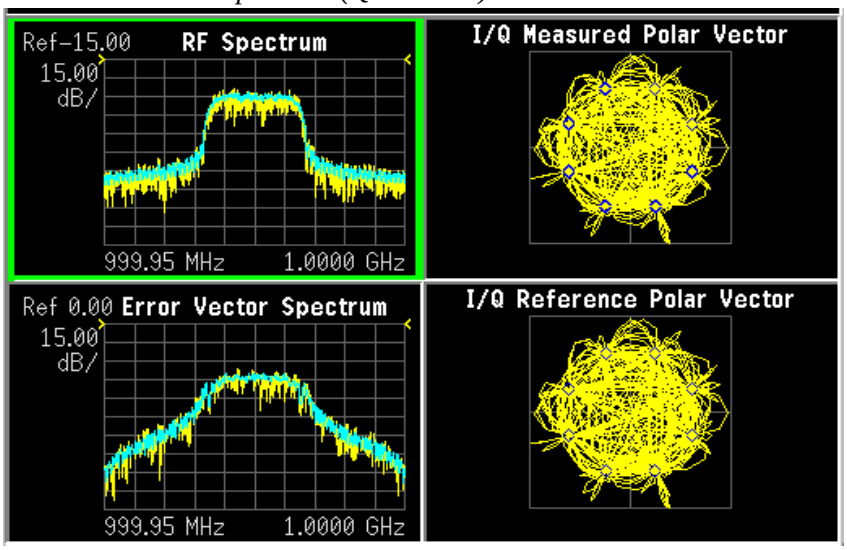
QPSK Modulation Characteristics

Figure 4-30 *QPSK Error Vector Spectrum (Quad View)- W-CDMA Signal*



8PSK Modulation Characteristics

Figure 4-31 *8PSK Error Vector Spectrum (Quad View)*



DQPSK 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 π/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 π/4 DQPSK modulation format is widely used in many applications including

CELLULAR

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

CORDLESS

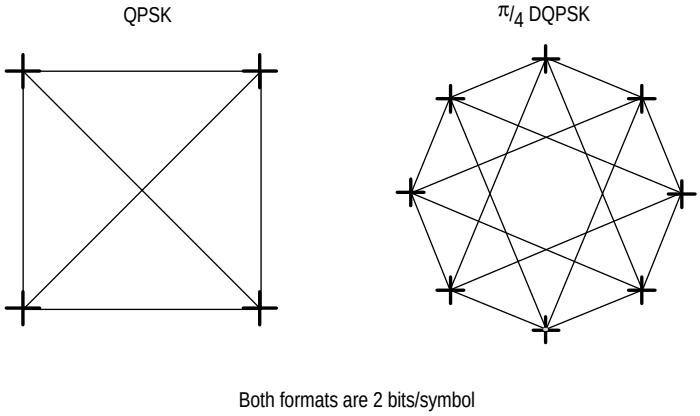
- PHS (personal handyphone system)

TRUNKED RADIO

- TETRA (Trans European Trunked Radio)

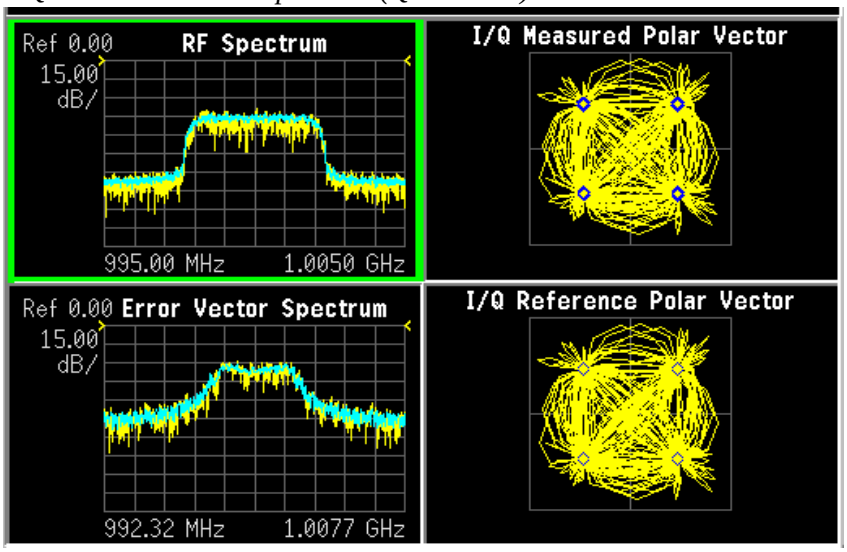
The π/4 DQPSK modulation format uses two QPSK constellations offset by 45 degrees (π/4 radians). Transitions must occur from one constellation to the other. This guarantees that there is always a change in phase at each symbol, making clock recovery easier. The data is encoded in the magnitude and direction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

Figure 4-32 *Differential Modulation*



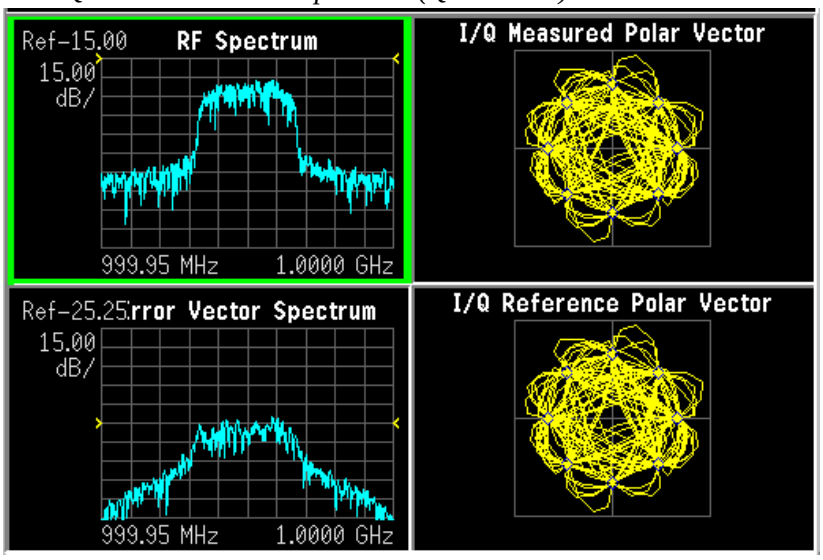
DQPSK Modulation Characteristics

Figure 4-33 *DQPSK Error Vector Spectrum (Quad-View)*



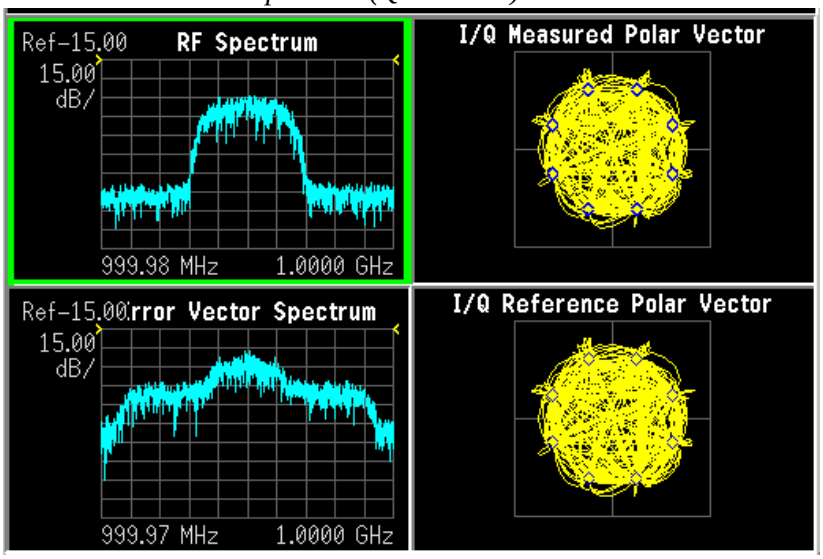
π/4 DQPSK Modulation Characteristics

Figure 4-34 *π/4 DQPSK Error Vector Spectrum (Quad-View)*



D8PSK Modulation Characteristics

Figure 4-35 *D8PSK Error Vector Spectrum (Quad-View)*



π/8 D8PSK Concepts

π/8 D8PSK (Differential 8 PSK) is a differential modulation format where the bits for a given symbol are determined by the phase change from the previous symbol. π/8 D8PSK is the same as D8PSK with a π/8 rotation between each symbol. This leads to a physical 16PSK constellation. Due to this rotation, the ideal trajectory between symbols never crosses through zero.

Table 4-2 Phase Transitions for π/8 D8PSK Modulation

Transmitted Bits	Phase Transitions
000	+π/8
001	+3π/8
101	+5π/8
100	+7π/8
010	-π/8
011	-3π/8
111	-5π/8
110	-7π/8

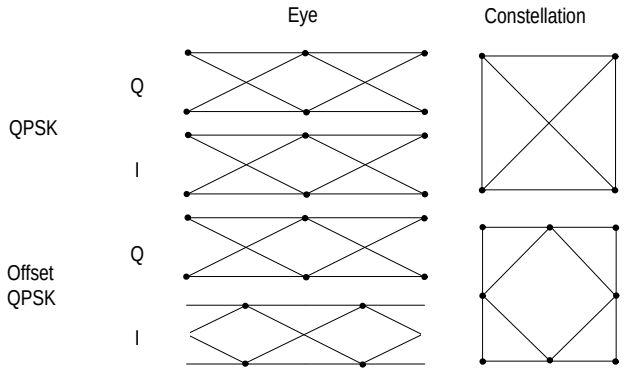
Offset QPSK Modulation Concepts

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.

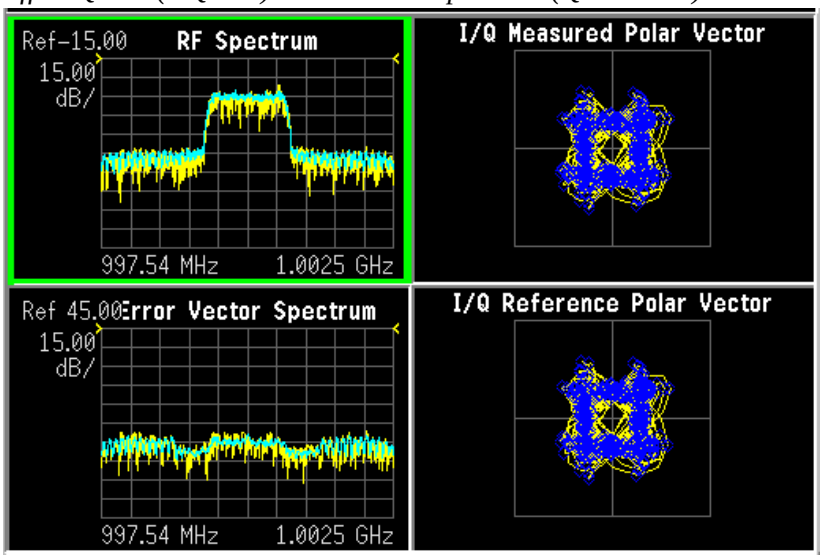
The following figure shows a comparison of the Eye diagrams of QPSK and Offset QPSK. To learn more, see “Eye diagrams” on page 189.

Figure 4-36 *I/Q "Offset" Modulation*



Offset QPSK Modulation Characteristics

Figure 4-37 *Offset QPSK (OQPSK) Error Vector Spectrum (Quad-View)*



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 that 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

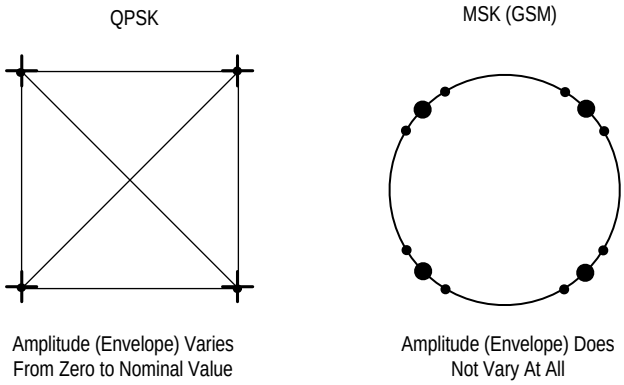
GSM uses a variation of constant amplitude modulation format called 0.3 GMSK (Gaussian Minimum Shift Keying).

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.

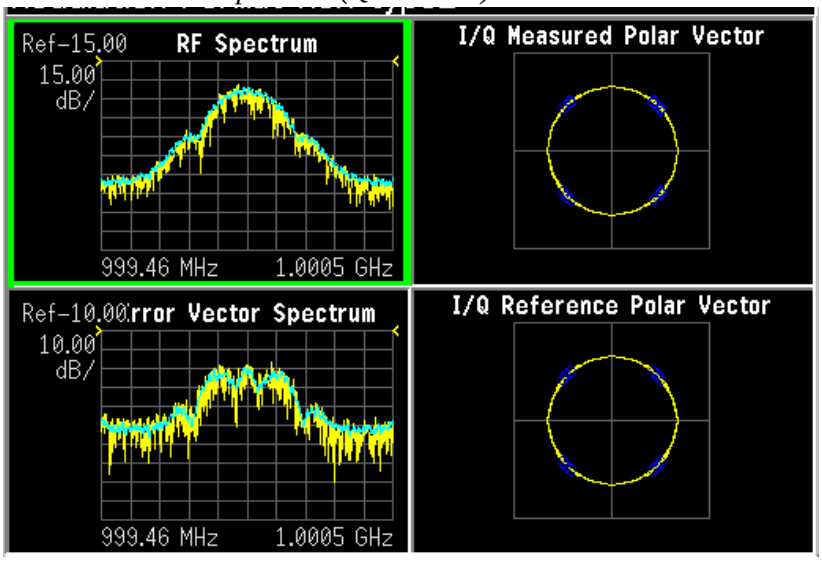
GMSK is a derivative of MSK where the bandwidth required is further reduced by passing the modulating waveform through a Gaussian filter. The Gaussian filter minimizes the instantaneous frequency variations over time. GMSK is a spectrally efficient modulation scheme and is particularly useful in mobile radio systems. It has a constant envelope, spectral efficiency, good BER performance, and is self-synchronizing.

Figure 4-38 *Constant Envelope MSK Modulation*



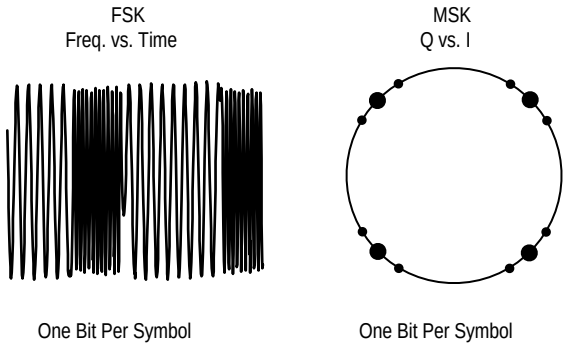
MSK Modulation Characteristics

Figure 4-39 *MSK Error Vector Spectrum (Quad-View)*



Frequency Shift Keying (FSK) Concepts

Figure 4-40 *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 4-41 *FSK Error Vector Spectrum (Quad-View) - 2 FSK Signal*

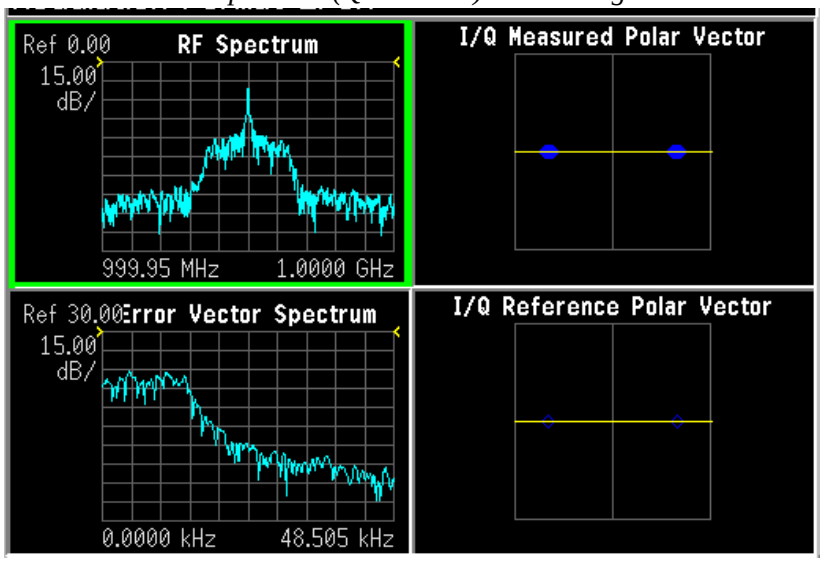


Figure 4-42 *FSK Error Vector Spectrum (Quad-View)- 4FSK Signal*

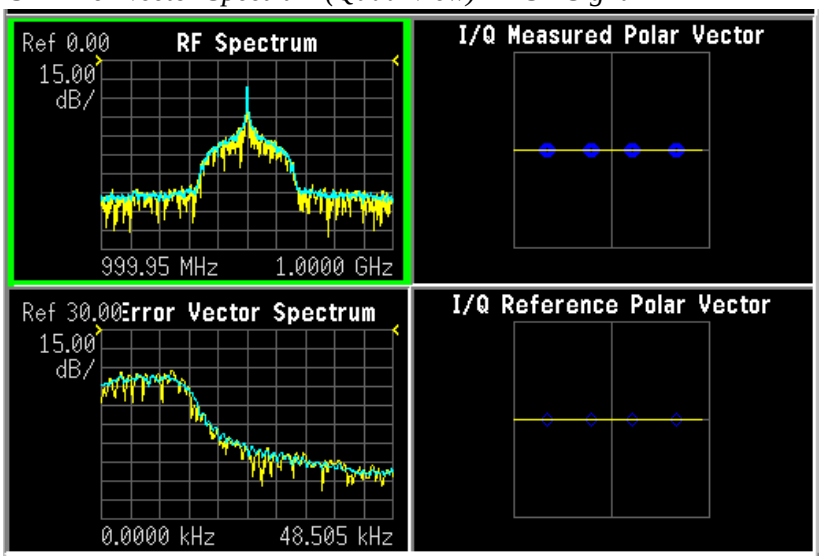
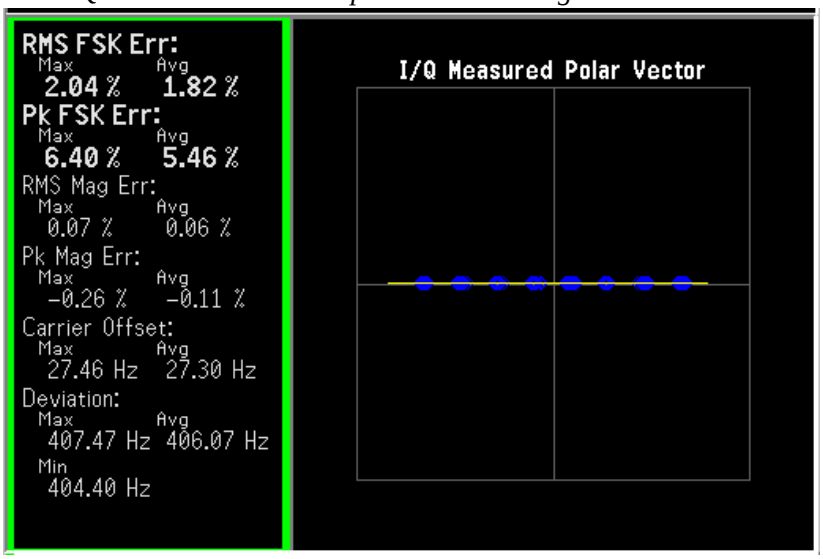


Figure 4-43 *FSK I/Q Measured Polar Graph View- 8FSK Signal*



Digital Video Broadcast QAM (DVB QAM) Concepts

The DVB QAM (Quadrature Amplitude Modulation) format conforms to the DVB (Digital Video Broadcast) standard, EN 300 429. The VXA supports the following DVB QAM formats:

Table 4-3 Supported DVB QAM Formats

Format	DVB QAM signal format
DVB QAM 16	16 QAM signals
DVM QAM 32	32 QAM signals
DVB QAM 64	64 QAM signals
DVB QAM 128	128 QAM signals
DVB QAM 256	256 QAM signals

The standard defines the bits that represent each state as follows:

- The first two bits are differentially encoded so that π/2 rotations in the QAM constellation do not affect detection of the two MSBs.
- The LSBs are positioned to be rotation-invariant as defined in EN 300 429.

I/Q Origin Offset Compensation

Unlike QAM, DVB QAM does not compensate for I/Q origin offset. When the demodulation format is DVB QAM, the VXA reports I/Q origin offset in the symbol table, but doesn't remove it from the measurement. When the demodulation format is QAM, the VXA reports I/Q origin offset in the symbol table AND removes it from the measurement.

To see the effects of I/Q origin offset on your DVB QAM signal, change the demodulation format to QAM. For example, if your signal is 16 DVB QAM, select 16-QAM to see the effects of I/Q origin offset removal on your signal.

TIP The Error vector magnitude (EVM) for DVB QAM will be higher than QAM because DVB QAM includes IQ origin offset in the measurement.

Reliable Carrier Lock

This table shows the minimum result length and frequency offset values for reliable carrier lock for DVB QAM signals:

Table 4-4 Result Length and Frequency Offset Values

Digital Modulation Format	**Minimum Result Length (0 Hz frequency offset)**	**Maximum frequency offset (Result Length = 1000 symbols)**
DVB QAM 16	50 symbols	4.65% symbol rate
DVB QAM 32	75 symbols	2.85% symbol rate
DVB QAM 64	150 symbols	4.65% symbol rate
DVB QAM 128	250 symbols	0.45% symbol rate
DVB QAM 256	400 symbols	0.15% symbol rate

Vestigial Side Band (VSB) Concepts

Select the VSB 8 or VSB 16 demodulation format to demodulate 8 VSB or 16 VSB (Vestigial Side Band) modulated signals.

The following topics provide additional information that is unique to VSB signals that will help successfully analyze VSB signals:

- "Symbol Rate" on page 89
- "Signal-to-Noise Ratio" on page 91
- "Carrier locking and pilot search (VSB)" on page 117
- "Digital Video Preset-To-Standard Formats" on page 141

The VSB demodulator shifts the center frequency of the time data by Symbol Rate/4 in order to align the constellation points in vertical lines. Without this shift, the constellation would be a set of concentric circles. This shift makes it easier to visually determine signal quality.

NOTE The center frequency change will not be apparent in the time traces.

In addition, the equalizer frequency response has been changed so that the filter generated is centered about the VXA center frequency. This allows the filter to be applied using the Fixed Equalization feature of the VXA.

Carrier locking and pilot search (VSB)

The same parameters that affect carrier locking for QAM signals also affect carrier locking for VSB signals. For VSB signals, the VXA must also find the pilot signal to achieve carrier lock.

If your VSB signal uses a high-side pilot, configure the VXA to demodulate a high-side pilot by selecting mirror frequency spectrum. If this is not done, the VXA cannot find the pilot signal and cannot lock to your signal.

If the VXA cannot lock to your signal, it displays CARRIER LOCK?. There are several conditions that may cause loss of carrier lock, one of which is an unsuccessful pilot search. If carrier lock is not obtained after several measurements, the VXA assumes the pilot search failed and repeats the pilot search.

NOTE CARRIER LOCK? may appear even when the data appears to be locked. If this occurs, the results may be inaccurate. Normally, this condition clears in a few measurements as the instrument obtains better estimates of the carrier frequency.

The following paragraphs describe other conditions that may cause loss of carrier lock. The VXA always assumes pilot search failed if there are carrier lock problems, even if the cause is one of the following conditions.

Like QAM signals, the VXA's center frequency must be close to the transmitted carrier frequency to achieve carrier lock for VSB signals. The following formulas show how to calculate the ideal center frequency. Use the formula for low-side pilot if the pilot is on the left (low) side of the spectrum; use high-side pilot if the pilot is on the right (high) side of the spectrum.

Center Frequency (High Side Pilot) = Pilot Frequency - (Symbol Rate/4)

Center Frequency (Low Side Pilot) = (Symbol Rate/4) + Pilot Frequency

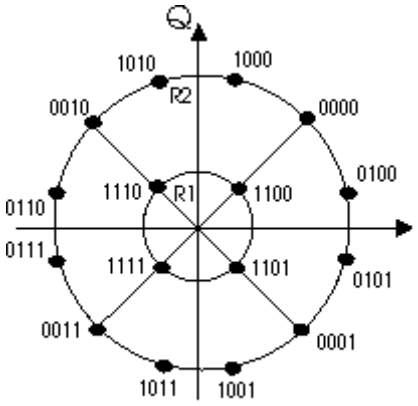
The Result Length also affects the VXA's carrier locking. For VSB measurements, the Result Length should be at least 800 symbols. Smaller Result Lengths may cause unreliable carrier locking. The following may also cause loss of carrier lock:

- A frequency span that is too narrow.
- An incorrect range setting.
- Using the wrong measured or reference filter.
- Not using mirror frequency spectrum.
- A pilot that is not in phase with the transmitted data. Pilot-phase problems may be compensated for by using clock adjust to change when the VXA samples the I/Q trajectory.

Amplitude Phase-Shift Keying (APSK) Concepts

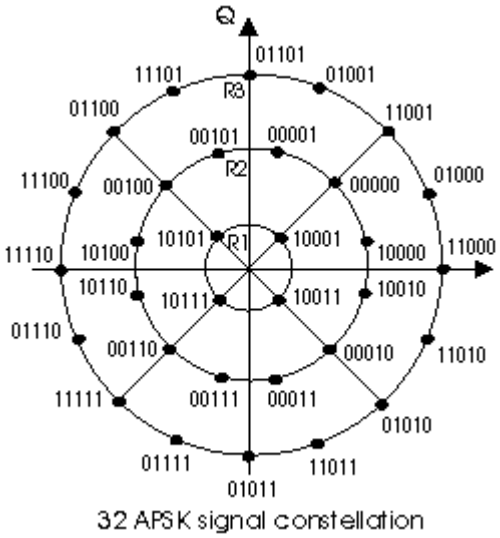
Amplitude phase-shift keying (APSK) conveys data by modulating both the amplitude and the phase. To demodulate 16 or 32 APSK signals, select the APSK 16, APSK 32, APSK 16 w/DVB, or APSK 32 w/DVB demodulation format. The APSK 16 w/DVB and APSK 32 w/DVB support to the Digital Video Broadcast (DVB) standard: ETSI EN 302 307 V1.1.1.

The APSK 16 modulation constellation is composed of two concentric rings of uniformly spaced 4 and 12 PSK points, respectively in the inner ring (R1) and the outer ring (R2).



16 APSK signal constellation

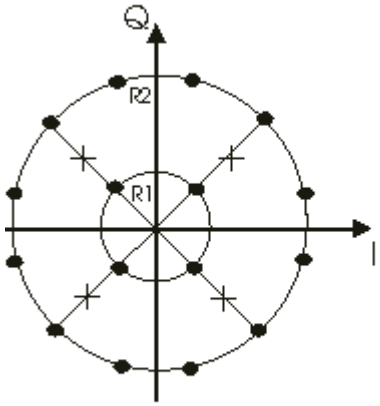
The APSK 32 modulation constellation is composed of three concentric rings of uniformly spaced 4, 12, and 16 PSK points, respectively in the inner ring (R1), the intermediate ring (R2), and the outer ring (R3).



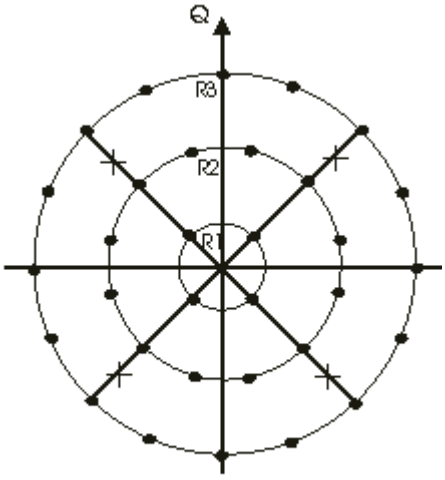
32 APSK signal constellation

DVB signals have periodic π/2 BPSK header slots and may have randomized QPSK pilot slots. These non-APSK slots can affect the measurement. To solve this problem, the VXA has defined synthetic constellations composed of the real APSK states and other states for the headers and pilots. These additional formats are called APSK 16 w/DVB and APSK 32 w/DVB. The ideal state positions are shown with circles in the

default setup and these alternate states (header and pilot states) are shown with a cross. The header and pilot states have the same power as the average of the ideal states (APSK 16 or APSK 32).



16 APSK signal constellation



32 APSK signal constellation

There are some side-effects of the synthetic constellation:

- The header and pilot demodulated symbols are treated as 4 or 5 bit symbols instead of 1 bit. These symbols are displayed in the Syms/Err trace. To simplify setting up the constellation sync search on the DVB header SOF (Start of Frame), search patterns for the SOF are provided in the drop-down list of Sync Search Patterns (**Meas Setup**, **Demod Setup**, **Burst/Sync Search**, **Sync Search** (selected), **Sync Patterns**). These sync search patterns are named APSK16_SOF and APSK32_SOF.
- The EVM on these pseudo-states is computed relative to the magnitude of the outer APSK ring instead of the QPSK/BPSK magnitude. SNR (MER) is computed normally.
- It is not possible to correctly demodulate just a part of these non-APSK slots with no APSK data present. The demod couldn't tell which of the rings, or the header, the symbols are on. This situation could happen only if the Result Length is 90 symbols or less.

Enhanced Data for Global Evolution (EDGE) Concepts

Enhanced Data for Global Evolution (EDGE) uses GMSK for its lower four modulation and coding schemes and 8PSK for its upper five modulation and coding schemes.

TIP Use the VXA's standard preset feature to automatically configure the measurement parameters: Select **Meas Setup**, **Preset to Standard**, **Cellular**, **EDGE**.

When using EDGE, note the following:

- Set the points per symbol to 1 point/symbol
  Because EDGE signals incorporate rotation and the EDGE filter introduces ISI (inter-symbol interference), symbol locations in the vector and constellation diagrams should appear random. However, at one Point/Symbol (the value set by the EDGE standard setup), the VXA removes the effects of ISI so a clean vector diagram can be viewed. Above one Point/Symbol, the VXA does not remove the effects of ISI.
- EDGE reference filter:
  The EDGE filter is available as the reference filter and is used for demodulating EDGE PSK signals. One of two filters may be used depending on the selection of the measured filter.
  1. When the measurement filter is set to No Filter, and the EDGE reference filter is selected, the EDGE reference filter will be a linearized Gaussian filter as defined by ETSI (European Telecommunications Standard Institute) GSM 05.04.
  2. When the measurement filter is EDGE and the EDGE reference filter is selected, the reference filter will be the GSM 05.04 filter described above convolved with the EDGE filter.
  The BT (Bandwidth Time Product) of the EDGE reference filter is fixed. The value of BT does not affect this filter.
- EDGE measurement filter:
  The EDGE filter is available as the measured filter and is used for demodulating EDGE PSK signals. This filter is a windowed, raised-cosine filter that has an approximate 180 kHz, 6 dB bandwidth, as defined by ETSI (European Telecommunications Standard Institute) GSM 05.05. The BT (Bandwidth Time Product) of the EDGE filter is fixed. The value of BT does not affect this filter.
- Pk EVM and 95% EVM error data results
  The EDGE demodulation format adds two new error data results to the symbol table: Pk EVM and 95% EVM. Pk EVM is the mean (average) of the peak EVMs - one per measurement (it is a mean of the peaks, not a peak of the peaks). 95% EVM is the error-vector-magnitude (EVM) below which 95% of the individual symbol EVMs occur.

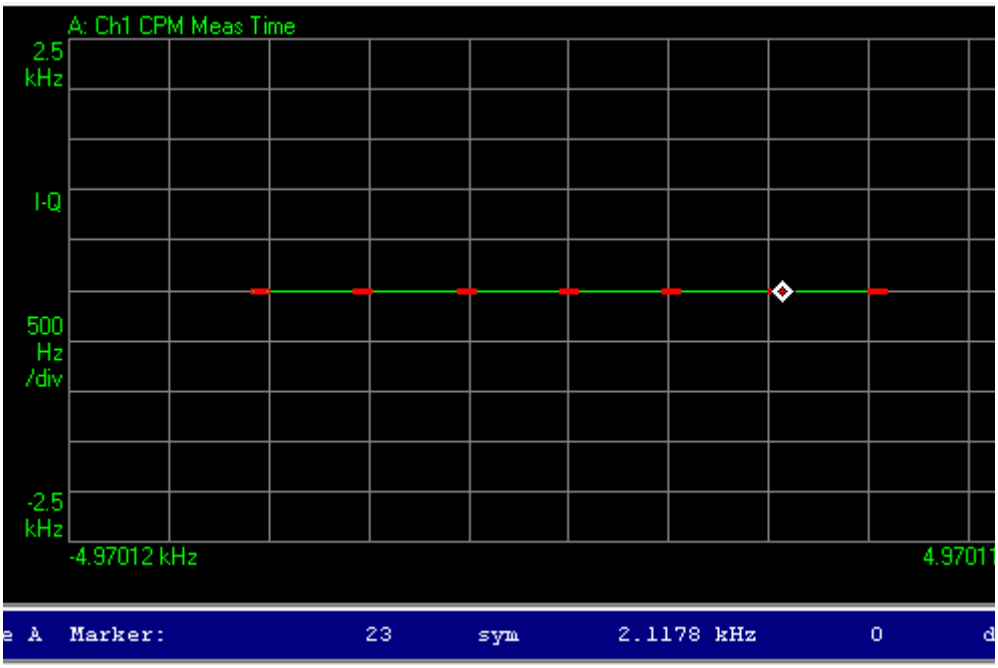
Continuous Phase Modulation (CPM) Concepts

CPM signals send data using the change of the carrier phase. The amplitude of the carrier stays constant.

NOTE CPM signals are demodulated using the FSK demodulator instead of decoding the change in phase from symbol to symbol. What this means is that IQ traces do not contain an imaginary component and the values represent the frequency of the signal with reference to the carrier.

Below is an example CPM constellation diagram. The center point is the center frequency and the points to the left and right of the center represent frequency shifts above and below the center frequency, respectively.

The marker shows that the frequency shift at symbol 23 is 2.1178 kHz. The phase shown on the marker applies to IQ traces in general, but is not applicable for CPM(FM) IQ traces.



CPM signals can be demodulated this way because the rate of change of phase is the same as the frequency shift.

The change in phase can be ± π or ± 3 π times the H parameter for the current symbol. Since there are 4 possible phase changes for each symbol, 2 bits of data are transmitted each symbol.

There are two H parameters, H1 and H2. The H parameter used to calculate the phase transition to the next symbol changes between H1 and H2 each symbol.

Filtering for CPM occurs on the phase component of the signal, similar to MSK and FSK. Therefore, the combination of filter definition and the values of H1 and H2 will determine the number of distinct FM states for a particular CPM signal. For example, HCPM as defined by APCO-25 Phase 2 generates a CPM signal with 7 unique FM states.

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 123

"PSK Bit State Diagrams" on page 125

"QAM Bit State Diagrams" on page 128

"DVB QAM Bit State Diagrams" on page 132

FSK Bit state Diagrams

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

Figure 4-44 *2FSK Bit State Diagram*



Figure 4-45 4FSK Bit State Diagram



Figure 4-46 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 4-47 *BPSK Bit State Diagram*

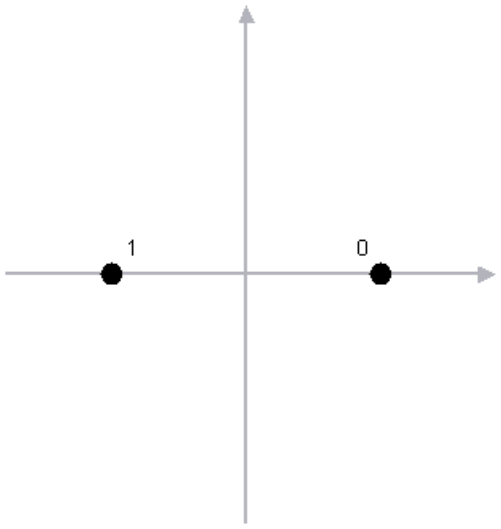


Figure 4-48 *QPSK Bit State Diagram*

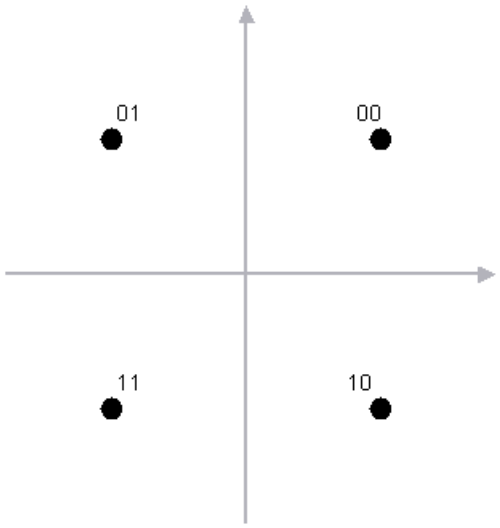


Figure 4-49 OQPSK (Offset QPSK) Bit State Diagram

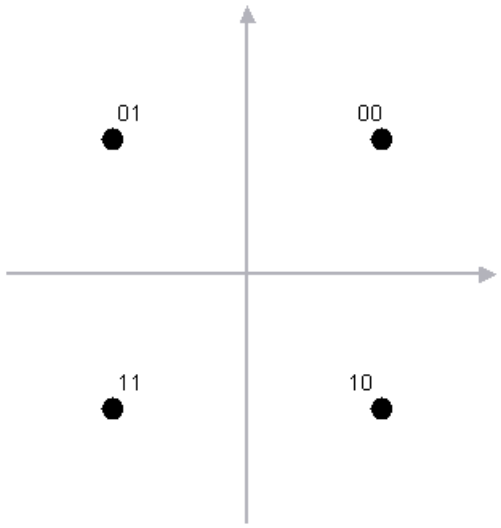


Figure 4-50 DQPSK (Differential QPSK) Bit State Diagram

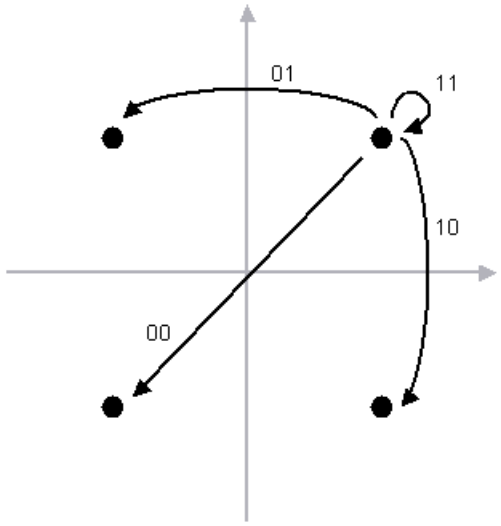


Figure 4-51 8PSK Bit State Diagram

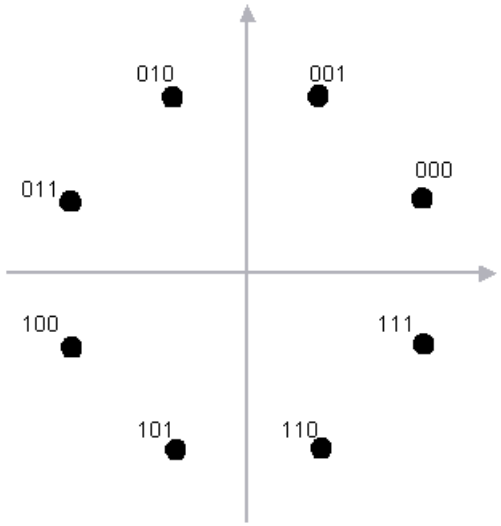


Figure 4-52 D8PSK (Differential 8PSK) Bit State Diagram

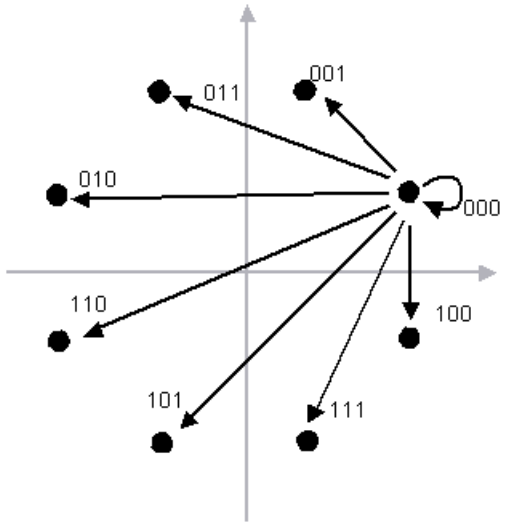
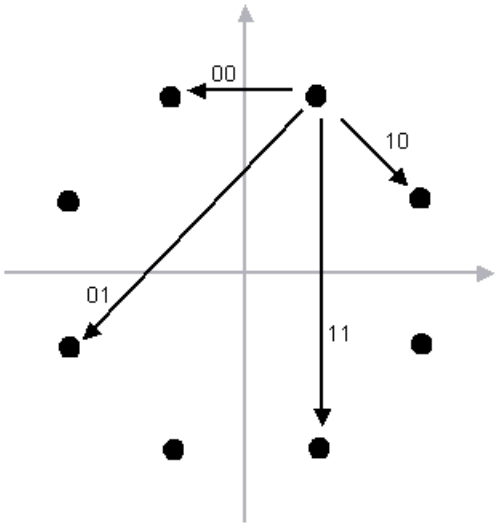


Figure 4-53 *π/4 DQPSK Bit State Diagram*



QAM Bit State Diagrams

QAM bit states are represented below in constellation diagrams.

Figure 4-54 *16 QAM Bit State Diagram*

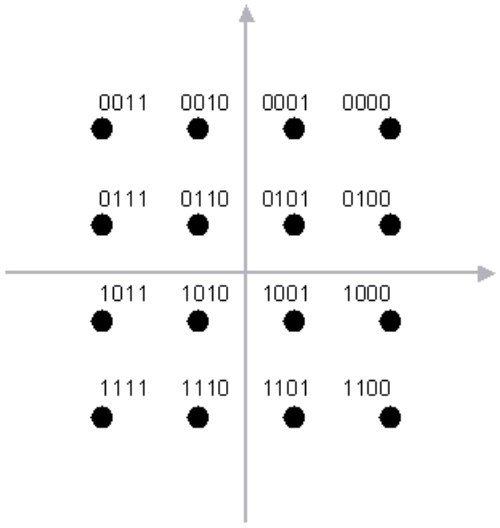


Figure 4-55 32 QAM Bit State Diagram

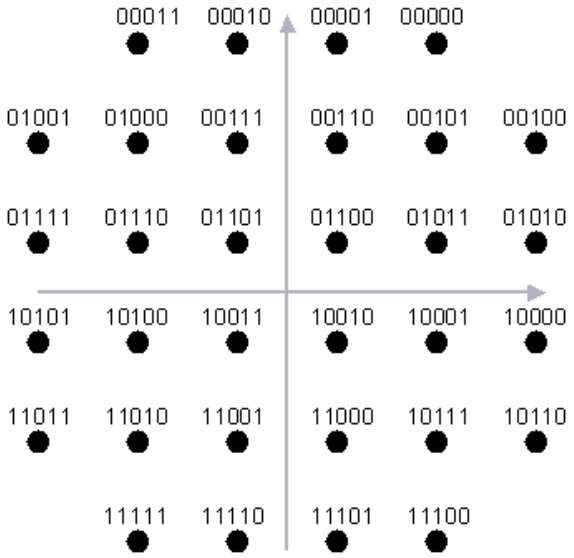


Figure 4-56 64 QAM Bit State Diagram

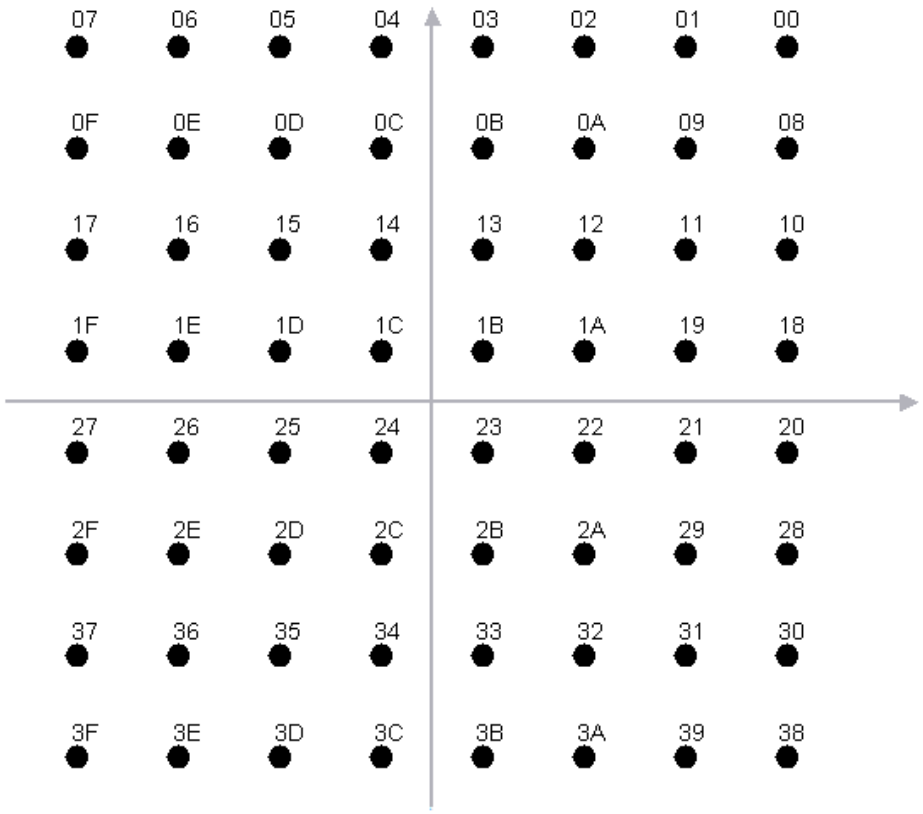


Figure 4-57 128 QAM Bit State Diagram

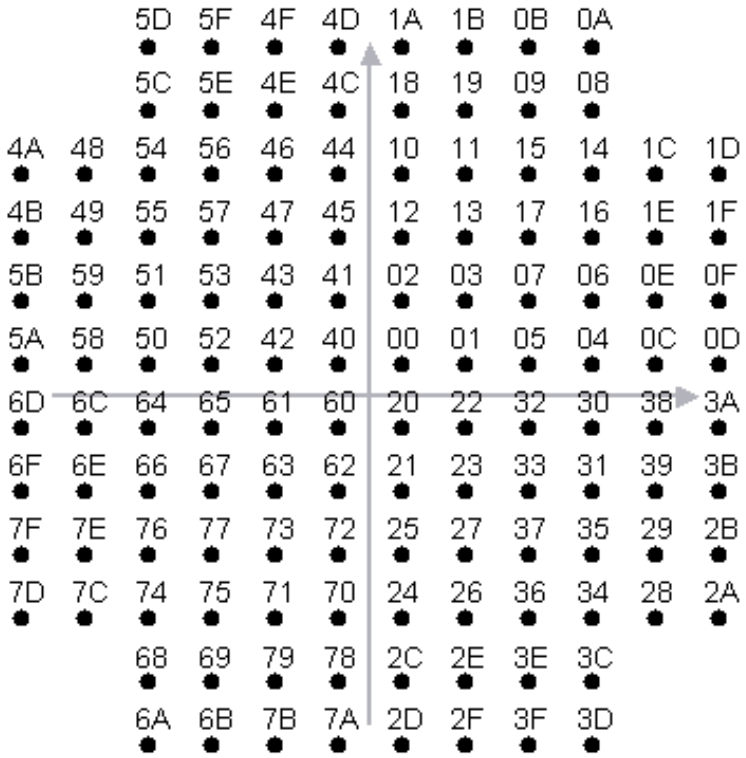
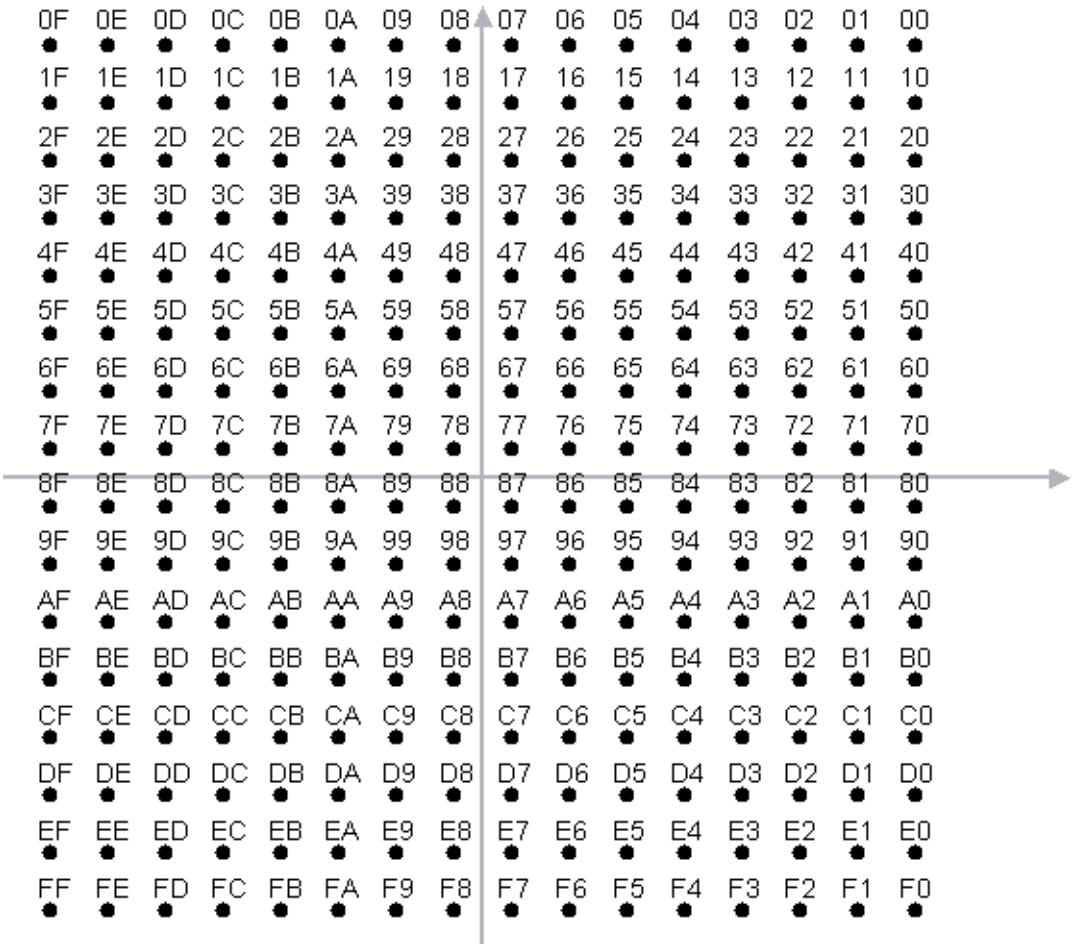


Figure 4-58 256 QAM Bit State Diagram



DVB QAM Bit State Diagrams

DVB QAM bit states are represented below in constellation diagrams.

As shown in Figure 4-59 on page 132, Figure 4-60 on page 133, and Figure 4-61 on page 134, the constellation points in Quadrant 1 are converted to Quadrants 2, 3, and 4 by changing the two MSBs (i.e., Ik and Qk) and by rotating the q LSBs according to the rule given in the table below.

Table 4-5 DVB 16QAM, 32 QAM, 64QAM Rotation Rules

Quadrant	MSBs	LSBs Rotation
1	00	
2	10	+π/2
3	11	+π
4	01	+3π/2

Figure 4-59 DVB 16QAM Bit State Diagram

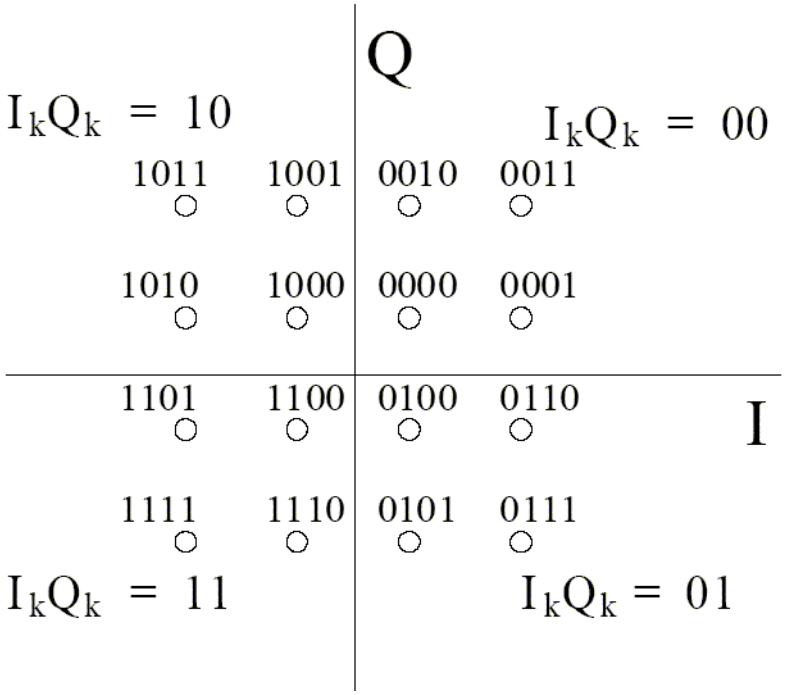


Figure 4-60 DVB 32QAM Bit State Diagram

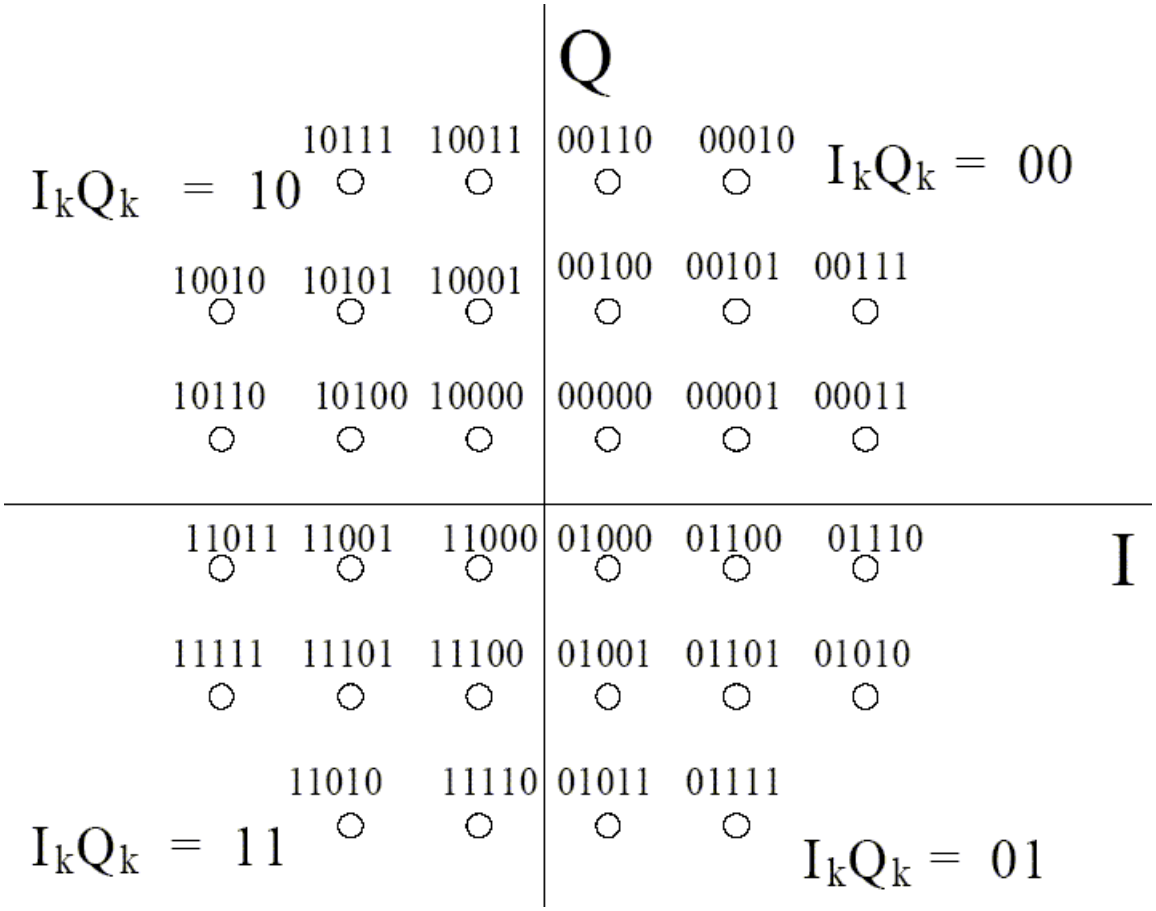


Figure 4-61 DVB 64QAM Bit State Diagram

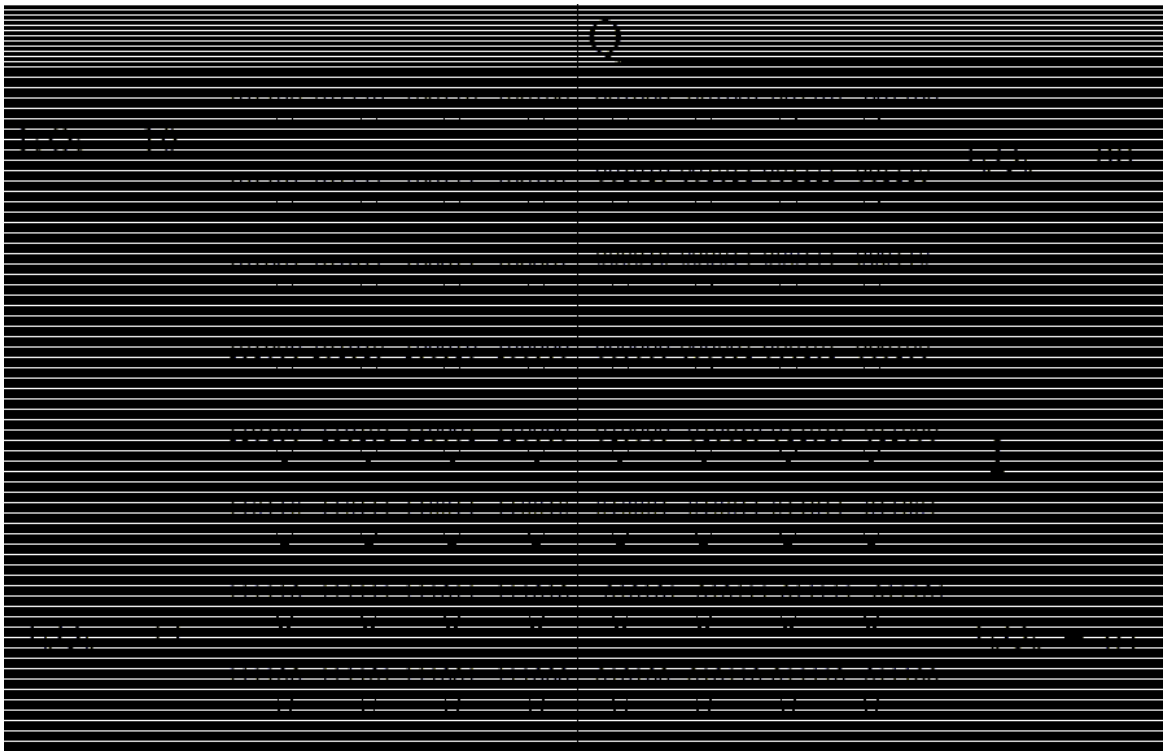


Figure 4-62 DVB 128QAM Bit State Diagram

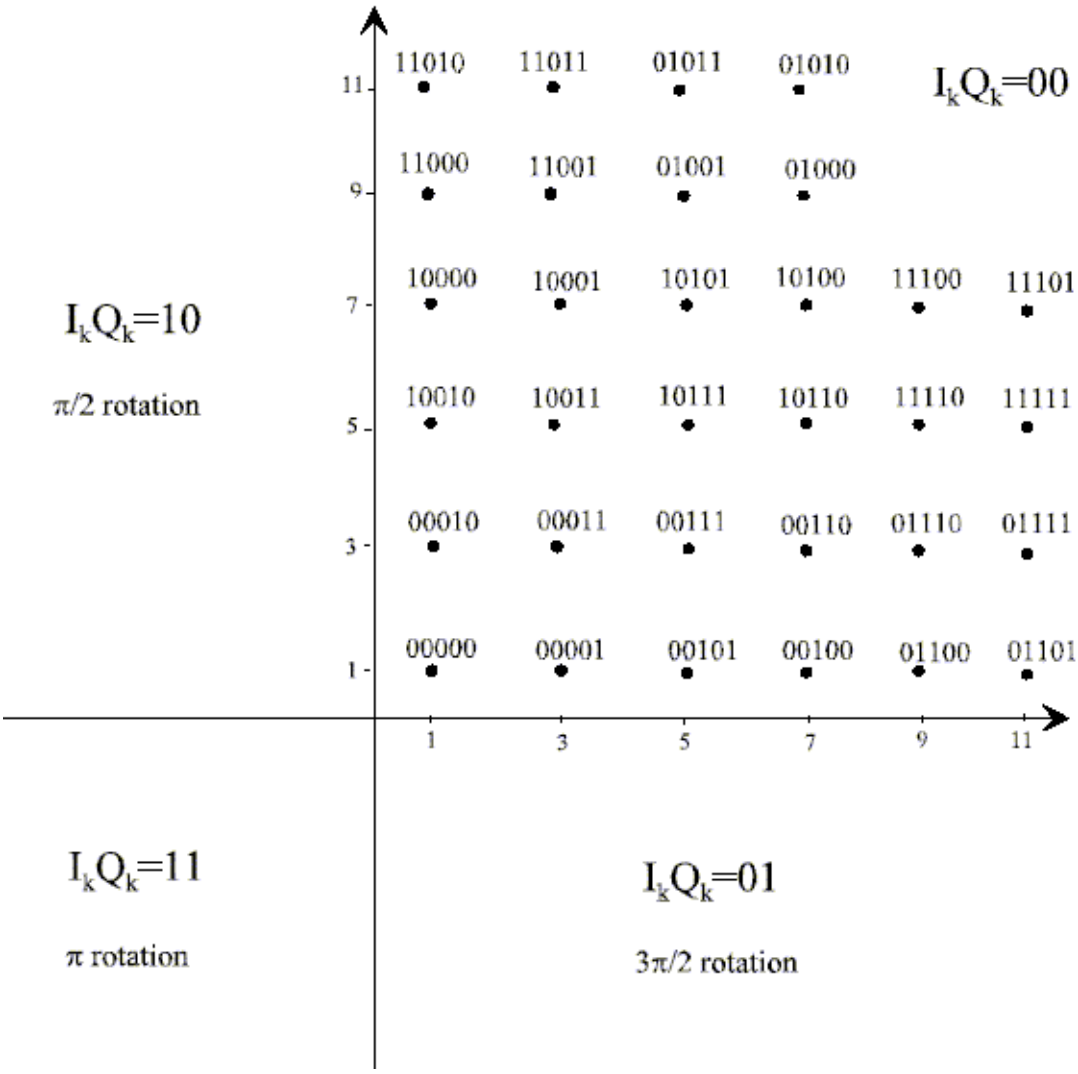
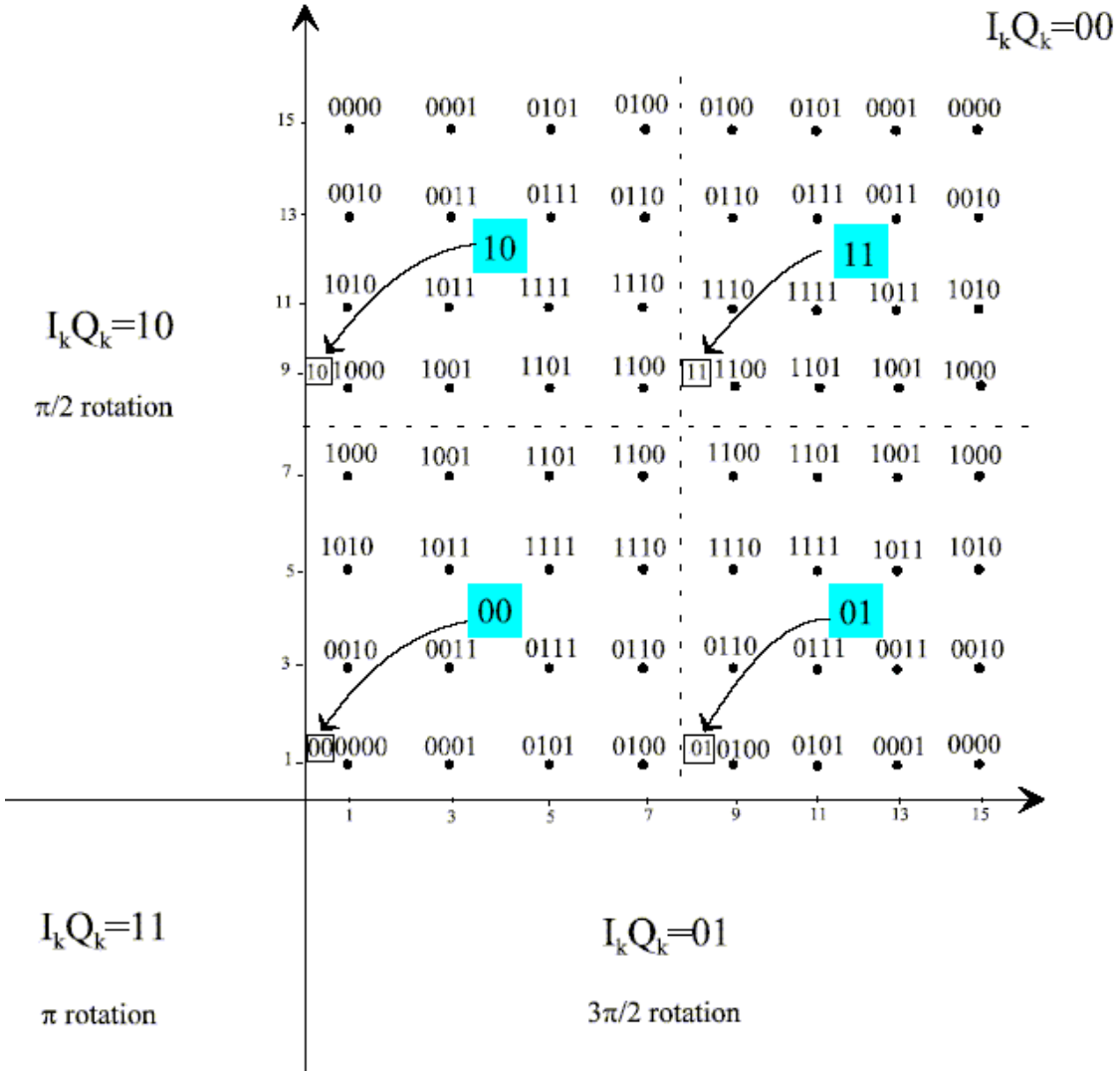


Figure 4-63 DVB 256QAM Bit State Diagram



Communication System Formats

N9064A VXA Supported Communications Format Standards

Table 4-6 Available "Preset to Standards" Formats

Cellular	Wireless Networking	Digital Video	Other
"CDMA BASE" on page 137	"Bluetooth" on page 139	"DTV 8" on page 141	"APCO 25" on page 144
"CDMA MOBILE" on page 137	"HIPERLAN/1(HBR)" on page 139	"DTV 16" on page 141	"DECT" on page 144
"CDPD" on page 138	"HIPERLAN/1 (LBR)" on page 139	"DVB 16" on page 141	"TETRA" on page 144
"EDGE" on page 138	"WLAN(802.11b)" on page 139	"DVB 32" on page 142	"VDL Mode 3" on page 144
"GSM" on page 138	"ZigBee 868 MHz" on page 140	"DVB 64" on page 142	"HCPM" on page 144
"NADC" on page 139	"ZigBee 915 MHz" on page 140	"DVB 128" on page 142	"HDQPSK" on page 144
"PDC" on page 139	"ZigBee 2450 MHz" on page 140	"DVB 256" on page 143	"MIL-STD CPM" on page 144
"PHP (PHS)" on page 139	"WiSUN (MR-FSK-PHY)" on page 140	"DVB 16APSK" on page 143	
"W-CDMA" on page 137		"DVB 32APSK" on page 143	

TIP In the following tables, to convert symbols to seconds, divide by the symbol rate.

Table 4-7 Cellular Preset-To-Standard Formats

Parameter	CDMA BASE	CDMA MOBILE	W-CDMA
Demod Format	QPSK	OQPSK	QPSK
Frequency Span	2.6 MHz	2.6 MHz	5 MHz
Symbol Rate	1.2288 MHz	1.2288 MHz	3.84 MHz
Filtering			

Table 4-7 Cellular Preset-To-Standard Formats

Parameter	CDMA BASE	CDMA MOBILE	W-CDMA
- Measured	IS-95 base base EQ	Cleared	Root Cosine
- Reference	IS-95 baseband	IS-95 baseband	Cosine
Alpha/BT	---	---	0.22
Points/Symbol	4	4	5
Result Length	200 symbols	200 symbols	200 symbols
Search Length	---	---	2560 symbols
Pulse Search	Cleared	Cleared	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0
Bit Definitions	defined by IS-95	defined by IS-95	---

Table 4-8 Cellular Preset-To-Standard Formats

Parameter	GSM	CDPD	EDGE
Demod Format	MKS Type 1	MKS Type 2	EDGE (3π/8 8PSK)
Frequency Span	1.0 MHz	75 kHz	625 kHz
Symbol Rate	270.83 kHz	19.2 kHz	270.83 kHz
Filtering			
- Measured	Cleared	Cleared	EDGE
- Reference	Gaussian	Gaussian	EDGE
Alpha/BT	0.3	0.5	0.25
Points/Symbol	5	5	1
Result Length	148 symbols	378 symbols	142 symbols
Search Length	1434 symbols	400 symbols	1434 symbols
Pulse Search	Selected	Cleared	Selected

Table 4-8 Cellular Preset-To-Standard Formats

Parameter	**GSM**	**CDPD**	**EDGE**
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0
Equalization	---	---	Cleared

Table 4-9 Cellular Preset-To-Standard Formats

Parameter	**NADC**	**PDC**	**PHP (PHS)**
Demod Format	π/4 DQPSK	π/4 DQPSK	π/4 DQPSK
Frequency Span	75 kHz	75 kHz	625 kHz
Symbol Rate	24.3 kHz	21 kHz	192 kHz
Filtering			
- Measured	root cosine	root cosine	root cosine
- Reference	cosine	cosine	cosine
Alpha/BT	0.35	0.5	0.5
Points/Symbol	5	5	5
Result Length	157 symbols	135 symbols	111 symbols
Search Length	1175 symbols	1000 symbols	1100 symbols
Pulse Search	Selected	Selected	Selected
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0

Table 4-10 Wireless Networking Preset-To-Standard Formats

Parameter	***Bluetooth***	**HIPERLAN/1(HBR)**	**HIPERLAN/1 (LBR)**	**WLAN(802.11b)**
Demod Format	FSK2	MSK Type 1	FSK 2	QPSK
Frequency Span	2.5 MHz	36 MHz	18.7 MHz	36 MHz [a]

Table 4-10 Wireless Networking Preset-To-Standard Formats

Parameter	***Bluetooth***	**HIPERLAN/1(HBR)**	**HIPERLAN/1 (LBR)**	**WLAN(802.11b)**
Symbol Rate	1 MHz	23.5294 MHz	1.4705875 MHz	11 MHz
Filtering				
- Measured	Cleared	Cleared	Cleared	Cleared
- Reference	Gaussian	Gaussian	Rect	Gaussian
Alpha/BT	0.5	0.3	--	0.5
Points/Symbol	2	5	20	4
Result Length	320 symbols	1000 symbols	1000 symbols	1000 symbols
Search Length	1650 Symbols	1434 symbols	1434 symbols	1434 Symbols
Pulse Search	Cleared	Cleared	Cleared	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0	0.0

a. If the acquisition hardware does not support the default frequency span, then the span will be set to the closest span that the acquisition hardware can support.

Table 4-11 Wireless Networking Preset-To-Standard Formats

Parameter	**ZigBee 868 MHz**	**ZigBee 915 MHz**	**ZigBee 2450 MHz**	**WiSUN (MR-FSK-PHY)**
Demod Format	BPSK	BPSK	O-QPSK	2 FSK
Frequency Span	1 MHz	2 MHz	10 MHz	200 kHz to 1.2 MHz (based on symbol rate)
Symbol Rate	300 kHz	600 kHz	1 MHz	50/100/150/200/ 300 kHz
Filtering				
- Measured	Cleared	Cleared	Cleared	Cleared
- Reference	Raised Cosine	Raised Cosine	Half Sine	Gaussian

Table 4-11 Wireless Networking Preset-To-Standard Formats

Parameter	ZigBee 868 MHz	ZigBee 915 MHz	ZigBee 2450 MHz	WiSUN (MR-FSK-PHY)
Alpha/BT	1	1	---	0.5
Points/Symbol	4	4	10	20
Result Length	1000 symbols	1000 symbols	1001 symbols	2875 symbols
Search Length	10 ms	5 ms	3 ms	115 ms to 19.16667 ms (based on symbol rate)
Pulse Search	Selected	Selected	Selected	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0	0.0

Table 4-12 Wireless Networking Preset-To-Standard WiSUN (MR-FSK-PHY) Formats

Parameter	2FSK 50/1	2FSK 100/1	2FSK 100/0.5	2FSK 150/0.5	2FSK 200/1	2FSK 200/0.5	2FSK 300/0.5
Freq Span	200 kHz	400 kHz	400 kHz	600 kHz	800 kHz	800 kHz	1.2 MHz
Symbol Rate	50 kHz	100 kHz	100 kHz	150 kHz	200 kHz	200 kHz	300 kHz
FSK Dev Ref	25 kHz	50 kHz	25 kHz	37.5 kHz	100 kHz	50 kHz	75 kHz
Search Length	115 ms	57.5 ms	57.5 ms	38.3333 ms	28.75 ms	28.75 ms	19.16667 ms

Table 4-13 Digital Video Preset-To-Standard Formats

Parameter	DTV 8	DTV 16	DVB 16
Demod Format	VSB 8	VSB 16	16 DVB QAM
Frequency Span	7 MHz	7 MHz	8 MHz
Symbol Rate	10.762 MHz	10.762 MHz	6.9 MHz
Filtering			

Table 4-13 Digital Video Preset-To-Standard Formats

Parameter	**DTV 8**	**DTV 16**	**DVB 16**
- Measured	Root Cosine	Root Cosine	Root Raised Cosine
- Reference	Cosine	Cosine	Raised Cosine
Alpha/BT	0.1152	0.1152	0.15
Points/Symbol	2	2	2
Result Length	800 symbols	800 symbols	800 symbols
Search Length	---	---	---
Pulse Search	Cleared	Cleared	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0

Table 4-14 Digital Video Preset-To-Standard Formats

Parameter	**DVB 32**	**DVB 64**	**DVB 128**
Demod Format	32 DVB QAM	64 DVB QAM	128 DVB QAM
Frequency Span	8 MHz	8 MHz	8 MHz
Symbol Rate	6.9 MHz	6.9 MHz	6.9 MHz
Filtering			
- Measured	Root Raised Cosine	Root Raised Cosine	Root Raised Cosine
- Reference	Raised Cosine	Raised Cosine	Raised Cosine
Alpha/BT	0.15	0.15	0.15
Points/Symbol	2	2	2
Result Length	800 symbols	800 symbols	800 symbols
Search Length	---	---	---
Pulse Search	Cleared	Cleared	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Cleared	Cleared

Table 4-14 Digital Video Preset-To-Standard Formats

Parameter	**DVB 32**	**DVB 64**	**DVB 128**
Clock Adjust	0.0	0.0	0.0

Table 4-15 Digital Video Preset-To-Standard Formats

Parameter	**DVB 256**	**DVB 16APSK**	**DVB 32APSK**
Demod Format	256 DVB QAM	16 APSK	32 APSK
Frequency Span	8 MHz	50 MHz	50 MHz
Symbol Rate	6.9 MHz	25 MHz	25 MHz
Filtering			
- Measured	Root Raised Cosine	Root Raised Cosine	Root Raised Cosine
- Reference	Raised Cosine	Raised Cosine	Raised Cosine
Alpha/BT	0.15	0.35	0.35
Points/Symbol	2	5	5
Result Length	800 symbols	180 symbols	180 symbols
Search Length	---	1175 symbols	1175 symbols
Pulse Search	Cleared	Cleared	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0
Ring Ratio	---	See table below	See table below

Table 4-16 DVB APSK Ring Ratios

	16 APSK	**32 APSK**	
Code Rate	**R2/R1**	**R2/R1**	**R3/R1**
Code Rate 2/3	3.15	---	---
Code Rate 3/4	2.85	2.84	5.27
Code Rate 4/5	2.75	2.72	4.87

Table 4-16 DVB APSK Ring Ratios

	16 APSK	**32 APSK**	
Code Rate	**R2/R1**	**R2/R1**	**R3/R1**
Code Rate 5/6	2.7	2.64	4.64
Code Rate 8/9	2.6	2.54	4.33
Code Rate 9/10	2.57	2.53	4.30

Table 4-17 Other Preset-To-Standard Formats

Parameter	**APCO 25**	**DECT**	**TETRA**
Demod Format	4 FSK	FSK 2	π/4 DQPSK
Frequency Span	40 kHz	5 MHz	40 kHz
Symbol Rate	4.8 kHz	1.152 MHz	18 kHz
Filtering			
- Measured	Rect	Cleared	Root Cosine
- Reference	Raised Cosine	Gaussian	Cosine
Alpha/BT	0.2	0.5	0.35
Points/Symbol	5	4	4
Result Length	200 symbols	480 symbols	231 symbols
Search Length	400 symbols	11,200 symbols	1300 symbols
Pulse Search	Cleared	Selected	Selected
Constellation Sync Search	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0

Table 4-18 Other Preset-To-Standard Formats

Parameter	**VDL Mode 3**	**HCPM**	**HDQPSK**	**MIL-STD CPM**
Demod Format	D8PSK	CPM (FM)	4FSK	CPM (FM)
Frequency Span	25 kHz	25 kHz	25 kHz	25 kHz

Table 4-18 Other Preset-To-Standard Formats

Parameter	**VDL Mode 3**	**HCPM**	**HDQPSK**	**MIL-STD CPM**
Symbol Rate	10.5 MHz	6 kHz	6 kHz	4.8 kHz
Filtering				
- Measured	Cleared	None	Rect	None
- Reference	Raised Cosine	1REC	Rect	1REC
Alpha/BT	0.6	0.75	1	0.35
Points/Symbol	5	5	5	5
Result Length	315 symbols	168 symbols	180 symbols	500 symbols
Search Length	120 ms	380 symbols	380 symbols	800 ms
Pulse Search	Selected	Selected	Cleared	Cleared
Constellation Sync Search	Cleared	Cleared	Cleared	Cleared
Normalize IQ Traces	Selected	Selected	Selected	Selected
Clock Adjust	0.0	0.0	0.0	0.0
CPM Auto {h1, h2}	---	{1/3} [HDQPSK]	---	Selected, {5/16, 6/16}

What is the CDMA Communication System?

Code Division Multiple Access (IS-95 Base and Mobile) 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

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.

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 sectored cells. The capacity limit is soft. That is, capacity can be increased with some degradation of the error rate or voice quality.

In 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 CDMA 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 CDMA. One of the major differences in access, compared to a non-cdma system, is that any CDMA frequency can be used in all sectors of all cells. This is possible because CDMA is designed to decode the proper signal in the presence of high interference.

The CDMA 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:

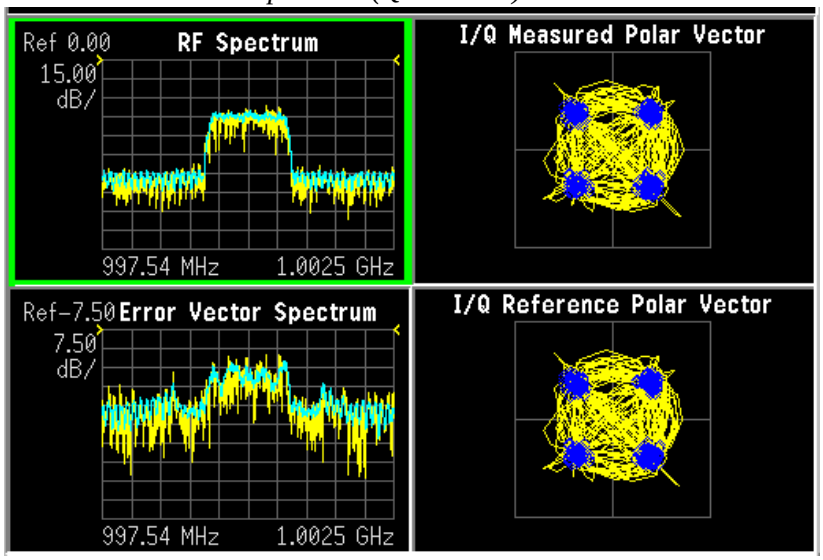
J-STD-008 Personal Station-Base Station Compatibility Requirements for 1.8 to 2.0 GHz Code Division Multiple Access (CDMA) Personal Communications Systems

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

CDMA Communication System

Figure 4-64 *CDMA 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:

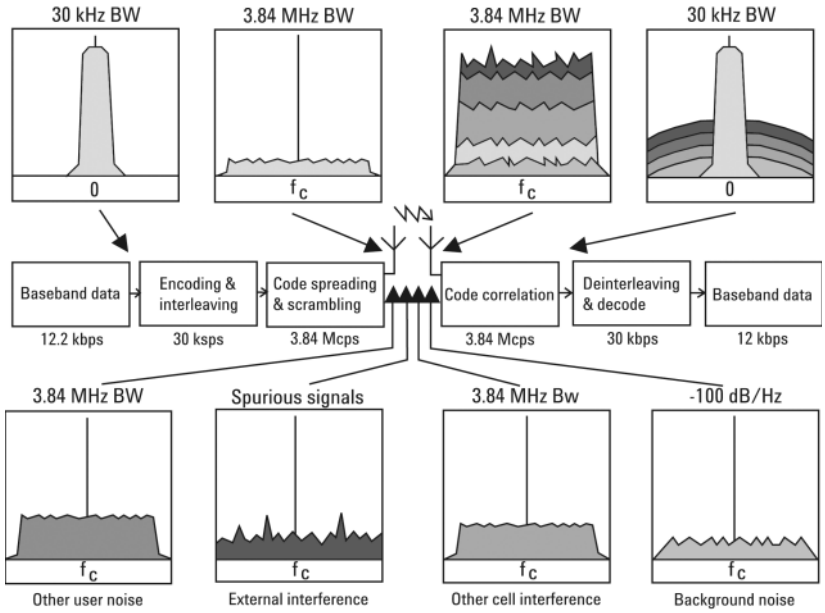
- greater capacity
- immunity to signal loss and degradation due to high-level broadband interference, multipath, scattering, and fading
- power consumption of mobile stations or user equipment (UE) is strictly minimized by both base station and mobile controls
- supports variable data rates up to 144 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 sectored 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 4-65 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 ksps 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.

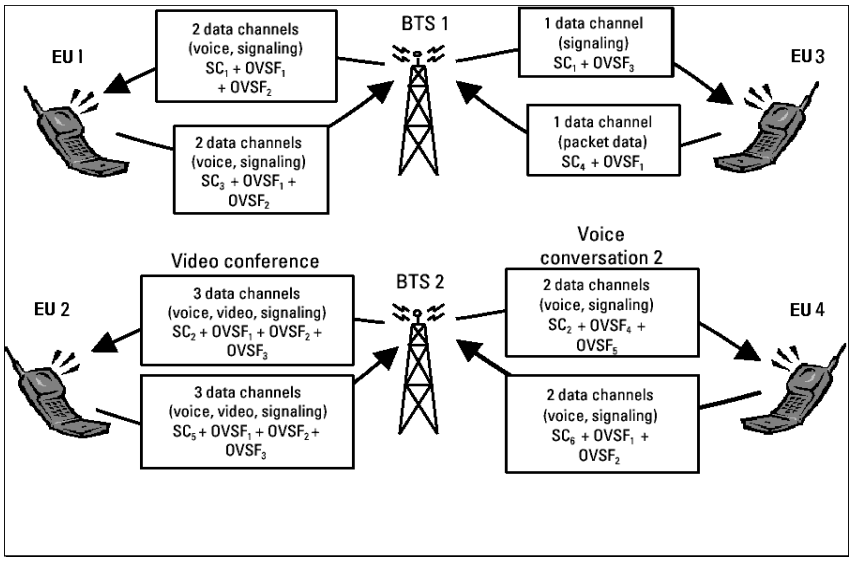
OVSF codes are orthogonal codes similar to the Walsh codes used in IS-95. Each channel originating from a W-CDMA BTS or UE is multiplied by a different OVSF codes. In IS-95, Walsh codes are fixed at 64 chips in length; in W-CDMA, the length of these codes, also known as the spreading factor (SF), can 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 ksps.

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 OVSF 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 OVSF4 and OVSF5 to send voice and signaling information to UE 4. This UE uses OVSF1 and OVSF2 to send voice and signaling information back to BTS 2. Note that other BTSs and UEs also use the same OVSF codes (OVSF1 and OVSF2). This is not a problem since the scrambling codes decorrelate the re-used OVSF codes.

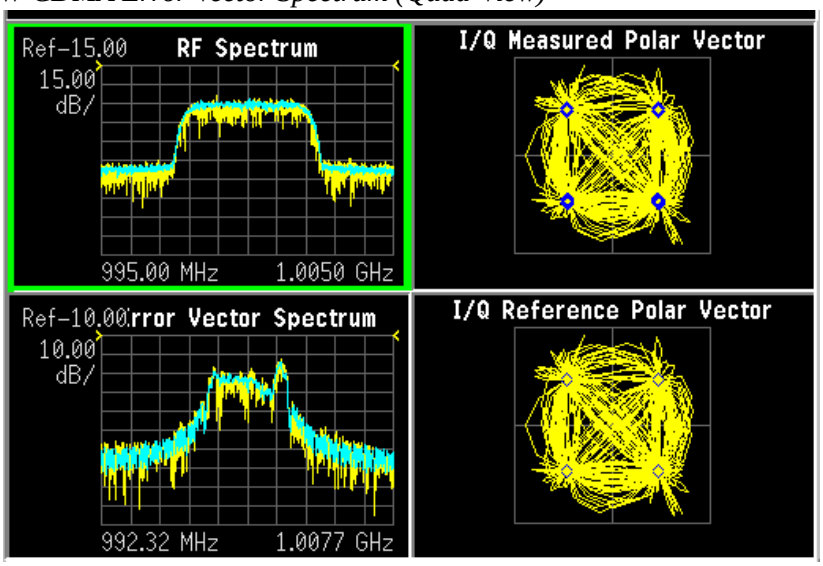
Figure 4-66 *W-CDMA Code Allocations*



The combination of OVSF 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 (Eb/No).

W-CDMA Communication System

Figure 4-67 *W-CDMA 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 π/4 differential quadrature phase shift keying (π/4 DQPSK). The π/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.

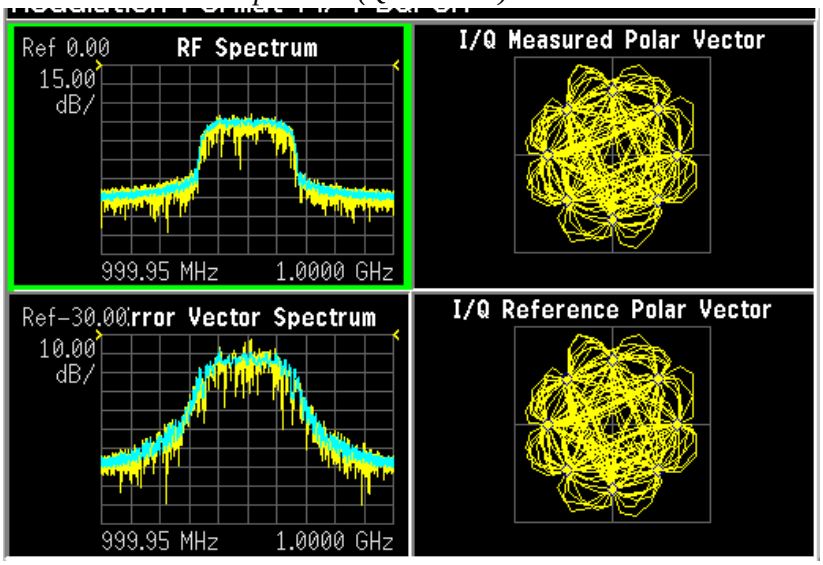
Following is a summary of the NADC air interface. Note that the frequency range is the same as the analog cellular. Since it is a dual-mode system, NADC will use the same frequency band currently assigned to the AMPS cellular. The available channels are divided into analog and digital channels. The channel 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 π/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 µs.

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 4-68 *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.

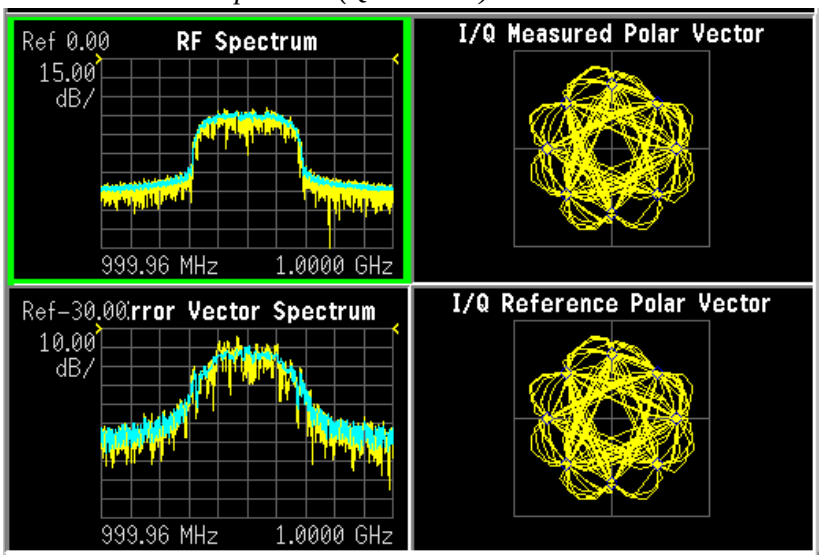
800 MHz	Uplink	940 to 958 MHz	887 to 889 MHz
	Downlink	810 to 828 MHz	832 to 834 MHz
800 MHz	Uplink	898 to 901 MHz	915 to 940MHz
	Downlink	843 to 846 MHz	860 to 885 MHz
1500 MHz	Uplink	1429 to 1453 MHz	
	Downlink	1477 to 1501 MHz	

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 4-69 *PDCError Vector Spectrum (Quad-View)*



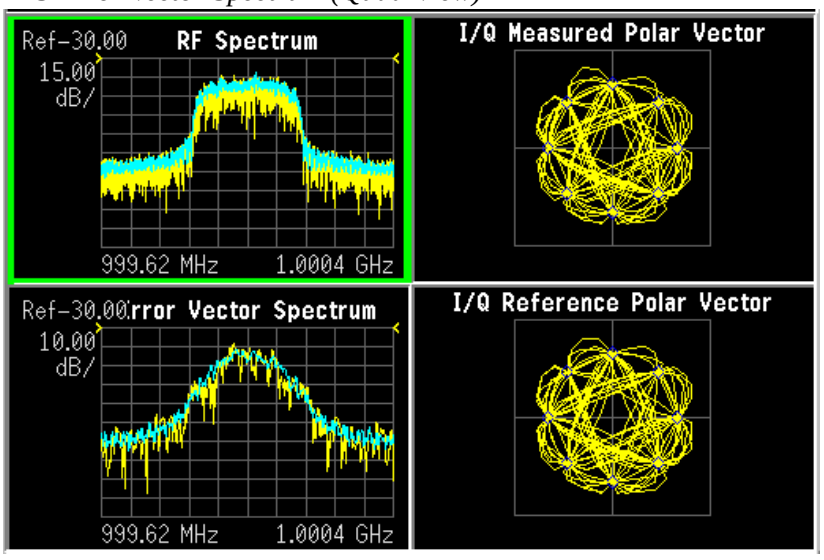
What is the PHS Communication System

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 4-70 *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 that are difficult to achieve with the public cellular networks.

The digital modulation format used is π/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 400 MHz 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

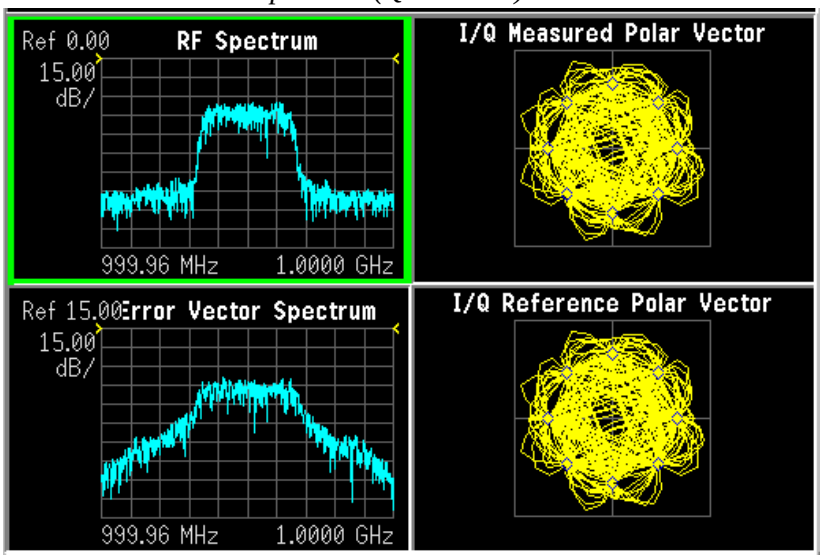
time slot per frame to increase the data rate. This is useful for transmitting graphical information (including maps), scanned images (such as fingerprints) or transmitting low bit rate compressed camera images.

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 4-71 *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/second. 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 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 4-72

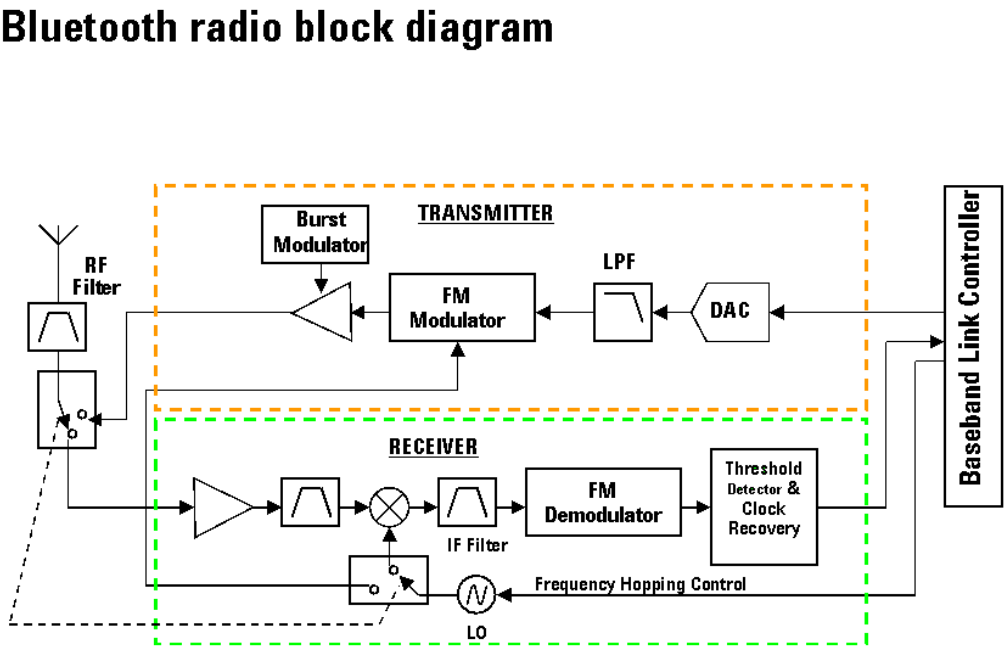


Table 4-19 Bluetooth RF Characteristics

Characteristic	Specification	Notes
Carrier Frequency	2400 to 2483.5 MHz (ISM radio band)	f=2402+k MHz, k=0,...,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

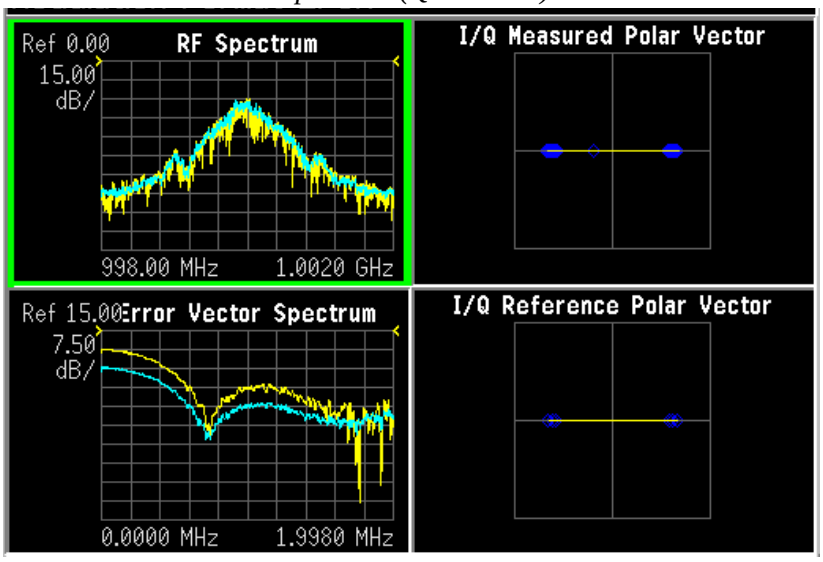
Table 4-19 Bluetooth RF Characteristics

Characteristic	Specification	Notes
Hopping	1600 hops/s (in normal operation)[a] 1 MHz channel spacing The system has 5 different hopping sequences: 1) Page hopping sequence 2) Page response sequence 3) Inquiry sequence 4) Inquiry response sequence 5) Channel hopping sequence 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.	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.
Transmit Power	Power Class 1: 1 mW (0 dBm) to 100 mW (+20 dBm) Power Class 2: 0.25 mW (–6 dBm) to 2.5 mW (+4 dBm) Power Class 3: 1 mW (0 dBm)	Class 1 power control: +4 to +20 dBm (required) –30 to 0 dBm (optional) Class 2 power control: –30 to 0 dBm (optional) Class 3 power control: –30 to 0 dBm (optional)
Operating Range	10 cm to 10 m (100 m with Power Class 1)	
Maximum Data Throughput	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.	Data throughput is lower than the 1 Msymbol/s rate as a result of the overhead, which is inherent in the protocol.

a. Hop speed may vary depending on packet length.

Bluetooth Communication System

Figure 4-73 *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 4-20 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 4-21 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 µs	576.9 µs	576.9 µs	576.9 µs	576.9 µs	576.9 µs	576.9 µs	576.9 µs	576.9 µs
GSM Bit and Symbol Period	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs
EDGE Symbol Period	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs	3.692 µs
Modulation GSM EDGE	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/8 8PSK	0.3 GMSK 3π/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 4-21 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)
- mobile stations, referred to as MS (frequency ranges dependent on the standard)

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) that designates the carrier frequency.

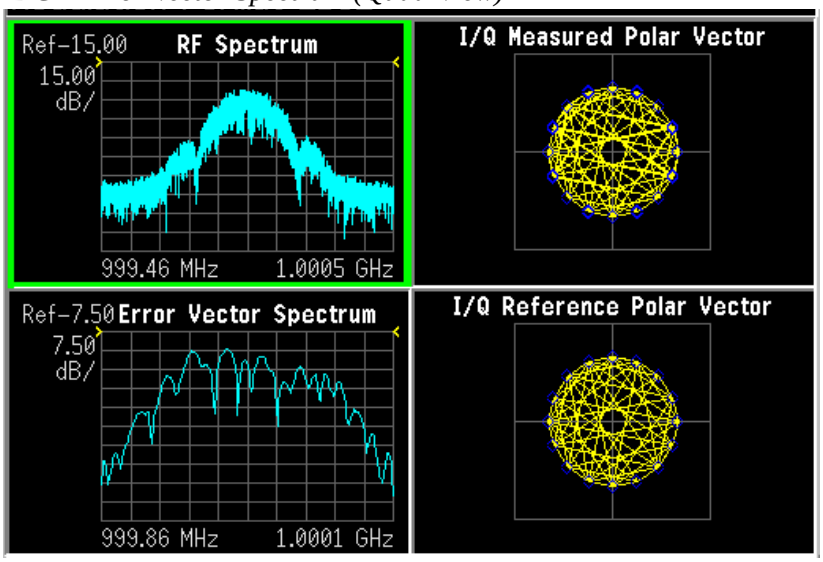
What Is A Timeslot?

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 µs long. The eight user timeslots are numbered from 0 to 7.

Typically, each 577 µs 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 4-74 *EDGE Error Vector Spectrum (Quad-View)*



What is APCO25 phase 1?

APCO25 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. APCO25 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 APCO25 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 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 $|f| <$ 2880Hz. 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 (pif/4800)/(pif/4800).

Digitized Voice Coder Method After evaluating several candidates, APCO25 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 APCO25 techniques have been designed to operate in bit error rate environments of up to 7 percent.

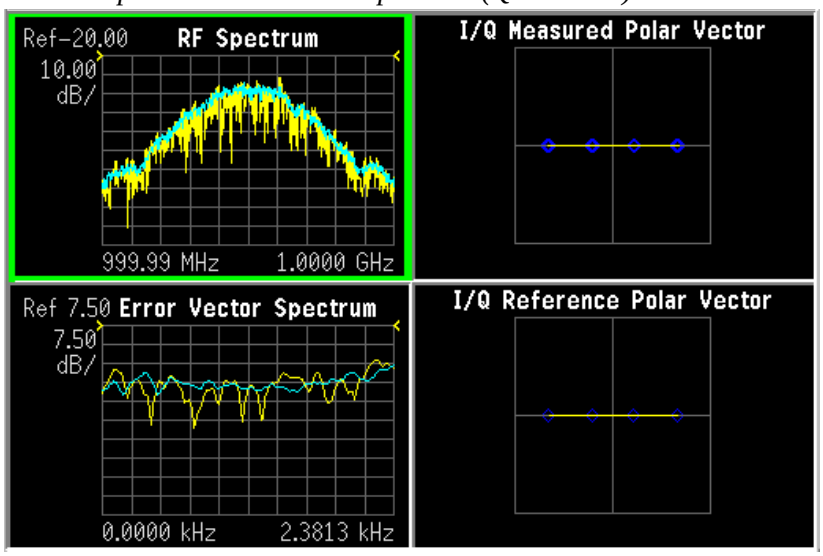
Flexible Modulation Method A pair of modulation methods have been selected that utilize a common receiver. The first, which utilizes a constant-envelope 4-level Frequency Modulation (FM) variant, can utilize simple, high-efficiency amplifiers and has emissions that fit within a 12.5 kHz bandwidth. This 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).

APCO25 phase1 Communication System

Figure 4-75 *APCO25 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 4-22 *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 4-23 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.

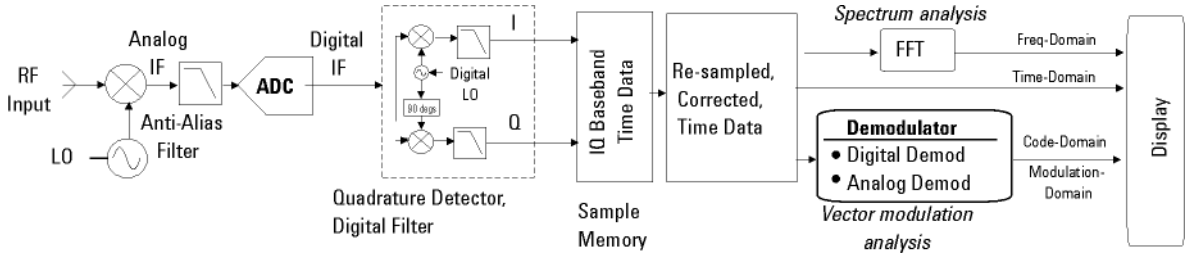
This section gives an overview of how the N9064A VXA demodulates a digitally modulated signal for analysis. A description of the three measurement domains is followed by the modulation quality measurements made on the system formats supported. A review of I/Q, constellation and Eye diagrams is given, 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 4-76 The N9064A VXA as a Receiver



The figure above shows an Keysight 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.

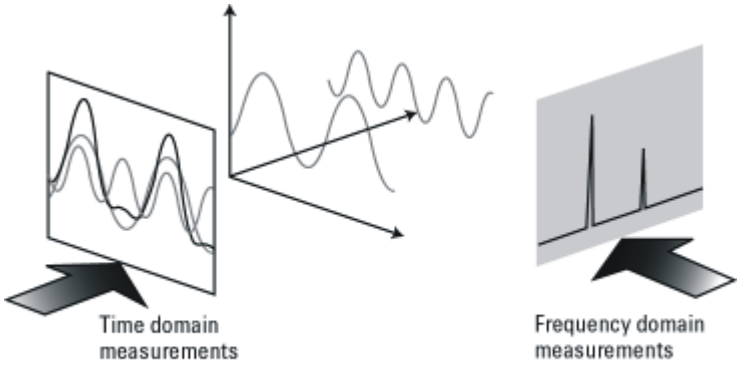
Complex trade-offs in frequency, phase, timing, and modulation are made for interference-free, multiple-user communications systems. It is necessary to accurately measure parameters in digital RF communications systems to make the right trade-offs. Measurements include analyzing the modulator and demodulator, 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 4-77 *Time and Frequency Domains*



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 55.

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.

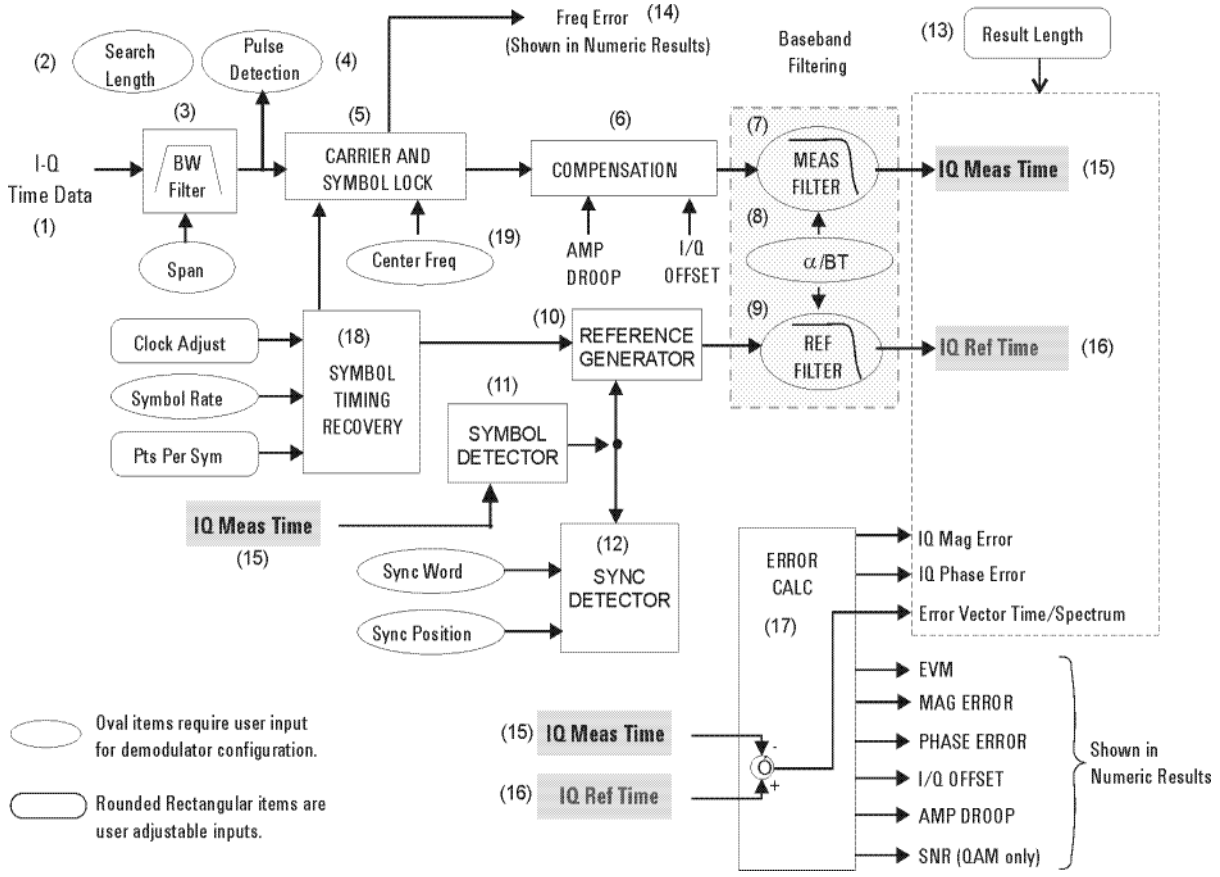
Combinations of the display formats and capabilities above can be used to troubleshoot potential problems in the design.

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 Keysight 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 4-78 Digital Demodulation Block Diagram



The Digital Demodulator Block Diagram by Section

1. **Input Signals:** the IF signal is digitized and in I/Q format. These samples also go to the Symbol Detector block.

2. **Search Length**: this user entry tells the demodulator how many symbols to search through in order to find the user specified synchronization word.
3. **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, and so on.
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) 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 4-78 on page 177, 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 Keysight 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.

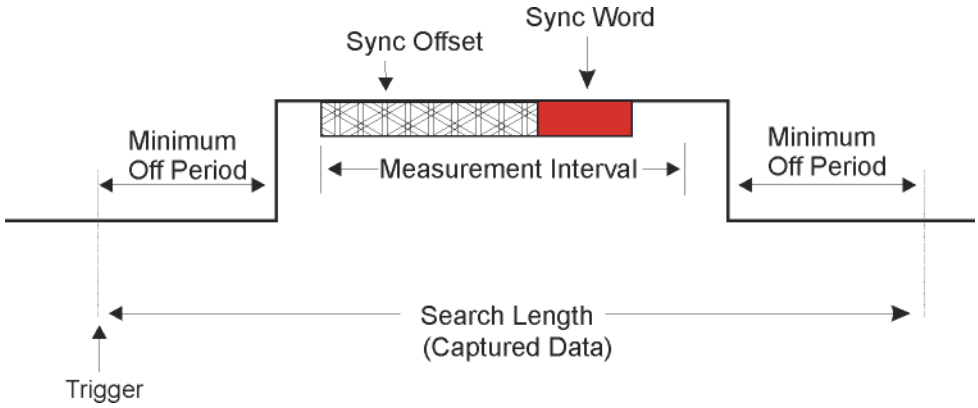
The reference generator uses the detected symbols in conjunction with the modulation format, the symbol rate, and the specified filtering, to synthesize an ideal set of I/Q reference baseband waveforms (I/Q Ref Time data). Finally, the measured I/Q waveforms and reference I-Q waveforms are compared to 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.

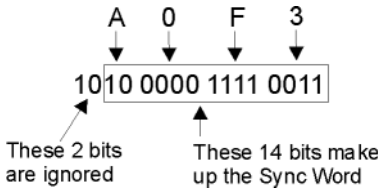
Measurement Interval (Meas Interval key) determines how much data is displayed. The location of the sync word plus the offset determines the position of the measurement interval. This data is used to calculate EVM.

Search Length determines how much data is collected.

An example of **Sync Word** using QPSK as the modulation format would have 2 bits/symbol. The **Sync Pattern** might be A O F 3. The sync word length for this example would be 7 symbols. This means the sync word would be:

7 symbols x 2 bits/symbol = 14 bits.

The Sync Word is shown below:



Modulation quality measurements

There are a number of different ways to measure the quality of a digitally modulated signal. These usually involve precision demodulation of the transmitted signal and comparison of this transmitted signal with a mathematically generated ideal or reference signal, as we saw earlier. The definition of the actual measurement depends mainly on the modulation scheme and standard followed.

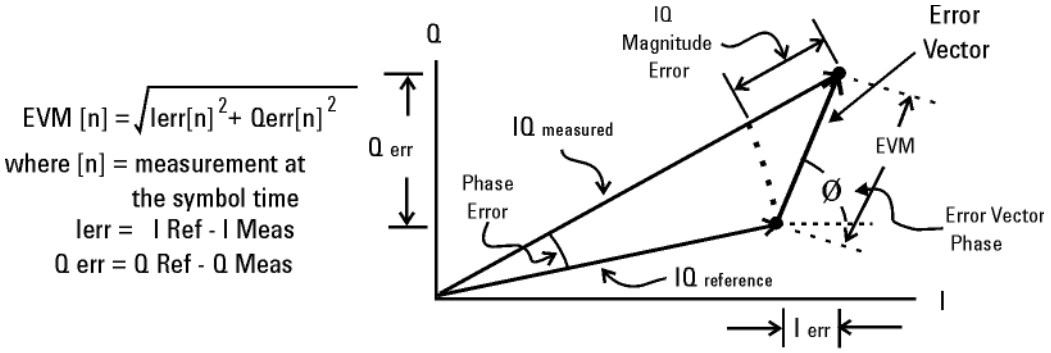
- NADC and PDC, for example, use “Error Vector Magnitude (EVM)” on page 182
- GSM uses “Phase and Frequency Errors” on page 184
- CDMA uses “Rho” on page 185

Error Vector Magnitude (EVM)

The most widely used modulation quality metric in digital communications systems is error vector magnitude (EVM). The error vector is the vector difference at a given time between the ideal reference signal and the measured signal (the following figure). The error vector is a complex quantity that contains a magnitude and phase component. It is important not to confuse the magnitude of the error vector with the magnitude error, or the phase of the error vector with the phase error.

Expressed another way, the EVM is the residual noise and distortion remaining after an ideal version of the signal has been stripped away.

Figure 4-79



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 4-80 *Without Equalization*

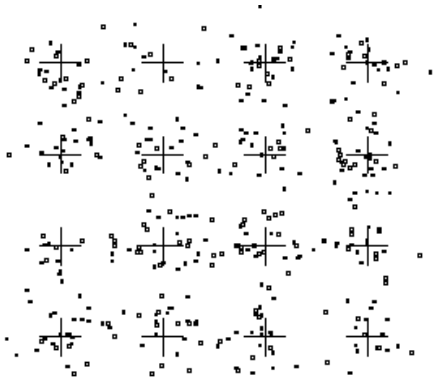
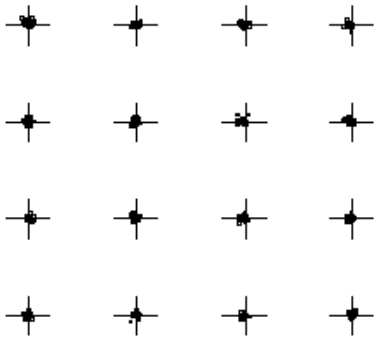


Figure 4-81 *With Equalization*



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 in 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 201 for more information on phase and frequency error and other GSM measurements.

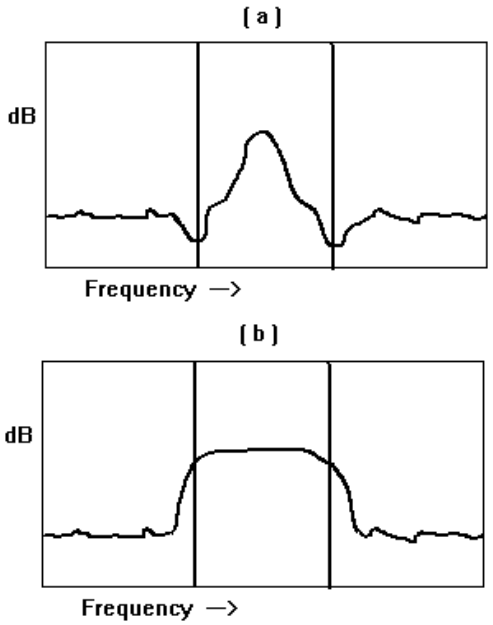
Frequency Response

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 201. 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.

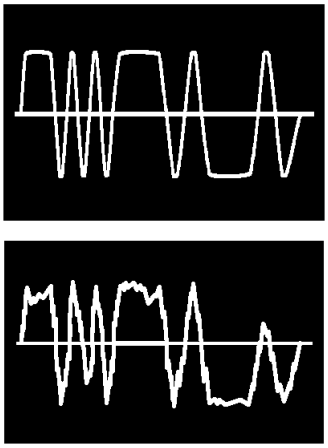
Figure 4-82



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 4-83 on page 186. 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 4-83 *Rho*



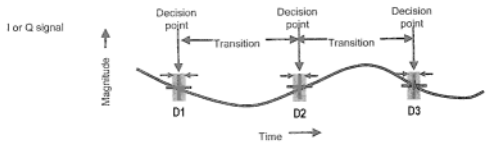
The rho measurement indicates the overall modulation performance level of a CDMA transmitter when transmitting a single channel. Since uncorrelated power appears as interference, poor rho performance affects the capacity of the cell. See "References" on page 201.

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 2n, 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 4-84 *Decision Points*



The layout of the constellation diagram and its ideal symbol locations is determined generically by the modulation format chosen (BPSK, 16QAM, π /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.

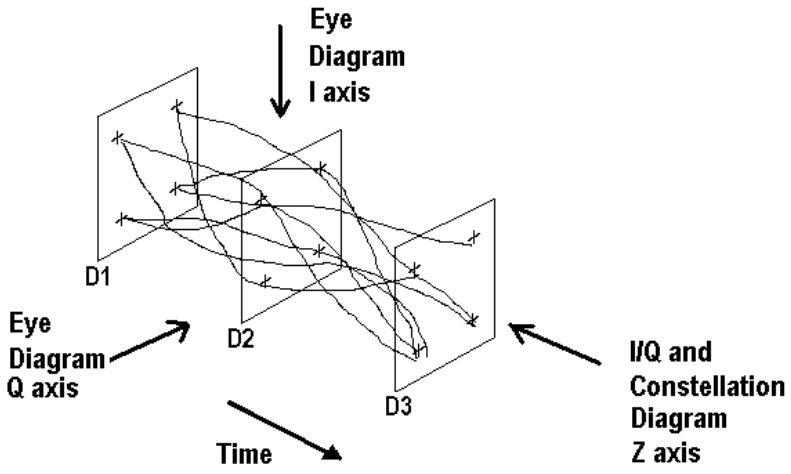
Relationship Between I/Q, Constellation and Eye Diagrams

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 4-86 on page 188.

An observer standing on the I or Q axis looking at the three decision points would observe an Eye diagram, if each trajectory where to persist after the signal had gone. An accumulated record of all the trajectories between these three decision points would appear like Figure 4-87 on page 189.

Figure 4-85

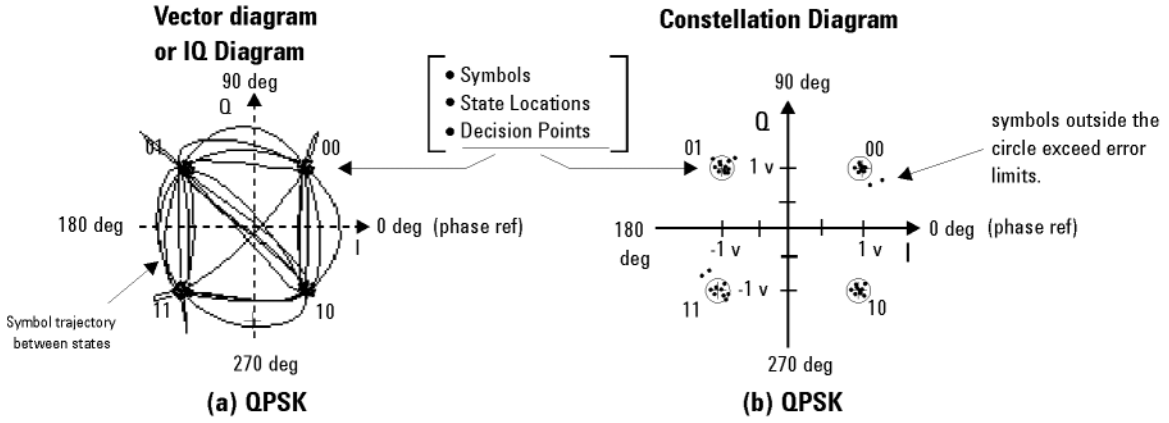


I/Q and Constellation Diagrams

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 4-86



(a) The Vector or IQ diagram shows the detected symbols and the transitions between them. I shows the instantaneous power levels during state transitions. (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

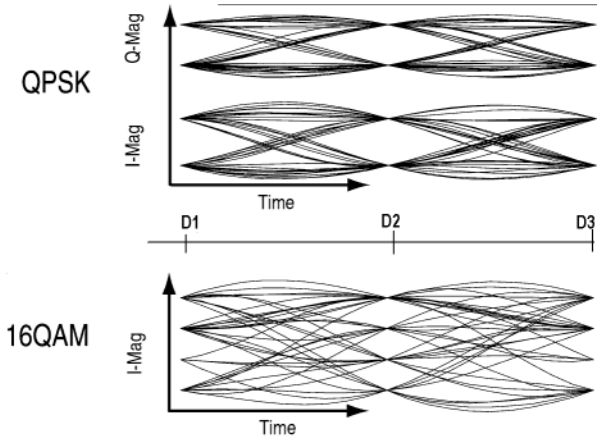
The previous figure (b) shows the constellation diagram for the same QPSK signal. The constellation diagram shows the carrier's magnitude and phase synchronous with the symbol clock. The measurement points are commonly referred to as detection decision-points and represent the detected symbols. It is 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 4-87 Eye diagram



Impairments

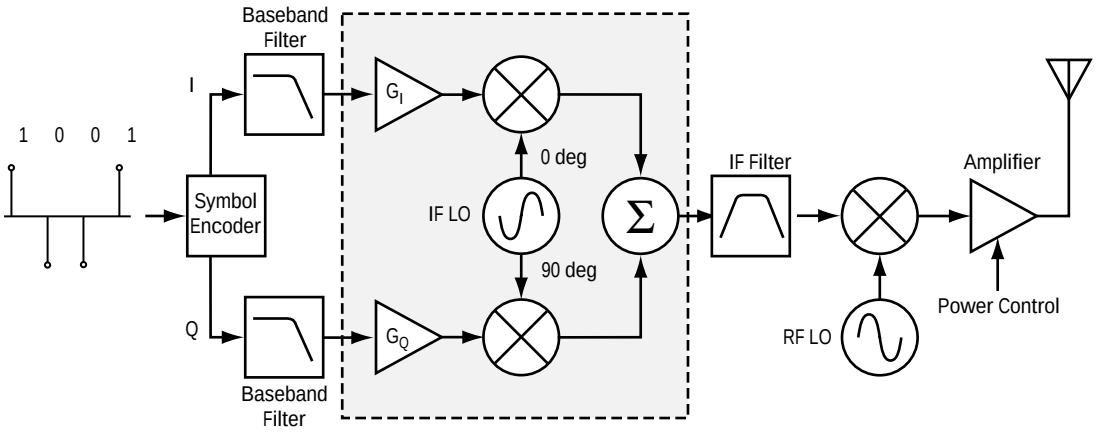
How can you verify the different I/Q impairments? The best way to verify most I/Q impairments is to look at the constellation and EVM metrics.

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:

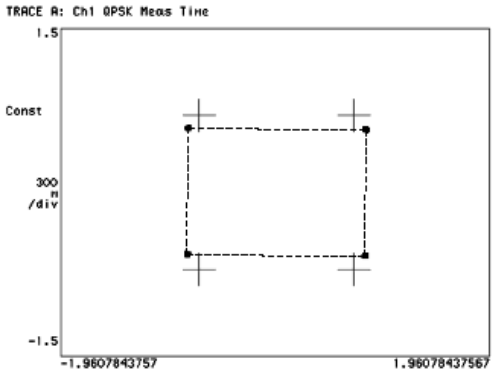
Figure 4-88 *I/Q Modulator a source of Impairments*



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 4-89 *I/Q Gain Imbalance*

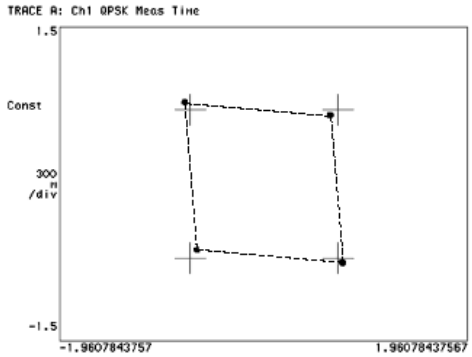


Quadrature errors

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 4-90 *I/Q Quadrature Errors*

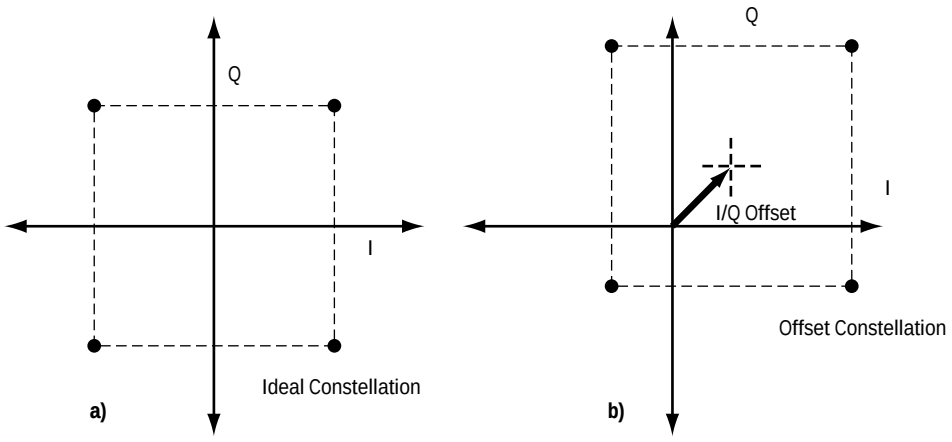


I/Q Offsets

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 4-91 *Ideal Versus I/Q Offset Constellation*



Delays in I/Q paths

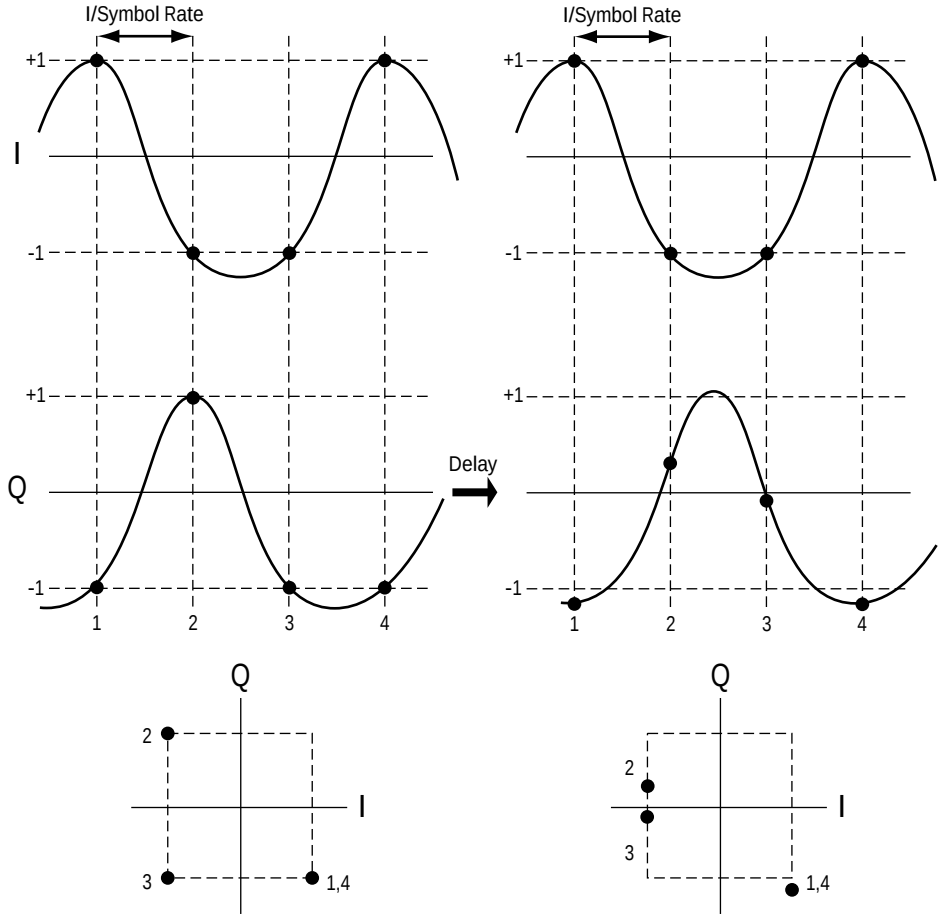
Delays in the I or Q paths also distort the measured constellation.

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.

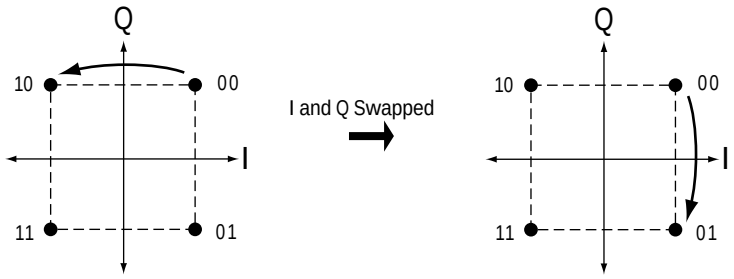
Figure 4-92 *Delays in I/Q paths*



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(w LO t)–jsin(w LO t) versus cos(w LO t)+jsin(w LO t). The mapping of the IF I and Q signals is reversed, which causes symbol errors, as seen in the following figure.

Figure 4-93 *I/Q Signals “Swapped”*

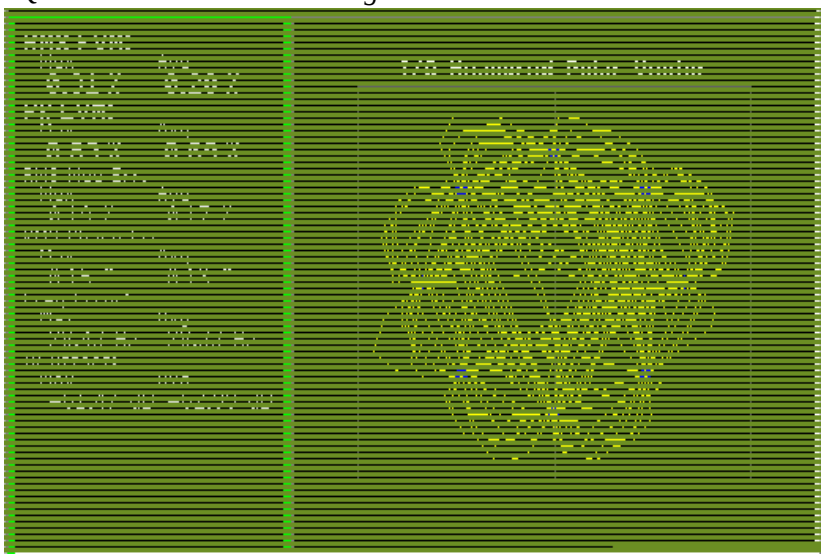


The condition I/Q swapped, results in an inverted spectrum. However, because of the noise-like shape of digitally modulated signals, the inversion is usually undetectable in the frequency domain.

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 APCO25 phase1 (FSK) signal. Upon completion of the measurement, the views were selected by pressing **View/Trace**, and selecting the view.

Figure 4-94 *I/Q Measured Polar Vector diagram*



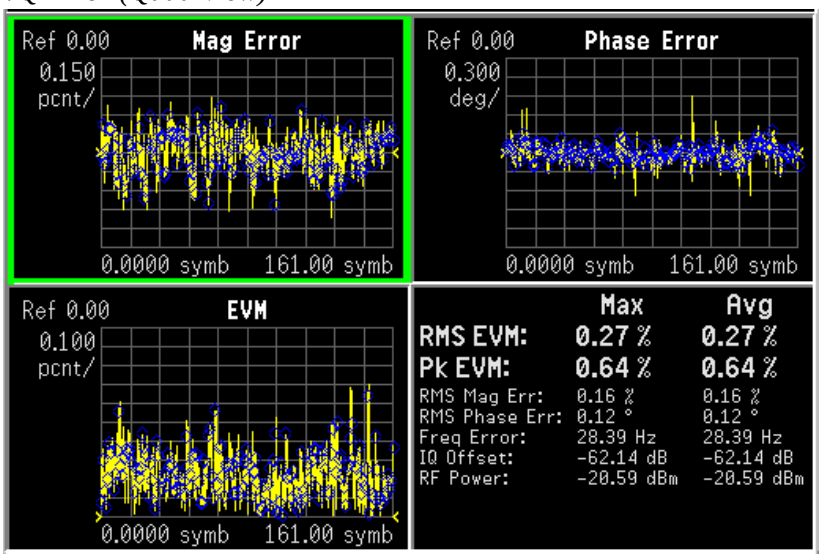
The previous figure shows the “I/Q Measured Polar Graph view”. Individual displays of a large “I/Q Measured Polar Graph” and a summary of the “Numeric Results”.

- 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.

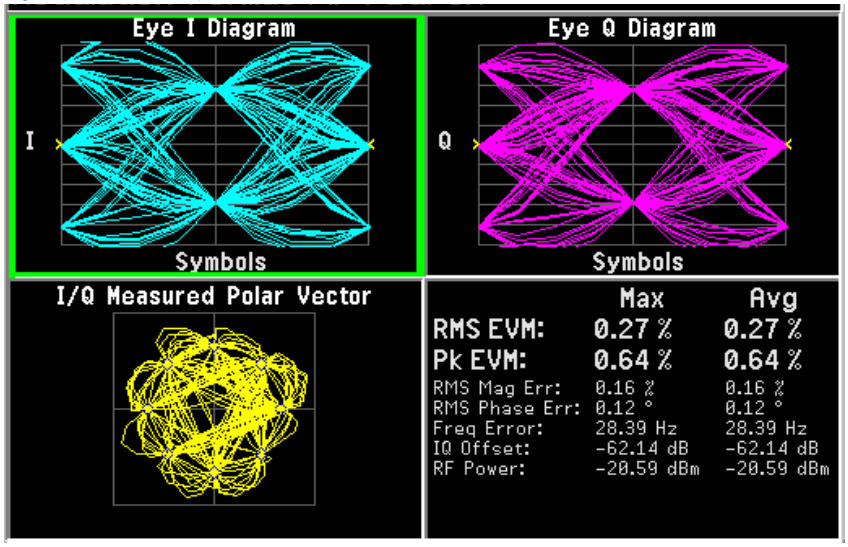
Figure 4-95 *I/Q Error (Quad View)*



- 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.

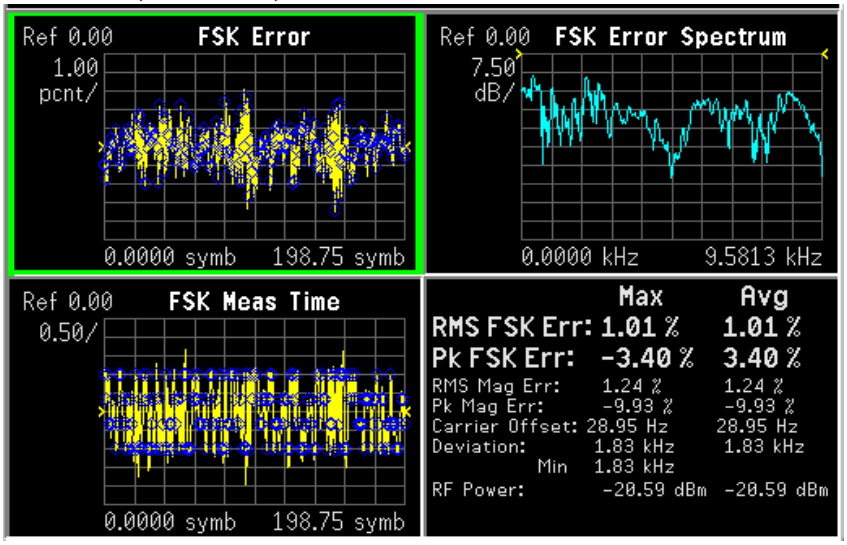
Figure 4-96 *Eye (Quad-View)*



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 4-97 *FSK Error (Quad-View)*

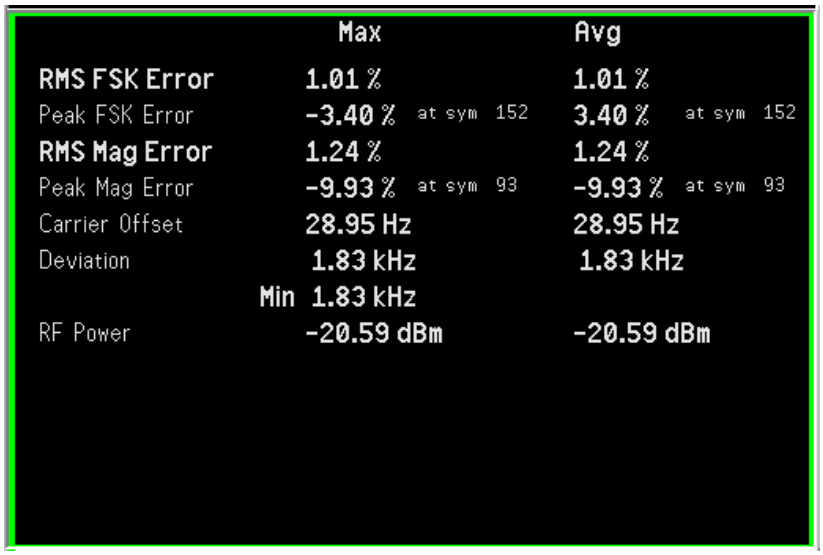


The figure above shows the “FSK Error”, “FSK Error Spectrum”, “FSK Meas Time”, and a summary of “Numeric Results”.

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 4-98 *Numeric Results*

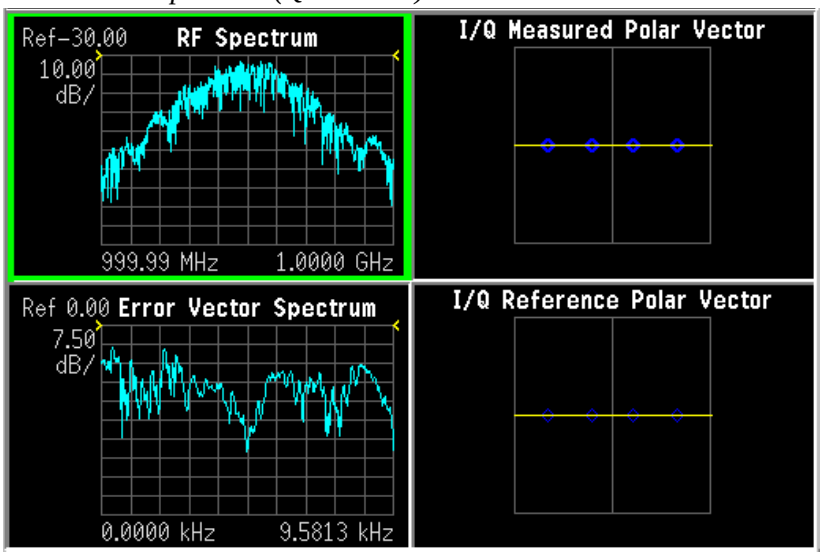


NOTE For more information on signal impairments, see Chapter 2, "Making N9064A VXA Measurements."

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.

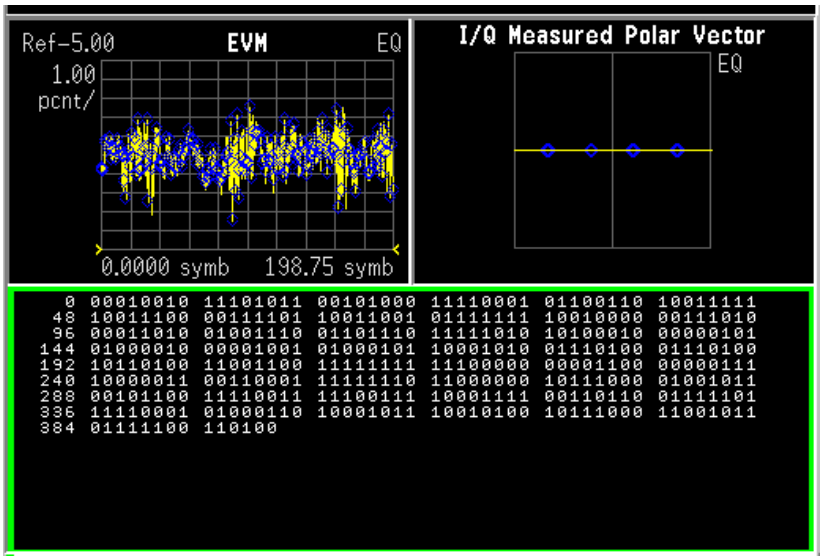
Figure 4-99 *Error Vector Spectrum (Quad-View)*



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 4-100 *Demod Bits View*



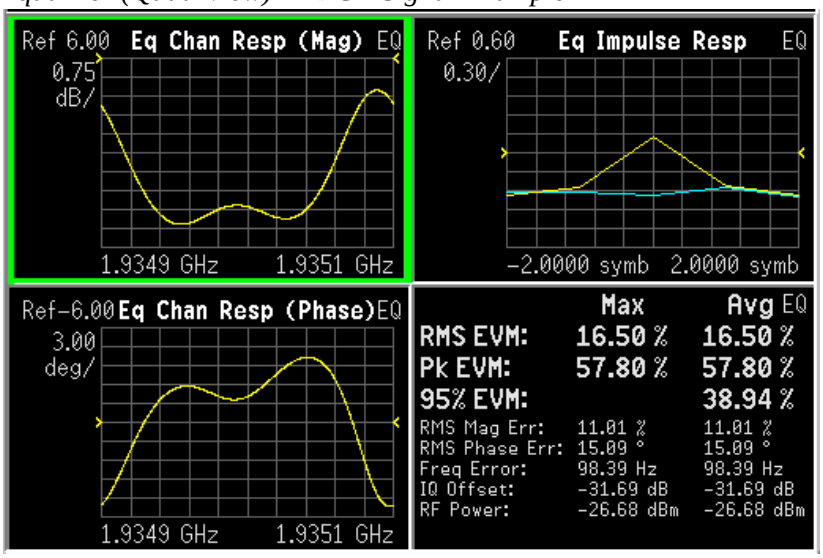
Equalizer (Quad-View)

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 55.

Figure 4-101 Equalizer (Quad-View) - EDGE Signal Example



References

- Application Note 1298

  Digital Modulation in Communications Systems - An Introduction
  Keysight part number 5965-7160E

- Application Note 150

  Spectrum Analysis
  Keysight part number 35952-0292

- Application Note 1313

  Test and Troubleshooting Digital RF Comm Transmitters
  Keysight part number 5968-3578E

- Application Note 1314

  Designing and Testing W-CDMA User Equipment
  Keysight part number 5968-3579E

- Application Product Note 89400-14A

  10 Steps to a Perfect Digital Demod Measurement
  Keysight part number 75996-0444E

- Application Note 1311

  Understanding CDMA Measurements for Base Stations and Their Components
  Keysight part number 5968-0953E

- Application Note 1312

  Understanding GSM/EDGE Transmitter and Receiver Measurements for Base Transceiver Stations and their Components

5 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 Keysight'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.keysight.com/find/ivi-com
- Most of the examples are written in C, Visual Basic, VEE, or LabVIew using the Keysight VISA transition library.

  The Keysight I/O Libraries Suite must be installed and the GPIB card, USB to GPIB interface, or Lan interface USB interface configured. The latest Keysight I/O Libraries Suite is available: www.keysight.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 Programing 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 Keysight VEE Pro.

These examples are available in either the "`progexamples`" directory on the Keysight 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 Keysight Technologies, Inc. web site at URL:

http://www.keysight.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 Keysight VEE Pro:

- **Transfer Screen Images** from my Spectrum Analyzer using Keysight 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 Keysight 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 Keysight VEE Pro.

These examples are available in either the "`progexamples`" directory on the Keysight Technologies N9064A VXA documentation DVD 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 Keysight Technologies, Inc. web site at URL:

http://www.keysight.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 Keysight 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