Tektronix®

**TSG4100A Series
RF Signal Generators**

User Manual

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RF Signal Generators**

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www.tek.com

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- In North America, call 1-800-833-9200.
- Worldwide, visit www.tek.com to find contacts in your area.

Table of Contents

List of Figures

List of Tables

Important safety information

This manual contains information and warnings that must be followed by the user for safe operation and to keep the product in a safe condition.

To safely perform service on this product, additional information is provided at the end of this section. (See page vii, *Service safety summary*.)

General safety summary

Use the product only as specified. Review the following safety precautions to avoid injury and prevent damage to this product or any products connected to it. Carefully read all instructions. Retain these instructions for future reference.

Comply with local and national safety codes.

For correct and safe operation of the product, it is essential that you follow generally accepted safety procedures in addition to the safety precautions specified in this manual.

The product is designed to be used by trained personnel only.

Only qualified personnel who are aware of the hazards involved should remove the cover for repair, maintenance, or adjustment.

Before use, always check the product with a known source to be sure it is operating correctly.

This product is not intended for detection of hazardous voltages.

Use personal protective equipment to prevent shock and arc blast injury where hazardous live conductors are exposed.

While using this product, you may need to access other parts of a larger system. Read the safety sections of the other component manuals for warnings and cautions related to operating the system.

When incorporating this equipment into a system, the safety of that system is the responsibility of the assembler of the system.

To avoid fire or personal injury

Use proper power cord. Use only the power cord specified for this product and certified for the country of use.

Do not use the provided power cord for other products.

Ground the product. This product is grounded through the grounding conductor of the power cord. To avoid electric shock, the grounding conductor must be connected to earth ground. Before making connections to the input or output terminals of the product, make sure that the product is properly grounded.

Do not disable the power cord grounding connection.

Power disconnect. The power cord disconnects the product from the power source. See instructions for the location. Do not position the equipment so that it is difficult to operate the power cord; it must remain accessible to the user at all times to allow for quick disconnection if needed.

Observe all terminal ratings. To avoid fire or shock hazard, observe all ratings and markings on the product. Consult the product manual for further ratings information before making connections to the product. Do not exceed the Measurement Category (CAT) rating and voltage or current rating of the lowest rated individual component of a product, probe, or accessory. Use caution when using 1:1 test leads because the probe tip voltage is directly transmitted to the product.

Do not apply a potential to any terminal, including the common terminal, that exceeds the maximum rating of that terminal.

Do not float the common terminal above the rated voltage for that terminal.

The measuring terminals on this product are not rated for connection to mains or Category II, III, or IV circuits.

Do not operate without covers. Do not operate this product with covers or panels removed, or with the case open. Hazardous voltage exposure is possible.

Avoid exposed circuitry. Do not touch exposed connections and components when power is present.

Do not operate with suspected failures. If you suspect that there is damage to this product, have it inspected by qualified service personnel.

Disable the product if it is damaged. Do not use the product if it is damaged or operates incorrectly. If in doubt about safety of the product, turn it off and disconnect the power cord. Clearly mark the product to prevent its further operation.

Examine the exterior of the product before you use it. Look for cracks or missing pieces.

Use only specified replacement parts.

Use proper fuse. Use only the fuse type and rating specified for this product.

Wear eye protection. Wear eye protection if exposure to high-intensity rays or laser radiation exists.

Do not operate in wet/damp conditions. Be aware that condensation may occur if a unit is moved from a cold to a warm environment.

Do not operate in an explosive atmosphere.

Keep product surfaces clean and dry. Remove the input signals before you clean the product.

Provide proper ventilation.   Refer to the installation instructions in the manual for details on installing the product so it has proper ventilation.

Slots and openings are provided for ventilation and should never be covered or otherwise obstructed. Do not push objects into any of the openings.

Provide a safe working environment.   Always place the product in a location convenient for viewing the display and indicators.

Avoid improper or prolonged use of keyboards, pointers, and button pads. Improper or prolonged keyboard or pointer use may result in serious injury.

Be sure your work area meets applicable ergonomic standards. Consult with an ergonomics professional to avoid stress injuries.

Use only the Tektronix rackmount hardware specified for this product.

Service safety summary

The *Service safety summary* section contains additional information required to safely perform service on the product. Only qualified personnel should perform service procedures. Read this *Service safety summary* and the *General safety summary* before performing any service procedures.

To avoid electric shock.   Do not touch exposed connections.

Do not service alone.   Do not perform internal service or adjustments of this product unless another person capable of rendering first aid and resuscitation is present.

Disconnect power.   To avoid electric shock, switch off the product power and disconnect the power cord from the mains power before removing any covers or panels, or opening the case for servicing.

Use care when servicing with power on.   Dangerous voltages or currents may exist in this product. Disconnect power, remove battery (if applicable), and disconnect test leads before removing protective panels, soldering, or replacing components.

Verify safety after repair.   Always recheck ground continuity and mains dielectric strength after performing a repair.

Terms in this manual

These terms may appear in this manual:

⚠️ **WARNING.** *Warning statements identify conditions or practices that could result in injury or loss of life.*

⚠️ **CAUTION.** *Caution statements identify conditions or practices that could result in damage to this product or other property.*

Symbols and terms on the product

These terms may appear on the product:

- DANGER indicates an injury hazard immediately accessible as you read the marking.

- WARNING indicates an injury hazard not immediately accessible as you read the marking.

- CAUTION indicates a hazard to property including the product.

⚠️ When this symbol is marked on the product, be sure to consult the manual to find out the nature of the potential hazards and any actions which have to be taken to avoid them. (This symbol may also be used to refer the user to ratings in the manual.)

The following symbol(s) may appear on the product:

CAUTION Refer to Manual   Protective Ground (Earth) Terminal   Earth Terminal   Chassis Ground   Standby

Preface

This manual describes the installation, operation, and related signal concepts of the TSG4100A Series RF Signal Generators. This manual supports the following instruments

■ TSG4102A

■ TSG4104A

■ TSG4106A

NOTE. Check the Tektronix Web site for updates to this manual, which will include more information about your product. Visit www.tektronix.com/manuals.

For compliance, environmental, and safety information, see the *TSG4100A Series RF Signal Generators Installation and Safety Instructions* that shipped with your instrument. The document can also found on the Tektronix Web site at www.tektronix.com/manuals.

Key features

The TSG4100A Series RF Signal Generators provide waveform generation and support both analog (standard) and vector/digital (optional) modulation. The instruments use a new technique to provide spurious free outputs with low phase noise (-113 dBc/Hz at20 KHz offset from 1 GHz carrier) and extraordinary frequency resolution (1 μHz at any frequency). An ovenized SC-cut oscillator (M00 or E1 optioned models) timebase provides 100 times improvement in stability (and a 100 times reduction in the in-close phase noise) compared to instruments that use a TCXO time-base. Key features include:

■ True DC to 2 GHz, 4 GHz, or 6 GHz

■ Typical ±0.30 dB amplitude accuracy (0 dBm CW signal at 22 ºC) from 100 MHz to 6 GHz

■ Dual baseband ARB generators

■ Analog modulation

■ Soft key to vector modulation upgrade

■ I/Q modulation inputs (400 MHz RF BW)

■ ASK, FSK, MSK, PSK, QAM, VSB, and custom I/Q

- Digital modulation applications for GSM, EDGE, W-CDMA, APCO-25, DECT, NADC, PDC, and TETRA

- USB, GPIB, RS-232 and LAN interfaces

Documentation

The following documentation is available for your Tektronix TSG4100A Series RF Signal Generator. The product documentation CD provided contains documents available at the time of publication. For the most current documentation, refer to the Tektronix Web site at www.tektronix.com/manuals.

To read about	Use these documents
Basic installation, safety, and compliance	*Installation and Safety Instructions* This document contains basic information about instrument connectors, how to turn it on and off, compliance, environmental, and safety information. This manual is shipped as a printed book with your product and provides information in English and Russian. It is also available as a PDF file, downloadable from www.tektronix.com/manuals.
Operation and installation	*User Manual* (this manual) The user manual contains information about how to navigate the instrument UI, how to operate the instrument, and information about signals. This manual is available in printed form in English or Russian. Both are also available as PDF files.
Programming commands	*Programmer Manual* This manual contains descriptions of programming commands and their use. This manual is available as a PDF file.
Specifications and performance verification	*Specifications and Performance Verification Manual* This manual contains the instrument specifications and a procedure to check instrument performance against warranted characteristics. This manual is available as a PDF file.
User service	*Service Manual* This manual provides a list of replaceable parts, care and maintenance information, and information for servicing the instrument to the module level. This manual is available as a PDF file.
Data security	*Declassification and Security Instructions* This document helps customers with data security concerns to sanitize or remove memory devices. This document is available as a PDF file.

Software upgrades

Software option upgrades are available. Software upgrades for options become operational only after you enter a valid option key for the specific generator model and serial number.

To check for upgrades:

1. Use your Web browser to go to **www.tektronix.com/software**.

2. Enter the product name (for example TSG4104A) to find available software upgrades.

Conventions used in this manual

The following icons are used throughout this manual:

Sequence Step	Front panel power	Connect power	Network	PS2	SVGA	USB

TSG4100A Series RF Signal Generators User Manual

Installation

Before installation

Unpack the instrument, and check that you received all items listed as *Standard Accessories*. Optional accessories and instrument options are also listed in this section. Check the Tektronix Web site (www.tektronix.com) for the most current information.

Standard accessories

Your instrument comes with the following accessories: installation and safety instructions (English and Russian languages), product software and documentation CD, and power cord.

Documents
- *TSG4100A Series RF Signal Generators Installation and Safety Instructions* is a multi-language document (English and Russian). Tektronix part number 071-3390-XX.

- *TSG4100A Series RF Signal Generators Product SW and Documentation CD*, Tektronix part number 063-4557-XX.

Software
- *TSG File Assistant* is a software application that allows you to convert raw data of custom waveforms, constellations, and filters (*.txt or *.csv files) to *.tsw, *.tsf, and *tsc files that are supported by the TSG. This software is available on the SW and Documentation CD that shipped with the instrument and for download from the Tektronix Web site at www.tektronix.com/downloads.

NOTE. You can read more about how the TSG File Assistant works in this manual.

RF cable
- RF cable (Tektronix part number 012-1738-00): 1 meter, 50 Ω, N-type to N-type

Power cords
The TSG4100A Series RF Signal Generators are shipped with one of the following power cord options. Power cords for use in North America are UL listed and CSA certified. Cords for use in areas other than North America are approved by at least one authority acceptable in the country to which the product is shipped.

- Opt. A0 - North America power

- Opt. A1 - Universal EURO power

- Opt. A2 - United Kingdom power

- Opt. A3 - Australia power

- Opt. A5 - Switzerland power

- Opt. A6 - Japan power

- Opt. A10 - China power

- Opt. A11 - India power

- Opt. A12 - Brazil power

- Opt. A99 - No power cord

Optional accessories

- Option TSG4100A-RM1; Single rackmount kit for all TSG4100A models

- Option TSG4100A-RM2: Dual rackmount kit for all TSG4100A models

- Option TSG4100A-ATT: 30 dB, 5 Watt RF attenuator up to 6 GHz

- Option GPIB: Adds GPIB interface

- Option D1: A list of performance verification test results

- Option L0: Printed User manual (this manual). English. (You can always download an English or Russian User manual from the Tektronix Web site at www.tektronix.com/manuals.)

Instrument options

The following options must be specified at time of instrument order.

All regions except North America. The following instrument configuration options are available in all regions except North America.

- **M00**: Instrument with oven-controlled crystal oscillator (OCXO).

- **M01**: Instrument with voltage-controlled crystal oscillator (VCXO).

- **GPIB**: Adds GPIB interface.

North America only. The following instrument configuration option is available only in North America.

- **E1**: Instrument with oven-controlled crystal oscillator (OCXO) time-base and GPIB interface.

Software options   You can add the following software options to your generator:

- Option VM00: Basic vector modulation package with internal 6M Hz modulation bandwidth

- Option VM01: GSM modulation (requires Option VM00)

- Option VM02: GSM EDGE modulation (requires Option VM00)

- Option VM03: W-CDMA modulation (requires Option VM00)

- Option VM04: APCO-25 modulation (requires Option VM00)

- Option VM05: DECT modulation (requires Option VM00)

- Option VM06: NADC modulation (requires Option VM00)

- Option VM07: PDC modulation (requires Option VM00)

- Option VM08: TETRA modulation (requires Option VM00)

- Option VM10: Audio clip (analog AM and FM) (requires Option VM00)

- Option EIQ; External 200 MHz modulation bandwidth (requires Option VM00)

Connect to a network

You can communicate with or remotely control your instrument through the LAN, RS232, or GPIB interfaces. (GPIB requires Option GPIB.)

LAN interface   The LAN connector may be used to connect the instrument to a 10/100 Base-T Ethernet LAN. Before connecting the instrument to your LAN, check with your network administrator for the proper method of configuration of instruments on your network.

To set up the LAN interface:

1. Connect a LAN cable to the rear panel LAN port.

2. Press the **Utility** button from the main menu.

3. Select **I/O Interface**.

4. Select **LAN** to view the Ethernet network settings.

5. Use the menu buttons and number keys to enter the desired IP address and other network information.

   By selecting the DHCP **ON**, the instrument can set its network address automatically through DHCP. If you cannot establish communication using DHCP, you need to manually set up an IP address and a Subnet Mask, if necessary.

6. Press the **Enter** button.

7. Press the **Return** button three times to return to the main menu.

TCP/IP configuration methods. In order to function properly on an Ethernet based local area network (LAN), the unit needs to obtain a valid IP address, a subnet mask, and a default gateway or router address. There are three methods for obtaining these parameters: DHCP, Auto-IP, and Static IP. Check with your network administrator for the proper method of configuration of instruments on your network.

TCP/IP based remote interfaces. Three TCP/IP based remote interfaces are supported: raw socket, telnet, and VXI-11 net instrument. Raw socket access is available on port 5025. Telnet access is available on port 5024. The VXI-11 interface enables IEEE 488.2 GPIB-like access to the unit over TCP/IP. It enables controlled reads and writes and the ability to generate service requests. Most recent VISA instrument software libraries support this protocol.

Link speed. The physical Ethernet layer supports 10 Base-T and 100 Base-T link speeds. The default link speed is set to 100 Base-T, but it can be set to 10 Base-T.

To reset the TCP/IP interface. When configured from the front panel, the TCP/IP is automatically reset. Otherwise, changes to the TCP/IP configuration do not take effect until the TCP/IP interface is either reset or the instrument power is cycled. When reset is selected, any active connections will be aborted. The TCP/IP stack will be reinitialized and configured using the latest configuration options.

> ⚠ **CAUTION.** *Network security is an important consideration for all TCP/IP networks. This instrument does not provide security controls, such as passwords or encryption, for controlling access. If such controls are needed, you must provide it at the network level. For example, you can use an internet firewall.*

GPIB interface   The GPIB connector supports the IEEE-488.1 (1978) interface standard. It also supports the required common commands of the IEEE-488.2 (1987) standard.

NOTE. Changes to the GPIB configuration do not take effect until the interface is reset or the instrument power is cycled.

To set up the GPIB interface:

1. Connect a GPIB cable to the rear panel GPIB port.

2. Press the **Utility** button from the main menu.

3. Select **I/O Interface**.

4. Select **GPIB**.

5. Check that GPIB is set to **ON**. If it is not, highlight **ON** in the GPIB menu to turn it on.

6. Press the **Address** button and use the number keys to assign a unique address to the instrument.

NOTE. Each device connected to the GPIB bus must have a unique GPIB address. The GPIB address must be from 0 to 30.

7. Press the **Enter** button.

8. Press the **Return** button three times to return to the main menu.

RS-232 interface   The RS-232 interface connector is a standard 9 pin, type D, female connector configured as a DCE (transmit on pin 2, receive on pin 3). In order to communicate properly over RS-232, the instrument and the host computer both must be set up to use the same configuration. The following baud rates are supported: 115200 (default), 57600, 38400, 19200, 9600, and 4800. The rest of the communication parameters are fixed at 8 data bits, 1 stop bit, no parity, and RTS/CTS hardware flow control.

To set up the RS-232 interface:

1. Connect a cable to the rear panel RS-232 port. Use a cable best suited for the desired baud rate (modulation rate).

2. Press the **Utility** button from the main menu.

3. Select **I/O Interface**.

4. Select **RS232**.

5. Check that RS232 is set to **ON**. If it is not, highlight **ON** in the RS-232 menu to turn it on.

6. Press the **BaudRate** button and turn the general knob to set the desired baud rate.

7. Press the **Return** button three times to return to the main menu.

Upgrade the firmware through the USB port

The USB port allows you to upgrade the instrument firmware using a USB memory device. To upgrade the firmware using the USB port, do the following:

1. From a computer with an internet connection, download the most recent instrument firmware from the Tektronix Web site at www.tektronix.com/downloads onto a USB memory device. Note the firmware version.

2. Press the **Utility** button from the instrument main menu.

3. Select **System** > **About**.

4. Look at the instrument display screen and verify that the firmware version shown is older than the firmware version you downloaded from the Tektronix Web site.

5. Insert the USB memory device into the USB port on the front panel of the instrument.

6. Check that the **Firmware Update** menu option becomes active after approximately 10 seconds as the instrument recognizes the USB memory device.

7. Press the **Firmware Update** button. A dialog box will appear asking if you want to update the firmware.

8. Use the arrow keys to highlight **Yes** if you want to start the update process, or **No** if you want to cancel the process.

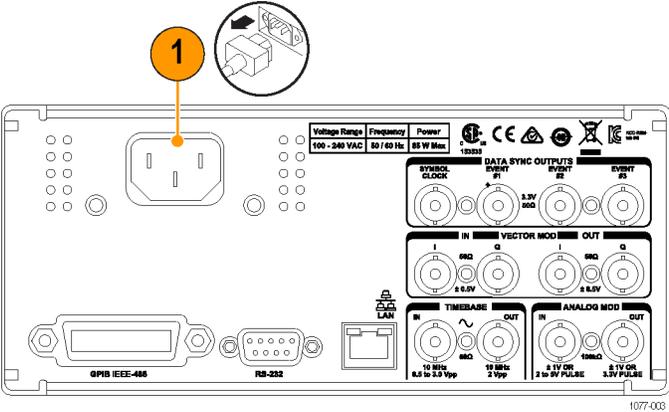9. Press the **Enter** button to start the update process (or cancel it if you selected No).

Powering on the instrument
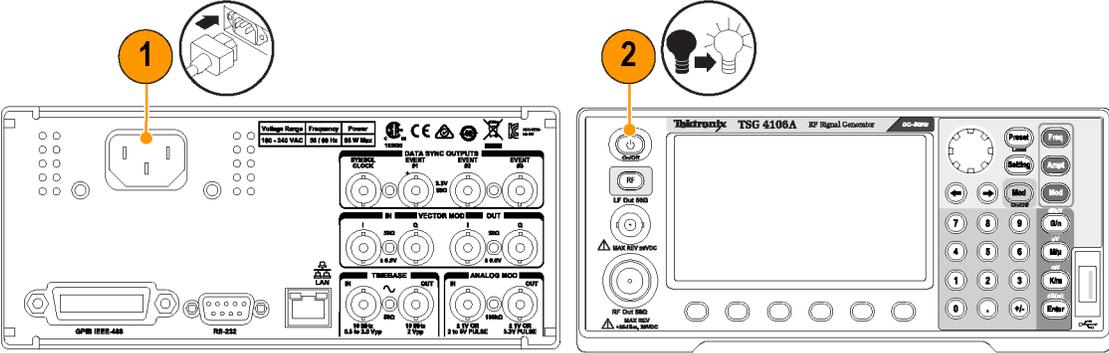
Powering off the instrument
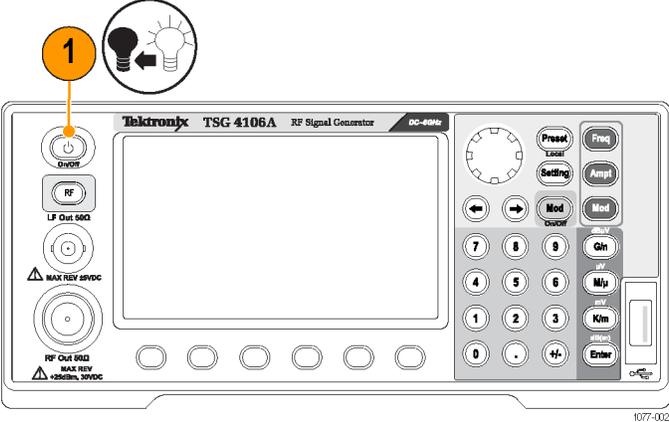
Removing power from the instrument

Inspecting the instrument

Run the Self Test (Utility > System > Self Test) to run a series of tests to verify that the instrument is operating correctly. It tests communication to various peripherals on the main board, including the GPIB chips, the PLL chips, the DDS chips, the octal DACs, the FPGA, and the serial EEPROM. Errors will be reported on the front-panel display when detected. The errors detected are stored in the instrument error buffer and may be accessed through the error status menu after the self test completes. See section Error Codes on page 126 for a complete list of error codes.

If you want to check the accuracy specifications of your instrument, see the *TSG4100A Series RF Signal Generators Specifications and Performance Verification Technical Reference* PDF available on the Tektronix Web site at www.tektronix.com/manuals.

Instrument maintenance

Clean your instrument

Clean the exterior surfaces of the chassis with a dry lint-free cloth or a soft-bristle brush. If any dirt remains, use a cloth or swab dipped in a 75% isopropyl alcohol solution. Use a swab to clean narrow spaces around controls and connectors. Do not use abrasive compounds on any part of the instrument because they might damage the instrument.

⚠ *CAUTION. Avoid getting moisture inside the instrument during exterior cleaning; use just enough moisture to dampen the cloth or swab. Do not wash the front-panel On/Off button. Cover the button while washing the instrument. Use only deionized or distilled water when cleaning. Use a 75% isopropyl alcohol solution as a cleanser and rinse with deionized or distilled water. Do not use chemical cleaning agents; they might damage the chassis. Avoid chemicals that contain benzene, toluene, xylene, acetone, or similar solvents.*

⚠ *CAUTION. To prevent damage to the flat panel display, do not use improper cleaning agents or methods. Avoid using abrasive cleaners or commercial glass cleaners to clean the display surface. Avoid spraying liquids directly on the display surface. Avoid scrubbing the display with excessive force.*

Clean the display surface by gently rubbing the display with a clean-room wipe. If the display is very dirty, moisten the wipe with distilled water or a 75% isopropyl alcohol solution and gently rub the display surface. Avoid using excess force; this might damage the display surface.

Upgrade your instrument

Software upgrades are available from Tektronix. They can either be downloaded from the Tektronix Web site or they can be ordered from your local Tektronix representative. To add additional software options or features, you will need an option key from Tektronix. When you receive the software from Tektronix, you will also receive an option key. Follow the instructions you receive to install the software on your instrument. You will be prompted to enter the option key. See the About menu on the instrument to enter an option key. This information is in the Menus section of this manual. (See page 16, *Menus*.)
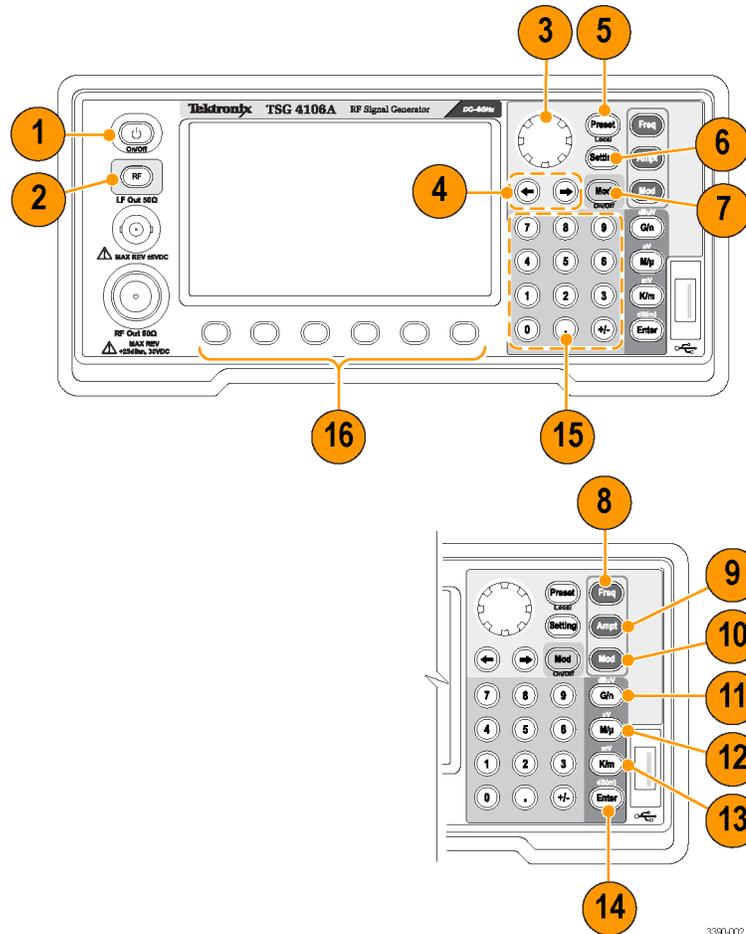
Return your instrument

If you return your instrument to Tektronix:

- When repacking the instrument for shipment, use the original packaging. If the packaging is unavailable or unfit for use, contact your local Tektronix representative to obtain new packaging.

- Seal the shipping carton with an industrial stapler or strapping tape.

Operating basics

Front panel controls

The following illustration shows the instrument front panel. The table describes the controls and elements noted in the illustration.
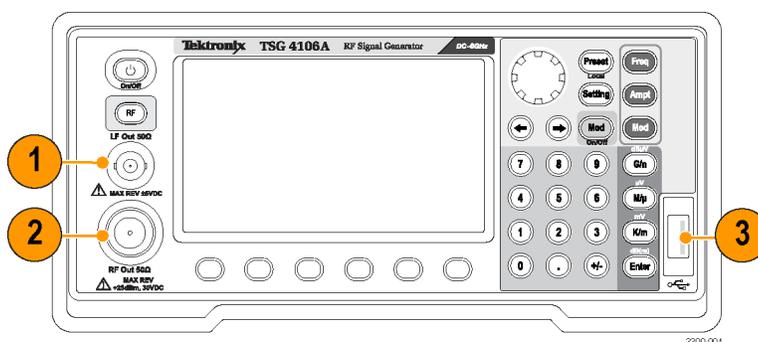

Front panel

TSG4100A Series RF Signal Generators User Manual

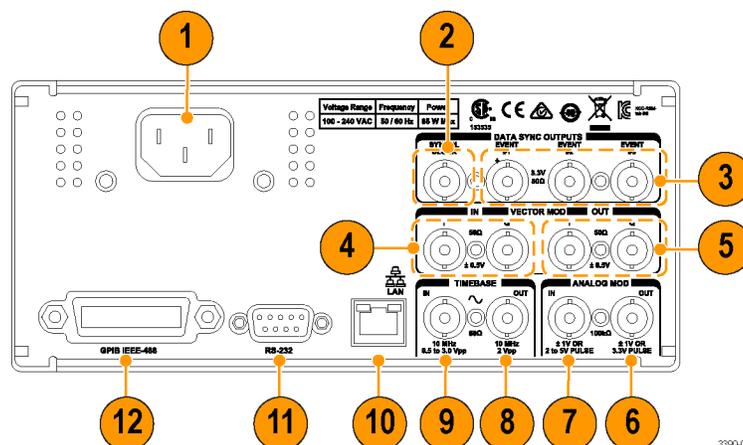| Item number	Control element or group	Description
1	Power button	Press to turn power on or off. The power button has two modes: STANDBY and ON. In STANDBY mode, power is only supplied to the internal timebase and the power consumption will not exceed 20 W once the instrument is warmed up. In ON mode, power is supplied to all circuitry and the instrument is on.
2	RF	Press to turn RF signal output ON (LED light on) or OFF (LED light off). Only outputs that are active for the current frequency setting will be accessible. If an output is set below its minimum value it will be disabled and the LED light will turn off.
3	Adjustment knob	Turn knob to navigate menus and adjust parameters.
4	Select keys	Press to enter submenu (right arrow), return to main menu (left arrow), or to adjust the underscore position when editing a parameter.
5	Preset	Press and hold to recall default setup.
6	Setting	Press to access the top menu.
7	Mod On/Off	Press to turn modulation function ON or OFF.
8	Freq	Press to adjust RF frequency.
9	Ampt	Press to adjust amplitude.
10	Mod	Press to access modulation menu.
11	G/n (dBμV)	Press to select units (GHz, ns, nv, dBμv).
12	M/μ (μV)	Press to select units (MHz, μs, μv).
13	K/m (mV)	Press to select units (KHz, ms, mv)
14	Enter (dB(m))	Press to select units (Hz, s, dBm).
15	Numeric keypad	Use these keys to enter numeric values for a variety of parameters.
16	Menu selection buttons	Use these buttons to select menu items on the screen.

Connectors

The following figures and tables show and describe various connectors located on the front panel and rear panel of the instrument.

Front panel connectors

Table 1: Front panel connectors

Item number	Connector	Description
1	LF Output	BNC output. Active for frequency settings between DC and 62.5 MHz. The amplitude may be set independently for levels from 1 μV_{RMS} to 1 V_{RMS} (–47 dBm to 13 dBm). This output is protected against externally applied voltages of up to ±5 V.
2	RF Output	Type N output. Active for frequency settings between 950 kHz and 2 GHz (TSG4102A), 950 kHz and 4 GHz (TSG4104A), and 950kHz and 6 GHz (TSG4106A). The output power may be set from −110 dBm to 16.5 dBm (0.7 μV_{RMS} to 1.5 V_{RMS}).
3	USB	A USB connector allows you to connect an external memory device to the instrument for data storage.

Rear panel connectors

Table 2: Rear panel connectors

Item	Connector	Description
1	AC power (input)	Connect the unit to a power source through the power cord provided with the instrument. The center pin is connected to the chassis so that the entire box is earth grounded. The unit will operate with an AC input from 100 to 240 V_{AC}, and with a frequency of 50/60 Hz. The instrument requires 85 W and implements power factor correction. Connect only to a properly grounded outlet.
2	SYMBOL CLOCK (output)	This BNC provides a square wave synchronized to the symbol clock used in the modulation. The rising edge of this clock triggers the programmed event markers associated with the arbitrary waveform.
3	EVENT (outputs)	Three BNC outputs labeled #1, #2, and #3 are available for synchronizing external instrumentation to programmable events within a generated arbitrary waveform. These may be programmed, for instance, to mark the start of a frame, or a slot within a frame, or the start of a synchronizing pattern in the waveform. One of the event markers may be further programmed to control the RF power of the front panel output for the generation of TDMA signals. Events are triggered on the rising edge of the symbol clock.
4	VECTOR MOD IN I VECTOR MOD IN Q	These BNC inputs enable external I/Q modulation. They accept signals of ±0.5 V, corresponding to full scale modulation, and have 50 Ω input impedances. Both inputs support signal bandwidths from DC to 100 MHz providing an RF modulation bandwidth of up to 200 MHz.
5	VECTOR MOD OUT I VECTOR MOD OUT Q	These BNC outputs replicate the baseband I/Q modulation waveforms currently being used to modulate the RF. Both outputs have a source impedance of 50 Ω and when terminated into 50 Ω, will generate a full scale output of ±0.5 V.
6	ANALOG MOD OUT	This output replicates the analog modulation waveform and has a 50 Ω reverse termination. When using the internal source for AM, FM, and ΦM, it provides a waveform determined by the function and rate settings with an amplitude of 1 V_{PP} into a high impedance. During external analog modulation, this output mirrors the modulation input. For Pulse modulation, the output is a 3.3 V logic waveform that coincides with the gate signal.

Table 2: Rear panel connectors (cont.)

Item	Connector	Description
7	ANALOG MOD IN	External analog modulation is applied to this input. The input impedance is 100 kΩ with a selectable input coupling of either DC or AC (4 Hz roll off). For analog modulations (AM, FM, ΦM), a signal of ±1 V will produce a full scale modulation of the output (depth for AM or deviation for FM and ΦM). It supports bandwidths of 100 kHz and introduces distortions of less than –50 dB. For Pulse modulation types, this input is used as a discriminator that has a fixed threshold of +1 V.
8	TIMEBASE OUT (10 MHz 2 V_{pp})	The instrument also provides a 10 MHz output for referencing other instrumentation to the internal timebase.
9	TIMEBASE IN (10 MHz 0.5 to 3.0 V_{pp})	This input accepts an external 10 MHz reference. The external reference should be accurate to at least 2 ppm, and provide a signal of no less than 0.5 V_{PP} while driving a 50 Ω impedance. The instrument automatically detects the presence of an external reference and locks to it, if possible. If the unit is able to lock to the reference, this is indicated on the front panel display.
10	LAN	The Ethernet uses a standard RJ-45 connector to connect to a local area network (LAN) using standard Category-5 or Category-6 cable. It supports both 10 and 100 Base-T Ethernet connection and a variety of TCP/IP configuration methods.
11	RS-232	The RS-232 port uses a standard 9 pin, female, subminiature-D connector. It is configured as a DCE and supports baud rates from 4.8 kb/s to 115 kb/s. The remaining communication parameters are fixed at 8 Data bits, 1 Stop bit, No Parity, with RTS/CTS configured to support Hardware Flow Control.
12	GPIB	The GPIB (IEEE-488) communications port is for communications over a GPIB bus. The instruments support the IEEE-488.1 (1978) interface standard. It also supports the required common commands of the IEEE-488.2 (1987) standard.

NOTE. *When EXT is selected as the Source, the instrument will look for an external 10 MHz reference at the timebase input BNC. If detected, the instrument will attempt to lock its internal clock to the external reference.*

Display, navigation, and menus

Controls and display elements are shown in the following illustrations and tables.

Display The display screen is divided into the following four sections:

Ref number	Display area function	Description
1	Status	Indicates instrument status. When an item is highlighted yellow or is displayed with bold typeface, that feature is active. This area shows modulation types, and if Modulation and RF are ON or Off. Error messages, if applicable, show in the right corner of this area.
2	Quick view	Shows frequency and amplitude values. Units can be changed using the unit buttons on the front panel.
3	Settings	Shows the parameters that can be modified for the currently selected item. You can modify a parameter by pressing the corresponding menu button and then using the arrow keys, general knob, and Enter key on the front panel.
4	Menus	Menu buttons show items that you can select to access submenus for specific actions, such as LAN or GPIB setup, or setting a particular modulation type. Use the arrow keys, general knob, and Enter key on the front panel to navigate the menus.

Saving display images (screen shots) You can save *.bmp files of the instrument display to a USB memory device as follows:

1. Insert a USB memory device into the USB port on the front of the instrument.

2. Set the display as desired.

3. Simultaneously press and hold the < and > keys for 1 second.

4. Remove the memory device and download the saved *.bmp files to your PC or other device.

Navigation   Navigate the Menus and Settings areas of the display by using the arrow keys (left, right), general knob (up, down, and push in knob to select), and Enter key (select). When a parameter is selected in the Settings area, you can use the arrow keys to select a digit, the number keys to enter a value, and the Enter key to make a selection. When you are finished, press the Enter key to set the parameter and then any menu item to deselect the parameter.

Menus   The following menus are available.

Table 3: Menus

Menu	Description
RF/LF Mod AWGN/IMP Utility Err Log	Main menu.
RF/LF Setting LF Output: OFF Phase: 0.00 deg LF Ampl: -30.00 dBm LF Offset: 0.000 V RF PLL Mode: mode 1 LF Output ON OFF LF Amplitude LF Offset PLL Mode 2 1 Phase Return	RF/LF menu and settings.
FSK Modulation - P25 Constellation: 4FSK Deviation: 1.800 KHz Source: PRBS PRBS Len: 9 Filter: C4FM Symbol Rate: 4.800 KHz MOD Type FSK Conste-llation Source Filter -more- 1/2 Return Symbol Rate Mod Index PRBS Len BT -more- 2/2 Return FM Modulation Source: Sine Rate: 1.000 KHz Deviation: 1.000 KHz Couple: DC MOD Type FM Source Rate Deviation Couple DC AC Return	Mod menu and settings. Access modulation presets, constellation, source, rate, filter and other submenus. The menu options in this menu change depending on the active modulation type.

Table 3: Menus (cont.)

Menu	Description

	Mod Type submenus: Analog, Vector, Presets.
	Constellation menu. This is a Mod submenu. It is available when the appropriate modulation type is active. The items in this menu vary depending on the active modulation type.

Table 3: Menus (cont.)

Menu	Description
	Source menu. This is a Mod submenu. It is available when the appropriate modulation type is active. The items in this menu vary depending on the active modulation type.
	Filter menu. This is a Mod submenu. It is available when the appropriate modulation type is active. The items in this menu vary depending on the active modulation type.
	AWGN/IMP menu: Noise submenu and AWGN/IMP settings.
	Utility menu.

Table 3: Menus (cont.)

Menu	Description
	I/O Interface menu. This is a Utility submenu.
	RS232 menu and settings. This is an I/O Interface submenu.
	GPIB menu and settings. This is an I/O Interface submenu. This requires the instrument have the GPIB option.

Table 3: Menus (cont.)

Menu	Description
	LAN menu, submenus, and settings. This is an I/O Interface submenu.
	System menu. This is a Utility submenu. Allows you to set display backlight, date, time, run a self test, and remove private data (Secure).
	Secure setting. This is a System menu action that allows you to remove private data. Use the arrow keys to select Yes or No and then press the general knob or the Enter button on the front panel.

Table 3: Menus (cont.)

Menu	Description

Menu

Utility-File
Arb Waveform	Conste- llation	Filter	Setup		Return

Arbitrary User Waveforms - Internal	
0	<Empty>
1	<Empty>
2	<Empty>
3	<Empty>
USB	Save To	Delete	Erase All		Return

Arbitrary User Setup - Internal
0
1
2
3
USB	Save To	Recall			Return

Description

File menu.

This is a Utility submenu. It allows you to access saved files such as waveform, constellation, filter, and setup files. Available files will show in the Settings area of the display when you select the file type.

You can load a file from the USB to location 0 on the instrument (USB), save a file (Save To) to location 1 through 9, delete a file (Delete), and delete all files (Erase All).

The Setup submenu allows you recall and save setups (Recall).

Utility-Status	
Ext Ref: No	Remote: No
Overload: No	Error: No
Act: No	RF Lock: Yes
Timebase: OCXO	
					Return

Status menu.

This is a Utility submenu. It shows the status of the instrument in the Settings area.

Table 3: Menus (cont.)

Menu	Description
 Utility-About Product: Tektronix TSG4106A SN: C000 Firmware Version: 2.03.26(1.0.0) Installed Option: Vector/Audio/NADC/PDC/DECT/ P25/TETRA/GSM/GSM EDGE/W-CDMA/EIQ/ License Manage | Firmware Update | | | | Return	About menu. This is a Utility submenu. It shows the instrument firmware version, installed options, instrument serial number in the Settings area.
 Utility-About-License Key: [ ] A B C D E F G H I J K L M N O P Q R S T U V W X Y Z Input Key | BKSP | | | Decode | Return	License Manage menu. This is an About submenu. It allows you to enter option/software keys to activate options.
 Frequency: Amplitude: 10.000 0.00dBm Do you want to update the firmware? Yes No **Utility-Abou** Product: Tektronix TSG4106A SN: C010103 Firmware Version: 2.03.26(1.0.0) Installed Option: Vector/Audio/NADC/PDC/DECT/ P25/TETRA/GSM/GSM EDGE/W-CDMA/EIQ/ License Manage | Firmware Update | | | | Return	Firmware Update menu. This is an About submenu. It allows you to upgrade the firmware using the USB port. *NOTE. Upgrade procedures are available in this manual. (See page 6, Upgrade the firmware through the USB port.)*
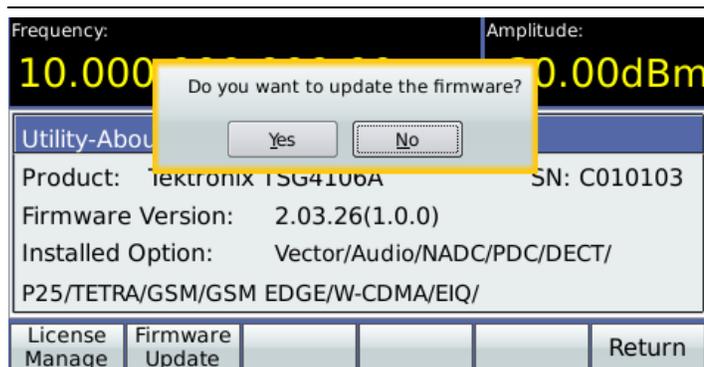
Table 3: Menus (cont.)

Menu	Description
	USB menu. This is a Utility submenu. It allows you to access files from a USB memory device. Available files show in the Settings area of the display.
	Error code menu. This is a Utility submenu. It is an error log and allows you to view any error codes that have appeared.

Quick start and functional check

This section is intended to help first time users get started using a Tektronix TSG4100A Series RF Signal Generator and to help verify that the instrument is functioning correctly.

Turn on the instrument

1. Connect the supplied power cord to the rear panel power input and then to the AC mains power supply (100 to 240 V_{AC} ±10%).

2. Push the power button located on the left top corner of the front panel of the instrument.

3. Check that the model number, firmware version, and instrument serial number briefly display.

NOTE. Your instrument will resume operating with the same settings that were active when it was last turned off. You can preset the instrument to a default state without changing any of the stored settings or the communications configuration. (See page 24, Set default settings (Preset button).)

Set default settings (Preset button)   To set the instrument to the factory default settings without affecting saved presets, press and hold the **Preset** button on the front panel for three seconds. The following table shows some of the default settings that will be loaded.

Table 4: Preset default settings

Setting	Default value
Frequency	10 MHz
Amplitude (BNC)	0 dBm (1 mW into 50 Ω or 0.63 V_{PP}
Amplitude (Type N)	0 dBm (1 mW into 50 Ω or 0.63 V_{PP}
Modulation	OFF
Modulation Type	FM
RF	ON
Source	Sine
Rate	1 kHz
Deviation	1 kHz

Connect outputs to oscilloscope

1. Use appropriate cables to connect the front panel BNC and Type N outputs to an oscilloscope.

2. Set the oscilloscope timebase to 50 ns/div and vertical sensitivity for 200 mV/div with DC coupling and 50 Ω input impedance.

3. Check that the displayed cycle period is 100 ns (2 divisions).

4. Check that the displayed amplitude is 630 mV_{PP}.

NOTE. The displayed amplitude will be 630 mV if the oscilloscope input is not set for 50 Ω.

Basic functional check   Do the following after connecting to an oscilloscope to check that the information shows as expected on the display screen and that you can adjust the parameters and navigate the menus properly.

1. Change the frequency to 5 MHz as follows:

   a. Press the **Freq** button on the front panel to select the Frequency parameter in the Quick View area.

   b. Press the **5** number key.

   c. Press the **M/μ** button to set the units to MHz.

   d. Press the **Setting** button to exit the frequency setting.

Navigation quick tip. You can set the frequency parameter without changing the units as follows: press the **Freq** button, use the general knob to increase/decrease the value, and then press the **Setting** button.

2. Change the amplitude for the Type N output by 1 dBm as follows:

   a. Press the **Ampt** button on the front panel to select the Type-N output amplitude parameter in the Quick View area.

   b. Press the **Enter** button to set the units to dBm.

   c. Use the general knob to increase the amplitude by 1 dBm.

   d. Press the **Setting** button to set and exit the amplitude setting.

Navigation quick tip. You can use the number keys and unit keys to set the amplitude parameter value and units as follows: press the **Ampt** button, press the desired number key, press the desired unit key, and then press the **Setting** button.

3. Change the amplitude for the BNC output by 0.001 V as follows:

   a. Select **RF/LF** from the main menu.

   b. Select **LF Amplitude** from the submenu.

   c. Press the 5 number key.

   d. Press a unit key to set the LF Amplitude to Vpp or Vrms.

   e. Press the **k/m** button to set the units to mV.

   f. Use the general knob to increase the amplitude by 1 mV.

   g. Press the **Setting** button to set and exit the amplitude setting.

Modulation presets functional check Your instrument includes a number of modulation presets that automatically configure the generator to produce modulation waveforms for a number of different communications protocols, such as GSM, DECT, and TETRA. Do the following to see how this preset type is enabled.

1. Press the **Freq** button and then set the frequency to 935.2 MHz.

2. Select **Mod** from the Main menu.

3. Select **Mod Type** from the **Mod** submenu.

4. Use the general knob to select **Preset** from the **Mod Type** menu.

NOTE. Turn the general knob to highlight your selection. Press the general knob to select it.

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5. Turn the general knob to highlight **GSM** and then press the **Enter** button to load the GSM preset.

6. Press the **Mod On/Off** button to enable modulation. The LED will be lit and **MODON** will show in the Status area of the display when modulation is on. The instrument will generate a GSM frame consisting of one TDMA slot of random data.

7. Connect the following to the oscilloscope: I/Q outputs, symbol clock, and event marker #1.

8. Trigger the oscilloscope on event marker #1 and set the time/div to 10 μs. The oscilloscope trace should look similar to that shown below.
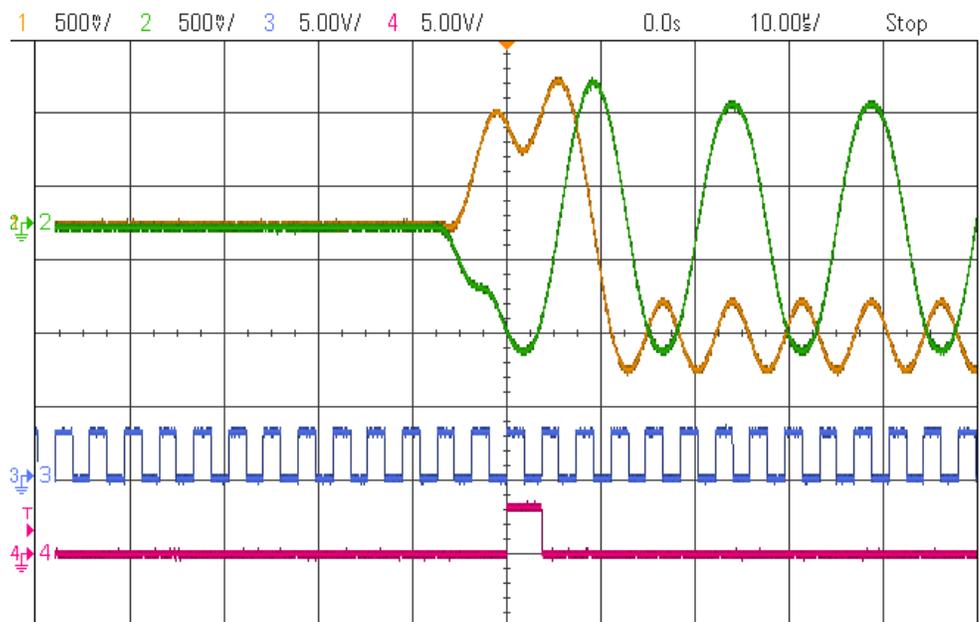
The oscilloscope traces above show that before the TDMA slot begins, the I and Q outputs are at ground, indicating that the RF power is off. Two symbols before the beginning of the time slot, the power is ramped up to full power. The beginning of data transmission for the time slot is indicated by event marker #1, which is trace 4 in the figure. The symbol clock shows the timing of symbol transmission relative to the I/Q outputs.

Settings

Frequency   Pressing the **Freq** button allows you to adjust the carrier frequency of the front panel BNC (LF Out) and Type N (RF Out) outputs. A frequency can be entered in any of the following units: GHz, MHz, kHz, or Hz using the unit buttons on the front panel. The frequency resolution is 1 μHz at all frequencies. The frequency setting determines which outputs are active at any given time. Enabled outputs are noted in the front panel display and in the RF button light on the front panel. None of the outputs operate across the entire frequency range, but are dependant on the instrument model.

Phase   The Phase setting is accessed through the main menu: **RF/LF** > **Phase**. This setting shows the relative phase of the output in degrees and is adjustable over ±360º. If the phase adjustment exceeds 360º, the phase is displayed modulo 360º. The displayed phase is reset to 0° whenever the carrier frequency is changed. The phase resolution depends on the current setting of the frequency. For frequencies up to 100 MHz, the phase resolution is 0.01°, with reduced resolution for higher frequencies.

Amplitude   Pressing the **Ampt** button allows you to adjust the output amplitude or power of the displayed output. If an output is set below its minimum value, it will be disabled. This is indicated on the display as **RFOFF** and the **RF** LED button on the front panel being extinguished. Amplitude can be displayed in units of dBm, dBuV, or V_{RMS}. All stated values assume a load termination of 50 Ω.

LF Offset   The Offset setting for the LF Out output is accessed through the main menu: **RF/LF** > **LF Offset**. This setting shows the output offset voltages. Only the LF Out (BNC) output has a settable DC offset. The Type N RF output is AC coupled and so has no DC offset setting. The DC offset for the LF Out is always accessible and active (independent of the frequency setting).

I/Q Offset   The Offset setting for the I/Q outputs is accessed through the main menu: **AWGN/IMP** > **I Offset** or **Q Offset**. This setting shows the offset as %.

RF On/Off   The front panel outputs can be turned on and off by pressing the **RF** button on the front panel. When the RF is off, the **RF** LED button on the front panel is extinguished and the **RFON** text on the display is grey. When RF is on, the **RF** LED button on the front panel is lit and **RFON** on the display is yellow.

Mod On/Off   Modulation can be turned on and off by pressing the **Mod** button on the front panel. When the modulation is off, the **Mod** LED button on the front panel is extinguished and the **MODON** text on the display is grey. When modulation is on, the **Mod** LED button on the front panel is lit and **MODON** on the display is yellow.

Noise (AWGN)   The Noise setting is accessed through the main menu: **AWGN/IMP** > **Noise**. This setting allows you to degrade a vector modulation waveform with additive white Gaussian noise (AWGN). You can select Add, Only, and Off in the Noise menu.

Power (AWGN)   The Power setting is accessed through the main menu: **AWGN/IMP** > **Power**. This setting allows you to adjust the noise power for a vector modulation waveform with additive white Gaussian noise (AWGN). Use the general knob to adjust the power value in the Settings area of the display.

NOTE. More settings are available than are described in this manual.

Presets

Presets allow you to load preconfigured setups. The following presets types are available:

- Preset button (factory defaults preset) (See page 28.)
- Modulation presets (See page 28.)
- User presets (See page 30.)
- Arbitrary waveform user presets (See page 30.)

Preset button (factory default preset)   To set the instrument to the factory default settings without affecting saved presets, press and hold the **Preset** button on the front panel for three seconds. Default settings will be loaded. (See Table 4 on page 24.)

Modulation presets   The modulation presets shown in the following image and described in the following table are available.

The presets configure the instrument to perform the selected modulation, but the modulation is turned off. To turn on the modulation, press the **Mod** button until the LED is lit and **MODON** shows in the Status area of the display.

NOTE. Some presets may require specific options and may not be available on all instrument models.

Table 5: Modulation presets

Preset	Description
AM Audio	Analog AM modulation of an audio clip.
FM Audio	Analog FM modulation of an audio clip.
NADC	Vector modulation parameters used in North American Digital Cellular (NADC) communications.
PDC	Vector modulation parameters used in Personal Digital Cellular (PDC) communications.
DECT	One TDMA slot within one frame of random data using the vector modulation parameters of Digital Enhanced Cordless Telecommunications (DECT). The waveform transmits a P32 packet which includes the Z field and is 424 symbols long.
P25	Vector modulation parameters used in the APCO Project 25 communications system.
TETRA	One TDMA slot within one frame of random data using the vector modulation parameters used in Terrestrial Trunked Radio (TETRA) communications. The waveform transmits a normal uplink burst, 231 symbols long, using normal training sequence 1.
GSM	One TDMA slot within one frame of random data using the vector modulation parameters of the Global System for Mobile communications (GSM). The packet is 148 symbols long and the midamble is filled with training sequence 0.
GSM EDGE	One TDMA slot within one frame of random data using the vector modulation parameters of the GSM with Enhanced Data rate for GSM Evolution (GSM-EDGE) communications. The packet is 148 symbols long and the midamble is filled with training sequence 0.
W-CDMA	One frame with one control channel and six data channels of random data using the vector modulation parameters of Wideband Code Division Multiple Access (W-CDMA) communications for an uplink channel in a frequency division duplex (FDD) installation. The control channel uses a spreading factor of 256 while the data channels use a spreading factor of 4. The control and data channels are scrambled with long scrambling code 0.

Arbitrary waveform user presets

You can save arbitrary waveforms to the generator. Select **Utility** > **File** > **Setup** to access the user setups menu. To recall a setup, navigate to the desired setup number in the menu and then press **Recall**. You can also select to access files from the USB device and to save to a specific location.

Modulation user presets (custom)

You can access modulation user presets by selecting **Modulation** > **Source** > **Custom**. To recall a preset, navigate to the desired user number in the menu and then press the general knob.

Modulation sources

The instrument's modulation capabilities include both internal and external modulation sources. The modulating waveform is replicated on the rear panel Analog Mod Out BNC.

Linear modulation

The modulation source for AM / FM / ΦM, can be either the internal generator or the rear panel external modulation input.

The internal modulation source is capable of generating sine, ramps, triangular, or square waves, at frequencies of up to 500 kHz. The instrument limits the modulation rate to 50 kHz for carrier frequencies above 62.5 MHz (93.75 MHz for the TSG4106A).

The rear panel external modulation input supports bandwidths of 500 kHz, but the modulation bandwidth is limited to 100 kHz for fc greater than 62.5 MHz (93.75 MHz for the TSG4106A). The sensitivity is set such that a 1 V signal results in a full scale deviation (depth) in the output. For example: in ΦM, if the deviation is set for 10°, applying –1 V produces a –10° shift; applying 0 V produces no shift; and applying +1 V produces a +10° shift.

When modulation is enabled using an internal source, the rear panel modulation output will provide a waveform of the selected function with a full scale range of ±1 V. When external modulation is selected the modulation output tracks the applied signal.

Pulse modulation

In pulse modulation, the RF signal is turned on by the internally generated or externally applied signal.

The internal pulse modulation source is a digital waveform with period settable from 1 μs to 10 s with 5 ns of adjustability, and on time settable from 0.1 μs to 9999.9999 ms. The period of the digital waveform is set using the **Period** setting in the **Mod** menu. The on time (for pulse mode) is set using the **Width** setting in the **Mod** menu.

When an external input is selected the rear panel external modulation input is set for a threshold of 1 V. The resulting signal is used in place of the internal source. In pulse mode, the modulation output is a 3.3 V logic signal, which tracks the pulse waveform.

Example. The following image shows the front panel BNC and Type N outputs for a pulse modulated carrier frequency of 50 MHz. The internal pulse modulator was set to 1 μs period with a 300 ns pulse width (or a 30% duty cycle). The output amplitudes were set to 2 V_{PP} into 50 Ω. The top trace is the rear panel Modulation Output signal. The middle trace is the BNC output. The bottom trace is the Type N output. Both traces show about 50 ns latency in their response to the gating signal. The Type N output also shows some gate feedthrough at the leading edge of the signal.

Linear Noise modulation

For AM, FM and ΦM, the noise source is pseudo random additive white Gaussian noise (AWGN). The bandwidth of the noise and the RMS deviation are set using the **Rate** and **Deviation** settings in the **Mod** menu, respectively.

The peak deviation will be about five times the set RMS deviation. This forces limits on the maximum allowed deviation corresponding to one fifth of the non-noise counterparts. For example, at a carrier frequency of 500 MHz the maximum FM deviation for a sine wave function is limited to 4 MHz, and so the maximum deviation for noise modulation is limited to 800 kHz.

For linear modulation, the rear panel output will provide 200 mV_{RMS} that will be band limited to the selected modulation rate. Again, the peak deviation will be five times this, or ±1 V_{PP}.

Pulse Noise modulation

For pulse modulation, the noise source is a Pseudo Random Binary Sequence (PRBS). The bit period is set using the **Period** setting in the **Mod** menu. The PRBS supports bit lengths of $2n$, for $5 \leq n \leq 32$ which correspond to a noise periodicity from 31 to 4,294,967,295 periods. The bit length n is adjusted from the **PRBS Len** setting in the **Mod** menu.

During pulse PRBS modulation, the rear panel output will be a 3.3 V_{PP} waveform with a duty factor equal to $2n/2$ / $2n$-1 (approximately 50 %).

Example. The following image shows the front panel BNC and Type N outputs for a pulse modulated carrier frequency of 50 MHz. The internal pulse modulator was set to 1 μs period with a 300 ns pulse width (or a 30% duty cycle).

The output amplitudes were set to 2 V_{PP} into 50 Ω. The top trace is the rear panel Modulation Output signal. The middle trace is the BNC output. The bottom trace is the Type N output. Both traces show about 50 ns latency in their response to the gating signal. The Type N output also shows some gate feed-though at the leading edge if the

signal.
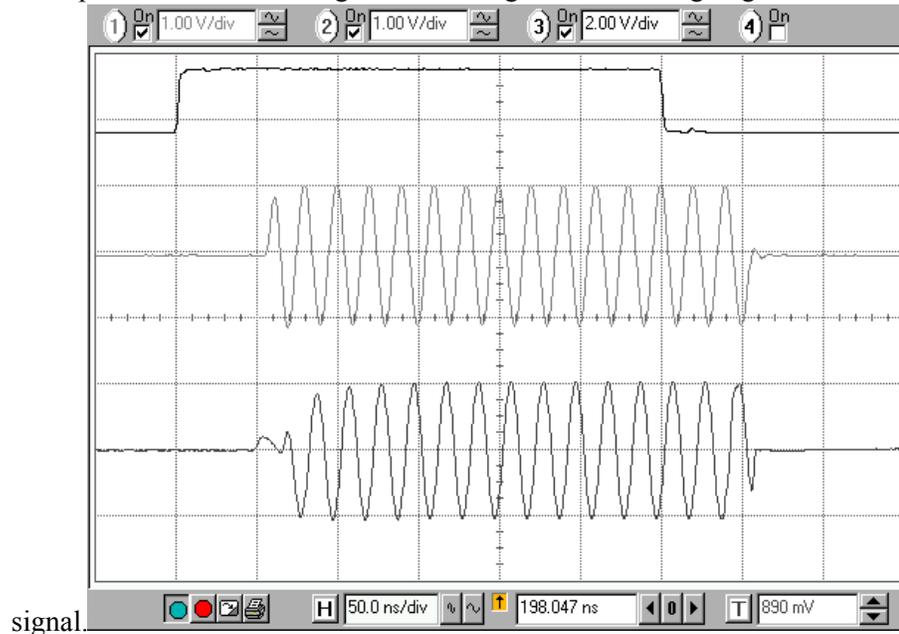
User Arbitrary Waveform modulation

User arbitrary waveforms can be downloaded to the instrument over the remote interfaces into on board SRAM. Once downloaded, the waveform can be saved onto a USB memory device. Waveforms stored in SRAM or FLASH may be selected as possible modulation sources from the **Mod** > **Source** > **Custom** menu.

NOTE. You can read more about user waveforms and how to create them. (See page 58, Using the file Assistant utility software.)

Modulation outputs   The rear panel Analog and Vector Mod Out BNCs provide a copy of the modulation function with ±1 V full scale range. This output will be a sine, ramp, triangle, square wave, pulse or noise depending on the selected internal modulation function.

When an external source is applied to the modulation input it will be bandwidth limited, digitized, and reproduced at the modulation output. The transfer function has a bandwidth of about 1 MHz and a latency of about 950 ns.

When an external source is applied to the modulation input it will be bandwidth limited, digitized, and reproduced at the modulation output. The transfer function has a bandwidth of about 1 MHz and a latency of about 950 ns.

The modulation output has a 50 Ω source impedance (to reverse terminate reflections from the user's load) but the output should not be terminated into 50 Ω.

Amplitude modulation   Amplitude modulation can use either the internal modulation generator or an external source. The internal modulator can generate sine, ramp, triangle, square, noise, or user waveforms.

Example.   The following image shows a 20 kHz carrier, with an amplitude of 1 V_{PP} into 50 Ω, amplitude modulated by an internally generated sine wave. The modulation rate is 1 kHz and the modulation depth is 100%. Two traces are shown. The upper trace is the 1 kHz modulation waveform from the rear panel Analog Modulation Output BNC, offset up two divisions. The lower trace is the modulated carrier (from the front panel BNC output), offset down one

division.
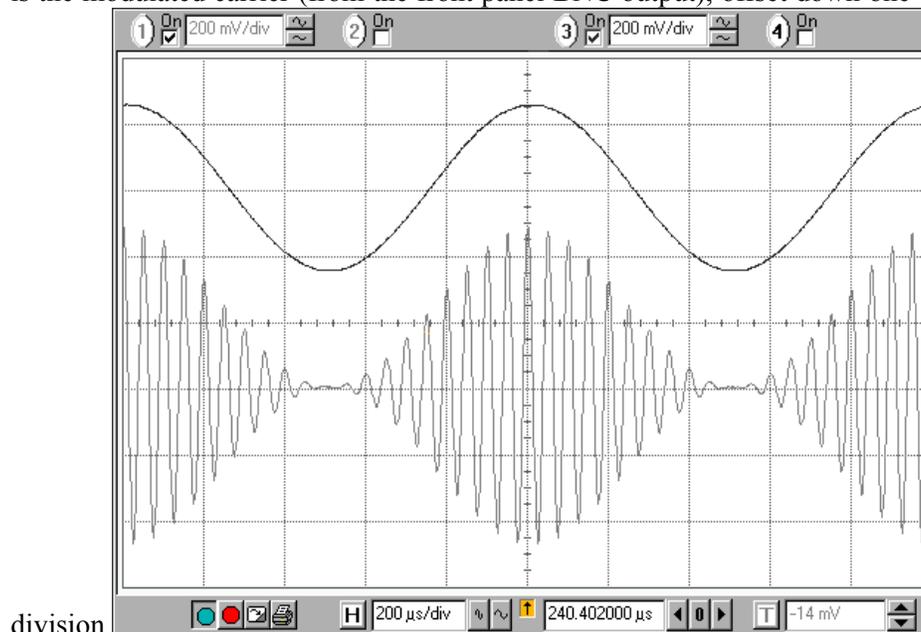
Frequency modulation The internal modulation generator or an external source may be used to modulate the frequency outputs from the front panel BNC and Type N outputs. The internal modulator can generate sine, ramp, triangle, square, noise, or user waveforms.

During FM, the output frequency traverses fc ± MOD DEV at the specified MOD RATE. For example, if the frequency is set for 1000 MHz (1 GHz), and the modulation rate and deviation are set for 10 kHz and 1 MHz, respectively, then the output will traverse from 1000 MHz, up to 1001 MHz, down to 999 MHz, and back to 1000 MHz at a rate of 10 kHz (a period of 100 μs).

The FM modulation parameters are dependent on the frequency setting. The following tables list the FM parameters as a function of frequency. All frequency bands span octaves except for the first band. The internal FM rates correspond to the upper range that the internal function generator supports. The external bandwidth is defined as the −3 dB response referenced to the external modulation source. For the bands 2 to 8, the rates and bandwidths are similar. However, the deviation increases by a factor of two, from 1 to 64 MHz, for octaves 2 through 8.

Table 6: TSG4102A and 4104A FM modulation vs. frequency

Frequency range	Internal FM rate, 1 μHz to (kHz):	External FM bandwidth DC (or 4 Hz AC) to (kHz):	FM deviation (MHz)
DC to 62.5 MHz	500	500	Smaller of f_c or 64 MHz–f_c (MHz)
62.5 to 126.5625 MHz	50	100	1
126.5625 to 253.125 MHz	50	100	2
253.125 to 506.25 MHz	50	100	4
506.25 to 1.0125 GHz	50	100	8
1.0125 to 2.025 GHz	50	100	16
2.025 to 4.050 GHz	50	100	32

Table 7: TSG4106A FM modulation vs. frequency

Frequency range	Internal FM rate, 1 μHz to (kHz):	External FM bandwidth DC (or 4 Hz AC) to (kHz):	FM deviation (MHz)
DC to 93.75 MHz	500	500	Smaller of f_c or 96 MHz–f_c (MHz)
93.75 to 189.84375 MHz	50	100	1
189.84375 to 379.6875 MHz	50	100	2
379.6875 to 759.375 MHz	50	100	4
759.375 to 1.51875 GHz	50	100	8
1.51875 to 3.0375 GHz	50	100	16
3.0375 to 6.075 GHz	50	100	32

Example. The following image shows a 2 MHz carrier being frequency modulated by a 100 kHz square wave with a 1 MHz deviation. In this example of Frequency Shift Keying (FSK), the carrier frequency is being rapidly switched between 1 MHz and 3 MHz. The top trace is from the rear panel Modulation

Output BNC which shows the 100 kHz modulating waveform. The middle trace is the front panel BNC output, whose amplitude was set to 1 V_{PP}. The bottom trace is from the front panel Type N output, whose amplitude was set to 2 V_{PP}.
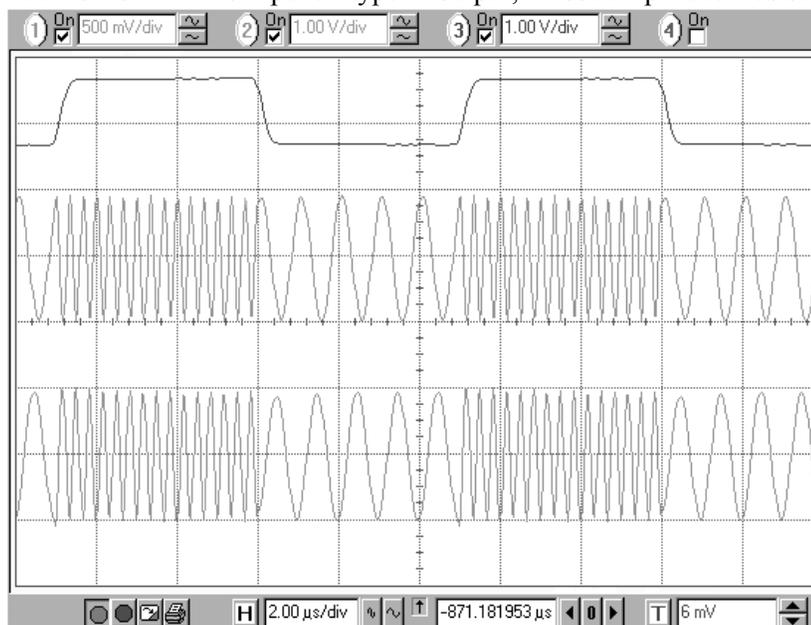
Phase modulation   Phase modulation can use either the internal modulation generator or an external source. The internal modulator can generate sine, triangle, ramp, square, noise, or user waveforms. The phase of the output traverses the specified deviation at the modulation rate. For example, with a frequency of 1000 MHz (1 GHz), and modulation rate and deviation set to 10 kHz and 45°, respectively, the output will be a fixed frequency with its phase traversing ±45 degrees at a 10 kHz rate.

Example. The following image shows the frequency spectrum of a 0 dBm, 50 MHz carrier being phase modulated by a 10 kHz sine wave with a deviation of 137.78°. Here, the modulation index, β = phase deviation = 137.78° × 2π / 360° = 2.40477 radians. For phase modulation by a sine, the carrier amplitude is proportional to the Bessel function J0(β), which

has its first zero at 2.40477, which suppresses the carrier to below -88 dB.
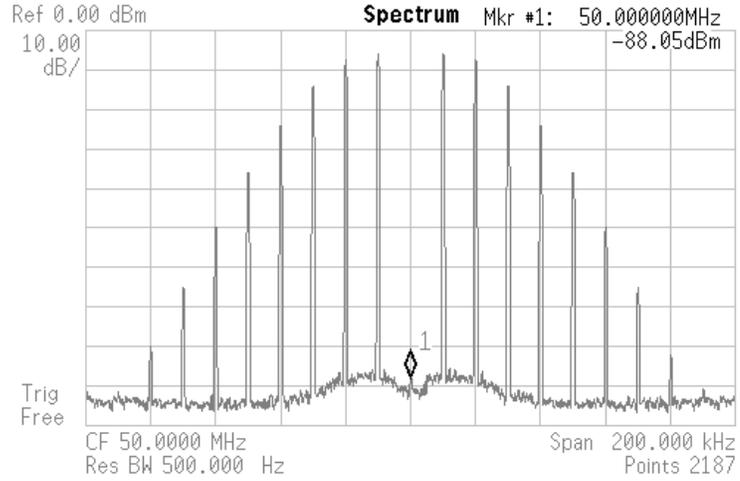
Error log

This instrument contains an error buffer that can store up to 20 error codes associated with errors encountered during power-on self tests, command parsing, or command execution. Errors that occur will show in red colored font in the right corner of the Status area of the display. The errors in the buffer can be read one by one by executing successive LERR? commands. You can also view the errors from the main menu by select **Err Log**. The errors are displayed in the order in which they occurred.

Digital communications

The TSG4100A Series generators support two types of modulation: analog and vector. Analog modulation refers to the modulation of a scalar parameter of the carrier signal, such as amplitude, frequency, or phase. Vector modulation refers to the modulation of the vector characteristics (amplitude and phase) of the carrier signal. Vector modulation is implemented using In-phase/Quadrature (I/Q) modulation techniques.

Introduction

Prior to the industrial revolution, communications over long distances took long periods of time using written words or images. Today, long distance communication is most frequently accomplished by encoding information onto an electrical signal that can be transmitted over very long distances at close to the speed of light. The electrical signal is usually an RF carrier and the information is encoded by modulating or altering the carrier in some way. The modulations are usually one of three types: amplitude, frequency, or phase.

In most cases, the information being transmitted is an analog signal. The acoustic vibrations from a person's voice, for instance, can be converted into an electrical signal with the use of a microphone. The resulting electrical signal is an analog signal, which may be easily converted back into voice with an amplifier and a speaker. In traditional analog communications, the analog signal itself is used to modulate the RF directly. In FM radio, for example, the amplified analog voice signal from the microphone is used to modulate the frequency of the RF carrier directly. The primary advantage of such a scheme is its simplicity and affordability. Receivers were fairly easy to design and cheap to produce. The disadvantage of analog communication is that it is wasteful of power and bandwidth, and susceptible to degradation by noise.

Digital communications refers to the transmission of digital data or numbers, instead of analog signals. Analog signals can be converted into digital data with the use of an analog to digital converter (ADC). The ADC measures the analog signal at an instant in time and assigns a number to it. Big signals are assigned big numbers and small signals are assigned small numbers. The ADC samples the size of the analog signal every few microseconds and assigns a number proportional to the size of the signal at each instant. In this way, an analog signal is ultimately converted into a sequence of numbers.

Digital data may then be converted back into analog signals with the use of a digital to analog converter (DAC). A DAC takes a number and converts it into a voltage proportional to the number—small numbers produce small voltages, and large numbers produce large voltages. By updating the number in the DAC every few microseconds with the sequence of numbers produced by the ADC, the original analog signal may be reproduced.

Vector modulation

All TSG4100A Series generators include standard support for I/Q modulation on RF carriers between 400 MHz and 6.075 GHz. In addition, they feature a dual, arbitrary waveform generator operating at 125 MHz for baseband signal generation. The generator has built-in support for the most common vector modulation schemes: ASK, QPSK, DQPSK, $\pi/4$ DQPSK, 8PSK, FSK, CPM. QAM (4 to 256), 8VSB, and 16VSB. It also includes built-in support for all the standard pulse shaping filters used in digital communications: raised cosine, root-raised cosine, Gaussian, rectangular, triangular, and more. Lastly, it provides direct support for the controlled injection of Additive White Gaussian Noise (AWGN) into the signal path.

The baseband generator supports the playback of pure digital data. It automatically maps digital symbols into a selected IQ constellation at symbol rates of up to 6 MHz and passes the result through the selected pulse shaping filter to generate a final waveform updated in real time at 125 MHz. This baseband signal is then modulated onto an RF carrier using standard IQ modulation techniques.

This architecture provides a simplified and productive user experience. PRBS data and simple patterns can be played back directly from the front panel. Trade-offs in filter bandwidth versus power efficiency can be explored from the front panel in real time without the need to download complex new waveforms each time. Likewise, the degradation of a signal by AWGN can be easily manipulated from the front panel.

Your instrument comes with a number of modulation presets for demonstrating various modulation capabilities. Sample modulation waveforms and setups are included for communications standards such as NADC, PDC, DECT, APCO Project 25, TETRA, GSM, GSM-EDGE, and W-CDMA.

Finally, the rear panel BNC I-Q modulation inputs and outputs enable arbitrary vector modulation through an external source. The external signal path supports 300 MHz of RF bandwidth with a full scale range of ±0.5 V and a 50 Ω input impedance.

Constellations

One important characteristic of digital signals that distinguishes them from analog signals is that they are quantized and bounded. Normally, digital signals are represented as binary sequences of finite length. A 1-bit (binary) signal has only two states: 0 or 1. A 2-bit signal is represented with two binary digits in sequence and, thus, has 4 states: 00, 01, 10, and 11. A 3-bit signal will have 8 states. An N-bit signal will have 2^N states.

The transmission of digital data is straight forward. Like analog communication, information is encoded in a modulation of the amplitude, frequency, or phase of an RF carrier. However, unlike analog communications, only a finite number of modulated states are allowed. In binary phase shift key (BPSK) modulation, for example, only two phases are allowed. These are usually chosen to be 0 and 180°. One phase represents a 0 and the other represents a 1. Similarly, in quadrature phase shift key (QPSK) modulation, only 4 phases are allowed. These are usually chosen to be ±45° and ±135°. Each of the four phases is associated with a unique 2-bit binary sequence: 00, 01, 10 or 11.

The set of allowed phases and their mapping to binary sequences constitutes a digital constellation. The constellation may be succinctly represented in a polar diagram of the I/Q plane identifying the allowed states and their mapping.

A vector signal generator can modulate both the amplitude and the phase of an RF carrier, simultaneously. This enables many more options for defining symbol constellations. In quadrature amplitude modulation (QAM), both the amplitude and phase of the allowed states are defined, usually in a rectangular array.

Gray code   It is important to recognize that the mapping from symbol to constellation point is completely arbitrary and at the discretion of the communications protocol designer. Usually, some form of Gray coding is utilized in order to minimize the possible transmission of multi-bit errors. A Gray code mapping has the property that all nearest neighbor constellation points differ in code by at most 1 bit. The example QPSK constellation in Figure 39 satisfies this property, but the example QAM 16 constellation in Figure 40 does not. For the QPSK constellation, the nearest neighbors to 00 are 01 and 10. Both of these transitions involve a single bit transition. This property holds true for all the QPSK constellation points. In contrast, point 0001 in the QAM 16 constellation, of Figure 40 includes the nearest neighbor point 0010, which involves two simultaneous bit transitions, violating the basic property of Gray codes.

Gray code helps to reduce the accidental transmission of multi-bit errors, thereby increasing the effectiveness of any error correction measures included in the communications protocol. Unfortunately, Gray code mappings are not unique. Nor is there any agreement on a standard mapping. Each protocol includes its own unique Gray code mapping. As such the SG390 series generators use the simple mapping scheme shown in the examples and leave it to the user to encode their data to match the mapping scheme of the protocol they are using.

Susceptibility to noise

As mentioned previously, digital constellations have a finite number of allowed states. A BPSK constellation, for instance, has only two allowed states: 0° and 180°. This property greatly enhances the robustness of digital communications in the face of noise. Since a BPSK constellation contains only two allowed states, any transmission which includes a deviation from these two states must be the result of noise. If the noise deviations are small, the receiver can recover the actual transmission with 100% accuracy by assuming the nearest allowed constellation point was the intended transmission. This is in stark contrast to analog communications, where any noise in the bandwidth of the channel will degrade the fidelity of the transmitted signal. Digital transmissions suffer no degradation until the noise becomes so great that the nearest neighbor principle is not always true. Even then, errors can often be corrected by the receiver if the protocol makes use of Gray code and sufficient redundancy has been built into the transmission.

Intersymbol interference

Pulse shaping filters fix the frequency domain problems by filtering out the high frequency components that would interfere with neighboring users. Unfortunately, they introduce a new problem in the time domain, intersymbol interference (ISI). The problem can be understood by observing the impulse response of the pulse shaping filter as a function of time. Generally speaking, pulse shaping filters with low bandwidth have long response times. Conversely, filters with relatively high bandwidth have short response times. Low bandwidth is good, but long response times create a problem.

A digital communications receiver must make a decision about which symbol was transmitted after every symbol period. The decision is usually made when the impulse response for that symbol is at its peak. Intersymbol interference occurs when the response of adjacent symbols interferes with the response of the current symbol at the moment the decision is made.

The following figure shows the impulse responses of three symbols superimposed on each other. At time t = 0, the receiver must decide which symbol was transmitted. Notice that the responses from both the previous symbol and succeeding symbols are nonzero. The full response at time t = 0 is the superposition of all three responses. The residual responses of the adjacent symbols will add or subtract to the symbol under question, thus, interfering with the decision about what was transmitted.
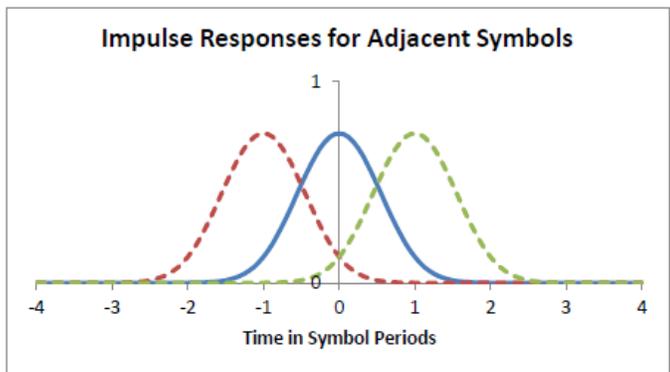
Pulse shaping filters Up to now, we have emphasized the fact that digital constellations have a finite number of allowed states, but we have not discussed how the signal transitions from one allowed state to the next. The simplest method would be to jump as quickly as possible from state to state. Although simple, this method turns out to be undesirable in most cases, because it creates spurious energy at large offsets from carrier. This is important because the RF spectrum is a limited resource that has to be shared by many people cooperatively at the same time. Lots of people are trying to transmit data simultaneously. Without cooperation, all of these transmissions would interfere with one another and nobody would be able to communicate.

One of the most common means of sharing the RF spectrum is with frequency division multiple access (FDMA). In this scheme the RF spectrum is divided into many small frequency bands. Each user is assigned one band and may transmit at will as long as his transmission is confined to his assigned band. If this basic rule is obeyed, everyone can communicate simultaneously without interference. Unfortunately, transmissions that jump from symbol to symbol as quickly as possible invariably violate this rule. Thus, almost all communication protocols stipulate pulse shaping filters to overcome this problem.

Pulse shaping filters limit the bandwidth of a digital transmission by converting the sharp transitions into gradual transitions with much lower bandwidth. They are essentially low pass filters, which filter out all the high frequency components of the sharp transitions.

Three different pulse shaping filters are commonly used in digital communications: the raised cosine filter, the root-raised cosine filter, and the Gaussian filter. Each addresses the problem of ISI differently.

Raised cosine. The first strategy for dealing with ISI is to remove it with a cleverly designed filter that has zero intersymbol interference. The raised cosine filter meets this criterion. It is defined by the following frequency response:

$$H(f) = \begin{cases} T, & |f| \le \dfrac{1-\alpha}{2T} \\[2ex] \dfrac{T}{2}\left[1 + \cos\left(\dfrac{\pi T}{\alpha}\left[|f| - \dfrac{1-\alpha}{2T}\right]\right)\right], & \dfrac{1-\alpha}{2T} < |f| < \dfrac{1+\alpha}{2T} \\[2ex] 0, & |f| \ge \dfrac{1+\alpha}{2T} \end{cases}$$

where f is the frequency, T is the symbol period and α is a dimensionless parameter controlling the excess bandwidth of the filter. When α = 0, the filter approximates a brick wall. When α = 1.0 the filter has 100 % excess bandwidth over the brick wall filter, i.e. it is twice as wide.

The impulse response of the raised cosine filter is given by

$$h(t) = \text{sinc}\left(\frac{t}{T}\right)\frac{\cos\left(\frac{\pi \alpha t}{T}\right)}{1 - \frac{4\alpha^2 t^2}{T^2}}$$

where sinc(x) = sin(πx)/(πx). The following figure shows the impulse response of the raised cosine filter for α = 1.0, α = 0.5, and α = 0.3. Notice that as α is reduced the impulse response lasts longer and extends over many symbols. Normally, this behavior would cause intersymbol interference. However, the sinc(x) function in the impulse response of the raised cosine filter has the important property that it goes to zero at all integer values of x except 0 where it is 1.0. This is what leads to zero intersymbol interference. A plot showing the impulse response of adjacent symbols should make this clear.

Raised Cosine Impulse Response

Adjacent Raised Cosine Impulse Responses
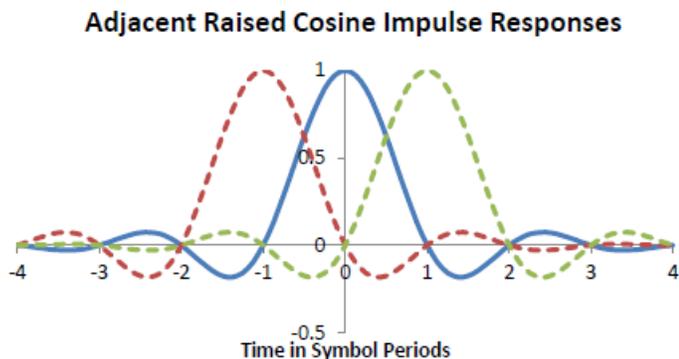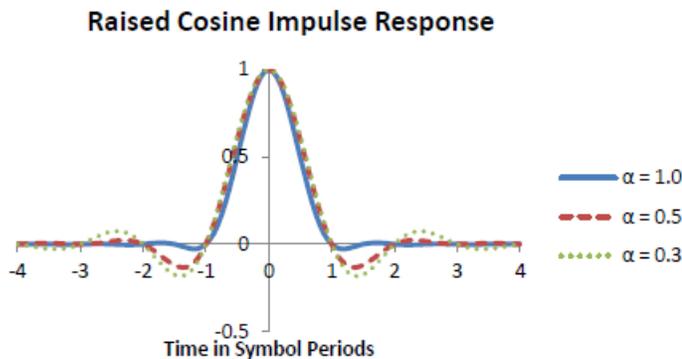
The previous graphs show the impulse responses of adjacent symbols for a raised cosine filter with α = 0.3. Notice that the impulse responses of all adjacent symbols goes to zero at t = 0 when the receiver makes its decision. Thus, even though the full response lasts for about 8 symbol periods, the response of neighboring symbols is always zero at the moment a decision is being made.

Root-raised cosine. This filter is perhaps the most common pulse shaping filter. Its frequency response is given by the square root of the raised cosine filter:

$$H_{root}(f) = \sqrt{|H(f)|}$$

The impulse response of the root-raised cosine filter is given by

$$h(t) = \frac{sin\left[\pi\frac{t}{T}(1-\alpha)\right] + 4\alpha\frac{t}{T}cos\left[\pi\frac{t}{T}(1+\alpha)\right]}{\pi\frac{t}{T}\left[1-\left(\frac{4\alpha t}{T}\right)^2\right]}$$

where all parameters have the same definitions as in the raised cosine filter.

Root Raised Cosine Impulse Response

Time in Symbol Periods
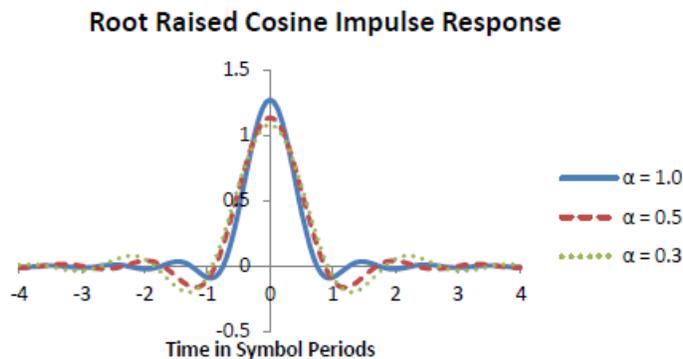
The previous graph shows the impulse response of the root-raised cosine filter for $\alpha = 1.0$, $\alpha = 0.5$, and $\alpha = 0.3$. The response is qualitatively similar to the raised cosine response, but it does not generally have zero ISI. However, cascading two such filters together creates a raised cosine filter which does have zero ISI. Thus, many communication protocols stipulate that both the transmitter and the receiver use root-raised cosine filters. The transmitter's filter limits the bandwidth of the transmitted waveform to prevent adjacent channel interference. The receiver's filter improves signal recovery by further filtering out noise in the communication's channel. Finally, the two filters in combination produce a raised cosine response which does have zero ISI.

Gaussian. The last strategy for dealing with intersymbol interference is to accept it, but limit its reach to just the nearest neighboring symbols in time. The Gaussian filter is a common choice here because it has no ringing, a short duration, and relatively compact bandwidth. It is created by convolving a rectangular filter with a Gaussian:

$$h(t) = g(t) * rect\left(\frac{t}{T}\right)$$

where T is the symbol period, g(t) is a Gaussian, and rect(t/T) is defined by

$$rect\left(\frac{t}{T}\right) = \begin{cases} \frac{1}{T}, & |t| < \frac{T}{2} \\ 0, & \text{otherwise} \end{cases}$$

The Gaussian g(t) is given by

$$g(t) = \frac{\exp\left(\frac{-t^2}{2\delta^2 T^2}\right)}{\sqrt{2\pi} \cdot \delta T}$$

with

$$\delta = \frac{\sqrt{\ln(2)}}{2\pi BT}$$

BT is the 3 dB bandwidth-symbol time product, a dimensionless factor similar to α in raised cosine filters that controls the bandwidth of the filter. The following graph shows the impulse response of the Gaussian filter for BT = 1.0, BT = 0.5, and BT = 0.3. Intersymbol interference is limited to the nearest neighbor symbols which simplifies receiver design.

Gaussian Impulse Response
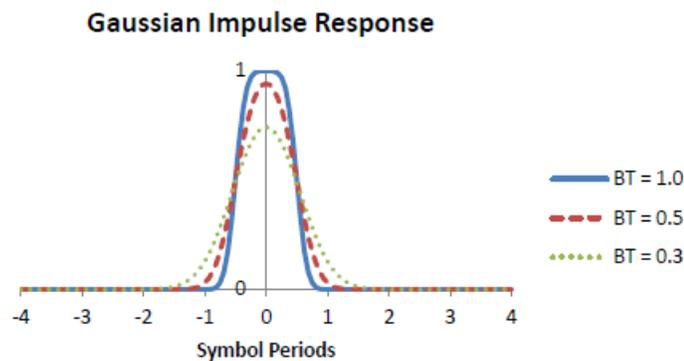
Error vector magnitude   As discussed previously, digital communication protocols often stipulate both a symbol constellation and a pulse shaping filter. Given a constellation, a pulse shaping filter, and a set of symbols to transmit, you can map out the expected trajectory of the modulated RF carrier as a function of time as each symbol is transmitted. The trajectory can be characterized by a vector quantity which identifies the amplitude and phase of the RF at a given moment in time. You can then evaluate the quality of a digital transmission by comparing the received trajectory with the expected reference trajectory. The deviation between the two is a vector quantity indicating the error of the received signal at a given moment in time. The magnitude of the error is called the error vector magnitude (EVM).

The following figure diagrams the relationship on the IQ plane. The measured signal is compared to the reference signal and the difference is given by the error vector. The length of the error vector is the error vector magnitude. The error vector magnitude is often reported as a percentage relative to some standard signal, such as the magnitude of a constellation point.
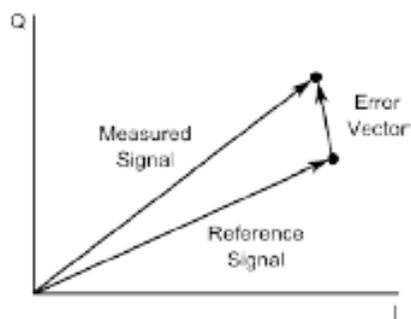
Figure 1: Error vector magnitude

Error vectors are helpful in characterizing the quality of a transmitted signal. They are a natural measure of the noise in a communications channel, but they can also help identify defects of a transmitter, such as amplifier compression or an IQ gain imbalance.

Modulation techniques

There are a number of modulation techniques used by the generator. They are described below.

ASK (amplitude shift keying)

ASK is a modulation technique in which digital symbols are encoded in the amplitude of the RF. The phase is ignored. ASK is implemented by only modulating the I channel and forcing the Q channel to zero.

Digital constellations. The generators provide four default constellations for use with 1-bit, 2-bit, 3-bit, and 4-bit digital modulation. Custom user constellations can also be downloaded, if desired. The default constellations are summarized in the following image. Waveforms for digital modulations include PRBS data, simple patterns, and user data. Frequency deviations of up to 6 MHz are supported. The configured deviation applies to symbol 0 in each of the constellations.

ASK Constellations

Figure 2: ASK constellations

FSK (frequency shift keying)   FSK is a modulation technique in which digital symbols are encoded in the frequency of the RF. The amplitude of the carrier is held constant. In the SG390 series generators FSK is implemented using an internal rate generator followed by cosine/sine tables to convert a phase into its respective I and Q components.

Simple waveforms.   As with analog modulation, the RF may be vector modulated in frequency with simple waveforms: sine, ramp, triangle, square, noise, and user waveforms.

Digital constellations.   The generators provide four default constellations for use with 1-bit, 2-bit, 3-bit, and 4-bit digital modulation. Custom user constellations can also be downloaded, if desired. The default constellations are summarized in the following image. Waveforms for digital modulations include PRBS data, simple patterns, and user data. Frequency deviations of up to 6 MHz are supported. The configured deviation applies to symbol 0 in each of the constellations.
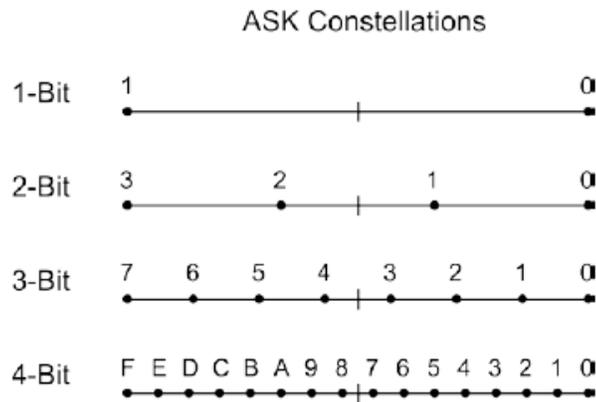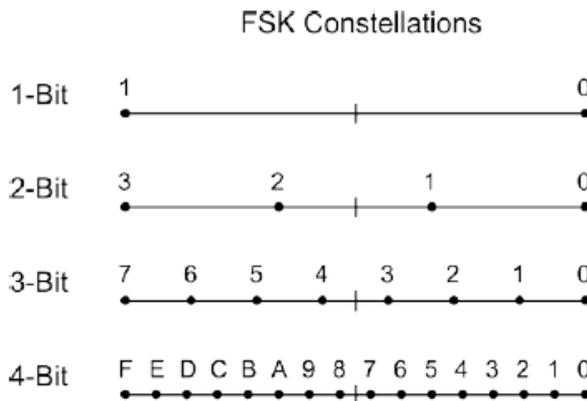
FSK Constellations

Figure 3: FSK constellations

TSG4100A Series RF Signal Generators User Manual

PSK (phase shift keying)   PSK is a modulation technique in which digital symbols are encoded in the phase of the RF. The amplitude of each constellation point is the same. In spite of this, the modulation is not constant amplitude as it is for FSK. The pulse shaping filters create amplitude variations as the modulation traverses from symbol to symbol, creating waveforms very similar to QAM. In fact, vector PSK modulation may be considered a subset of QAM modulation.

Simple waveforms. Vector phase modulation with some simple waveforms is supported. The supported waveforms are summarized in the following table.

Table 8: Vector phase modulation waveforms

Waveform	Description
Sin cos	Channel I is a sine wave and channel Q is a cosine wave. This combination moves the RF carrier down in frequency by the modulation rate.
Cos sin	Channel I is a cosine wave and channel Q is a sine wave. This combination moves the RF carrier up in frequency by the modulation rate.
Phase noise	Degrades the RF output with pure phase noise. The amplitude is held constant. The bandwidth and RMS deviation of the noise may be configured.
IQ noise	Degrades the RF output with IQ noise. The bandwidth of the noise may be configured. The noise power is equal to the RF carrier power when modulation is off.

Digital constellations. The generators provide four basic constellations and four specialized constellations. Custom user constellations can also be downloaded, if desired. The constellations are summarized in the following table. Waveforms for digital modulations include PRBS data, simple patterns, and user data. Frequency deviations of up to 6 MHz are supported.

NOTE. More information about basic and specialized constellations is available here. (See page 48, Basic PSK constellations.) (See page 52, Specialized PSK constellations.)

Table 9: PSK constellations

Display	Standard acronym	Bits / symbol	Comments
PM binary	BPSK	1	Normal binary shift keying
PM quadrature	QPSK	2	Normal quadrature shift keying
PM Quad offset	OQPSK	2	Offset quadrature shift keying
PM diff quad	DQPSK	2	Differential quadrature shift keying
PM π4 diff quad	π/4 DQPSK	2	DQPSK with π/4 rotation
PM 3π8 3 bit	3π/8 8 PSK	3	8 PSK with 3π/8 rotation
PM 3 bit	8 PSK	3	Normal 8 PSK
PM 4 bit	16 PSK	4	Normal 16 PSK

Basic PSK constellations. The four basic PSK constellations are summarized in the following image. Note that the QPSK constellation follows a different mapping pattern than the 8 PSK and 16 PSK constellations. Since this constellation is identical to the QAM constellation of the same size, it uses the same mapping.
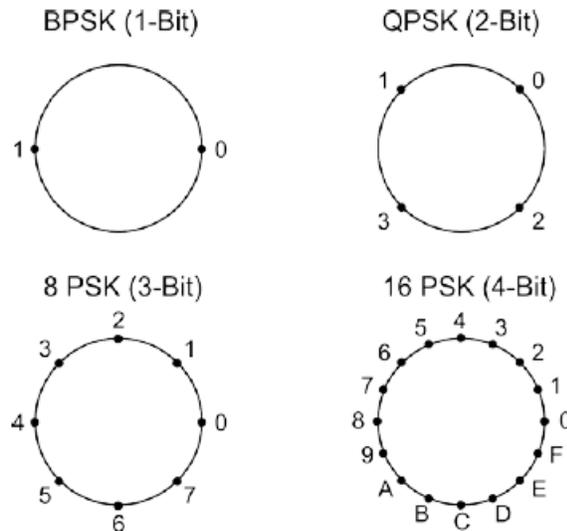

Figure 4: Four basic PSK constellations

CPM (continuous phase modulation)

CPM is a form of FSK modulation. Like FSK modulation, the RF carrier maintains a constant amplitude at all times. Only the phase is modulated. However, the general definition of FSK modulation allows for the phase to hop when the frequency is shifted. Such an allowance enables the creation of simple FSK modulators consisting of two independent oscillators and a multiplexer, driven by the data, switching between the two frequencies. When the multiplexer switches between the oscillators, both the frequency and the phase of the output change.

Continuous phase modulation, in contrast, guarantees that the phase will not suffer a discontinuous jump when switching to a new frequency. As the name implies, the phase will be continuous. The implementation of FSK in the SG390 series generators happens to be continuous phase, so in this respect, the two modulations are almost the same. Internally, however, the implementations have one distinct difference: the FSK implementation tracks frequency while the CPM implementation tracks phase. The FSK implementation allows arbitrary frequency deviations, but will, in general, slip phase relative to a fixed carrier. The CPM implementation, on the other hand, requires a rational modulation index, but will never slip phase. Aside from this, the two modulations are identical.

The following equation describes the correspondence between an FSK peak

$$h = \frac{2F_{dev}T}{2^N - 1}$$

frequency deviation, Fdev, and a CPM modulation index, h:

where T is the symbol period and N denotes the number of bits per symbol.

Phase trellis diagram. As mentioned previously, CPM modulation is a form of continuous phase FSK. However, it can also be viewed as a special form of offset phase shift keying, OPSK, with sinusoidal symbol weighting. Ultimately, this means that CPM transmissions may be decoded by demodulating the frequency or, alternatively, the phase. For binary CPM the phase will traverse hπ for every symbol transition. Thus, one can map out a trellis diagram of allowed transitions and phases over time. (See Figure 5.)

CPM Trellis Diagram
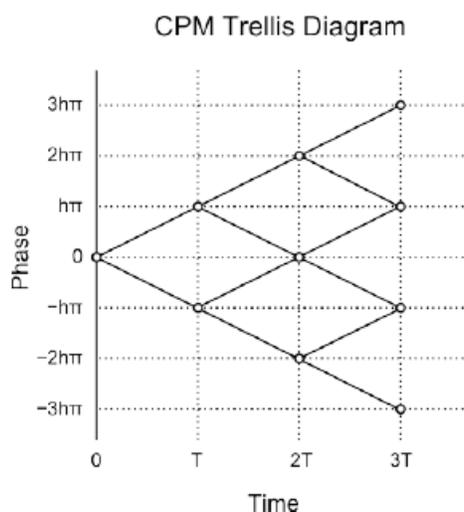
Figure 5: Phase trellis diagram for binary CPM with a rectangular filter

Note that if h is a simple rational fraction, the allowed phases will map onto a finite number of allowed phases. For h = 1/2, for instance, there are only 4 allowed phases: 0, $\pi/2$, π, and $3\pi/2$. Only 2 of the 4 phases are allowed at each transition, however.

QAM (quadrature amplitude modulation)

In quadrature amplitude modulation (QAM), both the amplitude and phase of the constellation points are varied, usually in a rectangular array. In all other respects, it is identical to phase shift keying.

QAM constellations. The generators provide default constellations for QAM 4, QAM 16, QAM 32, QAM 64, and QAM 256. The constellations are all arranged as rectangular arrays with a simple right to left and top to bottom naming pattern. The front panel displayed power corresponds to the constellation points in the corners of the array. For QAM 32, it indicates the power of the "missing" point in each corner. (See Figure 6.)
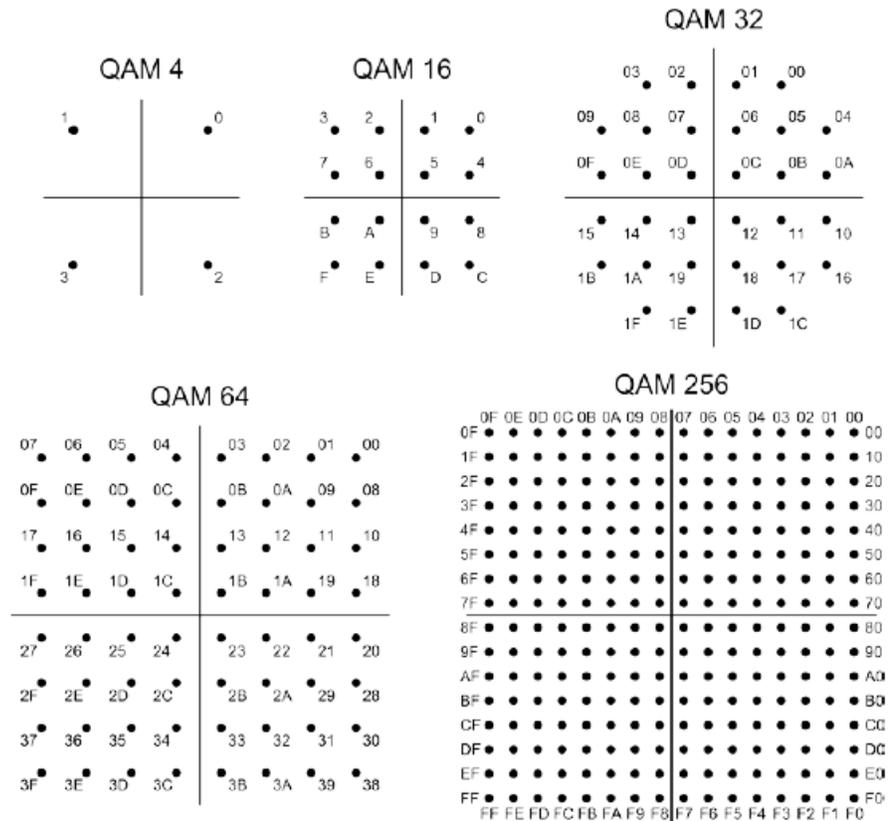
Figure 6: Constellations for QAM 4 through QAM 256

MSK and GMSK

Minimum shift keying (MSK) and Gaussian minimum shift keying (GMSK) are perhaps the two most well known examples of CPM modulation. MSK is binary CPM with a modulation index, h = 1/2, and a rectangular filter. It derives its name from the fact that the two frequencies of the modulation have the minimum frequency separation allowed for orthogonal detection. The frequency separation is just ¼ of the symbol rate. Thus, it is one of the most bandwidth efficient types of modulation.

GMSK further improves the bandwidth efficiency of MSK, by replacing the rectangular filter with a Gaussian filter. GMSK with a bandwidth symbol time product of BT = 0.3 is used in the GSM mobile communications protocol.

Modulation index. Modulation indices for CPM modulation may be specified to 3 decimal digits, but internally the value is rounded to the nearest rational factor, n/512, where n is an integer. For example, if you want to obtain a modulation index of 7/16 = 0.4375, you would enter 0.438. Internally, the instrument will round the result to 224/512 = 7/16.

VSB (vestigial sideband)   Vestigial sideband modulation (VSB) is a form of amplitude modulation used in the over-the-air transmission of digital television (DTV) in the United States. Amplitude modulation normally creates two sidebands: an upper sideband and a lower sideband. However, the information content in the upper sideband is identical to that of the lower sideband. Thus, one can increase the bandwidth efficiency of the modulation by nearly a factor of two, without loss of information by filtering out the lower sideband. This is referred to as single sideband amplitude modulation (SSB AM). In practice, however, it is very difficult to completely filter out the lower sideband. A vestigial portion of the lower sideband is often still present, hence the name vestigial sideband modulation.

Receivers required to demodulate VSB need to lock onto a clean reference frequency. To facilitate this, the ATSC digital television standard stipulates the addition of a pilot tone to the modulation at the carrier frequency. The pilot tone is located at the lower edge of the VSB spectrum. The standard describes 2 versions of the modulation to be used for over-the-air transmissions: 8 VSB, and 16 VSB. Both modulation types are supported by the generator at modulation rates of up to 12 MHz. The transmission rate required by the DTV standard is $4.5 \times 684 / 286 \cong 10.762$ MHz.

VSB constellations.   The generators provide two constellations for use with 8 VSB and 16 VSB modulation. Unlike the other modulation modes, these constellations are fixed and cannot be changed. (See Figure 7.)
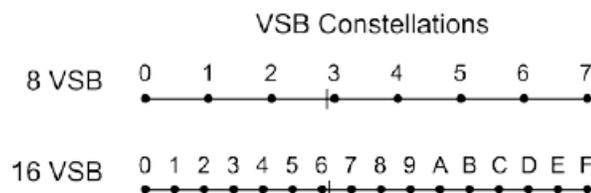
Figure 7: **VSB symbol constellations**

Notice that the constellations are not symmetric about the origin. They have been shifted to the right. This bias in the constellation is what creates the pilot tone required by the standard.

AWGN (additive white Gaussian noise)   All digital modulations may be optionally degraded by additive white Gaussian noise (AWGN). The noise is inserted just before the pulse shaping filters. The noise may range in power from –10 dB to –70 dB relative to the maximum power of a constellation.

External IQ modulation
The instrument can be modulated through an external source with bandwidths above 100 MHz. Rear panel BNC inputs are available as I and Q signal inputs. The inputs are terminated into 50 Ω with full-scale amplitude of 0.5 V. Note that an external vector modulation option is available for ASK, PSK, and QAM modulation modes. The options are identical in all modes and are available merely as a convenience to the user.

Specialized PSK constellations

The generators provide built-in support for four specialized PSK constellations listed in (See Table 9.): OQPSK, DQPSK, π/4 DQPSK, and 3π/8 8 PSK. All of these constellations are variations of the basic PSK constellations intended to address specific problems in receiver design.

Differential encoding of symbols
One of the difficulties in receiving and decoding the basic PSK constellations is that the demodulation requires a coherent detector. The receiver must lock onto and track phase of the RF carrier for the entire transmission in order to successfully decode the transmitted message. Differential encoding of digital symbols enables the use of noncoherent receivers which are simpler and more cost effective to produce.

In differential encoding the information is encoded in the difference in phase from one symbol to the next, rather than in the phase itself. Receiver design is simplified because the receiver can use the phase of the last symbol as a reference for decoding the next symbol. It does not need to lock onto a stable reference over the entire transmission. Rather, it only needs a reference that is stable from one symbol to the next, which a much easier goal to meet. In fact, for DQPSK, the reference may simply be a delayed version of the signal itself.

The DQPSK constellation looks identical to the QPSK constellation but the interpretation is different. Data is differentially encoded, and so what matters is how the phase changes from one symbol to the next, not the current phase. (See Figure 8.)

DQPSK Constellation
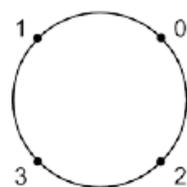
Symbol	Encoding
0	No change in phase
1	+90° change in phase
2	−90° change in phase
3	180° change in phase

Figure 8: Decoding DQPSK transmissions

Offset or staggered modulation

This type of modulation addresses transmitter problems in the communication design. RF amplifiers can be made to operate more efficiently if the signals they are amplifying are nearly constant in amplitude. This is especially important for satellites deployed in space. The difficulty is that the amplifiers have a nonlinear response in this regime. The nonlinearities are often not problematic as long as the amplitude variations are contained within a small band. Unfortunately, normal QPSK modulation does not meet this criterion. Remember that even though the constellation points are defined with constant amplitude, the RF amplitude varies as it transitions from one point to the next. For transitions of 180°, the signal power will momentarily go all the way down to zero. Nonlinear amplifiers forced to make such a transition will create out-of-band interference, thus, defeating the whole purpose of the pulse shaping filters.

Offset modulation addresses this problem by modifying the modulation to prevent a transition through the origin. (See Figure 9.)
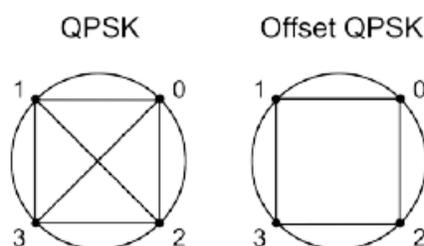

Figure 9: Offset modulation prevents transitions through the origin

In normal QPSK modulation, I and Q data are shifted into the pulse shaping filters simultaneously. With offset or staggered modulation, the shifting of data for the two channels is offset by half a symbol period. First I is shifted in. One half a symbol period later, Q is shifted in. One half a symbol period later, the next I is shifted in, and so on. On the IQ plane, I transitions are strictly horizontal, and Q transitions are strictly vertical. However, since both transitions cannot happen simultaneously, the trajectory must follow the outside edges between constellation points. It can never go through the origin, thus, solving the problem.

Rotating constellations

Offset modulation is not the only method of preventing transitions through the origin. The second commonly employed technique is to rotate the constellation after each symbol. This strategy is exemplified by the $\pi/4$ DQPSK and the $3\pi/8$ 8 PSK constellations. (See Figure 10.)

π/4 DQPSK Constellation
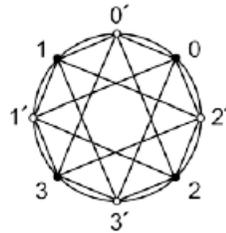
Symbol	Encoding
0	+45° change in phase
1	+135° change in phase
2	−45° change in phase
3	−135° change in phase

Figure 10: π/4 DQPSK uses differential encoding and a rotating constellation.

Like DQPSK, π/4 DQPSK employs differential encoding, which means information is encoded in the change in phase, rather than the phase itself. However, the constellation for π/4 DQPSK rotates by 45° or π/4 radians after each symbol transmission. See Figure 56. Unprimed constellation points may only transition to primed constellation points and vice versa. The allowed transitions are indicated in the figure. Notice that none of the transitions pass through the origin, thus, solving the problem.

The 3π/8 8 PSK constellation is similar in design to the π/4 DQPSK. In this case, data is not differentially encoded, but the constellation rotates to prevent transitions through the origin. In this case, the basic constellation is that of 8 PSK, except that the constellation rotates by 67.5° or 3π/8 radians after each symbol transmission. A version of this constellation with a Gray code mapping is used in the GSM EDGE mobile communication protocol. (See Figure 11.)

3π/8 8 PSK Constellation
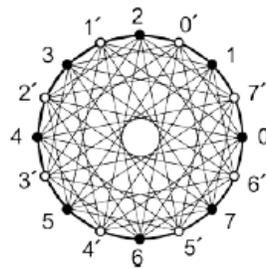
Figure 11: 3π/8 8 PSK follows standard 8 PSK, but the constellation rotates by 3π/8 after each symbol

Due to the rotation of the constellation, unprimed constellation points may only transition to primed constellation points and vice versa. The allowed transitions are indicated in the figure. Notice that none of the transitions pass through the origin, again solving the problem. The exclusion from the origin is smaller than for the π/4 DQPSK constellation, however. This constellation, therefore, places more stringent demands on the linearity of the transmitter.

Modulation functions

The modulation functions available for the vector function subtype are similar to those offered for analog modulation: sine, ramp, triangle, square, noise, user, and external. For the digital modulation subtypes, the available waveforms include: PRBS data, pattern data, and user data.

PRBS data This instrument can generate pseudo random binary sequences (PRBS) for use with digital modulation subtypes. The length of the PRBS waveform can be adjusted from 5 to 32. The default PRBS length is 9. The PRBS patterns are generated with linear feedback shift registers. The following table shows the generating polynomials for each PRBS pattern. The output of the PRBS generator is inverted so that the all-ones state is excluded, rather than the all-zeros state. All PRBS waveforms start in the all-zeros state.

Table 10: PRBS generating polynomials

Length	Polynomial
5	$x^5 + x^3 + 1$
6	$x^6 + x^5 + 1$
7	$x^7 + x^6 + 1$
8	$x^8 + x^7 + x^5 + x^3 + 1$
9	$x^9 + x^5 + 1$
10	$x^{10} + x^7 + 1$
11	$x^{11} + x^9 + 1$
12	$x^{12} + x^{11} + x^8 + x^6 + 1$
13	$x^{13} + x^{12} + x^8 + x^2 + 1$
14	$x^{14} + x^{13} + x^8 + x^2 + 1$
15	$x^{15} + x^{14} + 1$
16	$x^{16} + x^{15} + x^9 + x^6 + 1$
17	$x^{17} + x^{14} + 1$
18	$x^{18} + x^{11} + 1$
19	$x^{19} + x^{18} + x^{10} + x^2 + 1$
20	$x^{20} + x^{17} + 1$
21	$x^{21} + x^{19} + 1$
22	$x^{22} + x^{21} + 1$
23	$x^{23} + x^{18} + 1$
24	$x^{24} + x^{23} + x^{18} + x^{14} + 1$
25	$x^{25} + x^{22} + 1$
26	$x^{24} + x^{25} + x^{16} + x^5 + 1$
27	$x^{27} + x^{26} + x^{16} + x^2 + 1$
28	$x^{28} + x^{25} + 1$

Table 10: PRBS generating polynomials (cont.)

Length	Polynomial
29	$x^{29}+ x^{27}+ 1$
30	$x^{30}+ x^{29}+ x^{16}+ x^4+ 1$
31	$x^{31}+ x^{28}+ 1$
32	$x^{32}+ x^{31}+ x^{18}+ x^{10}+ 1$

Pattern data   Digital modulation subtypes can also be modulated with 16-bit patterns. The current pattern is shown as hexadecimal digits. Once selected, the pattern may be edited from the front panel by modifying each hexadecimal digit. The default pattern is the binary sequence 01010101 01010101, which corresponds to the hexadecimal value 0x5555.

User data   User data can be downloaded into on-board SRAM and subsequently saved into FLASH. If user waveforms are available for the selected modulation subtype, they can be selected as a modulation function. You can read more about user waveforms. (See page 30, *Arbitrary waveform user presets*.) and (See page 57, *User waveforms, constellations, and filters*.)

Modulation rate   The modulation rate is associated with the current modulation type. For digital modulation subtypes, this is the symbol rate; otherwise, it is the frequency or bandwidth of the selected waveform.

Modulation deviation (scale factor)   For FSK or CPM modulations, the modulation deviation identifies either the peak deviation or the modulation index of the modulation as indicated. For all other types of vector modulation, the power of the modulated waveform is defined by the constellation, the filtering, and the carrier power. However, in order to prevent clipping when waveforms are passed through the pulse shaping filters, the constellations are reduced by a factor of 7/16. The resulting scale is defined to have a scale factor of 1.0. Output power calibration assumes a scale factor of 1.0. Normally, this scale factor need not be changed, because the carrier power is set with the Amplitude button. However, you can alter this scale factor, if desired. Larger scale factors will use more of the available digital phase space and reduce the quantization noise of the final waveform. This might also be desirable if the amplitude is already at max power and you still need a bit more power. The risk is that the pulse shaping filters will occasionally clip the waveform to the rail during large excursions.

User waveforms, constellations, and filters

This generator provides a broad array of built-in support for the most common digital modulation formats, constellations, and filters. However, you may choose to download custom waveforms, constellations, and filters over the remote interface if the built-in support does not match your needs.

NOTE. See the TSG4100A Series RF Signal Generator Programmer Manual for detailed information about remote programming commands.

Downloading binary data

User waveforms, constellations, and filters can contain a considerable amount of data. In order to improve the efficiency of transfer, the data is sent in binary format. This can be done using remote commands that accept binary data follow the syntax for an IEEE 488.2 definite length <ARBITRARY BLOCK PROGRAM DATA>. You can also use the TGS File Assistant utility software to download supported file types to the generator when it is connected to the Ethernet through a LAN connection. (See page 58, *Using the file Assistant utility software*.)

The <ARBITRARY BLOCK PROGRAM DATA> message element has the following format:

<arb data> =#[ASCII digit 1 to 9][ASCII digit 0 to 9]+[Binary data]

The message element has 4 parts to it:

1. The ASCII character #.

2. An ASCII digit from 1 to 9. This digit identifies the number, M, of ASCII digits that follow.

3. M bytes containing ASCII digits from '0' to '9' that identify the number, N, of binary bytes that follow.

4. N bytes of binary data.

The following example may help clarify. The following block transmits the 26 ASCII bytes from A to Z:

#3026ABCDEFGHIJKLMNOPQRSTUVWXYZ

The first two characters indicate that an arbitrary block of data follows and that the length of the block is given by the following 3 digits, '026'. These digits indicate that the binary message is 26 bytes long. The actual data follows. For clarity, only printable characters were used in this example, but arbitrary 8-bit binary data may be transmitted as part of an <arb data> block.

Big-endian byte order   In many cases, 16-bit or 32-bit numbers must be encoded in a binary transmission. The native encoding for numbers in computers follows one of two common formats: little-endian and big-endian. The generators expect data in a big-endian format. Most Intel based computers natively store numbers in a little-endian format. For these machines, all binary numbers will have to be converted into a big-endian format before being transmitted.

As an example, the decimal number 43,891 is represented by the hexadecimal value 0xABCD. Storage of this number within the memory of a computer, however, depends on the native storage format. In the big-endian format the number is stored as the bytes AB CD. In the little-endian format, however, the number is stored as the bytes CD AB (the bytes are swapped). Numbers stored in this format will need to be swapped back into big-endian format before being transmitted over the remote interface.

SRAM versus flash storage   The generators include 2 MB of SRAM and flash for storage of arbitrary waveforms, constellations, and filters. SRAM is volatile memory that is lost when power is removed from the instrument. Flash is nonvolatile memory that is retained even when power is cycled. User data is always downloaded into SRAM first. Once downloaded, you can optionally copy the data into flash if desired with one of the commands SAVW, SAVC, or SAVF. Waveforms may be played directly out of SRAM or flash.

Using the file Assistant utility software

The TSG File Assistant is a utility software application that runs on Windows 7 and that allows you to convert custom user data files (waveforms, constellations, and filters) from *.txt or *.csv files to files types supported by the generator (*.tsw, *.tsc, or *.tsf). This utility also allows you to download supported file types to the generator when it is connected to the Ethernet through a LAN connection.

NOTE. Raw Socket Interface is not currently supported in the March 31, 2015 software version.

Download TSG File Assistant   The TSG File Assistant utility software is available for download at www.tek.com/downloads. To download the software, do the following:

1. Go to www.tektronix.com/downloads.
2. Select Software.
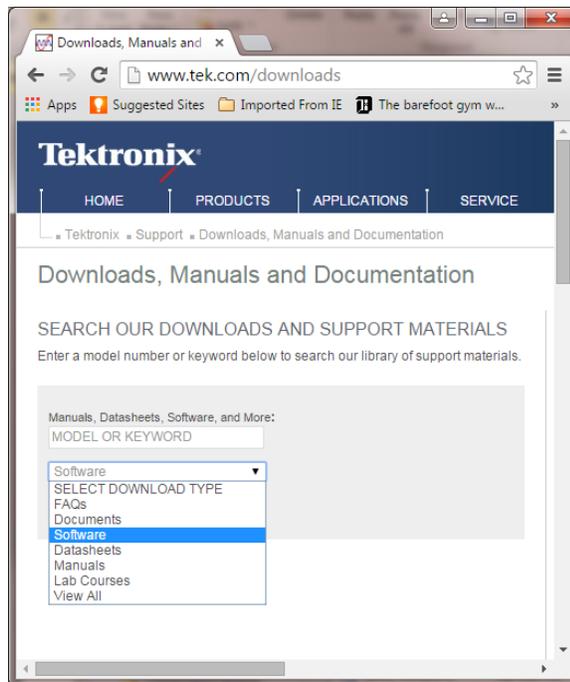
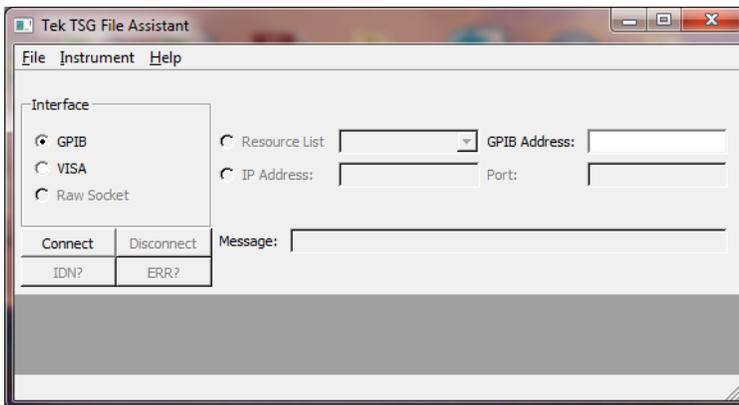**3.** Enter *TSG File Assistant* in the search field.
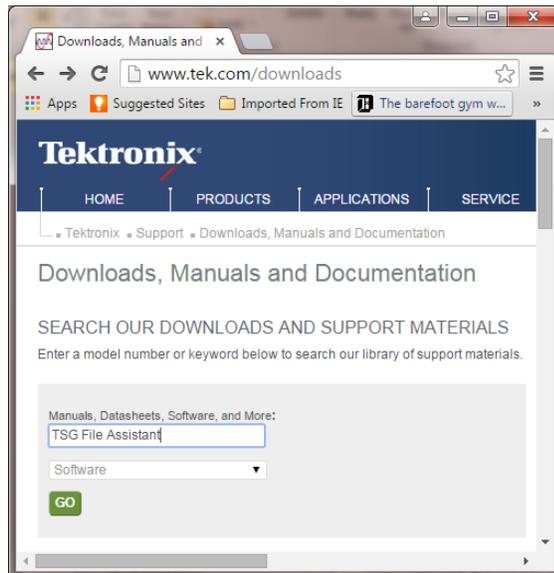
4. When the search results appear, select *TSG4k File Assistant* and follow the instructions to download and install the software.

Load or convert an existing file to the instrument

The following procedure shows you how to load a supported file (*.tsw, *.tsf, and *.tsc) or convert an unsupported file and send it to the instrument.

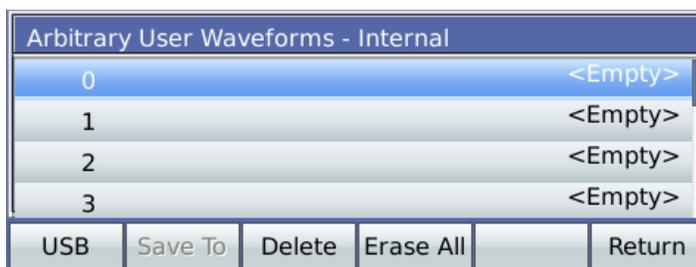1. Launch the TSG File Assistant.

2. Select the desired interface.

3. To check the ID of the instrument you are going to connect to, click the **IDN?** button. The instrument name will appear in the **Message** field.

4. Do one of the following:

    -   If you selected the GPIB interface, enter the GPIB address in the **GPIB Address** field and then click **Connect**.

    -   If you selected the VISA interface, select the instrument from the **Resource List** drop down menu and then click **Connect**.

    -   If you do not see the instrument you want in the Resource List, select **IP Address**, enter the IP address, and then click **Connect**.

5. Select **Instrument** > **Send File** from the TSG File Assistant menu bar.
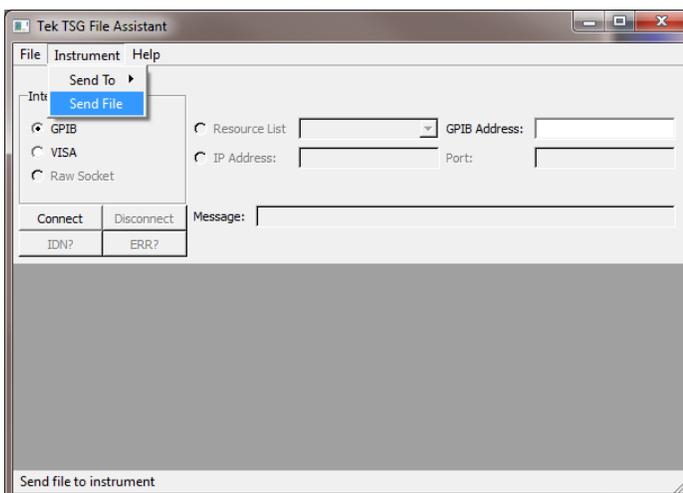
6. A dialog box will appear. In this box, select a number from the **User Number** drop down menu.
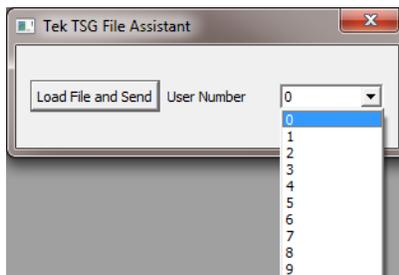
This number will determine where the file will be saved in the generator. For example, if you select 0, then the new file will be saved to the location in the generator that is associated with that User Number. In the image of the generator display below, the <Empty> field next to the 0 would disappear.

7. Click the **Load File and Send** button.

8. Select the *.tsw, *.tsf, or *.tsc file you want to save to the instrument. It will be saved to the instrument.

Create a new file   The following procedure shows you how to create a new file (*.tsw, *.tsf, and *.tsc) from raw data or a *.txt file and send it to the instrument.

1. Launch the TSG File Assistant.

2. Select the desired interface.

3. To check the ID of the instrument you are going to connect to, click the **IDN?** button. The instrument name will appear in the **Message** field.

4. Do one of the following:

- If you selected the GPIB interface, enter the GPIB address in the **GPIB Address** field and then click **Connect**.

- If you selected the VISA interface, select the instrument from the **Resource List** drop down menu and then click **Connect**.

- If you do not see the instrument you want in the Resource List, select **IP Address**, enter the IP address, and then click **Connect**.

5. Select **File** from the TSG File Assistant menu bar.
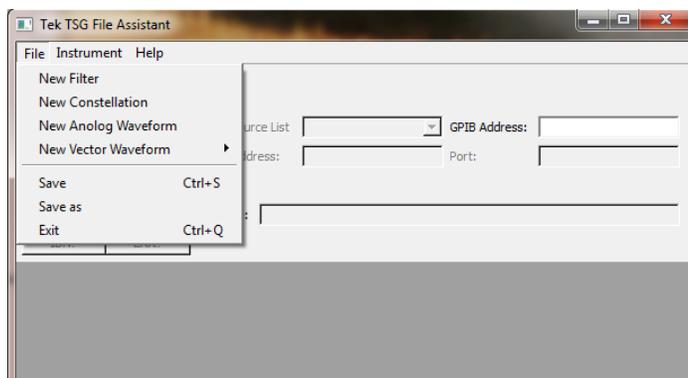
6. Do the following depending on the type of data you have:

Filter. To create a new filter file, do the following:

a. Select **New Filter** from the **File** menu.

b. Click the **Load Raw Data From File** button to open the *.txt file containing the filter data.

NOTE. The raw data format should be a number and then a comma and then a number, as shown in the following image. Once the data is loaded, you can also add or edit the data in the new filter window.

---
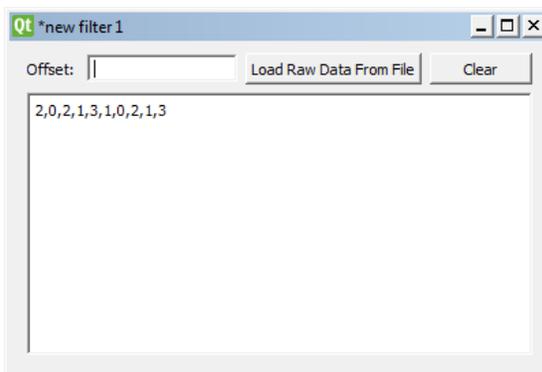
c. Enter the offset value in the **Offset** field.

Constellation. To create a new constellation file, do the following:

a. Select **New Constellation** from the **File** menu.

b. Click the **Load Raw Data From File** button to open the *.txt file containing the constellation data.

NOTE. The raw data format should include number pairs that define a point. Points should be listed one per line, as shown in the image below. Once the data is loaded, you can also add or edit the data in the new constellation window.
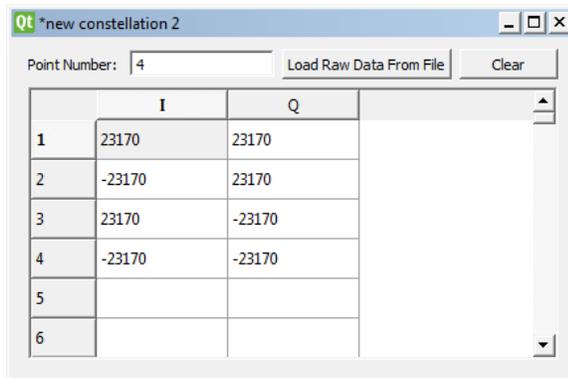
NOTE. There is a 520192 row maximum. More than 520192 rows will cause an error to occur.

Analog waveform. To create a new analog waveform file, do the following.

a. Select **New Analog Waveform** from the **File** menu.

b. Click the **Load Raw Data From File** button to open the *.txt file containing the waveform data.

NOTE. The raw data format should be a number and then a comma and then a number, as shown in the following image. Once the data is loaded, you can also add or edit the data in the new filter window.
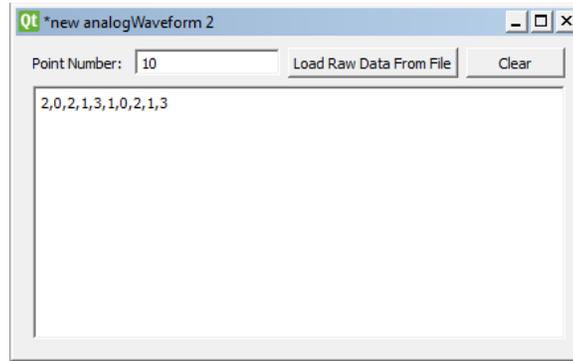
Vector waveform. To create a new vector waveform file, do the following.

a. Select **New Vector Waveform** from the **File** menu.

b. Select **Symbol** or **IQ Data**.

c. Click the **Load Raw Data From File** button to open the *.txt file containing the waveform data.

d. If you selected **Symbol**, then enter the Bits/Symbol value after the data has loaded.

NOTE. The raw data format should be a number and then a comma and then a number, as shown in the following image. Once the data is loaded, you can also add or edit the data in the new waveform window.

TSG4100A Series RF Signal Generators User Manual
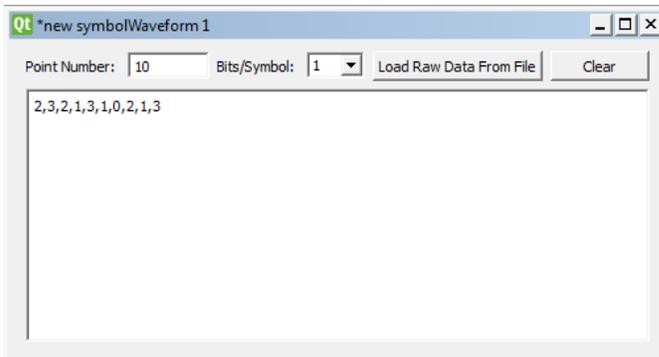
e. If you selected **IQ Data**, you do not need to enter anything after the data has loaded.

NOTE. *The raw data format should include number pairs that define a point. Points should be listed one per line, as shown in the following image. Once the data is loaded, you can also add or edit the data in the new waveform window.*
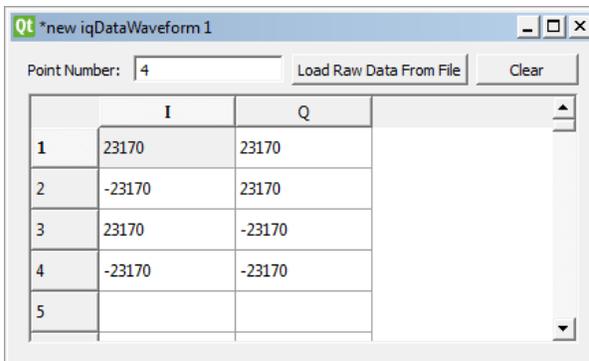
7. To send or save the new file, do one of the following:

- To send the new file to the generator, select **Instrument** > **Send To** and select the desired User number.

  This number will determine where the file will be saved in the generator. For example, if you select 0, then the new file will be saved to the location in the generator that is associated with that User Number. In the image of the generator display below, the <Empty> field next to the 0 would disappear.
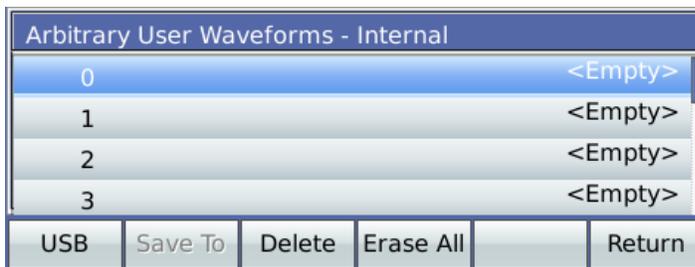
- To save the file, select **File** > **Save** (or Save As) and save the file to location 1 through 9 in the generator.

Arbitrary user waveforms

NOTE. See the TSG4100A Series RF Signal Generator Programmer Manual for detailed information about remote programming commands. It is available for download at www.tektronix.com/manuals.

NOTE. You can use the TGS File Assistant utility software to download supported file types of arbitrary user waveforms to the generator when it is connected to the Ethernet through a LAN connection. (See page 58, Using the file Assistant utility software.)

The generators support two different formats for arbitrary user waveforms: as a stream of digital bits, or as a series of 16-bit I/Q values. The former is much more efficient than the latter and is the preferred choice, if possible. In both cases, data is transmitted in 16-bit chunks with the following command:

WRTW i, j, <arb data>

Parameter i is a 32-bit value indicating the configuration format of the user data. The configuration bits are described in the following table.

Table 11: Arbitrary waveform configuration word

Bit	31-9	8	7-6	5-0
Meaning	reserved	analog	reserved	bits/symbol

Bits/symbol may be one of the values 1 to 9, 16, or 32. Use 32 for vector waveforms consisting of 16-bit, IQ value pairs that bypasses the symbol reader and constellation mapping. Use 16 for analog and vector waveforms that bypass the symbol reader and constellation mapping. Bit 8 should be set if the waveform is intended for analog modulation. All other bits should be cleared.

Parameter j is a 32-bit value indicating the total number of bits in the waveform.

<arb data> contains the binary data representing the data and it must contain an even integer number of bytes. Waveforms have a minimum size of 16 bits and are played back from MSB to LSB. If a waveform does not end on a 16-bit boundary, the least significant bits of the last word in the waveform will be ignored. For example:

WRTW 4, 28, #14XXXX

The first parameter indicates that the waveform consists of 4-bit symbols for vector modulation. The second parameter indicates that there are 28 bits in the total waveform. The third parameter indicates that 4 bytes, or 32-bits, of binary data are transmitted. Since the full waveform consists of 28 bits, the 4 least significant bits of the last 16-bits of transmitted data will be ignored. 4 bytes are transmitted because this is the minimum even integer of bytes which fully contains the waveform.

User constellations

NOTE. You can use the TGS File Assistant utility software to download supported file types of user constellations to the generator when it is connected to the Ethernet through a LAN connection. (See page 58, Using the file Assistant utility software.)

The generators have the ability to process pure digital data by dynamically mapping digital symbols into IQ constellation points in real time. The symbol mapping is quite versatile and can easily accommodate differential encoding and rotating coordinate systems. The mapping is performed with the data from two tables stored in RAM: a symbol table, and a symbol set table. The basic architecture is diagrammed here. (See Figure 12.)
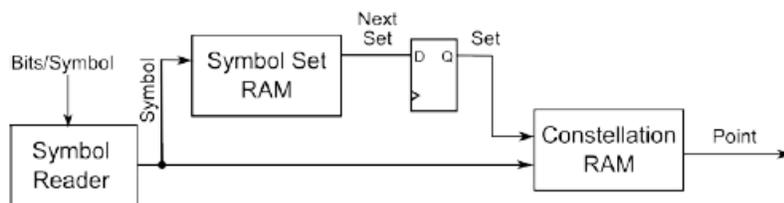
Figure 12: Architecture for mapping digital symbols into IQ constellation points

The constellation RAM is 1kW in size which provides space to define up to 512, 32-bit, IQ constellation points with each point allocating 16 bits for I and 16 bits for Q. Associated with each symbol is a symbol set. Thus, the constellation RAM is accompanied by 512 bytes of symbol set RAM which defines the symbol set to associate with the following symbol.

The constellation RAM is accessed with a 9-bit address that is the concatenation of a $(9 - N)$-bit symbol set and an N-bit symbol. The address is computed from the current symbol and set with the equation:

constellation address = (symbol + set × 2N) mod 512

where N is the number of bits per symbol. As an example, suppose the symbol reader is reading in 2-bit symbols and that the current symbol is 3 and that the current symbol set is 5. The symbol will be mapped to the constellation point stored at address $3 + 5 \times 2^2 = 23$. At startup the first symbol set is initialized to zero.

For simple constellations, symbol set RAM is cleared and the symbol maps directly to a constellation point. For a constellation that rotates by $\pi/4$ after each symbol, we will have 8 different constellations before the constellation has rotated by exactly 2π. For N-bit symbols, the rotation is accomplished by filling symbol set RAM with 2N 1s, followed by 2N 2s, followed by 2N 3s, etc until we reach 2N 7s, followed by 2N 0s. For differential encoding, the encoding of the next symbol is determined by the previous symbol. In this case, each symbol gets mapped to a different constellation, and so we have 2N different constellations.

For each user constellation, two parameters must be declared: bits/symbol and whether the I and Q points in the constellation are to be staggered or not. Most constellations do not operate in staggered mode; both I and Q points enter their respective pulse shaping filters simultaneously. Staggered mode is required for offset modulation in which the Q values shift into their filter half a symbol after the I values have shifted.

User constellations are downloaded into SRAM with the following command: WRTC i, j, <arb data>. Parameter i indicates the number of bits/symbol, N. It will normally range from 1 to 9. A value of 16 or 32 is accepted to enable staggered modulation when constellation mapping is bypassed. Parameter j indicates whether staggered operation is desired. Set j = 1 for staggered operation, otherwise set j = 0. <arb data> should be a definite arbitrary block with 2560 bytes of binary data. The <arb data> block is organized as 512 32-bit IQ pairs followed by 512 bytes of symbol set data. Each 32-bit IQ pair consists of a 16-bit I value followed by a 16-bit Q value in a big-endian format.

NOTE. *You can read more about big-endian byte order and downloading binary data here. (See page 58.)*

Constellation example   As an example, we will compute the constellation for QPSK with the symbol mapping defined in the following figure.

QPSK (2-Bit)
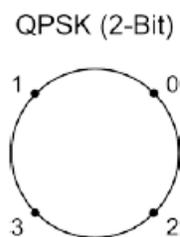
The points lie on a circle of constant amplitude. The radius of the circle is 32767. Thus, we can compute the IQ coordinates as shown in the following table.

Table 12: QPSK constellation point computations

Symbol	Formula	Value	Hex values
0	32767 (cos(π/4), sin(π/4))	(23170, 23170)	(5A82, 5A82)
1	32767 (cos(3π/4), sin(3π/4))	(–23170,23170)	(A57E, 5A82)
2	32767 (cos(7π/4), sin(7π/4))	(23170,–23170)	(5A82, A57E)
3	32767 (cos(5π/4), sin(5π/4))	(–23170,–23170)	(A57E, A57E)

Note that we need only define 4 constellation points. All others may be set to zero, since they will not occur for 2-bit waveforms. Furthermore, since the constellation does not change from symbol to symbol, we should zero out all symbol set RAM as well.

Combining all this information together we can synthesize the following command to download the constellation:

> WRTC 2, 0, #42560<5A 82 5A 82 A5 7E 5A 82 5A 82 A5 7E A5 7E A5 7E…><NL>

The first parameter indicates this is a 2-bit constellation. The second parameter indicates that the IQ values are not staggered. The third parameter indicates that we are transmitting 2560 binary bytes. The portion inside the brackets shows the first 16 bytes of the transmission. These bytes represent our 4 constellation points. The following 2544 bytes are all zero. The brackets are not part of the transmission. Finally, all commands must be terminated with a semicolon, a carriage return <CR>, or a new-line <NL>. This command is no exception. Thus, a <NL>, which has the hexadecimal value 0x0A, follows the 2560 binary bytes.

User filters

NOTE. You can use the TGS File Assistant utility software to download supported file types of user constellations to the generator when it is connected to the Ethernet through a LAN connection. (See page 58, Using the file Assistant utility software.)

This instrument provides built-in support for several commonly used digital filters. You also have the option to download custom filters. The filters have 24 symbols of memory and are defined with an oversampling ratio of 128, which means they are composed of $24 \times 128 = 3072$ coefficients. The large oversampling ratio is a consequence of the fact that the filters also play an integral part in the re-sampling of waveforms being played back at an arbitrary rate. Large oversampling ratios enable accurate re-sampling with simple, linear interpolation in a Farrow filter structure.

Internally, filter coefficients are stored with 17 bits of precision, but transmitted with 16 bits of precision along with a global 16-bit offset. This helps facilitate the binary transfer without compromising overall precision. Coefficients should be scaled so that the 17-bit value +32768 is equivalent to 1.000.

Most filters are symmetric and peak at the center, but these are not requirements. However, the event markers and TDMA control engine within the FPGA assume a 12 symbol latency for the filter. Filters shorter than 24 symbols are easily accommodated by padding the filter with zeros at the beginning and the end.

Reference

Phase noise and offset diagrams

TSG4102A/4104A SSB Phase Noise vs Offset Frequency

TSG4106A SSB Phase Noise vs Offset Frequency
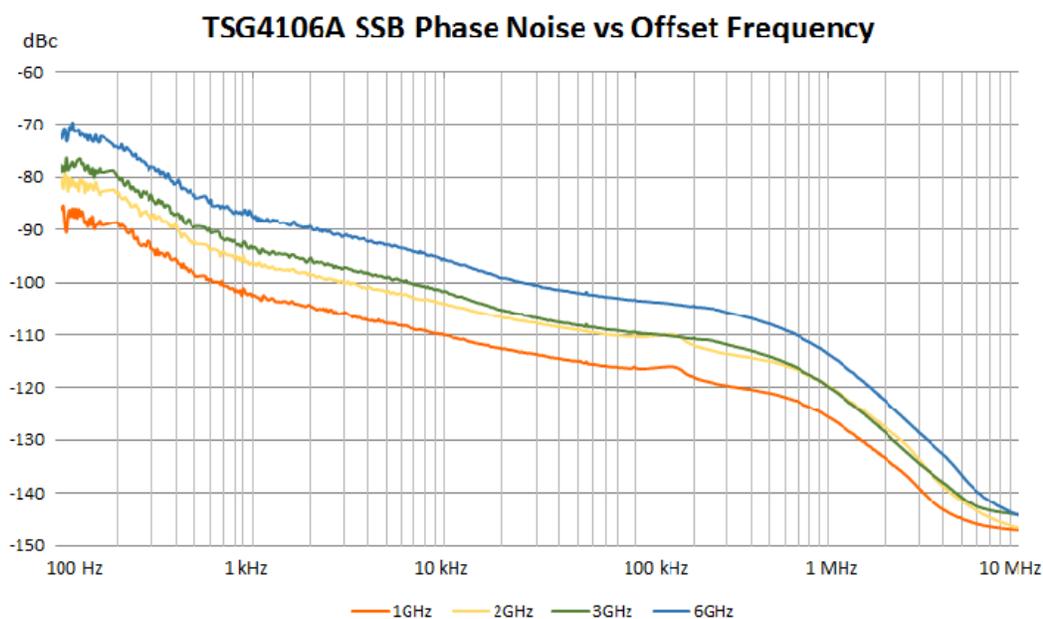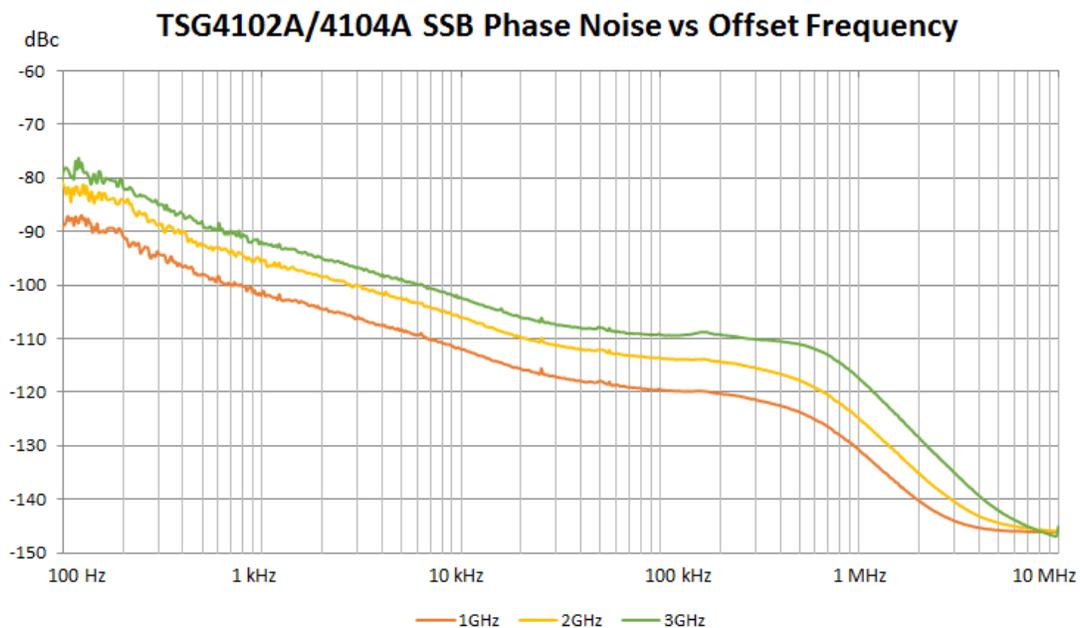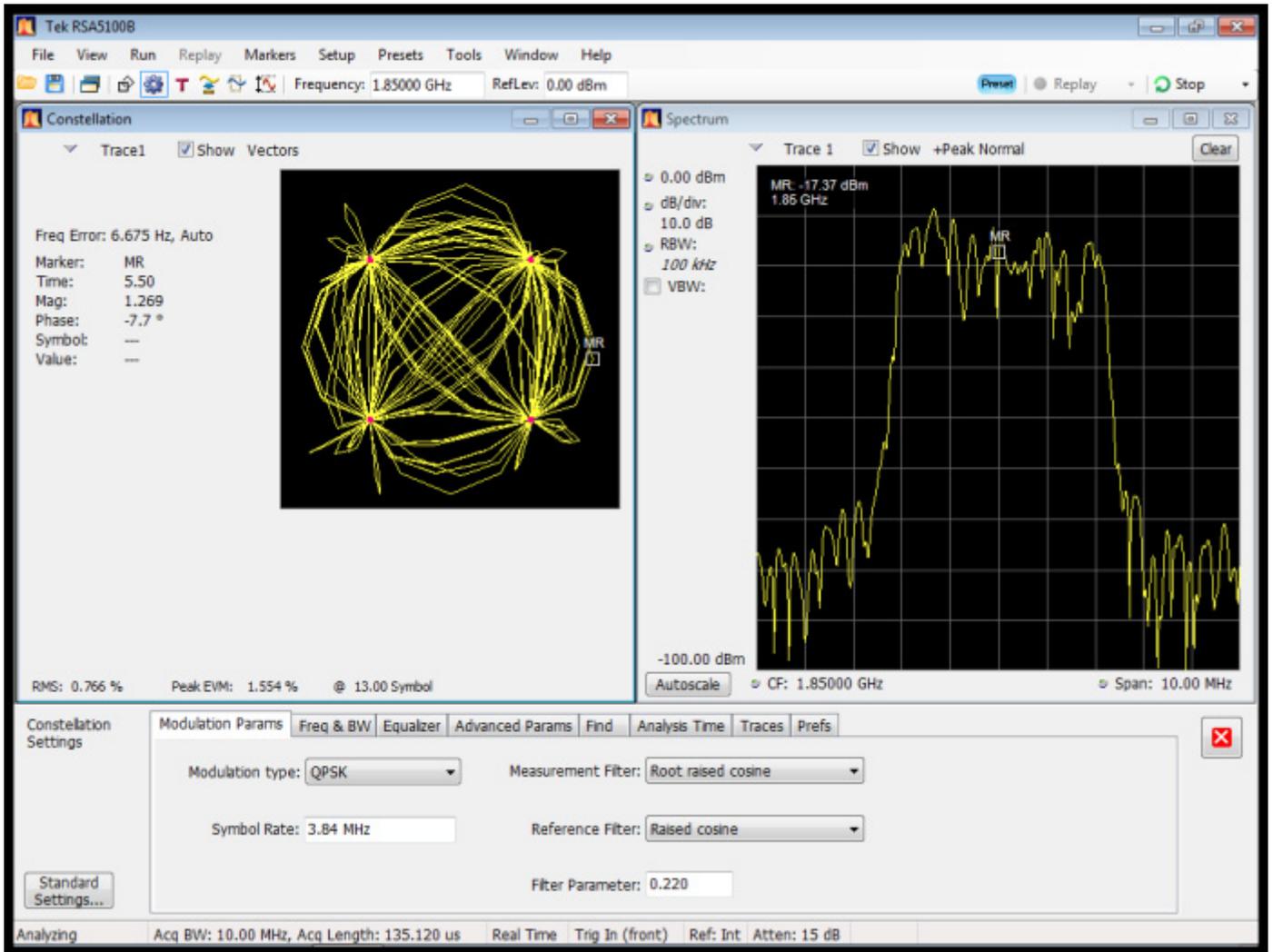
Figure 13: QPSK,3.840Mcps, 1.85 GHz, 0dBm), RMS EVM: 1.7%
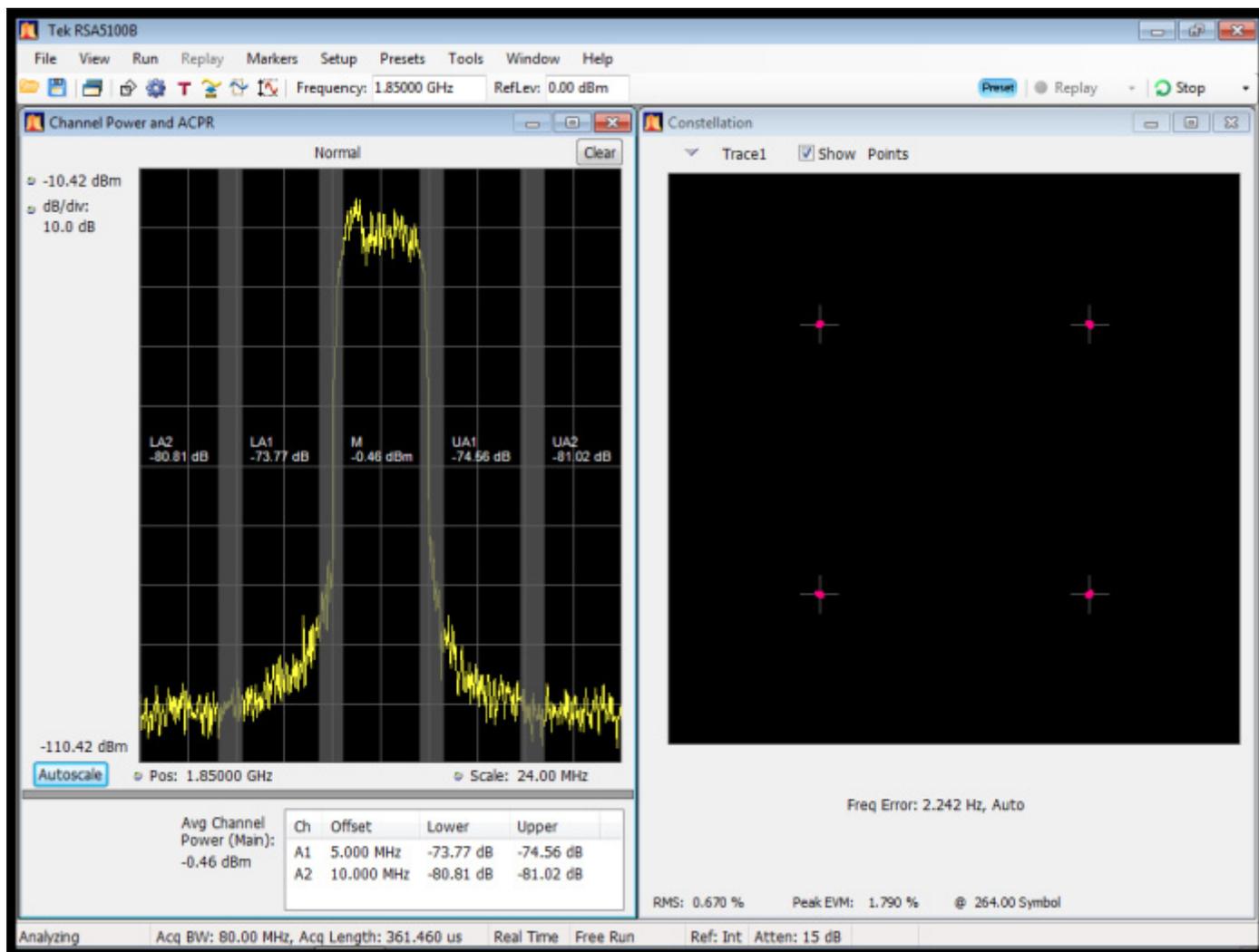
Figure 14: Image 2, QPSK,3.840Mcps, 1.85 GHz, 0dBm), RMS EVM: 1.7%
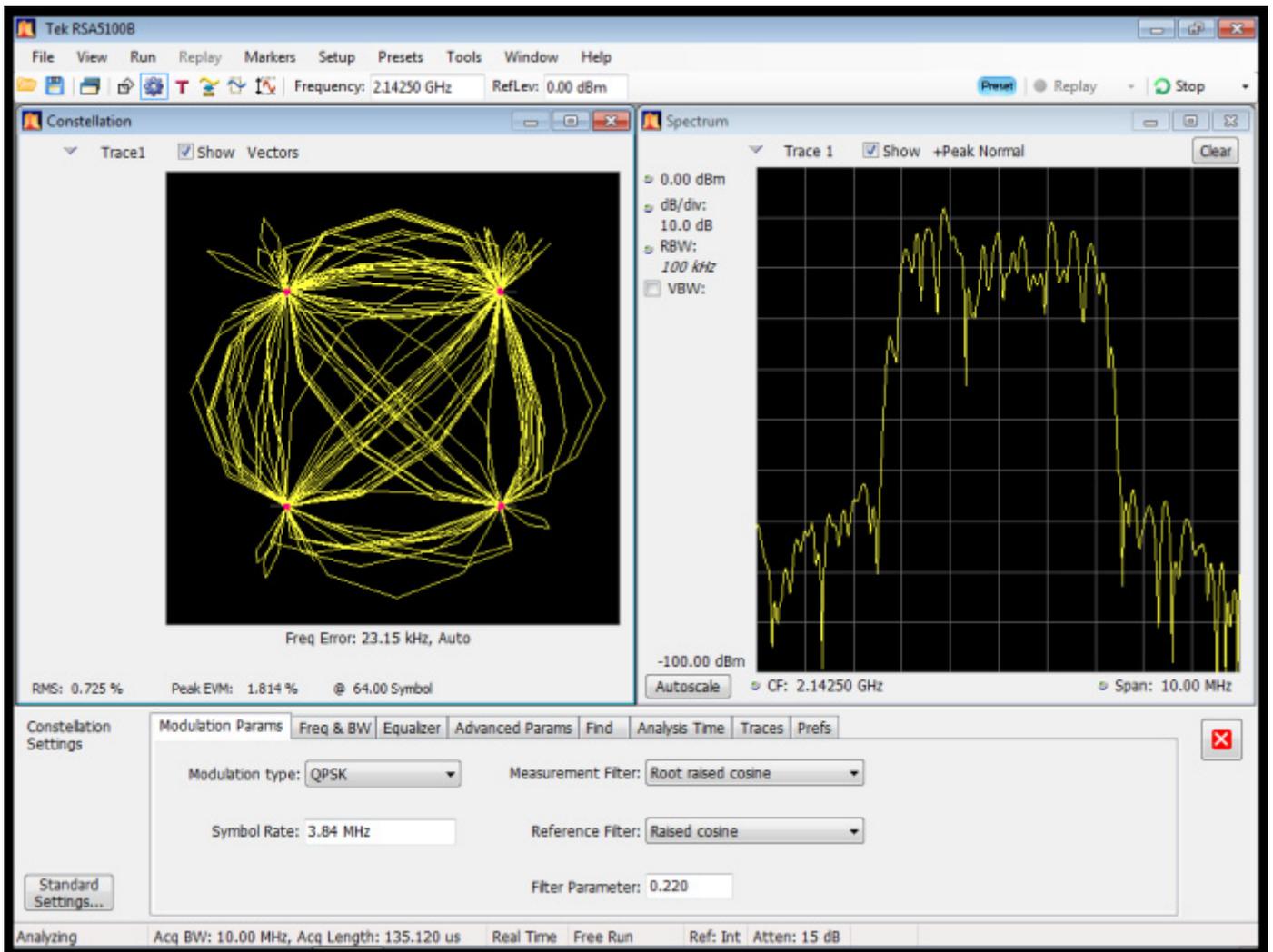
Figure 15: Option VM03 W-CDMA, (QPSK,3.840Mcps, 2.1425GHz, 0dBm), RMS EVM: 1.7%
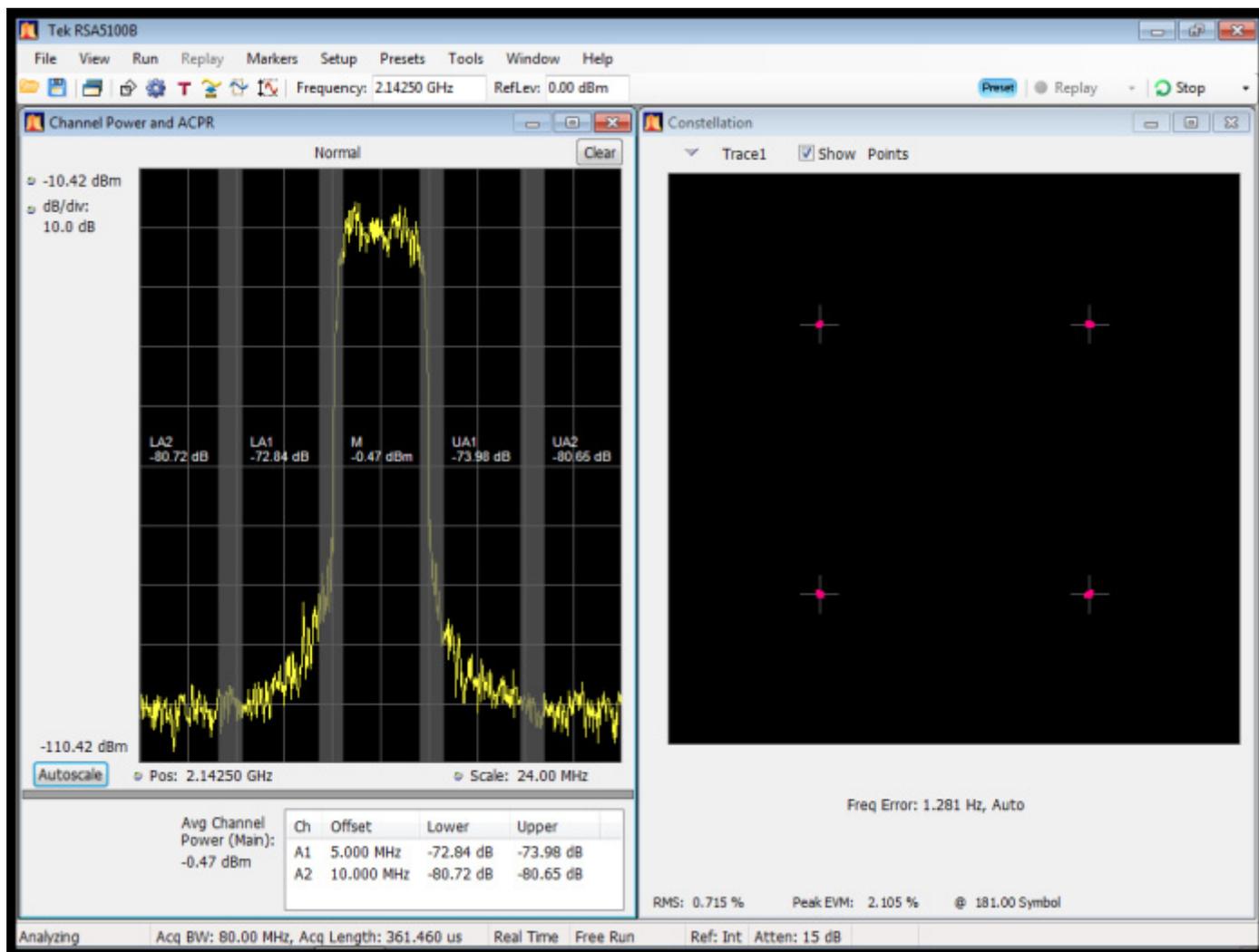
Figure 16: Image 2, Option VM03 W-CDMA, (QPSK,3.840Mcps, 2.1425GHz, 0dBm), RMS EVM: 1.7%
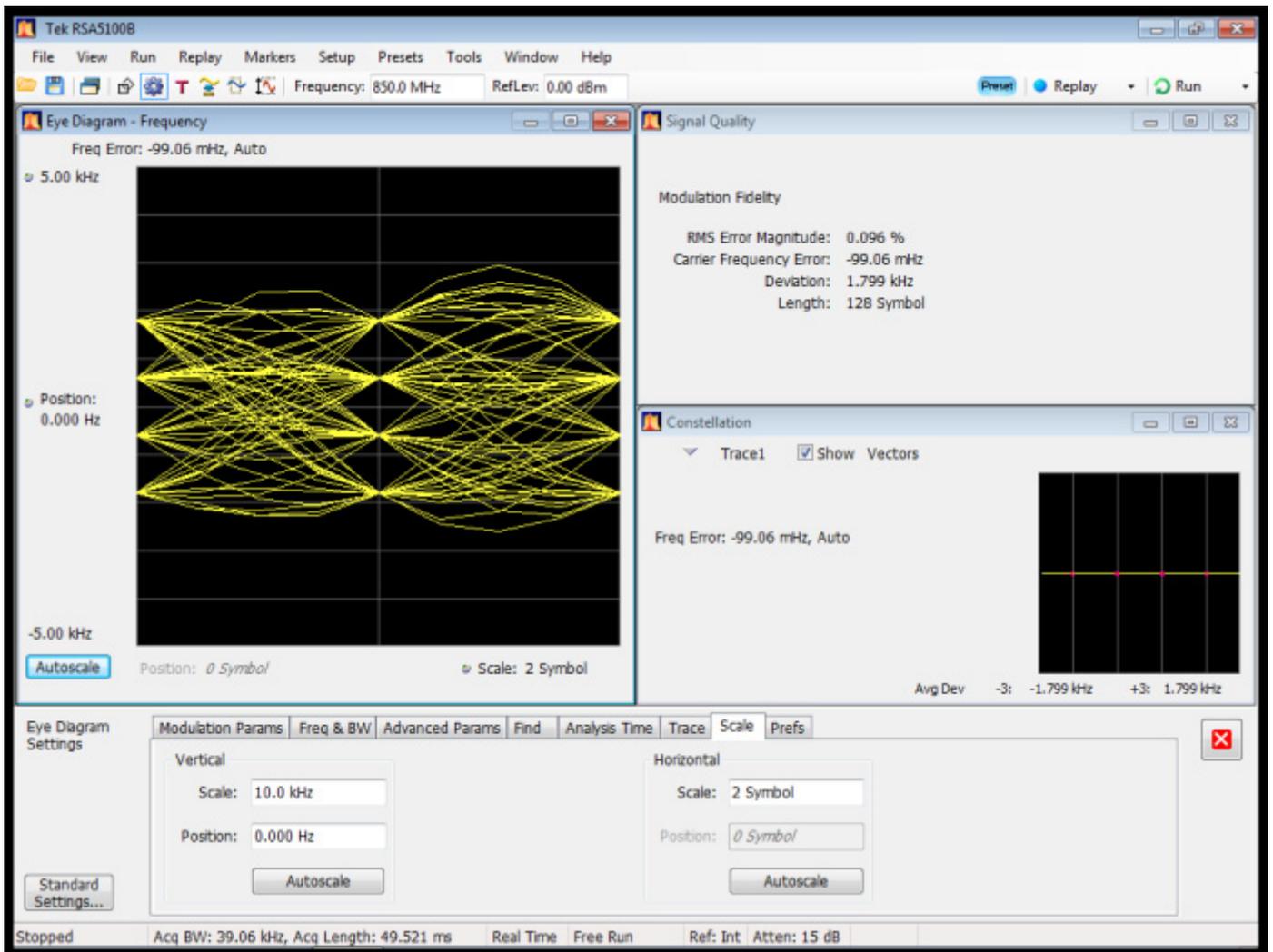
Figure 17: Option VM04 APCO-25, (4FSK-C4FM,4.8KS/s,850MHz, 0dBm), Freq Err: 0.5%
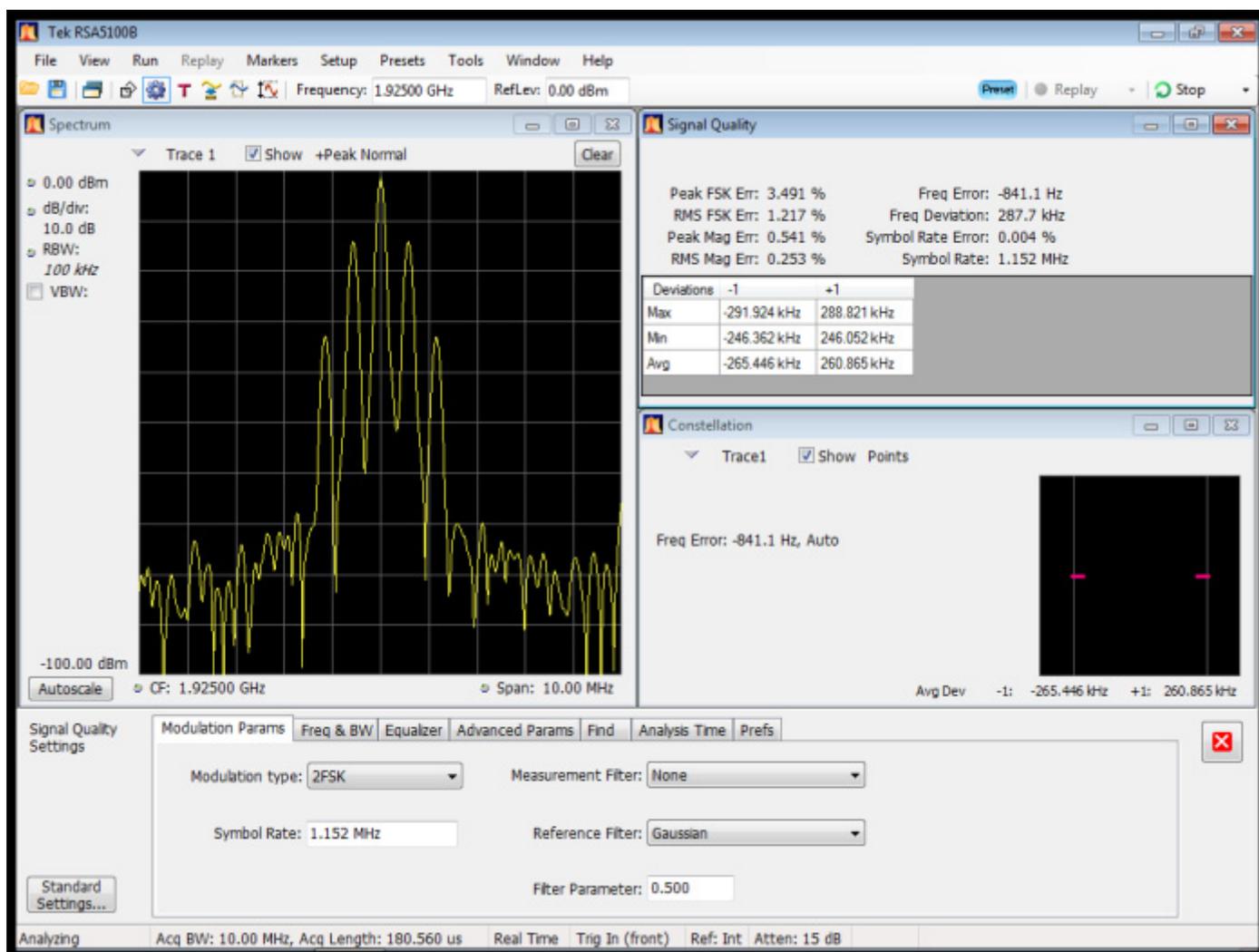
Figure 18: Option VM05 DECT, (2FSK1.152Mbps,1.925GHz, 0dBm), RMS FSK Err: 1.5%
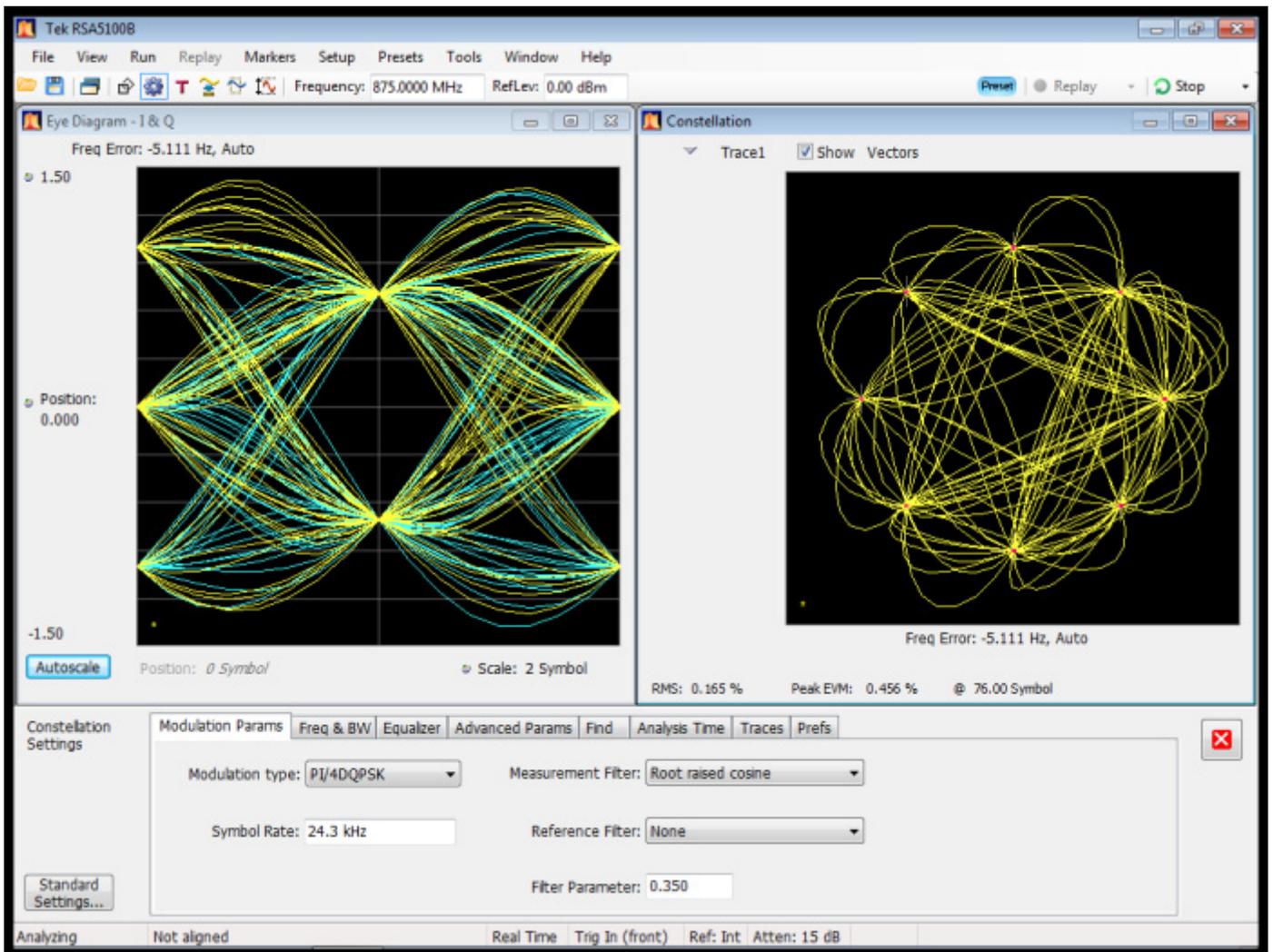
Figure 19: Option VM06 NADC, (π/4 DQPSK,24.3KS/s,875MHz, 0dBm), RMS EVM: 0.3%
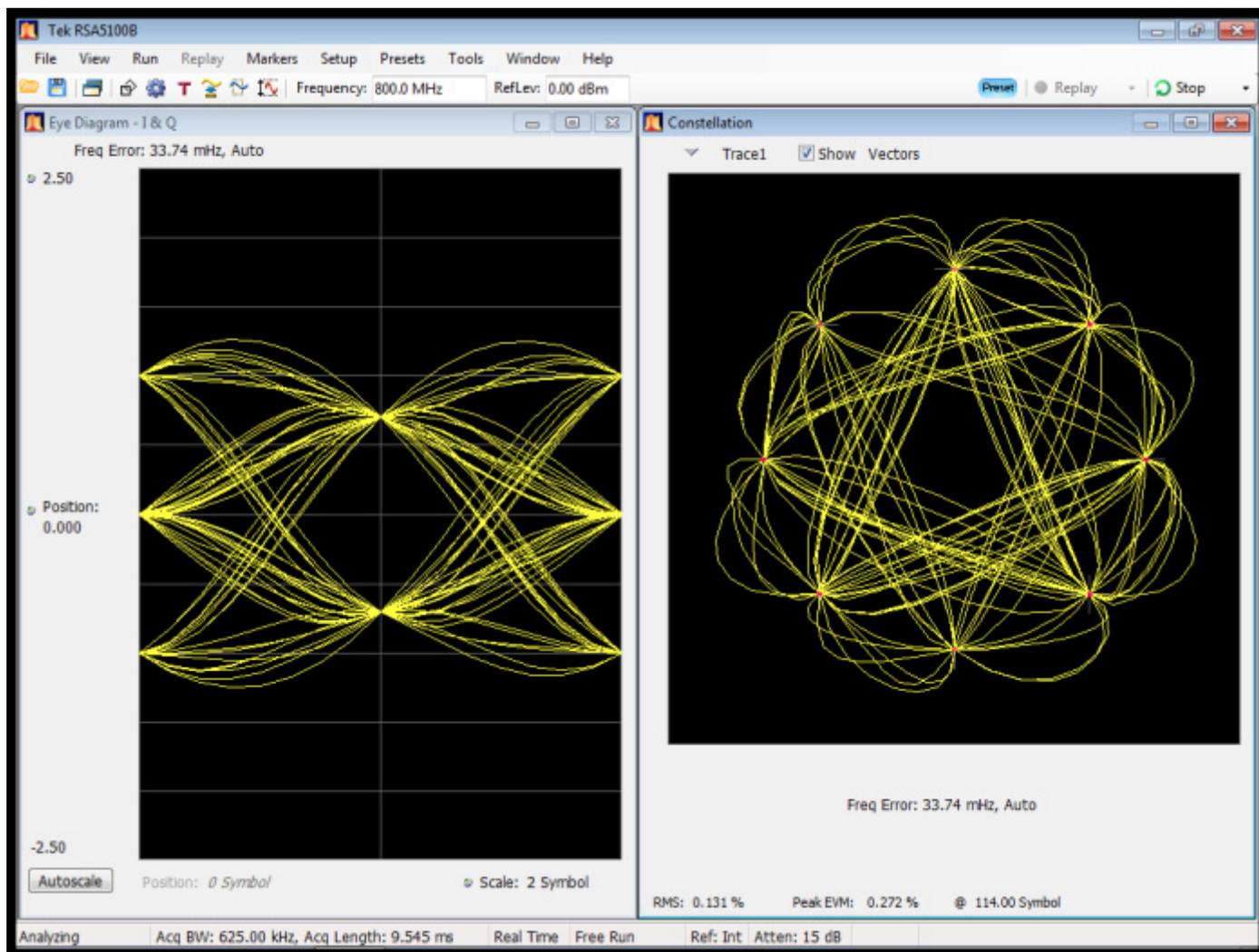
Figure 20: Option VM07 PDC, (π/4 DQPSK,21KS/s, 800MHz,0dBm), RMS EVM: 0.6%
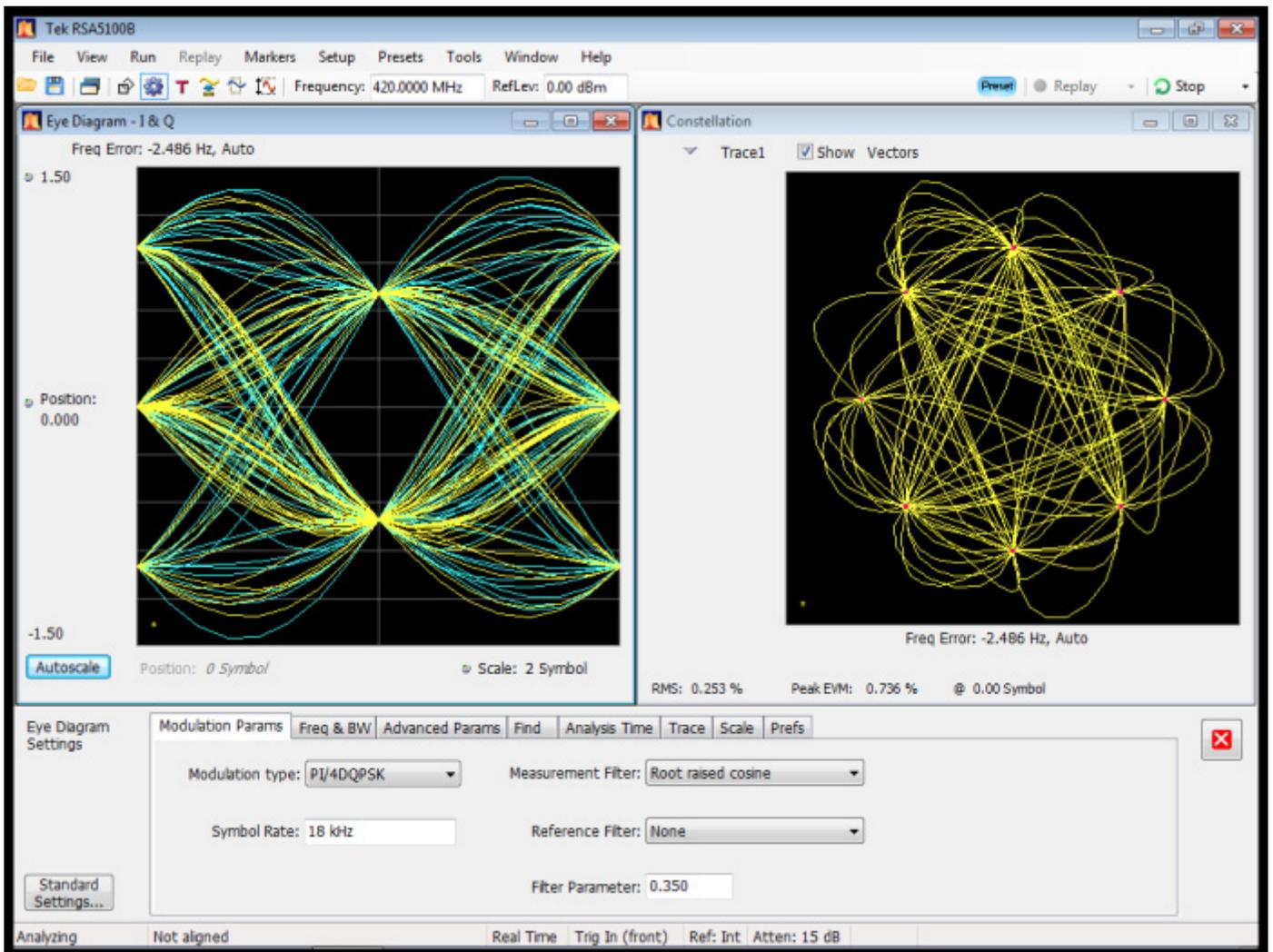
Figure 21: Option VM08 TETRA, (π/4 DQPSK,18KS/s, 420MHz, 0dBm), RMS EVM: 0.7%

Index

A

Accessories
    documents, 1
    optional, 2
    power cords, 1
    standard, 1
Amplitude, 27
    modulation, 33
    to change, 25
Analog mod in, 14
Analog mod out, 13
Arbitrary user waveforms, 30, 66
Arbitrary waveform
    modulation, 32
Arbitrary waveforms
    user, 66
ASK
    digital constellations, 45
ASK (amplitude shift keying), 45
AWGN (additive white Gaussian
    noise), 51

B

Backlight, 20
Basic constellations
    PSK, 48
Big-endian byte order, 58
Binary data, 57
BMP file
    save image of display as, 15
BNC, 15

C

Cable, 1
Cleaning procedures, 9
Connector
    Analog mod in, 14
    Analog mod out, 13
    symbol clock, 13
    Vector mod in I, 13
    Vector mod in Q, 13
    Vector mod out I, 13
    Vector mod out Q, 13

Connectors
    front panel, 11
    rear panel, 13
Constellation files
    accessing, 21
Constellations, 38
    QAM, 49
    user, 67
    VSB, 51
Controls, 10
    interface, 15
CPM
    Phase trellis diagram, 49
CPM (continuous phase
    modulation), 48
Custom modulation presets, 30
Custom modulation setups, 30

D

Date
    setting, 20
Differential encoding of
    symbols, 52
Digital communication, 37
Digital constellations
    ASK, 45
    FSK, 46
    PSK, 47
Display, 15
    save a screen shot of, 15
Documentation, x
    Tektronix part numbers, 1
Downloading files
    TSG File Assistant, 58

E

Error codes, 23
Error log, 36
Error messages, 15
Error vector magnitude, 44
Ethernet, 3, 20
Event outputs, 13
EXT, 15

External IQ modulation, 52

F

Factory default settings
    preset, 24, 28
File Assistant, 58
Filter files
    accessing, 21
Filters, 40, 41
    common pulse shaping, 41
    Gaussian, 43
    pulse shaping, 41
    raised cosine, 41
    root-raised cosine, 42
    user, 69
Firewall
    internet network security, 4
Firmware
    upgrade, 22
Firmware upgrade, 6, 22
Flash, 58
Frequency, 27
    modulation, 34
    to change, 25
Front panel
    buttons, 10
    connectors, 11
    controls, 10
FSK, 34
    digital constellations, 46
FSK (frequency shift keying), 46
Functional check, 24

G

Gaussian
    filter, 43
General knob
    press to select, 26
GMSK (Gaussian minimum shift
    keying), 50
GPIB, 5, 14

H

Help, x

I

Incoming inspection, 8
Index
    modulation, 50
Inputs, 12, 13
Installation, 1
Instrument
    options, 2
Internet, 20
Intersymbol interference, 40

K

Key
    install option, 22

L

LAN, 3, 14
LF Out, 27
License
    manage, 22
Linear
    modulation, 30
Linear noise
    modulation, 31

M

Maintenance
    cleaning procedures, 9
    repackaging, 9
Manuals, x
Menu
    accessing, 15

Menus, 15, 16
    About, 22
    analog, modulation type, 17
    AWGN/IMP, 18
    Constellation, 17
    Customized filters, 18
    Customized source, 18
    Error code, 23
    File, 21
    Filter, 18
    Firmware upgrade, 22
    GPIB, 19
    I/O Interface, 19
    LAN, 20
    Main, 16
    Mod (modulation), 16
    Mod (modulation) Type, 17
    navigating, 15
    Noise submenu, 18
    presets, modulation type, 17
    RF/LF, 16
    RS232, 19
    Self Test, 20
    Source, 18
    Status, 21
    System, 20
    USB, 23
    Utility, 18
    vector, modulation type, 17
Mod button, 28
Modulation
    amplitude, 33
    arbitrary user waveforms, 30
    available presets, 17
    custom user presets, 30
    frequency, 34
    linear, 30
    linear noise, 31
    outputs, 33
    Phase, 35
    presets functional check, 25
    pulse, 31
    pulse noise, 32
    sources, 30
    user arbitrary waveform, 32
    user presets, 30
    vector, 38

Modulation deviation, 56
Modulation index, 50
Modulation presets, 28
Modulation rate, 56
Modulation technique
    ASK, 45
    AWGN, 51
    CPM, 48
    External IQ, 52
    FSK, 46
    GMSK, 50
    MSK, 50
    PSK, 47
    QAM, 49
    VSB, 51
MSK (minimum shift keying), 50

N

Navigation, 25
    general knob, 26
Network connections, 3
Noise (AWGN), 28

O

Offset
    I/Q, 27
    LF, 27
Offset or staggered
    modulation, 53
Optional accessories, 2
Options
    GPIB, 19
    install key, 22
    instrument, 2
    Power cords, 1
    software, 3
Outputs, 13
    Event, 13
    LF, 12
    modulation, 33
    RF, 12

P

Part numbers, manuals, 1
Part numbers, media (CD), 1
Pattern data, 56