HIGHLAND TECHNOLOGY

T344 and T346

EMBEDDED WAVEFORM

GENERATORS

Technical Manual

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Contents

1 Introduction

This is the technical manual for revision D of the Highland Model T344 and T346 four-channel waveform generator modules.

Features of the T344 and T346 include:

- Four programmable channels of independent or synchronized sine, sawtooth, triangle, Gaussian noise, or square/pulse/PWM waveform generation
- Channels may be synchronized for coordinated polyphase or time-sync'd signals at same or ratio frequencies
- Multiple T344 or T346 units may be synchronized
- Programmable channel summing
- 4096-point arbitrary waveform memory per channel
- Output frequency range 0 to 32 MHz with 0.015 Hz resolution
- Up to 10.24 volts peak-to-peak output, programmable 5:1 attenuation and DC offset
- Programmable offset allows wave+offset or direct DC DAC functionality
- Programmable channel phase allows generation of quadrature or polyphase waveforms
- Programmable digital pulse/PWM outputs can simulate transducers or quadrature encoders
- RS-232 and Ethernet interfaces
- TTL connector allows external trigger inputs or channel resets
- SYS connector allows clock and channel synchronization over multiple units
- Includes channel test connector, allowing in-system check of channel performance without removing field wiring
- Test output and built-in self-test (BIST) are included
- Compact standalone, embeddable packaging

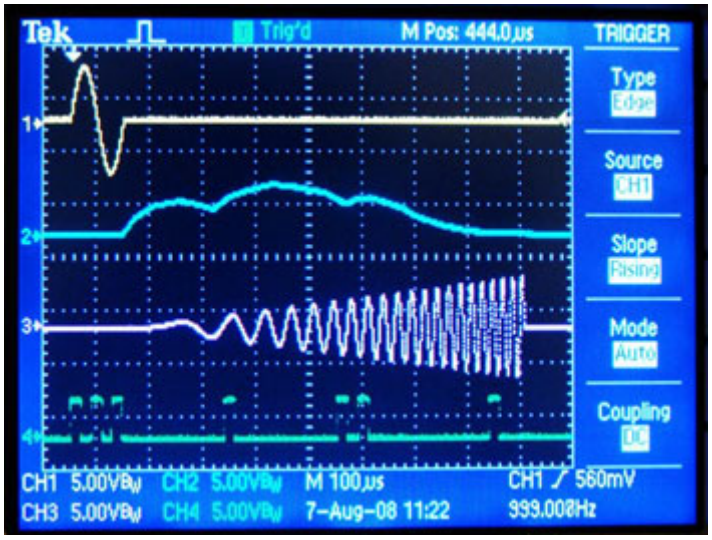
Additional features of the T346 version:

- Four additional internal wave generators are available as modulation or summing sources
- Complex modulations: AM, FM, PM, PWM
- Programmable sequencing up to 4096 steps

Other related products are available:

- T340: 2 MHz 4-channel waveform generator
- V340: 8-channel VME function generator with transformer coupling
- V344: 8-channel VME 32 MHz arbitrary waveform generator
- V346: 8-channel VME 32 MHz arbitrary waveform generator with complex modulation

This manual applies to the standard T344-1 and T346-1 versions, which include both RS-232 and Ethernet interfaces.



2 Specifications

FUNCTION	4-channel arbitrary waveform generator
STANDARD WAVEFORMS	Sine, sawtooth, triangle, Gaussian noise, or square/pulse/PWM outputs
ARBITRARY WAVEFORM	4096 point, 16 bit user-loadable arbitrary waveform with programmable hardware interpolation
SIGNAL SWING	Normal range: ±5.12 V ±1% Attenuated range: ±1.024 V ±1%
IMPEDANCE	50 Ω nominal output impedance
DC OFFSET	± 2 mV typ, 15-35°C ± 10 mV max, 0-60°C
GAIN ERROR	± 0.5 % max
FLATNESS	-0.1 dB at 12 MHz typical -1 dB at 32 MHz typical -3 dB at 46 MHz typical Amplitude rolls off monotonically with frequency
DAC RESOLUTION	14 bit DAC output resolution
FREQUENCY RANGES	High range: 0 to 32 MHz with 0.0149 Hz resolution Mid range: 0 to 4 MHz with 0.0018 Hz resolution Low range: 0 to 250 KHz with 116 µHz resolution Extra range usable to 40 MHz
GAUSSIAN NOISE	Programmable amplitude 0 to 1 V RMS, programmable 3 dB bandwidth 0 to 2 MHz
PHASE SHIFT	1/65536 cycles ≈ 0.0055°
PWM DUTY RESOLUTION	1/65536 = 0.0015%
SUMMING	Any channel may be summed with the output of channel 1 to 3 (1 to 7 on the T346), cascadable in any groupings Sums may be modulation sources (T346 only)
MODULATION (T346 ONLY)	Any channel may be amplitude, frequency, phase, or PWM modulated by the outputs of channels 1 to 7, in any combination

MODULATIONS (T346 ONLY)	Channel to channel AM, FM, PM, PWM Internal channels 4 to 7 may be used as modulation and summing sources
FREQUENCY ACCURACY	Frequency ± 20 PPM Lockable to external 10 MHz source
COMMUNICATIONS	RS-232 standard, 38.4 kbaud 10/100 Ethernet
CONNECTORS	Signals, SMB jacks Power, 2.5 mm coaxial, center positive RS-232 and alternate power, D9 female Ethernet RJ45
CALIBRATION INTERVAL	One year
POWER	+12 V, 750 mA max J12 12 volt power supply adapter furnished
PACKAGING	4.75" (L) x 4.05" (W) x 1.25" (H) extruded aluminum enclosure
CONFORMANCE	OEM product has no UL/FCC/CE compliance requirements Designed to meet UL/FCC/CE requirements Power adapter furnished is UL/CE certified

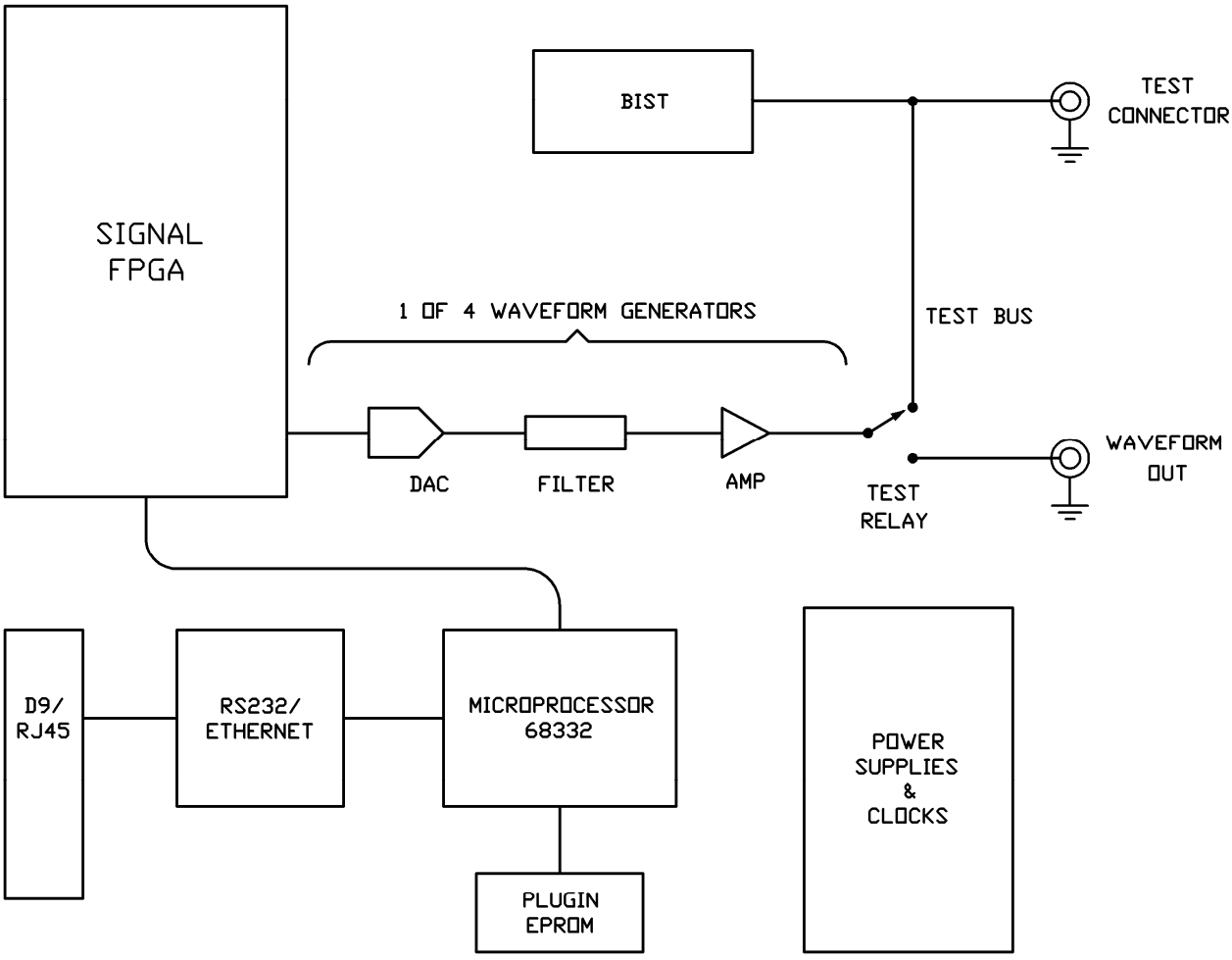
3 Overview

The T344/T346 includes 4 independent DDS-based waveform generators, referred to as channels 0, 1, 2, and 3. The T346 adds four additional internal channels: 4, 5, 6, and 7, which have no electrical outputs but can be used as modulation, summing, or control sources.

An internal microprocessor manages all data I/O and communicates via an RS-232 interface or 10/100 Ethernet.

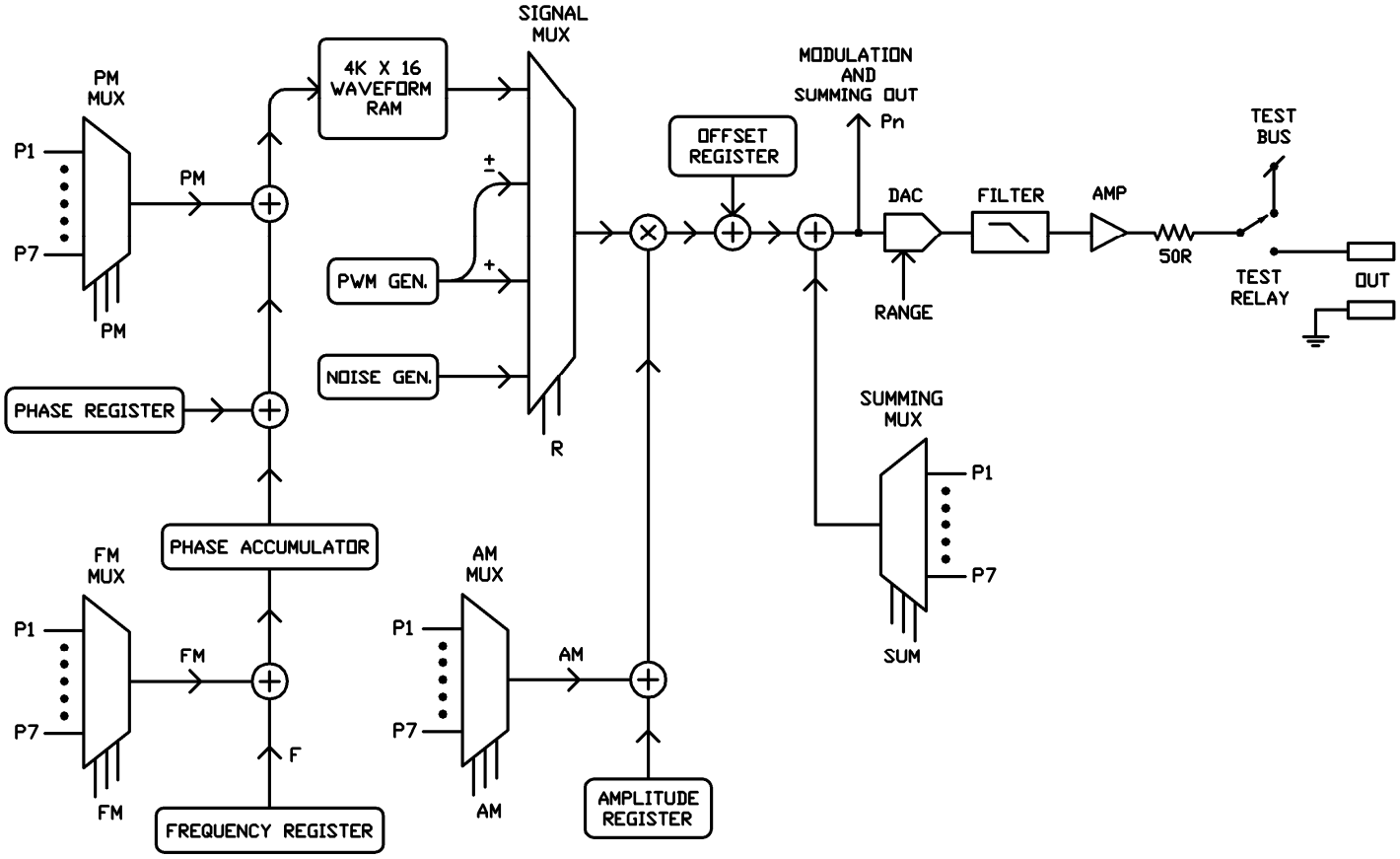
Relays are provided to reroute channel 0-3 outputs to the internal test bus, thence to the BIST block for self-test, or to the dedicated SMB test connector for external calibration checks without disrupting field wiring.

The overall block diagram is shown below:



Waveforms are generated by direct digital synthesis. A 32-bit phase accumulator is clocked at 128 MHz, advancing in phase by a programmable amount. The most significant 12 bits of the advancing phase word is passed through a 4K x 16 bit waveform lookup table, synthesizing a sine, triangle, or sawtooth wave, or a user-loaded arbitrary waveform. The output of the lookup table is amplitude scaled by digital multiplication, offset by an adder, and then drives a 14 bit D/A converter. The DAC output is then lowpass filtered and amplified to become the channel output.

The scale factor of each DAC is programmable X1 or X0.2, allowing low-level outputs to be generated at full 14-bit DAC resolution. Channel logic is shown below. Only the T346 version includes the modulation hardware.



Each channel also incorporates a pulse/PWM generator that may be substituted for the waveform lookup table. The PWM logic generates a waveform of variable duty cycle and full-scale bipolar swing, which can then be scaled by the amplitude, offset, and X0.2 signal path. Each channel also provides a programmable Gaussian noise generator.

The output stage of each channel consists of a lowpass filter, 50-ohm power amplifier, and a test-bus relay.

4 Connectors and Installation

4.1 Mechanical Installation

The T344/346 mechanical dimensions are shown in section 17. It is preferred that the units be securely bolted to a grounded metal surface. If rear fastener access is not convenient, the T566 mounting flange is available.

The standard versions are not suited to operation in wet or condensing environments.

4.2 Connectors

The T344/346 include the following connectors:

0	SMB jack	channel 0 waveform output
1	SMB jack	channel 1 waveform output
2	SMB jack	channel 2 waveform output
3	SMB jack	channel 3 waveform output
T	SMB jack	test output
CLK	SMB jack	external 10 MHz reference input
TTL	SMB jack	trigger/reset input
SYS	SMB jack	master/slave synchronization input/output
PWR	2.1 x 5 mm	+12 power input
RS-232	D9 female	RS-232 and alternate +12 power
ETH	RJ45 female	Ethernet

4.3 Channel Output Connectors

Connectors "0" through "3" are channel 0 through 3 signal outputs respectively. They are SMB jacks, with active output impedance of 50 ohms and unloaded signal swing as high as +-5.12 volts. Output voltages are reduced by 2:1 when connected to an external 50 ohm load.

4.4 Test Connector

"T" is an SMB jack used for verification of outputs. Under software control, any of the four channel outputs may be diverted to this connector, allowing verification of channel functions and calibration without disconnecting the normal output cables.

4.5 Clock Connector

The CLK connector is an SMB jack used for synchronizing the internal DDS timebase to an external 10 MHz source. Apply a sine or square wave of 0.2 to 5 volts p-p. The external frequency must be 10 MHz +-10 PPM. A bit in the MODCON register enables the external phaselock function, and bits in the CSTAT register indicate the presence of a 10 MHz input and the lock status.

4.6 TTL Connector

"TTL" is an SMB jack input whose function is selected by the TTLS register. It can be programmed to be a channel reset input, a Local Event trigger, or a Global Event trigger. The input signal convention is "TTL", with a threshold typically about 1.75 volts. User logic-low levels should be 0 to +0.8 volts, and logic high should be +2.4 to +5 volts. The input has a 5K pulldown to ground.

4.7 SYS Connector

"SYS" is an SMB jack that can be used to interconnect multiple boxes in a master/slave configuration. Slave units can be programmed to phase-lock their clocks to the master, and to accept Global Events, commands that operate on multiple channels simultaneously. The SYS bus protocol is compatible with the V344 and V346 VME modules, and is suitable for use in coordinating T344/T346 operations with larger system requirements.

4.8 Power Connector

The T344/346 requires +12 volts DC at 0.75 amps max. Typical power consumption is about 0.55 amps, and increases at high signal amplitudes, high output frequencies, and when channels are externally loaded. A wall-plug universal power supply is furnished with the evaluation kit, or users may supply +11 to +13 VDC power. The evaluation power supply with US plug is Highland part number J12. The international AC plug adapter kit is part number J14.

The standard power connector is a 2.1 x 5 mm coaxial power type, center positive. The unit grounds the low side of the power input. DC power can also be supplied to pins 6 (+12) and 9 (ground) of the D9 RS-232 connector.

The power input is protected by a self-resetting polyfuse and a transzorb zener diode, and will withstand reasonable overvoltage or polarity reversal.

4.9 RS-232 Connector

The female D9 connector provides the RS-232 interface and an optional power supply input. The pinout is:

Pin	Function
2	Serial TXD (reply data from T344)
3	Serial RXD (commands to T344)
5	Ground
6	alternate +12 volt power in
9	Ground

T344 may be connected to a standard 9-pin PC serial port with a straight-through male-female D9 cable.

Pin 6 connects through a power schottky diode to the normal +12 volt power input.

4.10 Ethernet Connector

A standard RJ45 10/100 Ethernet connector is provided. Both it and the RS-232 are active, although only one communications path should be used at any one time. See section 13.

4.11 LEDs

Two COMM LED's appear to the right of the RS-232 communications connector. The orange LED will flash whenever the module receives incoming serial characters, and the green LED will flash when it sends reply data.

A green LED is located on the outputs end-plate, labeled PWR. It will illuminate at powerup and then blink about once a second after startup initialization to indicate that the internal firmware is operating normally.

The red ERR LED is located above the PWR LED. It will normally be off, and will flash if any error flags are set.

See section 14 for notes on LED operation during BIST self-test.

4.12 Power Dissipation and Cooling

The T344 and T346 dissipate about 6 watts minimum. If all channels are programmed to output maximum amplitude sine waves (10.24 volts p-p) at 32 MHz, power dissipation increases to about 8.5 watts. With all channels at 32 MHz but amplitude reduced to 2 volts p-p, power is about 7 watts.

If the module is placed on a poor thermal conductor, like a wooden desk, in still air, the maximum suggested ambient temperature should be 60C for the low-dissipation case, and 40C for the high-dissipation case. If the unit is bolted to a metal surface and at least 200 LFPM air flow is available, the recommended maximum operating temperatures are 75 and 60C respectively.

The units are rated to operate down to -20C in a non-condensing environment.

Storage temperature range is -40 to +90C, non-condensing.

Consult Highland about exact operating margins and special versions.

5 Programming

5.1 General Comments

The generators accept ASCII serial commands from the standard RS-232 interface or from the 10/100 Ethernet adapter. Refer to Section 13 for details about configuring the Ethernet interface.

For evaluation, serial commands may be typed using any common serial communications program, for example HyperTerminal or the standard "Telnet" utility. A **HElp** command is available, summarizing serial commands and operating modes. The **STatus** command will send back a summary of current settings.

The standard baud rate is 38,400. The receive buffer is limited to 1024 bytes, and the module ignores serial input while it is processing the current command line.

In the following section, text using this font...

0Phase 45 <cr>

represents a command string sent to the module, terminated with a carriage return character <cr>. Italic text...

OK <cr> <lf>

represents a reply from the unit. All commands must be terminated with semicolon or <cr>, and all reply lines are terminated by <cr> <lf>.

5.2 Command Strings

Users send serial ASCII command strings to the module, to which it immediately replies. Incoming characters are not echoed. Because serial characters are buffered by both a PC OS and the module, and because it may spend milliseconds or more to process commands, user software must wait for a response to each command line before sending another command.

Each command consists of a command keyword, followed by an optional second alpha keyword or by a numeric argument. Multiple commands may be sent in a single line, separated by semicolons. When a full line is received, terminated by the final <cr> character, the buffered line is executed, in the order received.

Keywords may be fully spelled out, or may be sent as their first two characters; only the first two characters are significant. In this documentation, a word that has two possible

forms is written with the short form capitalized, and the rest of the word in lower-case letters. The actual protocol is case insensitive.

Examples

`2Phase 45` indicates that the short form is "**`2P 45`**", and the long form is

`2PHASE 45` both of which are recognized commands which set the phase shift of channel 2

All forms are case insensitive. One or more spaces are required to separate keywords from arguments.

Output signal amplitudes are sent in volts, as **`3Amplitude 1.50`**, short form **`3A 1.5`**, which sets the amplitude of the channel 3 output to 1.5 volts max.

Most value-setting commands may be sent without an argument, in which case they become queries of the associated value.

`2Phase` (no argument)

evokes the reply

`45.00`

which represents the phase lag of channel 2, in degrees.

A frequency may be sent as

`1Freq 455.22K` to set the frequency of channel 1

where acceptable suffixes are:

H - Hz
K - kiloHertz
M - megaHertz

and exponential notation is not supported. Default is Hertz.

When frequencies are sent in this form, some rounding will usually occur when the frequency is converted to the internal phase-accumulator scaling. In some cases, it is important that frequencies be exactly known, or that ratios of frequencies be exact integer multiples. For those cases, the **`nRaw`** command can be used; see section 5.9.4.

Since long strings of numbers can be difficult to read, a "verbose" mode is available, which will send frequencies and other long numbers in the form

`01,999,999.999`

Certain incoming ASCII characters are treated specially:

All lowercase letters are converted to uppercase

TAB is treated as a space.

ETX, ESC, and DEL are equivalent to BS, command line abort. When any of these characters is received, all command execution is aborted and the receive buffer is flushed.

Commas are absolutely ignored.

Most control characters and linefeed are ignored.

A "blank" input line, <cr> only, evokes the response

T344 <cr> <lf> *or* ***T346 <cr> <lf>***

A single backslash \ character, as the first and only character on a line, will immediately re-execute the last-received full command line. A terminating <cr> is not required.

Commands which accept integer arguments (like **2Set, 1Width, 3Raw**) also accept hex arguments, such as

```
1Set    0x8001

2Width 0xFFFF

3Raw    0x1A0024E9

3Raw   -0xFF000000
```

Commands which accept decimal points, such as **1Amp, 2Dc, 3Phase, 0Freq,** do not accept hex values.

The T340-series does not support hardware or software flow control. Other baud rates are available on special order.

A command begins with a command keyword (or its 2-letter abbreviation), followed by a secondary keyword or a numeric argument. Multiple commands on a line may be separated by semicolons.

One or more spaces are required between a keyword and its argument. Whitespace may not break up a command token or an argument, but is otherwise allowed. Commas are ignored.

Query commands are requests for specific data. A query is often a "set"- type command without an argument.

All commands must be terminated by either an end of line indicator (carriage return, ASCII 13, denoted <cr>) or the semicolon separator ***;*** for multiple commands on a line. Linefeeds are ignored.

Since the receive buffer is limited to 1024 bytes, users should not send multiple commands per line that might exceed this length. If at any time an ETX, backspace, ESC, or DEL character (ASCII codes 3, 8, 27, or 127) is received, the T34x will abort any command execution, flush its receive buffer, and prompt for a new command.

5.3 Reply Strings

Each received command will evoke a reply indicating the execution status of the command. For query commands, the reply is the requested data. For other commands, successful completion will yield a reply of ***OK***. If multiple commands are issued on one line, multiple responses will be sent back on a single line, separated by semicolons. For the command line...

```
1PHASE 90; 1PHASE; 1LOAD TRIANGLE
```

the reply will be of the form

```
OK; 090.00;OK
```

All reply strings are terminated with carriage return/linefeed.

If an error occurs while processing a command, the reply ***??*** will be returned. If multiple commands are present on a command line, and any command produces an error, the erroneous command will respond with the ***??*** indicator and no remaining commands will be processed on that line.

Numerical replies to queries will be in fixed-point decimal numeric form, with embedded commas included if Verbose mode is set.

5.4 Realtime Issues

User command lines are stored in a buffer until the <cr> character is received, at which time the entire command line is parsed and executed in the order received. Each command sends its reply characters, typically a requested value or the ***OK*** response, as the command is executed. Any additional incoming characters following the command-line <cr> are ignored until the entire command line is processed and the final response-line <cr> <lf> is returned.

Most simple commands execute in one or two milliseconds, and their realtime execution rate is dominated by the 38.4 kbaud (3840 characters/second) serial communications rate. Shortform commands reduce communications overhead. Long reports are of course baud rate limited, with the **STatus** report or the **HElp** pages taking as long as several hundred milliseconds.

When channel settings are changed via the **INstall** command (or an end-of-line autoinstall), the firmware will immediately strobe all channels, coherently updating the frequency, phase, and amplitude of all channels; see section 6.

5.5 Complexity

The T344 and T346 have a large number of features which allow complex sets of waveforms to be generated with flexible realtime control. The resulting architecture and command set are necessarily complex. Every effort has been made to keep basic functions simple, and to make advanced functions comprehensible.

For example, to generate a 10 KHz sine wave on the channel 2 output, the serial commands would be…

LOAD DEFAULT	sets module to basic known states
2FREQUENCY 10K	set channel 2 to 10 KHz
2AMPLITUDE 2.5	set peak voltage to 2.5 volts

or, in a single line,

LO DE; 2F 10K; 2A 2.5

Now channel 2 will make a 5-volt p-p sine wave at 10 KHz.

To generate a 3-phase 400 Hz sinewave set on outputs 0, 1, and 2, the commands are…

LOAD DEFAULT	sets module to basic known states
QFREQUENCY 400	set all ("quad") channels to 400 Hz
QAMPLITUDE 1.414	set all to 1 volt RMS out
1PHASE 120	channel 1 lags by 120 degrees
2PHASE 240	channel 2 lags by 240 degrees
SYNC	synchronize all channels

or, as a single line,

```
LO DE; QF 400; QA 1.414; 1P 120; 2P 240; SY
```

To run a full module self-test, send the command

```
BIST
```

To display a demonstration set of waveforms, type…

DEMO 1 then **STATUS**

For help, type…

```
HELP
```

5.6 Events

Serial commands are provided to do most desired operations immediately. For example, one can use the **FIRE** serial command to trigger any channels that are programmed to operate in one-shot mode, or the **SNAPSHOT** command to freeze current channel phase-reporting registers and cycle rollover counters, or **SYNCHRONIZE** to force multiple channels to restart at the same phase.

Operations on channels can also be performed over the internal Event bus. Commands are provided to define the action of an Event. It can be a channel update, reset, channels synchronize, phase snapshot, or one-shot trigger.

A "Local Event" is a command that is sent to all the channels on one module. A "Global Event" is a command that is sent from a master module to itself and any number of slave modules that are interconnected by their SYS connectors. Channels may be individually programmed to accept or ignore Events.

There are several possible sources for Events:

1. The TTL connector may be used as an input which statically resets channel phase accumulators.

2. The TTL connector may also be used as an input which creates a Local Event or a Global Event when an edge is detected.

3. The SYS connector may be used to connect multiple T344/T346/V346 modules in master-slave arrays. In this case, a serial **GLOBAL** command or a TTL-input edge can send a Global Event to all channels in the system.

4. T346 channels 6 and 7 can be programmed as sequence generators, with opcodes available to create Local or Global Events.

Events may include an 8-bit Event Address, and any channel to be programmed to respond to two separate target addresses. This allows Events to act on selected groups

of channels. See sections 10 and 11 for further discussion of Events and control sequences.

5.7 Frequency Scaling

Each channel of the T444/346 uses an internal DDS frequency algorithm to scan its internal 4096-point waveform table. A "raw" 32-bit register controls the frequency of each channel. Two serial commands may be used to set a frequency:

`3Frequency 250K` sets the frequency in engineering units, Hz or KHz or MHz

`3Raw 0x1000000` sets the 32-bit DDS register directly

The **`nFreq`** command may not set the frequency to the precise value requested, for two reasons: 1) the frequency may not be expressible perfectly in raw form due to the binary scaling nature of DDS and 2) the nFreq command, and the serial frequency strings returned, are quantized to 1 milliHertz resolution.

Three normal frequency ranges are provided: 32 MHz, 4 MHz, and 250 KHz.

There is also a 64 MHz range. Note that the 64 MHz range operates beyond the module's specified performance. The post-synthesizer lowpass filters are 7th order transitional Gaussian, with a 3 dB point of about 40 MHz, after which gain drops off rapidly with frequency, phase shift increases, and image/spur performance degrades. Given these constraints, frequencies up to about 40 MHz can be generated. Do not use this range in noise generation or sequence modes.

See range notes in section 6.

5.8 Command Summary

The following is a summary of serial ASCII commands which may be sent to the T344 or T346.

Commands identified with <T346 are unique to the T346.

Commands tagged with <B were changed from revision A versions.

5.8.1 Channel Control Commands

Each channel (0-3 for the T344, 0-7 for the T346) has a group of channel control commands. The first character of each command is the channel number, 0-7. The examples below are for channel 0.

LONG FORM		SHORT FORM		FUNCTION	
0AMP	**2.5**	**0A**	**2.5**	set channel amplitude	
0FREQ	**1.72K**	**0F**	**1.72K**	set channel frequency	
0RAW	**126500**	**0R**	**126500**	set channel raw frequency	
0PHASE	**45**	**0P**	**45**	set channel phase	
0DC	**-2**	**0D**	**-2**	set channel DC offset	
0WIDTH	**4096**	**0W**	**4096**	set channel PWM width	
0LOAD	**SINE**	**0L**	**SI**	load channel with sinewave	
0LOAD	**SAWTOOTH**	**0L**	**SA**	load channel with sawtooth	
0LOAD	**TRIANGLE**	**0L**	**TR**	load channel with triangle	
0B	**0 10 20**	**0B**	**0 10 20**	load/read arb memory	
0K	**2000**	**0K**	**2000**	load constant into arb memory	
0SET	**1**	**0S**	**1**	set channel controls numerically	
0SET	**RUN**	**0S**	**RU**	set channel to continuous run mode	
0SET	**OSHOT**	**0S**	**OS**	set to one-shot mode	
0SET	**POINT**	**0S**	**PO**	set to point mode (interpolation off)	
0SET	**INTERPOLATE**	**0S**	**IN**	set interpolation on	
0SET	**RANGE 2**	**0S**	**RA 2**	select frequency range	
0SET	**SUM 3**	**0S**	**SU 3**	set channel summing	
0SET	**X1**	**0S**	**X1**	normal output swing, +-5.12 volts max	
0SET	**D5**	**0S**	**D5**	attenuated output swing +-1.024 volts max	
0SET	**WAVE**	**0S**	**WA**	waveform mode	
0SET	**BPWM**	**0S**	**BP**	bipolar PWM mode	
0SET	**UPWM**	**0S**	**UP**	unipolar PWM mode	
0SET	**NOISE**	**0S**	**NO**	Gaussian noise mode	
0SET	**STEP**	**0S**	**ST**	table step mode	
0SET	**CONTROL**	**0S**	**CO**	control mode	<T346
0SET	**NRESET**	**0S**	**NR**	do not accept TTL resets	
0SET	**ARESET**	**0S**	**AR**	accept TTL resets	
0SET	**NEVENT**	**0S**	**NE**	do not accept Events	
0SET	**AEVENT**	**0S**	**AE**	accept Events	
0TARGET	**nnnn**	**0T**	**nnnn**	set channel target address	

0SET	AUTO	0S AU	operate in auto-update mode	
0SET	SYNC	0S SY	operate in synchronous update mode	
0MOD	AM 6	0M AM 6	amplitude modulation source	<T346
0MOD	PM 6	0M PM 6	phase modulation source	<T346
0MOD	PWM 6	0M PW 6	pulse width mod source	<T346
0MOD	FM 6	0M FM 6	frequency modulation source	<T346
0MOD	RA 1	0M RA 1	frequency modulation range	<T346
6CON	(args)	6C (args)	load control sequence, channels 6 and 7 only	<T346

5.8.2 "Quad" Channel 0-3 Control Commands

LONG FORM		SHORT FORM	FUNCTION
QAMP	2.5	QA 2.5	set channel 0-3 amplitudes
QFREQ	1.72K	QF 1.72K	set channel 0-3 frequencies
QRAW	126500	QR 126500	set channel 0-3 raw frequencies
QPHASE	45	QP 45	set channel 0-3 phases
QDC	-2	QO -2	set channel 0-3 DC offsets
QWIDTH	4096	QW 4096	set channel 0-3 PWM widths
QLOAD	SINE	QL SI	load channels 0-3, sinewave
QLOAD	SAWTOOTH	QL SA	load channels 0-3 , sawtooth
QLOAD	TRIANGLE	QL TR	load channel 0-3, triangle
QB	0 10 20	QB 0 10 20	load channels 0-3 arb memory
QCon	2000	QC 2000	load constant into arb memories
QSET	1	QS 1	set channel 0-3 controls numerically
QSET	RUN	QS RU	set channels 0-3 to continuous run mode
QSET	OSHOT	QS OS	set to one-shot mode
QSET	POINT	QS PO	set to point mode (interpolation off)
QSET	INTERPOLATE	QS IN	set interpolation on
QSET	RANGE 2	QS RA 2	select channels 0-3 frequency range
QSET	X1	QS X1	output swing +-5.12 volts max
QSET	D5	QS D5	output swing +-1.024 volts max
QSET	WAVE	QS WA	channels 0-3 waveform mode
QSET	BPWM	QS BP	bipolar PWM mode
QSET	UPWM	QS UP	unipolar PWM mode
QSET	NOISE	QS NO	Gaussian noise mode

QSET	**NRESET**	**2S NR**	ch 0-3, do not accept TTL resets
QSET	**ARESET**	**2S AR**	accept TTL resets
QSET	**NEVENT**	**2S NE**	do not accept Events
QSET	**AEVENT**	**2S AE**	accept Events
QSET	**AUTO**	**QS AU**	operate in auto-update mode
QSET	**SYNC**	**QS SY**	operate in synchronous update mode

5.8.3 "Octal" 8-Channel Control Commands (T346 only)

LONG FORM		SHORT FORM	FUNCTION
8AMP	**2.5**	**8A 2.5**	set channel 0-7 amplitudes
8FREQ	**1.72K**	**8F 1.72K**	set channel 0-7 frequencies
8DC	**-2**	**8D -2**	set channel 0-7 DC offsets
8SET	**4096**	**8S 4096**	set channel control registers, numerical form

5.8.4 System Control Commands

LONG FORM		SHORT FORM	FUNCTION	
INSTALL		**IN**	apply all buffered channel settings	
SYNC		**SY**	install and synchronize channels	
FIRE		**FI**	fire one-shot channels	
ZAP 4		**ZA 4**	hold channels reset; arg is bit map	
DIRTY		**DI**	show channels with uninstalled settings	
WAIT	**340**	**WA 340**	wait specified number of milliseconds	
CLOCK	**INTERNAL**	**CL IN**	ignore CLK connector	
CLOCK	**EXTERNAL**	**CL EX**	lock to 10 MHz signal on CLK connector	
CSTAT		**CS**	return clock status word	
MS	**1**	**MS 1**	numeric form of master/slave command	<B
MS	**OFF**	**MS OF**	SYS connector is unused	<B
MS	**MASTER**	**MS MA**	module is multi-unit master	<B
MS	**SLAVE**	**MS SL**	module is multi-unit slave	<B
MS	**TERM**	**MS TE**	module is terminating slave	<B
TTL	**256**	**TT 256**	program TTL functions numerically	<B
TTL	**OFF**	**TT OF**	TTL connector is unused	
TTL	**RHIGH**	**TT RH**	TTL input is active-high reset	

TTL	**RLOW**	**TT RL**	TTL input is active-low reset
TTL	**ERISE**	**TT ER**	TTL input is rising-edge Local Event
TTL	**EFALL**	**TT EF**	TTL input is falling-edge Local Event

LONG FORM		SHORT FORM	FUNCTION	
TTL	**GRISE**	**TT GR**	TTL input is rising-edge Global Event	<B
TTL	**GFALL**	**TT GF**	TTL input is falling-edge Global Event	<B
TADD	**55**	**TA 55**	set TTL Event address	<B
TEVENT	**4**	**TE 4**	define TTL Event numerically	<B
TEVENT	**NONE**	**TE NO**	no TTL Event	<B
TEVENT	**UPDATE**	**TE UP**	TTL Event is channel update	<B
TEVENT	**RESET**	**TE RE**	TTL Event is channel reset	<B
TEVENT	**SYNC**	**TE SY**	TTL Event is channel synchronize	<B
TEVENT	**SNAP**	**TE SN**	TTL Event is phase snapshot	<B
TEVENT	**FIRE**	**TE FI**	TTL Event is fire one-shot channels	<B
GADD	**100**	**GA 100**	set Global Event address	
GLOBAL	**1**	**GL 1**	broadcast Global Event, numerical form	
GLOBAL	**NONE**	**GL NO**	broadcast no-op Global Event	
GLOBAL	**UPDATE**	**GL UP**	broadcast Global Update	
GLOBAL	**INSTALL**	**GL IN**	alias for GLobal UPdate	
GLOBAL	**RESET**	**GL RE**	broadcast Global Reset	
GLOBAL	**SYNC**	**GL SY**	broadcast Global Synchronize	
GLOBAL	**FIRE**	**GL FI**	broadcast Global oneshot trigger	
GLOBAL	**SNAPSHOT**	**GL SN**	broadcast Global Snapshot	
ECOUNT		**EC**	read or clear Event counter	
VIEW 15		**VI 15**	make ch 4-7 electrically visible	<T346

5.8.5 Save/Recall/Reboot Commands

LONG FORM	SHORT FORM	FUNCTION
NAME SETUP text	**NA SE text**	declare the name of the current setup
SAVE	**SA**	save settings to EEPROM
RECALL	**RE**	recall settings from EEPROM
LOAD DEFAULT	**LO DE**	load default setup
DEMO 2	**DE 2**	run a demonstration setup
BOOT	**BO**	restart firmware

5.8.6 Reporting Commands

LONG FORM	SHORT FORM	FUNCTION
STATUS	**ST**	show status report
POWER	**PO**	return +12 volt supply voltage
UPTIME	**UP**	return uptime, seconds
ERRORS	**ER**	return error flags
IRQ	**IR**	query 1 KHz interrupt counter
USEC	**US**	query microsecond counter
SNAPSHOT	**SN**	snapshot and return channel phases
PHASES	**PH**	return snapped channel phases
CYCLES	**CY**	return snapped cycle counters
IDENTIFY	**ID**	return ID string
***IDENTIFY**	***ID**	LXI-compatible version of Identify
VERBOSE 1	**VE 1**	show long numbers with commas
VERBOSE 0	**VE 0**	show long numbers without commas
COMMENT text	**CO text**	command is ignored
CR	**CR**	echo a carriage return/linefeed

5.8.7 Test Commands

LONG FORM	SHORT FORM	FUNCTION
MODE 3	**MO 3**	control test relays
BIST 1	**BI 1**	run built-in self-test

5.8.8 Help Commands

LONG FORM	SHORT FORM	FUNCTION	
HELP	**HE**	return general HELP message	
HELP CHANNELS	**HE CH**	return help on channel operations	
HELP SETTINGS	**HE SE**	details of channel setups	
HELP CONTROLS	**HE CO**	return help on general controls	
HELP SYS	**HE SY**	return help on SYS and CLK controls	<B
HELP TTL	**HE TT**	return help on TTL functions	<B
HELP BIST	**HE BI**	return help on self-test	
HELP DEMO	**HE DE**	return help on demos	
HELP MODULATIONS	**HE MO**	return help on modulation	

5.9 Command Details

In the text below, **`nVerb`** represents a generic channel command, where "n" may be the characters 0, 1, 2, 3, or Q (or 4, 5, 6, 7 for the T346) and **`nV`** is the short form.

Most commands accept a second keyword or a numeric argument, and most commands become queries if an argument field is not present.

5.9.1 Channel Control Settings : nSet

5.9.1.1 nSet Numerical Format

Commands are provided to assert basic channel settings: **`0Set`** through **`3Set`** (**`7SET`** for the T346). Each may be followed by a numerical value, setting the channel control word of the respective channel. If the numerical argument is omitted, the command becomes a query of current settings. The value may be sent in decimal **`2Set 49155`** or in hex **`2Set 0xC003`**.

The unit powers up with all channel control words zeroed, which results in normal operation, with channels operating in auto-update mode. The channel control word may be treated as a 16-bit integer, arranged as…

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
OS	IN	R1	R0	D5	K2	K1	K0		S2	S1	S0	AR	AE		SU

If the SU (synchronous update) bit is off, the channel operates in auto-update mode. In this case, any changes written to any channel registers are installed automatically and asynchronously. This is the powerup default mode, wherein channels operate independently. Set the SU bit to enable use of the channel synchronization mechanisms described in section 6.

Setting AE (accept Events) enables this channel to accept either Global or Local Events. Local Events are multi-channel operations that are local to one module and triggered from the front-panel SYS input. Global Events are shared among a set of interconnected master/slave modules.

If the AR (accept reset) bit is set, this channel can be held statically reset by the front-panel SYS connector input, as programmed by the **`TTL`** command.

The three Sn bits allow channel summing. If the encoded value "S" is nonzero, then the output of channel S is summed into the output of this channel. Summing can be cascaded to any level; for example, if one sets the S field of channel 2 to "3" and the S field of channel 0 to "2", then the output of channel 0 will become the sum of its own programmed signal added to the signals from channels 2 and 3. Do not sum a channel

with itself. Each level of summing will add two clocks (15.6 ns) of signal delay. The S2 bit is not supported on the T344 version.

The two R bits set a frequency range for this channel. Ranges are…

Rcode	R1	R0	Range	LSB
0	0	0	32 MHz	14.90 mHz
1	0	1	4 MHz	1.836 mHz
2	1	0	250 KHz	116.4 uHz
3	1	1	64 MHz	29.80 mHz

Note that the 64 MHz range operates beyond the module's specified performance; see additional notes in sections 5.7 and 6.

If users leave the D5 bit low, the channel output range is +-5.12 volts peak (3.62 volts RMS), as scaled by the channel amplitude register. If this bit is set high, amplitude is reduced by a factor of 5:1, to +-1.024 volts peak. This affects this channel's analog outputs only, but not any internal summing paths.

The "K" bits control the channel signal source multiplexer. ..

Kcode	K2	K1	K0	Signal Source
0	0	0	0	WAV: Waveform RAM is signal source. This is used for standard wave shapes and for arbitrary waveforms.
1	0	0	1	BPWM: Use the PWM generator in bipolar mode, with output 0x8001 as "low" and 0x7FFF as "high".
2	0	1	0	UPWM: Use the PWM generator in unipolar mode, 0x0000 "low" and 0x7FFF "high"
3	0	1	1	Gaussian noise. See section 9.
4	1	0	0	Step mode. See section 7
5	1	0	1	Control mode, T346 only. See section 11

If users set the IN bit, waveform table interpolation is enabled. This improves the effective number of waveform table entries from 4096 to 65536, and reduces frequency-domain spurs. Interpolation only operates in R=0 (wave ram source) mode. Enabling interpolation can soften steep rising and falling edges.

If the OS bit is set, the channel operates in one-shot mode. Following a serial **`FIRE`** command, or a Local or Global FIRE Event, the phase accumulator will run for one full cycle, making one pass through the waveform memory (or one PWM pulse) and then return to address 0, essentially parking on the 0th wave table entry. See section 7.

At powerup, all channel control registers are cleared, and wave tables are set to sines, so all channels operate in normal, waveform mode, 32 MHz range, with maximum programmable output of 10.24 volts p-p, and operate in asynchronous update mode. Undefined bits are reserved and should not be set.

The **QSet nn** command sets up channels 0-3 simultaneously.

The **8Set nn** command sets up all eight channels on the T346.

5.9.1.2 nSet Text Format

Text commands are available as an alternate means to manipulate the various fields of channel control registers. They are, for channel 2 by example,

2SET RUN	**2S RU**	channel 2 operates in continuous-run mode
2SET OSHOT	**2S OS**	channel operates in one-shot mode
2SET POINT	**2S PO**	point mode, interpolation off
2SET INTERP	**2S IN**	interpolation on
2SET RA n	**2S RA n**	select frequency range, n = 0..3
2SET X1	**2S X1**	normal +-5.12 volts max output
2SET D5	**2S D5**	attenuated +-1.024 volts max output
2SET WAVE	**2S WA**	waveform/arb mode
2SET BPWM	**2S BP**	bipolar PWM mode
2SET UPWM	**2S UP**	unipolar PWM mode
2SET NOISE	**2S NO**	Gaussian noise mode
2SET STEP	**2S ST**	Step mode
2SET CONTROL	**2S CO**	Control mode <T346
2SET SUM n	**2S SU n**	sum channel n into this channel n=0-3 for T344, 0-7 for T346; n=0 for "off"
2SET NRESET	**2S NR**	do not accept TTL resets
2SET ARESET	**2S AR**	accept TTL resets
2SET NEVENT	**2S NE**	do not accept Events
2SET AEVENT	**2S AE**	accept Events
2SET AUTO	**2S AU**	operate in auto-update mode
2SET SYNC	**2S SY**	operate in synchronous update mode

It is often useful to use a numeric command like **2SET 0** to initialize a channel control register, then follow with text commands to set up specific fields.

For example, **3Set 0 ; 3Set SYnc ; 3Set INterp ; INstall**

QSet is also available in text mode to set up channels 0-3. **8Set** is not.

5.9.2 Set Channel Amplitude : nAmplitude

Commands are provided to set channel amplitudes: **0Amplitude** through **3Amplitude (7Amplitude** for the T346). Each may be followed by a numerical value, setting the peak output voltage of the respective channel. If the numerical argument is omitted, the command becomes a query.

0Amplitude 5.00 or **0Amp 5** or **0A 5**

sets the maximum channel 0 output to 5.00 volts. A sine, square, or sawtooth waveform would then swing from -5.00 to +5.00 volts peak. A bipolar PWM output would have a baseline of -5 volts and an active high level of +5.

The maximum allowed value is 5.12 volts. Negative numbers are allowed,

2Amp -3.33

where a negative amplitude corresponds to an inverted version of a positive signal.

Note that the specified levels are into a high-impedance load, and are reduced by 2:1 into a 50 ohm load.

If the D5 bit is set in the channel control register, analog outputs are divided by 5:1, to +-1.024 volts max. This scales the final DAC only, and does not affect internal data paths such as channel summing.

The **QAmp** ("quad amplitude") command sets all four levels simultaneously. As a query, **QAmp** will return a string of the form…

05.000, 05.000, 05.000, 02.500

The **8Amp** command sets amplitude for all eight T346 channels.

5.9.3 Set Channel Frequency : nFrequency

Commands are provided to set channel frequencies: **`0Freq`** through **`3Freq`** (**`7Freq`** for the T346). Each may be followed by a numerical value, setting the waveform frequency of the respective channel.

Frequency defaults to Hertz, where

`3Freq 15750H` or **`3F 15750`** sets channel 3 frequency to 15,750 Hz

Users may also specify K (KHz) or M (MHz), as

`2F 3.579545M`

The maximum legal frequency depends on the range selected; for the default range 0, it is 31.999,999,985 MHz; frequencies requested beyond the limits of the current range are truncated to that range. Negative frequencies are allowed. Negative frequencies essentially walk the waveform memories backwards. If, say, three channels were set up to simulate a "clockwise" 3-phase AC voltage set, programming them to a negative frequency would change their rotational sense to counter-clockwise. Similarly, a negative frequency will reverse a waveform in time.

When frequencies are set using this command, the numeric argument is quantized to 0.001 Hz, truncated to the current range limits, and converted into "raw" DDS phase accumulator values, so frequencies are usually rounded to the nearest DDS LSB.

If the numerical argument is omitted, the ***nFreq*** command becomes a query. The value is returned in Hertz, in the form…

`03579545.031` in non-verbose mode, or

`03,579,545.031` in non-verbose mode, or

The value represents the current channel phase accumulator summation value, converted back to Hz, so may be slightly rounded from a value previously sent using the **`nFreq`** command.

As a query, **`QFreq`** returns a verbose string of the form…

`00,001,000.000, 30,002,000.004, -22,003,000.006, 10,004,000.010`

or, in non-verbose mode,

`10001000.000, 20002000.004, -30003000.006, 10004000.010`

The above assumes the default 32 MHz frequency range. The "R" field in the channel control register can select alternate frequency ranges. Sections 5.7 and 6 discuss ranges in more detail.

The **QFreq** ("quad frequency") command sets channel 0-3 frequencies simultaneously.

The **8Freq** command sets the frequency of all eight T346 channels.

5.9.4 Set Raw Channel Frequency : nRaw

Frequencies entered in engineering units, via the **nFreq** command, are converted into the internal frequency-control register scaling, which often results in a small rounding error. In some cases, this rounding error is not acceptable. One case might be where the T344 is used to simulate speed sensors from a geared rotating machine, where one channel may need to run at precisely 5 times that of another, and phase coherence must be maintained. Any rounding errors in setting frequencies will cause phase creep between channels.

To avoid rounding errors, channel frequencies may be set using the **nRaw** commands. For the default 32 MHz frequency range,

0Raw 67108 sets channel 0 to 1 KHz, and

1Raw 335540 sets channel 1 to precisely 5x that frequency

The maximum legal value of N is 2,147,483,647, corresponding to a frequency of 31.999,999,985 MHz on the 32 MHz range. Negative values are allowed. See section 6 for the mathematical scalings on the various ranges.

An **nRaw** command, as a query, will return the current "raw" frequency setting as an integer. So one could "translate" frequencies to raw form by executing the two command lines…

```
0Frequency 60

0Raw
```

and get back the reply

```
4026
```

QRaw sets channels 0-3 to the same value. As a query, it returns, in verbose mode,

0,000,268,436, 0,000,536,872, -2,000,805,308, 0,001,073,744

The "raw" commands also accept hex arguments. **2R 0x40000000** sets the channel 2 frequency to exactly 16 MHz. **2R 0x80000000** sets the frequency to exactly -32.00 MHz.

See section 6 for further information on frequency ranges and scalings.

5.9.5 Set Channel Phase : nPhase

The **0Phase** through **3Phase** (**7Phase** on the T346) commands set channel phases. They are followed by a numeric argument, the phase in degrees, in the range -359.99 to +359.99. The command…

2Phase 102.55 or **2P 102.55**

causes the phase of channel 2 to lag (shift later in time) by 102.55 degrees. Negative phases introduce lead and move the waveform ahead in time. Phases are modulo 360, so that +90 degrees is equivalent to -270.

These commands without an argument become queries.

The **QPhase** command sets the phase of channels 0-3 to a common value. As a query, it returns a string…

090.00, 240.00, 120.00, 270.00

See section 6 for discussion of channel-channel phase synchronization.

5.9.6 Channel DC Offset : nDc

Commands are provided to set channel DC offsets: **0Dc** through **3Dc** (**7Dc** for the T346). Each may be followed by a numerical value, setting the offset of the respective channel. If the numerical argument is omitted, the command becomes a query.

2Dc 2.40 or **2D 2.4** sets the channel 2 offset to +2.4 volts

The specified value, in the range of +-5.12, becomes the DC baseline for the channel output. If the programmed waveform amplitude plus offset ever sum to more than +-5.12 volts, the output will clip.

If channel 3 were in bipolar PWM mode, a TTL level (0 volts low, +5 volts high) would result from the commands

3Amp 2.5; 3Dc 2.5

The **QDc** command sets all four offsets simultaneously. Any of these commands without an argument becomes a query of the current offset value.

The **8Dc** command sets the offsets of all eight T346 outputs.

5.9.7 Set Channel PWM Width : nWidth

If a channel has been set up to operate in bipolar (BPWM) or unipolar (UPWM) pulse-width mode, the **`0Width`** through **`3Width`** commands (through **`7Width`** for the T346) set pulse widths. They are followed by a numeric argument in the range 0 to 65535, where 0 corresponds to zero duty cycle (always low) and 65535 corresponds to 99.9985% high.

```
3Width 32768
```

would then request a square wave on channel 3. The square wave, or other requested duty cycle, remains at the requested duty cycle ratio as the channel frequency is varied.

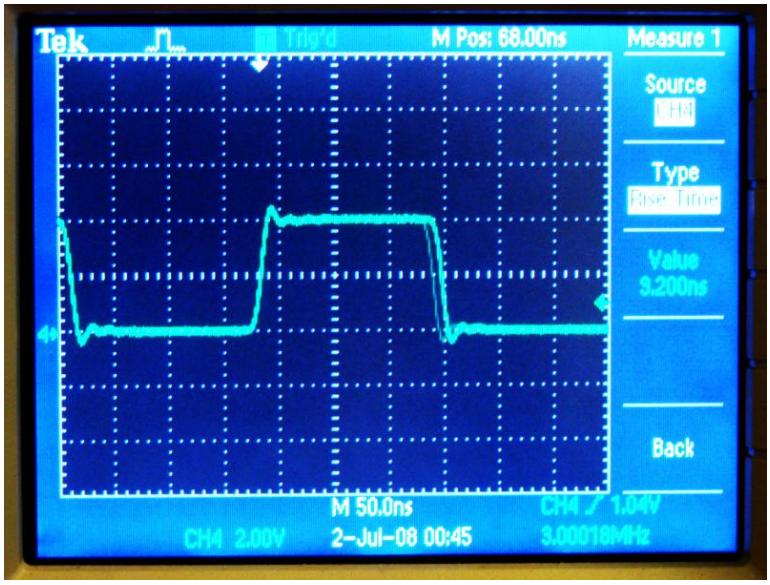
`QWidth` sets the width of channels 0-3 simultaneously.

Hex arguments are allowed; **`3W 0x8000`** specifies 50% duty cycle, a square wave.

These commands without an argument become queries.

The post-DAC analog signal processing includes a lowpass filter and output amplifier that limit PWM rise and fall times to about 9 ns. Frequency and width selections should not be programmed such as to make low or high times less than 25 ns, implying a maximum PWM frequency of about 20 MHz.

The nature of DDS synthesis results in 1 system clock (7.8 ns p-p) jitter on pulse widths for frequencies that are not an exact binary fraction of 32 MHz. This jitter is essentially invisible at low frequencies but can be significant for frequencies in the MHz range.



Unipolar PWM pulse at 3 MHz.

Rise/fall times are about 9 ns.

Note 8 ns width jitter.

5.9.8 Load Channel Waveforms: nLoad

T344/T346 units are shipped to load sine waves into all channel waveform memories at powerup. Other waveforms may be loaded into any channel.

The **0Load** through **3Load** (**7Load** for the T346) commands are provided to load standard waveforms; the arguments may be **SIne** **TRiangle** or **SAwooth**.

0Load Sawtooth or **0L SA**

loads a sawtooth into the channel 0 wave memory. It ramps from minus full scale (-5.12 volts max) to plus full scale (+5.12 max) and then rapidly returns low, at the selected channel frequency. Amplitude is of course adjustable downward using the channel **nAmplitude** command.

1Load TRiangle or **1L TR** loads a triangle into channel 1

2Load SIne or **2L SI** loads a sine wave into channel 2

The **QLoad xxx** command loads the named waveform into channels 0-3.

The query **0Load** will return the string

TRI or ***SAW*** or ***SIN*** or ***PWM*** or ***ARB*** or ***STP*** or ***CTL***

where ***ARB*** is returned if nonstandard waveforms have been loaded.

Query **QLoad** will return a string of the form

SIN, SAW, TRI, PWM

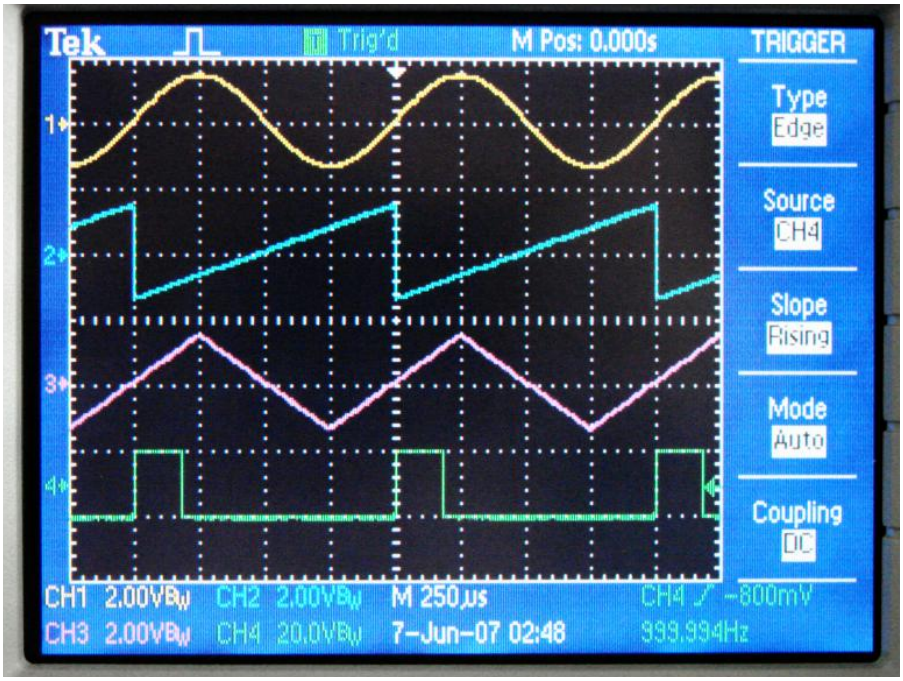
showing the waveforms currently loaded into channels 0, 1, 2, and 3 respectively.

Any of these commands will force the "K" field of the channel control register to zero, putting the channel into waveform memory mode.

Note that if a channel is programmed to operate in PWM mode, a query will return ***PWM*** as the channel setting, and will revert to the last-loaded memory content if PWM mode is later disabled.

If non-sine waveforms are loaded and then the **SAve** command is issued, the current waveform set will become the powerup default. Arbitrary waveforms cannot be saved.

The figure below depicts sine, sawtooth, triangle, and PWM signals programmed on the four output channels.



5.9.9 Load Arbitrary Waveform: nB Command

Each wave generator channel has a 4096-point waveform memory. The **nB** command allows this memory to be loaded or read back. The commands for the four T344 channels are **0B**, **1B**, **2B**, and **3B**; the T346 version adds **4B**, **5B**, **6B**, and **7B.**

To load a waveform into a channel, the command syntax is

```
nB  start point1 point2 point3...
```

where

n selects which channel to load,

start is the memory address of the first data item, an integer from 0 to 4095

point1 is the first value to load, an integer from +32767 to -32768

The fields here must be separated by spaces or tabs. Since the T344 absolutely ignores incoming commas, comma-delimited data is acceptable only if at least one space or tab also separates items. Any argument may be decimal or hex.

So,

```
3B  0 100 200 300 400 500 600
```

loads the first six locations of channel 3 memory. The length of the line is limited by the 1024-character command buffer size, so multiple commands will be needed to load an entire 4K waveform memory. Loading wraps after point 4095.

A point value of 32767 will create a voltage output of +5.12 if the channel's amplitude register is set to max. -32768 corresponds to an output of -5.12 volts.

The **nB** command may be used as a query,

nB aaaa

For example, **2B 2048** will read back 128 memory data points, beginning at the specified address. It will return 128 signed integers in ascii format, separated by spaces.

Whenever any memory point is loaded using the **nB** or **nC** commands, the channel control register K field is set to wave mode (0) and waveform type is thereafter reported as ***ARB***.

5.9.10 Load Constant: nK Command

The **nK** command allows a waveform memory to be loaded with a constant. The commands for the channels are **0K** through **3K,** or **7K** for the T346 version.

There are several forms to this command…

2CONST dddd or **2C dddd**

loads value dddd into all 4096 points of channel 2 memory

2C aaaa nnnn

zeroes nnnn points of channel 2 memory, starting at address aaaa.

2C aaaa nnnn dddd

loads value dddd into nnnn points of channel 2 memory, starting at address aaaa.

2C aaaa nnnn dddd iiii

loads nnnn points of channel 2 memory, starting at address aaaa. The first data point is value dddd, and successive points are incremented by iiii.

Any of the arguments may be decimal or hex. The quad form, **QC**, is supported.

5.9.11 Channels Synchronize Command: SYnchronize

To maintain phase coherence across channels, channels must be programmed and then reset, which synchronizes their phase accumulators and restarts all channels at their programmed phases.

The single **SYnc** command, with no argument, will install any pending channel settings and synchronize all channel phase accumulators. All waveforms will jump to their zero-phase position, or to their programmed phase if a phase offset is programmed, and run from there.

The **SYnc** command optionally accepts a numeric argument which is a bitmap which selects the channels to be updated and synchronized.

SYnc 1	sync channel 0	
SYnc 2	sync channel 1	
SYnc 4	sync channel 2	
SYnc 8	sync channel 3	
SYnc 16	sync channel 4	channels 4-7 for T346 only
SYnc 32	sync channel 5	
SYnc 64	sync channel 6	
SYnc 128	sync channel 7	

For example, channels 2 and 3 may be operating as a phase-synchronized pair, so the command **SY 12** would reset and synchronize their phase accumulators without affecting other channels. The argument may also be expressed in hex.

SYnc applies only to the module immediately addressed; Global Events may be used to synchronize multiple boxes. See section 6 for further comments on channel synchronization.

5.9.12 WAit Command

The WAit command delays command execution for the specified number of milliseconds. The maximum allowed delay is 10 seconds. For example, one could change the amplitude of channel 1, wait 250 milliseconds, and then change the amplitude of channel 2.

```
1Amp 2.5; INstall; WAit 250; 2Amp 4.4
```

Note that an explicit **INstall** command was needed to change the level of channel 1 before the normal end-of-line auto-install.

5.9.13 Saved Setups: NAme, SAve and REcall

The T344 stores a "current setup" string, which is displayed in the **STatus** report and may be queried with the **NAme SEtup** command. The name can be changed with a command of the form

```
NAme SEtup POLYPHASE 50 HZ AT 2.5 VOLTS
```

The **NAme SEtup** command is terminated by <cr>, so should be the last command on a line.

The **SAve** command saves current setups to nonvolatile EEPROM memory, including the current name. This saved setup will be restored at the next powerup, or whenever the **REcall** command is executed. So one could, say, program a T344 to make a 3-phase, 400 Hz sinewave set plus one additional PWM-mode trigger, name and save the setup, and have it continue to create those waveforms, even after a powerfail/powerup cycle.

All selected standard waveforms (sine, triangle, sawtooth, or PWM) are saved and restored. There is insufficient nonvolatile memory to save arbitrary waveforms, so if a channel is in arb mode and a save/restore cycle is done, the waveform memory is cleared at powerup/restore time.

New units are shipped with the default setup saved, so have zero outputs when first powered up. To restore a module to this state, one could execute the command string…

```
LOad DEfault; SAve
```

5.9.14 Default Setup: LOad DEfault

The **LOad DEfault** command restores the T344 to its factory-default settings. The default setup is:

All channels in Autoinstall mode, 32 MHz range, run mode, interpolation off.

Verbose mode On

Channel 0 1 KHz sine wave, zero offset, zero amplitude
Channel 1 2 KHz sine wave, zero offset, zero amplitude
Channel 2 3 KHz sine wave, zero offset, zero amplitude
Channel 3 4 KHz sine wave, zero offset, zero amplitude

Channel 4 5 KHz sine wave, zero offset, zero amplitude ch 4-7, T346 only
Channel 5 6 KHz sine wave, zero offset, zero amplitude
Channel 6 7 KHz sine wave, zero offset, zero amplitude
Channel 7 8 KHz sine wave, zero offset, zero amplitude

To see the sinewave outputs, send the command **QAMP 1 ,**
which will set channel 0-3 amplitudes to 1 volt peak.

5.9.15 Demo Command: DEmo n

The **DEmo n** command causes the T344 to load one of a number of demonstration setups.

DEmo 0 four sine waves, 1/2/3/4 KHz, 1 volt RMS

DEmo 1 3-phase 5V pk 60 Hz sines on 0/1/2, TTL sync on chan 3

DEmo 2 3-phase 5V pk 400 Hz sines on 0/1/2, TTL sync on chan 3

DEmo 3 sine/triangle/sawtooth/TTL pulse, 5V pk, 1 KHz

DEmo 4 four TTL PWM outputs, 10/25/50/90% duty, 100 KHz

DEmo 5 Ch 0 is sawtooth with Ch1 sine summed in;
Ch2 is noise with Ch3 sync pulse summed in.

DEmo 6 Complex setup for T346:

Channel 6 runs in control mode, firing other channels at 1 KHz

Ch 0 is a single-cycle sine burst

Ch1 is an amplitude/frequency chirp

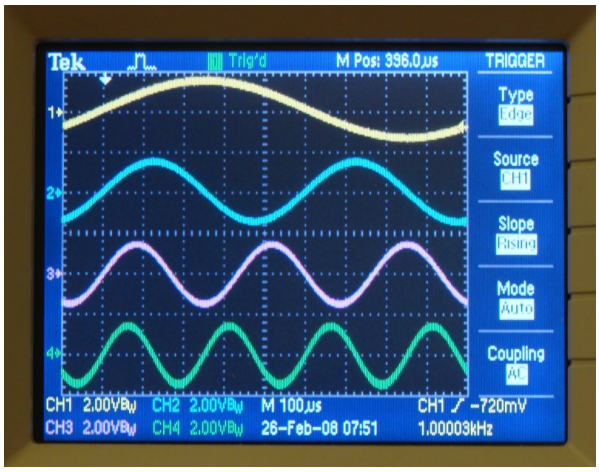
Ch2 is the "Highland Hills" drawn with line segments

Ch3 is a simulated shaft pickup, with a fixed pulse pattern representing a 5-tooth RPM pickup, and a moving pattern of two additional pulses representing a torque signal.

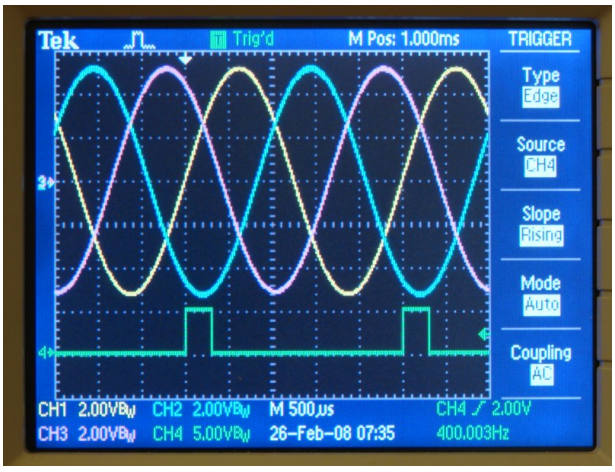
Ch4 generates the moving component of the ch3 waveform

Ch5 is the modulation source for the ch1 chirp

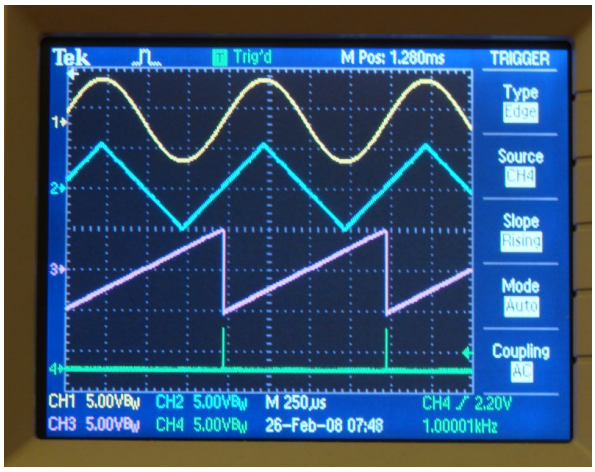
Ch7 randomly phase modulates ch4 to simulate varying torque



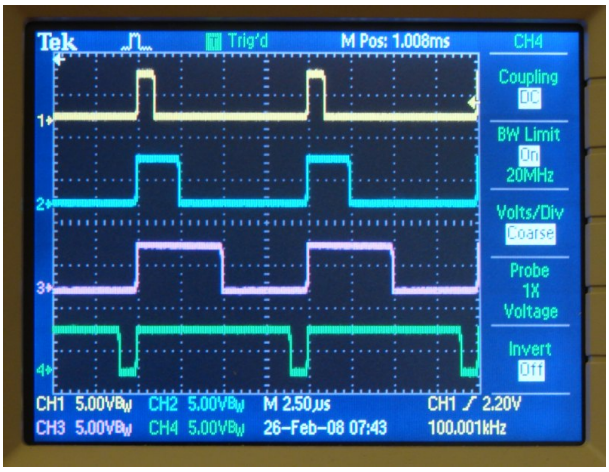
Demo 0



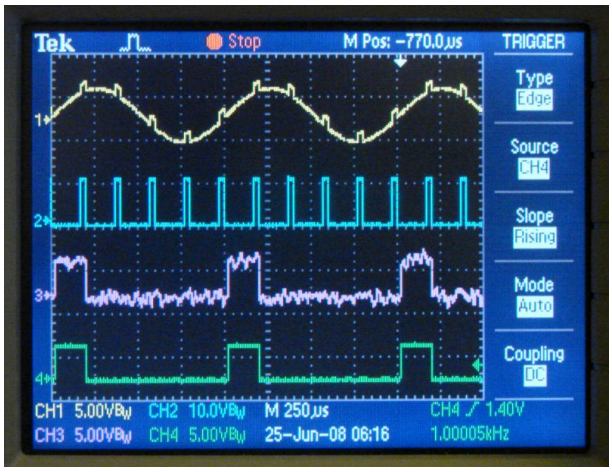
Demo 2



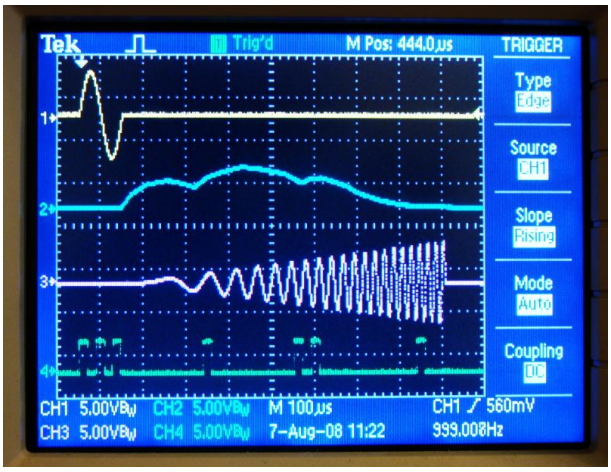
Demo 3



Demo 4



Demo 5



Demo 6

5.9.16 Restart Firmware: BOot Command

The **BOot** command restarts the firmware. The saved setup is installed.

5.9.17 Status Report: STatus Command

The **STatus** query returns a report of module settings. A typical report, the default setup, is shown below.

```
T346
STATUS

          Highland Technology  Model T346 Waveform Generator
Firmware 28E346-B  SN 9999  DASH   1     Cal 12-09-2008 11:00:36
Verbos ON     Mode 000   Pwr  12.003     Up  0,000,000,272
Errors  00000
Mod Ctrl  Off    CLK_int       TTL in Off
Global  none    addr  000      TTLop  none    addr  000
Event count  00000    Zaps  000     Cstat   00000
Setup  ****   T346 Default Setup: 1..8 KHz sines, amplitudes = 0   ****
Ch D  O I R D WAV S A A S =MOD=     Frequency     Ampl    Offs   Phase  PWM   TargetAdd  Cycle
#  X  S N A V FRM M R E Y PAFRW      Hertz        Volts   Volts  Degs  width  ==== ====  count

0     0 0 0 0 SIN 0 0 0 0 00000  00,001,000.002  00.000  00.000 000.00 32768   000  000  09708
1     0 0 0 0 SIN 0 0 0 0 00000  00,002,000.004  00.000  00.000 000.00 32768   000  000  19417
2     0 0 0 0 SIN 0 0 0 0 00000  00,003,000.006  00.000  00.000 000.00 32768   000  000  29126
3     0 0 0 0 SIN 0 0 0 0 00000  00,004,000.008  00.000  00.000 000.00 32768   000  000  38835

4     0 0 0 0 SIN 0 0 0 0 00000  00,005,000.010  00.000  00.000 000.00 32768   000  000  48544
5     0 0 0 0 SIN 0 0 0 0 00000  00,006,000.012  00.000  00.000 000.00 32768   000  000  58253
6     0 0 0 0 SIN 0 0 0 0 00000  00,007,000.014  00.000  00.000 000.00 32768   000  000  02425
7     0 0 0 0 SIN 0 0 0 0 00000  00,008,000.016  00.000  00.000 000.00 32768   000  000  12134
```

An asterisk will appear in the DX ("dirty") field of any channel which is not in auto-update mode and has un-installed settings. This is a warning that actual outputs may not match visible settings.

Channels 4-7 are displayed on the T346 only.

The channel control fields are…

OS	one-shot mode
IN	interpolation enabled
RA	frequency range, 0..3
DV	divide amplitude by 5
WAV	selected waveform: SIN TRI SAW ARB UPWM BPWM NOISE
SM	summing input, 0..3 or 0..7 for the T346
AR	accept TTL resets

AE accept Local/Global Events
SY synchronous update mode

The MOD field is valid for the T346. It names the channels which modulate the current channel, with 0 meaning no modulation. The modulation fields are PM, AM, FM, FM range, and PWM. For example, if the channel 2 line shows "04510" then channel 2 is being AM modulated by channel 4, and FM modulated by channel 5, with FM range 1 scaling.

Since the status report is subject to formatting changes, it is advised that it be used for display only, and not machine-parsed for data extraction. Use specific data queries for formal interfacing.

5.9.18 Report DC power: POwer

The **`POwer`** command returns the realtime value of the externally applied +12 volt power source, as a string of the form ***`12.084.`*** The measurement is made after the internal polyfuse so is typically about 50 mV below the externally-applied voltage.

5.9.19 Report Uptime: UPtime

The **`UPtime`** command returns the time since powerup, in seconds.

5.9.20 Report Errors: Errors

The **`ERrors`** command returns an integer which identifies any errors. The returned form is...

`00000` for no errors

`00512` or a numeric value if errors are present

where the integer value represents the error flags word. Bits are...

bit 8 internal logic error
bit 9 calibration table lost; default cals are used
bit 10 saved setup recall failed; default setup used
bit 11 BIST a/d converter error

bit 12 +12 volt power supply error
bit 15 BIST execution error

5.9.21 Report IRQ Counter: IRq

The **IRq** command returns the value of the 32-bit system interrupt counter. It is incremented 1000 times a second, once each millisecond. The **IRq 0** command will clear the counter.

5.9.22 Snapshot Channel Phases: SNapshot

The SNapshot command will coherently read all channel phase accumulators and return the values as instantaneous phase angles of 0 to 359.99 degrees.

The serial command

SNapshot or SN

might return a string of the form…

321.31, 321.31, 321.31, 166.45

which would indicate that the phase accumulators of channels 0, 1, and 2 are synchronized, but 3 is not. The T346 returns eight values.

Note that the absolute values returned, 321.31 in this case, is usually meaningless, as it represents the phase of channel 0 when sampled at essentially an arbitrary time. The difference between returned values is meaningful to verify relative phase alignment. The snapshot values that are returned are independent of any channel phase settings.

If channels have different frequency histories since last synchronized, their relative phases will be unaligned. If it is desired to pull them back into phase alignment, one can restore them to operate at exactly the same frequency, snapshot their phases, and adjust one or more in phase to achieve alignment as desired. One can also carefully "walk" relative channel frequencies to creep channels into phase. Of course, the **SYnc** command can be used if instantaneous phase jumps are acceptable.

5.9.23 Phase Reporting : PHases

The **PHases** command returns snapshotted phase accumulator values from all four channels, or all eight channels for the T346. The data format is identical to the **SNapshot** data, but no latch operation is performed. This is used to report phase values frozen by a Local or Global phase snapshot Event.

5.9.24 Cycle Counters : CYcle

The **CYcle** command returns four or eight counters which are integer extensions of the phase snapshots. Each is an unsigned 16-bit integer in the range of 0 to 65535. A channel running normally will increment its cycle counter every time it generates one full waveform cycle; if the channel is running at negative frequencies, it decrements the counter. To convert the unsigned value to signed, subtract 65536 from any values above 32767.

In one-shot mode, the counter indicates how many times the channel has been fired.

The cycle counts are useful in systems such as encoder simulation where it is useful to know how many "revolutions" a set of channels has simulated.

If a channel is reset by a Local or Global Event, or synchronized by a **SY** serial command, or reset by the **ZAP** command, its phase accumulator and cycle counter are cleared.

If a channel is operating in step mode, the cycle count is equivalent to the memory step position. If a T346 channel is in control sequence mode, the cycle count is equivalent to the sequence program counter.

5.9.25 IDentify Command

The **IDentify** command returns a string which identifies the T344 or T346 hardware and firmware version. The returned string is of the form...

T344 Wavegen Firmware 28E346-A

Note that the T344/T346 responds identically to the SCPI/LXI command ***IDN.**

5.9.26 VErbose Command

The **VErbose 1** command places the T344 in verbose mode, where commas are included in all long numeric strings that are returned. This mode makes frequency settings and 32-bit integers easier to read, but may not be compatible with external software.

The **VErbose 0** command will cancel verbose mode.

VErbose alone will query this setting.

5.9.27 COmment Command

The **COmment** command, and any following text up to a semicolon or end of line, is ignored.

5.9.28 Test Commands : BIst and MOde

The **BIst** command will execute the T344 self-test sequence.

The **MOde** command controls test relays when BIST is not running.

See section 14.

5.9.29 HELP Commands

The **HELP** command will display a short command summary.

HELP CHANNELS presents help about channel setup commands

HELP SETTINGS presents details about channel control setups

HELP CONTROLS lists general T344 control commands

HELP SYS lists control commands for the SYS and CLK connectors

HELP TTL lists control commands for the TTL connector

HELP BIST describes self-test and relay modes

HELP DEMO describes available demo setups

HELP MODULATIONS describes T346 modulation commands

5.9.30 Master/Slave and Clock Controls : MS and CLock Commands

An internal register controls the master/slave multi-unit synchronizing facility and the internal/external clock modes.

The MODCON register controls these functions. Its layout is...

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
										M1	M0				LK

If the LK bit is set, the unit will attempt to phase-lock its internal clock to a 10 MHz signal applied to the CLK connector. If LK is false, or if the module is in slave mode, the connector signal is ignored.

The encoded M bits control master/slave modes and the function of the SYS connector...

Mcode	M1	M0	Function
0	0	0	SYS connector is unused
1	0	1	unit is Master; SYS is output
2	1	0	unit is slave; SYS is hi-z input
3	1	1	unit is slave; SYS is terminating input

The **`MS nnn`** command will set the MODCON register numerically. The **`MS`** command with no argument will query the register.

Text-mode commands are provided to manipulate this register. They are...

`CLock INternal`	**`CL IN`**	Use internal clock
`CLock EXternal`	**`CL EX`**	Lock to external 10 MHz clock
`MS OFf`	**`MS OF`**	SYS connector is unused
`MS MAster`	**`MS MA`**	Module is master; SYS connector is sync output
`MS SLave`	**`MS SL`**	Module is slave; SYS connector is hi-z sync input
`MS TErminate`	**`MS TE`**	Module is slave; SYS connector is 50 ohm input

An SMB-SMB coaxial cable can connect one master to one slave module. Additional modules may be added using SMB tee connectors, with all modules in a single string. The controlling module should be programmed as master and the last module as the terminator, with intermediate modules programmed as slaves.

5.9.31 TTL Connector Controls : TTLS and TEVENT Commands

The **`TTLS`** command controls the function of the TTL connector.

The numeric form of this command is **`TTls nnn`** , where nnn is a decimal or hex number which loads the internal TTL Control register. The register layout is…

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
		R1	R0		T2	T1	T0								

The encoded R and T bits determine the function of the TTL connector.

Rcode	R1	R0	Function
0	0	0	no TTL reset
1	0	1	reserved
2	1	0	high is static channel reset
3	1	1	low is static channel reset

Tcode	T2	T1	T0	Function
0	0	0	0	no Event action
1	0	0	1	reserved
2	0	1	0	input rising edge triggers Local Event
3	0	1	1	input falling edge triggers Local Event
4	1	0	0	input rising edge triggers Global Event
5	1	0	1	input falling edge triggers Global Event
6	1	1	0	reserved
7	1	1	1	reserved

A channel will respond to a static reset input applied to the TTL connector if the R field is 2 or 3, and its channel control register is programmed to accept TTL resets.

If the T code is 2-5, an input edge will create a Local or a Global Event. Channels will respond to either event if programmed to accept Events. The specific edge-triggered action is defined by the TTL Event register (**`TEvent`** command.)

The R and T fields operate independently, but it is improbable that the TTL connector would be used in both Reset and Event modes simultaneously.

Text-mode commands are also available for managing the TTLS register. They are…

TTls OFf	**TT OF**	TTL connector is not used
TTls RHigh	**TT RH**	TTL connector is active-high channel reset
TTls RLow	**TT RL**	TTL connector is active-low channel reset
TTls ERise	**TT ER**	Rising edge on TTL connector is Local Event
TTls EFall	**TT EF**	Falling edge on TTL connector is Local Event
TTls GRise	**TT GR**	Rising edge on TTL connector is Global Event
TTls GFall	**TT GF**	Falling edge on TTL connector is Global Event

If the TTL input is programmed to be edge-sensitive and create a Local or a Global Event, the internal TTL Event register determines the event action. The register layout is...

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A7	A6	A5	A4	A3	A2	A1	A0					E3	E2	E1	E0

The E field defines the Event code to be executed, as a Local or a Global Event

Ecode	E3	E2	E1	E0	Function
0	0	0	0	0	no Event action
1	0	0	0	1	Update channels
2	0	0	1	0	Reset channels
3	0	0	1	1	Synchronize channels = Update + Reset
4	0	1	0	0	Phase snapshot
8	1	0	0	0	One-shot trigger

The A field specifies an optional 8-bit Event Address.

Text-mode commands are also provided to load the TTL Event register…

TAdd aaa	**TA aaa**	Set TTL Event Address aaa = 0 to 255
TEvent NOne	**TE NO**	TTL event = no operation
TEvent UPdate	**TE UP**	TTL event = update channels
TEvent REset	**TE RE**	TTL event = reset channels
TEvent SYnc	**TE SY**	TTL event = synchronize channels
TEvent FIre	**TE FI**	TTL event = fire one-shots
TEvent SNapshot	**TE SN**	TTL event = snapshot phases

The **SYnc** operation is equivalent to Update + Reset.

See section 10 for details.

One command sequence might be…

2Set 0; 2Set OS; 2Set AE	ch 2: one-shot mode, respond to Events
TT ER; TE FI	TTL rising edge is "Fire one-shots" Local Event

Now channel 2 is in one-shot mode, and a rising edge on the TTL connector will fire it to make one wave sweep.

5.9.32 Global Events: GLobal Command

The **GLobal nn** command causes a master module to immediately broadcast a Global Event to itself and to any connected slave modules. The values for **nn** correspond to the Ecode values in the previous section, and the MS byte is the optional Event Address.

Text-mode commands can also be used to initiate Global Events. they are…

GAddress aaa	**GA aaa**	Set Global Event Address, 0..255
GLobal NOne	**GL NO**	Global event = no operation
GLobal UPdate	**GL UP**	Global event = update channels
GLobal REset	**GL RE**	Global event = reset channels
GLobal SYnc	**GL SY**	Global event = synchronize channels
GLobal FIre	**GL FI**	Global event = fire one-shots
GLobal SNapshot	**GL SN**	Global event = snapshot phases

These immediate Global Events are FIFO buffered with any Local or Global Events which are created by edges on the TTL connector.

Any Global Event, even the no-op, increments the Event counter on master and slave modules.

See section 10.

5.9.33 EVENT COUNTER : ECount

The **ECount** command causes a module, master or slave, to report the value of its Event counter. The command **ECount 0** causes the counter to be cleared. This is useful for verifying the correct operation of addressed Events or master/slave systems.

The Event counter is incremented by any legal Local or Global Event.

5.9.34 Fire One-shots : FIre

The **FIre** command with no argument immediately fires all channels which are programmed in one-shot mode. The command accepts an optional channel mask, as **FIre n** which fires channels selectively; mask bits 0..3 select channels 0..3 respectively, or bits 0..7 for the T346. The numeric argument may be decimal or hex.

5.9.35 Clock Status : CStat

The **CStat** command returns a decimal value which indicates clock status. The value may be interpreted as a 16-bit register…

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DM							LE						BP	K10	LK

DM will be true if there is a serious internal timing error

LE is "lock error", true if lock is expected but fails

BP is true if a board-sync (master) signal is present on the SYS connector

K10 will be true if a 10 MHz signal is present on the CLK input connector

LK indicates successful lock.

Note that an independent or a master module can be programmed to lock to an external 10 MHz source. A slave module always locks to the master's clock.

5.9.36 Channel Resets: ZAP Command

The **ZAP** command allows channels to be held statically reset. The format is

ZAP nn where nn is a bit mask between 0 and 15, or 0-255 for the T346.

ZAP 1 holds channel 0 reset
ZAP 2 holds channel 1 reset
ZAP 4 holds channel 2 reset
ZAP 8 holds channel 3 reset
ZAP 15 holds all channels reset on the T344
ZAP 255 holds all channels reset on the T346
ZAP 0 frees all channels to run

When a channel is held reset, its phase accumulator and cycle counter are held clear. Its analog output is the first point of waveform memory, or the point selected by any

programmed phase rotation. The **ZAP** command with no argument is a query of the current reset mask.

5.9.37 Channel 4-7 View: VIEW Command

The **VIEW n** command allows the signals on V346 channels 4-7 to be viewed on the electrical "0" through "3" connectors. The argument is a bit map, with bits 0 through 3 enabling channels 4-7 to be diverted to the 0-3 outputs respectively.

The command **VIEW 15** diverts channels 4-7 to the normal 0-3 output connectors.

VIEW 0 restores normal operation.

5.9.38 Dirty Command

The **DIrty** command returns an integer bitmap which flags channels which have been sent new settings but whose settings are not yet installed.

5.9.39 Set Channel Target Address: nTarget Command

Local and Global Events may be issued with an attached Event Address. Each wave generator channel has two assignable Target Addresses, and will respond to an Event if either of its target addresses matches the Event Address and the channel is programmed to accept Events.

Target addresses are assigned to a channel by a command of the form

```
2Target  283
```

where **2Target** names channel 2, and the numeric argument sets both target addresses, as a pair of bytes, each in the range of 0 to 255. In this case, 283 is equal to 256 + 27, so the channel will respond to event addresses 1 and 27. This command could also be sent in hex as

```
2T 0x011B
```

with the MS byte being 01 and the LS byte 27 decimal.

It is common to assign a target address which is a small integer, allowing channels to be addresses in selective groupings for, perhaps, one-shot triggers. The default MS byte address is then zero, which can be reserved for an "all channels" broadcast address.

All channels respond to address 255 if programmed to accept Events.

5.9.40 Load Control Sequence: nC Command

The **6C and 7C** commands load control instructions into channel 6 or 7 of the T346.

These commands are identical to the **nB** load-arb-memory commands, except that they apply only to channels 6 and 7, and executing this command forces the channel into control sequence mode: the channel control register K field is set to 5, and channel waveforms are reported as "CTL"

See section 11 for discussion of control sequencing.

5.9.41 Microsecond Counter: USEC Command

The **USec** command returns a 32-bit counter which increments once every microsecond. The **USec 0** command will clear the counter. One use of this counter is to evaluate command execution times...

```
T346

USEC 0; USEC
OK;  0,000,000,376

T346

USEC 0; QFREQ 17.8K; USEC
OK;OK;  0,000,001,228
```

The command execution time here, adjusted for the USEC overhead itself, is about 912 microseconds.

6 Channel Synchronization and Ranges

The T344/T346 can maintain channels in exactly controlled frequency and phase relationships. In order to lock channels, their frequencies must be set equal or in **exact** integer ratios, then a command must be issued to restart them in phase. There are several ways to synchronize channels:

1. Issue a serial **SYnchronize** command

2. Program channels to respond to TTL Reset, then hold them reset them via the TTL connector, then release the reset.

3. Program channels to respond to a Local or Global Event; program the Event to be Reset or Synchronize; apply the appropriate edge to the TTL connector.

4. Program channels to respond to a Global Event, then issue a **GLobal REset** or **GLobal SYnc** serial command. This can synchronize multiple units configured in a master/slave system.

5. Use the **ZAp** command to reset channels, then release them together.

Once channels are synchronized, individual channel phases, amplitudes, and offsets may be changed at any time without loss of channel-channel sync. Uncoordinated changes of frequency, however, will cause channel phase relationships to drift apart, and thereafter another synchronize operation is needed to restore them to a known phase relationship.

If a channel is configured to work in auto-install mode, commands are applied to the waveform generator hardware at the end of every serial command line, when the final <cr> character is processed. So frequency changes that can all be programmed in a single command line preserve channel-channel phases.

To allow channel coordination with explicit control of when channel changes are installed, set channels to non-auto-install mode by setting the SU bit in their control registers; see section 5.9.1.

The general way to operate multiple channels with controlled phase relationships is…

Set the SU bits in all channel control registers to allow explicit control of channel updates.

Load channel frequencies using the **nFreq** or **nRaw** commands. The "raw" command form is appropriate if channels are to be run at non-unity frequency ratios.

Load channel phases using **nPhase** commands

Load any other channel parameters: amplitudes, channel control, etc

Use one of the synchronizing mechanisms listed above, such as the **SYnc** serial command, to install settings and synchronize the channels involved.

Now all channels will be synchronized and will run at the specified phases.

In order to maintain phase control, all future frequency and phase changes should be made simultaneously on all channels, by issuing new frequency or phase setting commands to all related channels and then doing an **INstall** operation or equivalent hardware update.

If all frequency change commands can be made by using the **QFreq** command, or by putting all frequency change commands in a single line separated by semicolons, the default auto-install mode is safe to use, and specific **INstall** commands are not needed.

Two or more channels can be synchronized, with coherent phase control, even while operating at different frequencies, and with different waveforms. For example, channel 0 could be set up run at 60 Hz and channel 1 at 120 Hz, then the channels could be synchronized to initialize them in-phase. In order that the phases not drift over time, the frequency setting of channel 1 must be precisely twice that of channel 0. Because of possible rounding errors in converting frequencies in Hertz to the internal phase accumulator scaling, the **nRaw** command should be used to set the channel frequencies in a precise 2:1 ratio.

The exact scalings of the available frequency ranges are listed below.

"R" represents the content of a raw frequency register, an integer in the range of +- (2^31-1), settable with the **nRaw** serial command.

"F" represents a frequency in Hz, as settable with the **nFreq** serial command.

Range 0 Max Frequency 31.999,999,985 MHz
LSB 0.014901161 Hz

F = R * 32e6 / 2^31 = R * 0.014901161...
R = F * 2^31 / 32e6 = F * 67.108864...

Range 1 Max Frequency 3.999,999,998 MHz
LSB 0.001862645 Hz

F = R * 4e6 / 2^31 = R * 0.001862645...
R = F * 2^31 / 4e6 = F * 536.870912...

Range 2 Max Frequency 0.249,999,999 MHz
LSB 0.000116415322 Hz

F = R * 250e3 / 2^31 = R *0.000116415322...
R = F * 2^31 / 250e3 = F * 8589.934592...

Range 3 Max Frequency 63.999,999,970 MHz (practical limit 40 MHz)
LSB 0.029802322 Hz

F = R * 64e6 / 2^31 = R * 0.029802322...
R = F * 2^31 / 64e6 = F * 33.554432...

7 One-Shot and Step Modes

Any T344/T346 channel may be programmed to operate in one-shot mode, by setting the OS bit in its channel control register.

If a channel is running when its OS bit is set, it will finish its current sweep through waveform memory and then enter the STOP state with its phase accumulator clear, at which time it will statically output the 0th waveform memory data point, possibly shifted by any phase offset value.

If a channel is armed for one-shot action (OS bit true and STOP state), and a FIRE action is performed on the channel, it will sweep through one pass of waveform memory, generating one cycle of waveform, then STOP. The channel's cycle counter will increment by one every time a full cycle is generated.

If the channel is already running, FIRE triggers are ignored.

A one-shot trigger can be invoked from a serial **`FIRE`** command, from a Local or Global Event (a trigger on the TTL connector), or from a Global Event invoked by a **`GLobal Fire`** serial command. A Global command can fire many channels on a group of master-slave interconnected modules.

If the OS bit is dropped, the channel will resume normal continuous waveform generation.

Note that it is the nature of DDS synthesis that waveform points are not necessarily selected in single-location sequence. Wave memory addresses are computed by accumulation of the selected frequency value in the channel phase accumulator. In general, waveform points will not be output in exact periodic sequence unless the selected frequency is exactly a binary fraction of the current range. On the 32 MHz range, the "magic" frequency of 31.25 KHz hits each of the 4096 wave memory points exactly once, creating a waveform of 32 microseconds duration. Any higher frequency will begin to skip waveform memory locations, but the output lowpass filter interpolates the missing points such that actual waveform quality does not suffer.

Suppose one wanted to program some specific arbitrary waveform shape and execute it on demand, with one-shot wave duration of 2.7 microseconds. First, define the shape as exactly 4096 points, each in the range of -32768 to +32767, and load them into a channel's memory using a number of **`nB`** serial commands. Since we want the waveform to play one full cycle in 2.7 microseconds, we'd program the channel frequency to its reciprocal, namely 370.370 KHz. Now a **`FIRE`** serial command, or a Local or Global Event, can be used to trigger a single waveform. Since the memory points are swept in 2.7 microseconds, and the internal clock rate is 128 MHz, only about every 12th table point is delivered to the DAC, and about 345 memory points are output in the sweep. If the programmed frequency were increased, to make a shorter-duration waveform, the number of points falls. If linear interpolation is enabled, the DAC will be updated at 128 MHz with the "best guess" interpolated value, which will produce a somewhat smoother waveform.

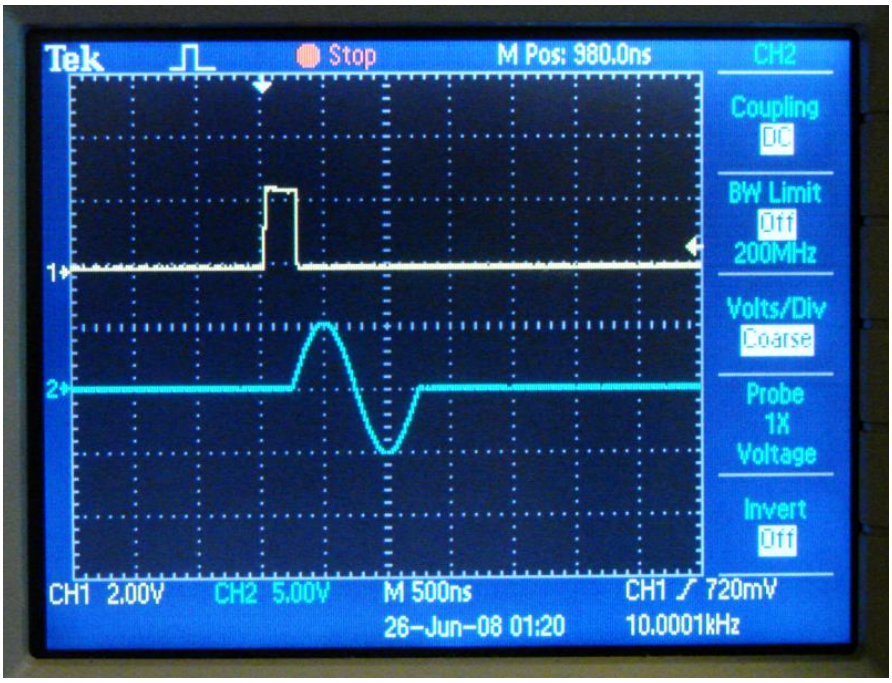
In the image below, channel 3 was set to one-shot mode and programmed to generate a sine wave at 1 MHz. The yellow trace is the external trigger pulse applied to the SYS connector, as a rising-edge Local Event, with the Event programmed to be FIRE. The blue trace is the resulting channel 3 output. The trigger rate was 10 KHz.

The serial commands to set up this display would be…

```
LOAD DEFAULT
3FREQ 1M
3AMPLITUDE 5
3SET OSHOT
TTL ERISE
TEVENT FIRE
```

or, in one line,

```
LO DE; 3F 1M; 3A 5; 3S OS; TT ER; TE FI
```



Channels can also be programmed to operate in step mode. In thus case, the channel cycle counter, rather than the phase accumulator, is used as the waveform table address. So if a channel is programmed to run at 1 KHz, the wave table will be stepped once a millisecond, essentially outputting the selected waveform at 1000/4096 = 0.244 Hz. When step mode is combined with one-shot mode, every one-shot trigger advances

the memory waveform pointer one location.

Combining step mode plus one-shot mode allows a list of values to be loaded into a waveform memory and delivered one at a time, in sequence. For example, channel 1 might be amplitude modulated by channel 6, and frequency modulated by channel 7. Channels 6 and 7 would be operated in one-shot plus step modes. Channel 6 memory would be loaded with a list of desired amplitudes (using the **6B** command) and channel 7 with a list of frequencies (using the **7B** command). Both channels 6 and 7 may be reset to start at the first amplitude:frequency point; thereafter, whenever channels 6 or 7 are one-shot fired, channel 1 advances to the next desired amplitude or frequency in the respective list.

Note that any one-shot fire will cause the channel phase accumulator to make one pass through waveform memory before incrementing the channel cycle counter. So there will be a delay from a one-shot fire until the step action takes place, and the channel will ignore additional one-shot fire events while the current cycle is busy. This can be useful as a trigger hold-off mechanism. If this delay is undesirable, program the channel frequency to 32 MHz for minimum delay.

8 Arbitrary Waveforms

The **nLOAD** serial command can load a standard waveform into a channel's 4096-point waveform memory. One can also load an arbitrary waveform using the **nB** serial command, as described in section 5.9.9.

The **nK** serial command can be used to initialize all or a segment of waveform memory to some fixed value, which is useful as a baseline for loading custom waveform segments. It can also create simple sloped line segments. See section 5.9.10.

When an **nB** or **nK** command is issued to a channel, the channel control register "K" field is set to zero, selecting "wave mode", and the reported waveform type becomes ***ARB*** .

In general, one should always load a channel with all 4096 waveform points.

9 Noise Generation

Any channel may be programmed to generate band-limited Gaussian noise, by setting its channel control register "K" field to 3, or by using the **`nSet NOise`** serial command.

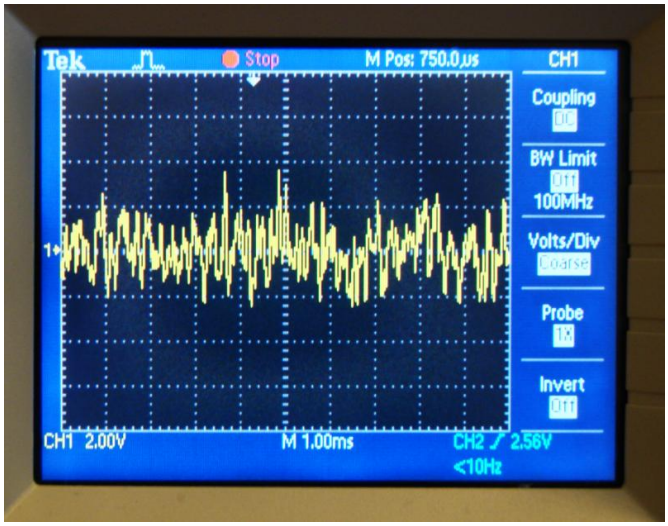
The channel noise output peak voltage will be close to the programmed channel amplitude, and will be 1.0 volts RMS at the maximum channel amplitude setting of 5.12 volts, independent of programmed bandwidth, with a nearly Gaussian probability distribution function. The probability distribution does not have the infinite-amplitude tails of truly random noise, so the crest factor is finite, so that clipping of the channel DAC beyond +-5.12 volts has zero probability.

The usual channel amplitude scaling, and the D5 attenuation bit, may be used to scale amplitude down from the 1.0 volt RMS maximum level.

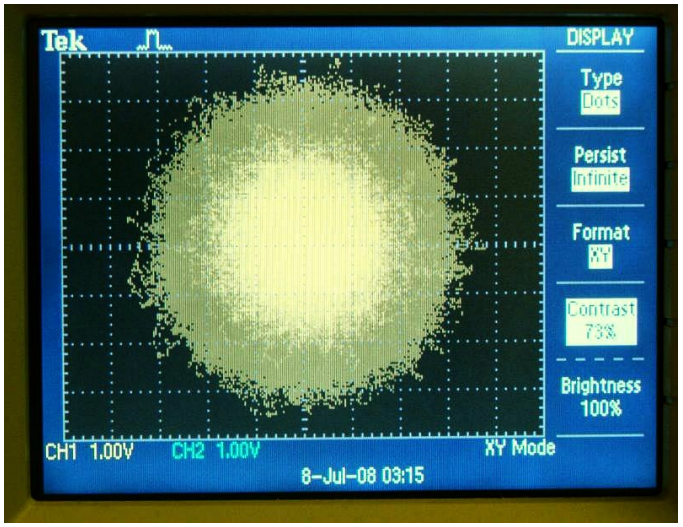
The noise is digitally lowpass filtered with a 3 dB bandwidth that is controlled by the regular channel frequency setting divided by 16. Setting a channel frequency to 32 MHz gives the maximum 2 MHz noise bandwidth. Frequency ranges scale the bandwidth. Do not select the 64 MHz range for noise generation.

Noise is generated from a digital random-number generator, with samples digitally filtered to produce the near-Gaussian distribution and programmed bandwidth. Noise is uncorrelated between channels and has no significant autocorrelations.

Noise can be summed into waveforms generated by other channels, or used to modulate other channels.



Single-channel noise



Two-channel noise XY plot

10 Events

The T344/T346 has an "Event Bus" which connects the Event logic block to all channels.

The Event bus has two fields, an operation code and an 8-bit Event Address. The operation codes are…

Ecode	Event Operation
0	none
1	Update channels: transfers settings from channel latches
2	Reset channels: clears phase accumulators
3	Synchronize channels, equivalent to Update and Reset
4	Phase Snapshot
8	Fire one-shot channels

Every channel has two programmable 8-bit Target addresses.

A channel will respond to an Event operation code if its AE (Accept Events) channel control register bit is set and the Event Address matches either of the channel Target Addresses. Additionally, Event Address 255 will activate all channels so long as their AE bit is set. This addressing logic allows operations to be performed on selected groups of channels.

Local Events are generated by edges applied to the TTL connector. They affect only the channels on one board.

Global Events can be generated by TTL inputs or by the **`GLobal`** serial command. Thet affect all channels connected in a master/slave array.

The possible sources of Events are…

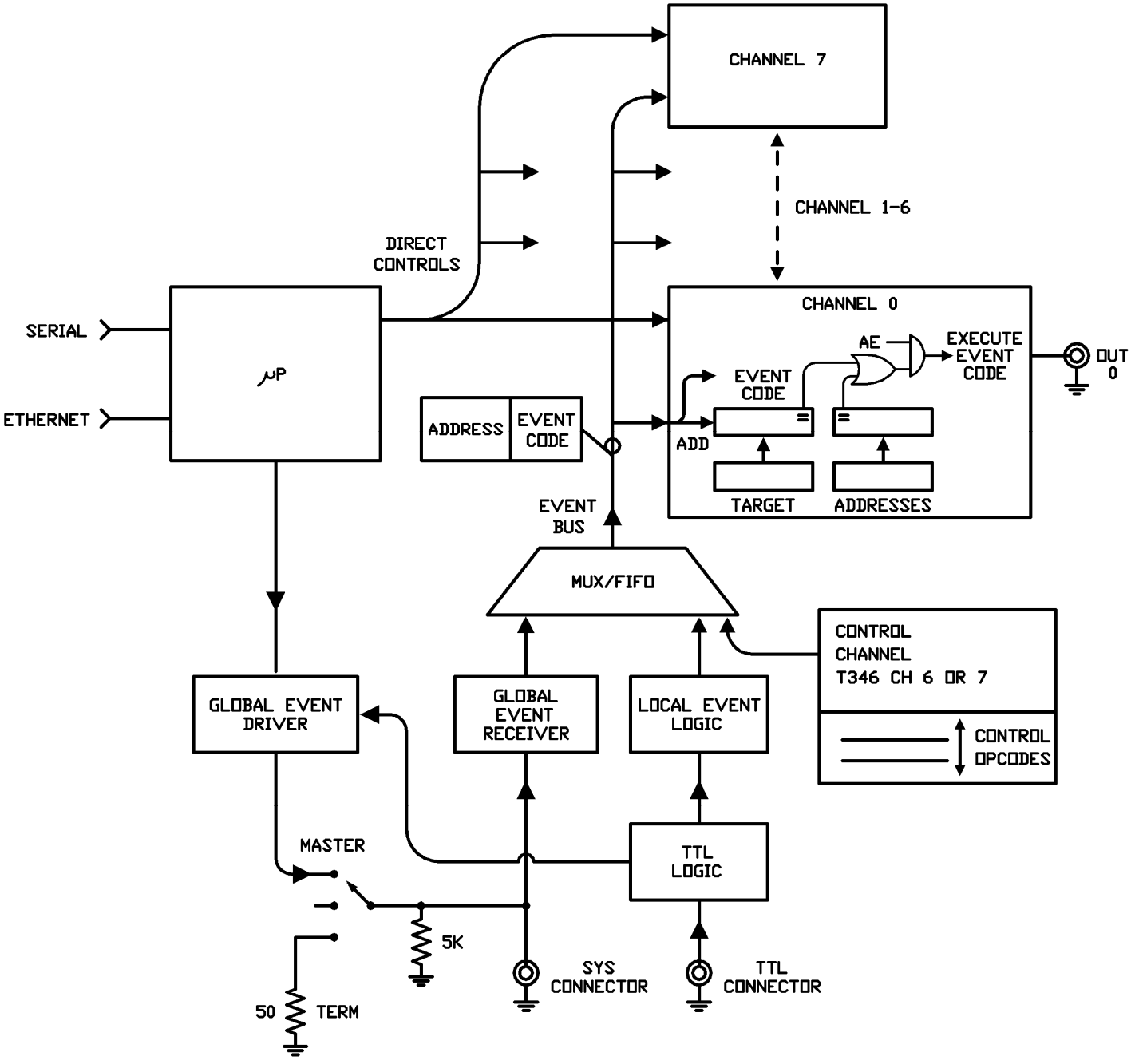
Local or Global Events may be triggered by logic input edges on the TTL connector. The event and its address are programmed using the **`TTl, TEvent`** and **`TAdd`** serial commands.

The **`GLobal`** serial command can be used to immediately launch a Global Event.

Global Events are propagated between modules by interconnect of their SYS connectors. Modules are programmed to be masters and slaves using the **`MS`** command.

On the T346, channels 6 or 7 may be configured as programmable control sequence generators, which run simple sequential programs which can themselves generate Local or Global Events. This facility is discussed in section 11.

The Event logic is summarized in the diagram below.



Example: the SYS connectors of two T346 modules were connected using a short SMB-SMB cable. Unit "A" was set up to be the master, and unit "B" as a terminating slave.

Serial commands to A were…

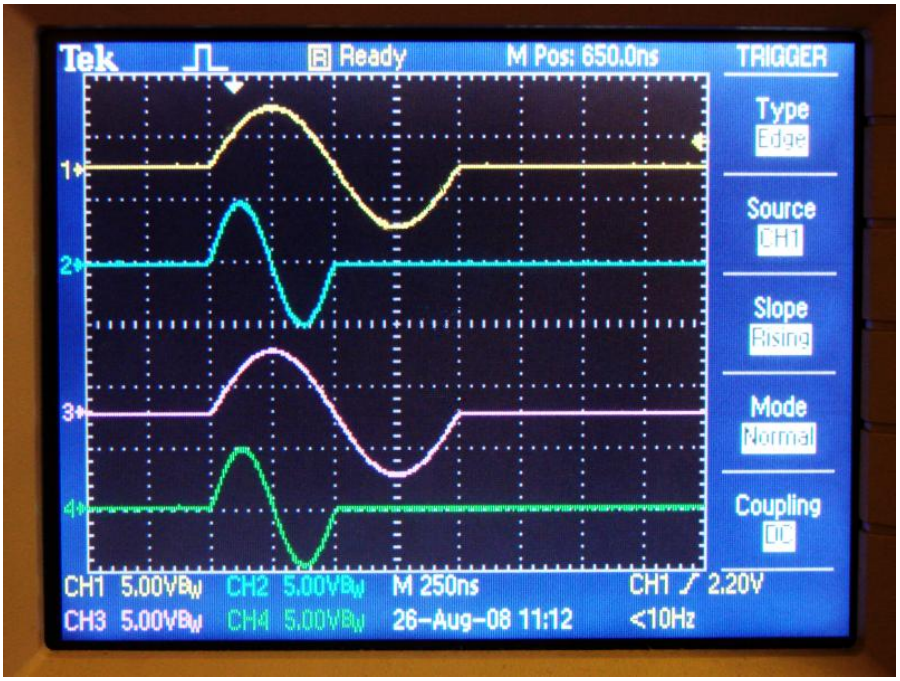
MS MASTER	be the system master
QSET OSHOT	operate channels in one-shot mode
QSET AEVENTS	all channels accept Events
QAMPL 5	amplitudes 5 volts peak
0F 1M	channel 0 frequency 1 MHz
1F 2M	channel 1 frequency 2 MHz

and commands to the B module were

MS TERM	be a terminating slave
QSET OSHOT	operate channels in one-shot mode
QSET AEVENTS	all channels accept Events
QAMPL 5	amplitudes 5 volts peak
0F 1M	channel 0 frequency 1 MHz
1F 2M	channel 1 frequency 2 MHz

The status of the B module will now indicate that it is receiving, and is locked to, the board sync signal from the master.

Now issuing the serial command **GLOBAL FIRE** to the A unit will fire the one-shot channels on both modules. In the scope shot below, the upper two traces are channels 0 and 1 of the master module A, and the bottom two traces are channels 0 and 1 of the slave module B.



11 Control Sequences

On the T346, channels 6 and 7 may be programmed to be control sequencers. In this mode, their waveform memory is loaded with a sequence of executable opcodes which are run using the channel cycle counter as a program counter.

A "program" may be loaded into a control channel using the **6C** or **7C** serial commands, generally starting at memory location 0. The command syntax is identical to the **nB** commands, as noted in section 5.9.9.

The available opcodes are…

Generate Local Event	Arguments are Event code, Event address
Generate Global Event	Arguments are Event code, Event address
Delay	Argument is delay count
Sleep	Pause until next Fire input
Restart	Jump to address 0

Opcodes are executed at the programmed frequency rate of the channel, and Delays are timed at that same rate.

Commands in the control channel wave table RAM are detailed below. **En** represents an Event Code bit, **An** an Event Address bit, and **Dn** a delay time bit.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	0	E5	E4	E3	E2	E1	E0	A7	A6	A5	A4	A3	A2	A1	A0
Generate Local Event															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	E5	E4	E3	E2	E1	E0	A7	A6	A5	A4	A3	A2	A1	A0
Generate Global Event															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Delay For A Time															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Sleep Until A FIRE Trigger															

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Restart to Address 0															

The Event Codes are…

Ecode	Event Operation
0	none
1	Update channels: transfers settings from channel latches
2	Reset channels: clears phase accumulators
3	Update and Reset
4	Phase Snapshot
8	Fire one-shot channels

The Delay command takes a 12-bit unsigned argument in the D field, corresponding to a delay of D ticks of the step clock, with a D of zero acting as a "nop" instruction. A delay argument of "D" takes D+1 clocks to execute.

Longer delays can be created by executing multiple Delay commands back to back.

The Restart command resets the channel to address 0 and begins executing the program again. In this way, the program can be made to loop over the same commands over and over.

The Sleep command puts the channel to sleep until it is awakened by a FIRE trigger. This FIRE trigger can come from any of the usual sources; a serial **`FIRE`** command, a TTL-edge Local Event, or a multi-module Global Event.

The timing of control programs can be manipulated by changing the frequency of the control channel, or by changing delays within the program on-the-fly.

Note that control channels may themselves be programmed to run at any frequency; may accept serial commands like **`FIRE`**, **`SYNC`**, and **`ZAP`**; may themselves accept addressed Local or Global Events; may respond to their own Events, or Events from other sources; may be FM modulated or frequency stepped.

Control channels can be used to advance Step-mode channels, which can in turn modulate output channels, allowing elaborate waveform sequences to be generated.

For example, suppose we wanted to fire one cycle of a 10 KHz sine wave, wait 250 us and fire again, and repeat that pattern at 1 KHz. The serial commands could be…

Establish default conditions…

```
LOAD DEFAULT
```

Initially hold all channels reset:

```
ZAP 255
```

Set channel 0 as 10 KHz sine, one-shot mode, accept Events, default target address 0

```
0SET OS ; 0SET AE ; 0FREQ 10K; 0AMPL  5
```

Set up channel 6 as the control, running at 1 MHz

```
6FREQ 1M
```

Opcodes are (Local Fire) (Delay 249) (Local Fire) (Delay 748) (Restart)

```
6CONTROL  0  0x8800  249  0x8800 748  0x8800  0x7000
```

Now turn everything loose…

```
INSTALL; ZAP 0
```

Note that the serial command **`6AMPL 5;VIEW 4`** will cause an analog "code profile" to appear at the output 2 connector, as shown in the lower trace.

12 Modulation

The T346 allows channel-to-channel modulations. Any channel can be AM, FM, PM, or PWM modulated by any other channels, in any combination, except that channel 0 cannot be a modulation source.

Each channel has a modulation control register, managed by the **nMod** command, as detailed in section 12. The register arrangement is

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
PW2	PW1	PW0	FR1	FR0	FM2	FM1	FM0		AM2	AM1	AM0		PM2	PM1	PM0
MODx Register															

The fields are:

Field	Meaning
PM	Phase modulation source
AM	Amplitude modulation source
FM	Frequency modulation source
FR	Frequency modulation scaler
PW	Pulse-width modulation source

For any given field, a modulation source of zero indicates no modulation, so channel 0 cannot be a modulation source.

When a channel is used as a modulation source, it provides its data after any summing has taken place, but before the DAC conversion to analog. So if channel 3 uses channel 4 as a summing source, then if channel 2 uses channel 3 as a modulation source, channel 2 be modulated with the sum of channels 3 and 4. The D5 amplitude attenuator has no effect on modulation.

Amplitude Modulation Scaling

Assume we wish to amplitude modulate target channel 0 by the output of channel 7. The MOD0 register will be set to 0x0070 to establish the modulation link. The appropriate serial command would be **0Mod 0x0070**, or the text-mode command **0Mod AM 7**.

The 16-bit equivalent output of channel 7 is added to the AMP0 register, with the sum applied to the CH0 amplitude multiplier. The channel 7 waveform output is treated as a signed 16-bit value. One might set the AMP0 register to zero when using amplitude modulation; in that case, the scaling of channel 0 outputs would be…

Channel 7 Value	Channel 7 Output	Channel 0 Multiplier
0x7FFF	+5.12V	+0.99997
0x4000	+2.56V	+0.5
0x0000	0V	0
0xC000	-2.56V	-0.5
0x8000	-5.12V	-1

The instantaneous output of channel 0 would then be

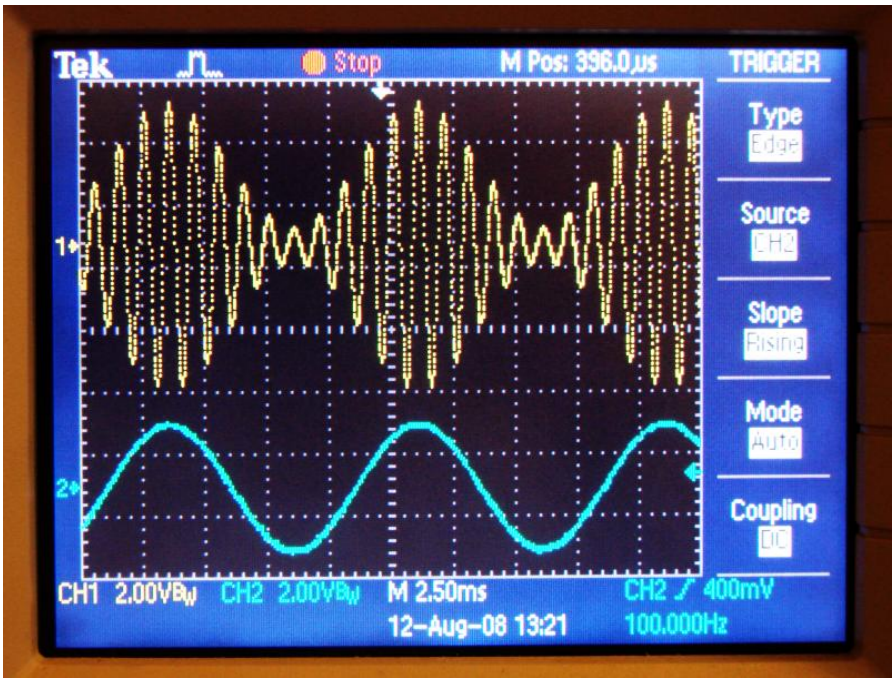
V0 = (Wx / 32768) * ((D7+AMP0) / 32768) * 5.12 volts

where Wx is the current channel 0 wave memory output (range +-32767) and D7 is the current channel 7 DAC code, scaled from 32767 (+5.11 volts) to -32768 (-5.12 volts.) Note that if the D7+AMP0 addition exceeds the signed 16-bit range, then the results will overflow.

So the commands…

```
LOAD DEFAULT
0FREQ 1K; 0AMPL 2.5; 0MOD AM 1
1FREQ 100; 1AMPL 2
```

produce, on channels 0 and 1, the waveforms



The dots on the upper waveform are digital oscilloscope artifacts.

Phase Modulation Scaling

Assume we wish to phase modulate target channel 0 by the output of channel 6. The MOD0 register would be set to 0x0006 to establish the modulation link. The serial command is **`0Mod 0x0006`** or **`0Mod PM 6`**.

The 16-bit equivalent output of channel 6 effectively added to the PHA0 register, with the sum applied to the CH0 phase rotation adder. If the channel 6 output were 0x4000 (equivalent to +2.56 volts DAC output), the phase of the channel 0 output will be advanced 90 degrees sooner in time; i.e. the channel 0 wave table pointer will be advanced 1024 locations. Thus the modulating input can be treated as a 16-bit unsigned integer in the range 0x0000 to 0xFFFF that scales to 0 to 359.99 degrees of phase lead, or it can be treated as a signed integer from 0x8000 to 0x7FFF that scales from -180 to +179.99 degrees; these views of the situation are mathematically equivalent. The sum of PHA0 and the incoming channel 6 modulation is treated as an angle modulo 360 degrees, with no possible overflow.

Frequency Modulation Scaling

Assume we wish to frequency modulate target channel 0 by the output of channel 5. The MOD0 register will be set to 0x0500 to establish the modulation link. Serial commands would be **`0Mod 0x0500`** or **`0Mod FM 5`**.

Assume the FR bits are all zero.

The scaled and offset output of the channel 5 waveform generator is treated as a signed 32-bit integer that is added to the programmed frequency of channel 0. Assume that channel 0 is programmed for a frequency of F_0. The correspondences are…

Channel 5 Value	**Channel 5 Output**	**Channel 0 Frequency**
0x7FFE0002	+5.12V	F_0 + 15.999023 MHz
0x40000000	+2.56 V	F_0 + 8.0000000 MHz
0x0000	0V	F_0
0xC0000000	-2.56V	F_0 - 8.0000000 MHz
0x80000000	-5.12V	F_0 - 16.000000 MHz

where the 0x7FFE0002 is the signed product of the maximum channel 5 wave table entry (0x7FFF) times the maximum AMP5 amplitude scaler (0x7FFF).

So if channel 5 were programmed to generate the standard sawtooth wave (with wave table entries sweeping from 0x8001 to 0x7FFF) and the AMP5 register were set to 0x7FFF, the resulting peak-to-peak FM modulation of channel 0 would be 31.999 MHz. If the channel 0 center frequency Fo were programmed to 16 MHz, the result would be a linear sweep from 0 to just under 32 MHz.

With the scaling noted above, the narrowest sweep that the full-scale sawtooth can make will be when the AMP5 register is set to 0x0001, at which point the sweep will be 976 Hz wide. Narrower span sweeps can be had by setting the FR bits in the MOD register, scaling down the FM range. A typical serial command is **`0Mod RA 2`**

FR Code	FR1	FR0	Divisor	Sweep Range
0	0	0	1	32 MHz
1	0	1	16	2 MHz
2	1	0	256	125 kHz
3	1	1	4096	7.8 kHz

Note that the FM deviation is not affected by the frequency range of the target channel, namely the state of the R bits of the modulated channel's control register.

Since channel frequency is signed, it is possible to sweep across positive and negative frequencies by sweeping through zero.

Should the sum of the channel's programmed frequency and the scaled frequency modulation signal exceed the range of ±64 MHz, the results will overflow.

PWM Modulation Scaling

If a channel is operating in one of its PWM modes, and that channel's PW modulation register field is set to 1 through 7, then the target channel's PWM duty cycle will be controlled by the output of the named source channel, and the target channel's PWMx register will be ignored. The integer value from the modulating channel is mapped such that the scaling is…

Channel 7 Value	Channel 7 Output Equiv	Mapped Equivalent	Channel 0 Duty Cycle
0x7FFF	+5.12V	0xFFFF	99.9985%
0x4000	+2.56V	0xC000	75%
0x0000	0V	0x8000	50%
0xC000	-2.56V	0x4000	25%
0x8000	-5.12V	0x0000	0%

For example, suppose channel 7 were programmed to generate a 400 Hz sine wave at full (+-5.12 volts) amplitude.

Now suppose we program target channel 2 to operate in PWM mode at 200 KHz, and set its PW modulation bit field to "100", selecting channel 4 to control its pulse width. Serial commands could be **`2Mod 0x8000`** or **`2Mod PW 4`**.

We could now use the output of channel 2 to control a switchmode power H-bridge, operating at 200 KHz, which will now produce a full-scale, bipolar, 400 Hz sinewave power output. Channel 4 can be programmed for new frequencies, amplitudes, or phases as desired, and the H-bridge output will follow.

13 Xport Ethernet Module Setup

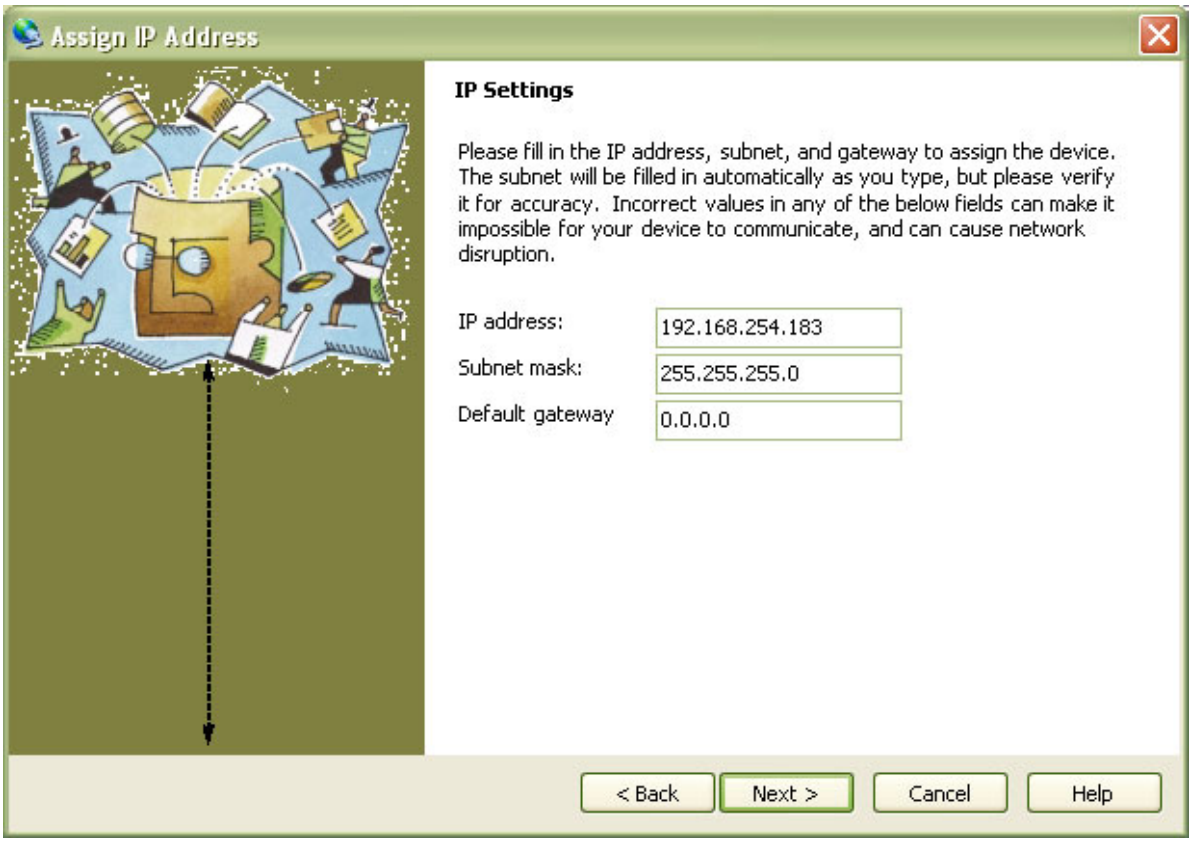
The T344 and T346 use a Lantronix Xport module as their Ethernet/TCP-IP interface.

Units are normally shipped set to IP address 192.168.254.199, port 2000. Most users will need to reassign the IP address to be compatible with their networks. If multiple T344s are used, assign a unique IP address to each. The Xport also supports dynamic IP address assignment.

Lantronix provides a PC utility "XportInstaller" to locate an Xport module by MAC address and assign it an IP address. The Lantronix software utilities may be downloaded from

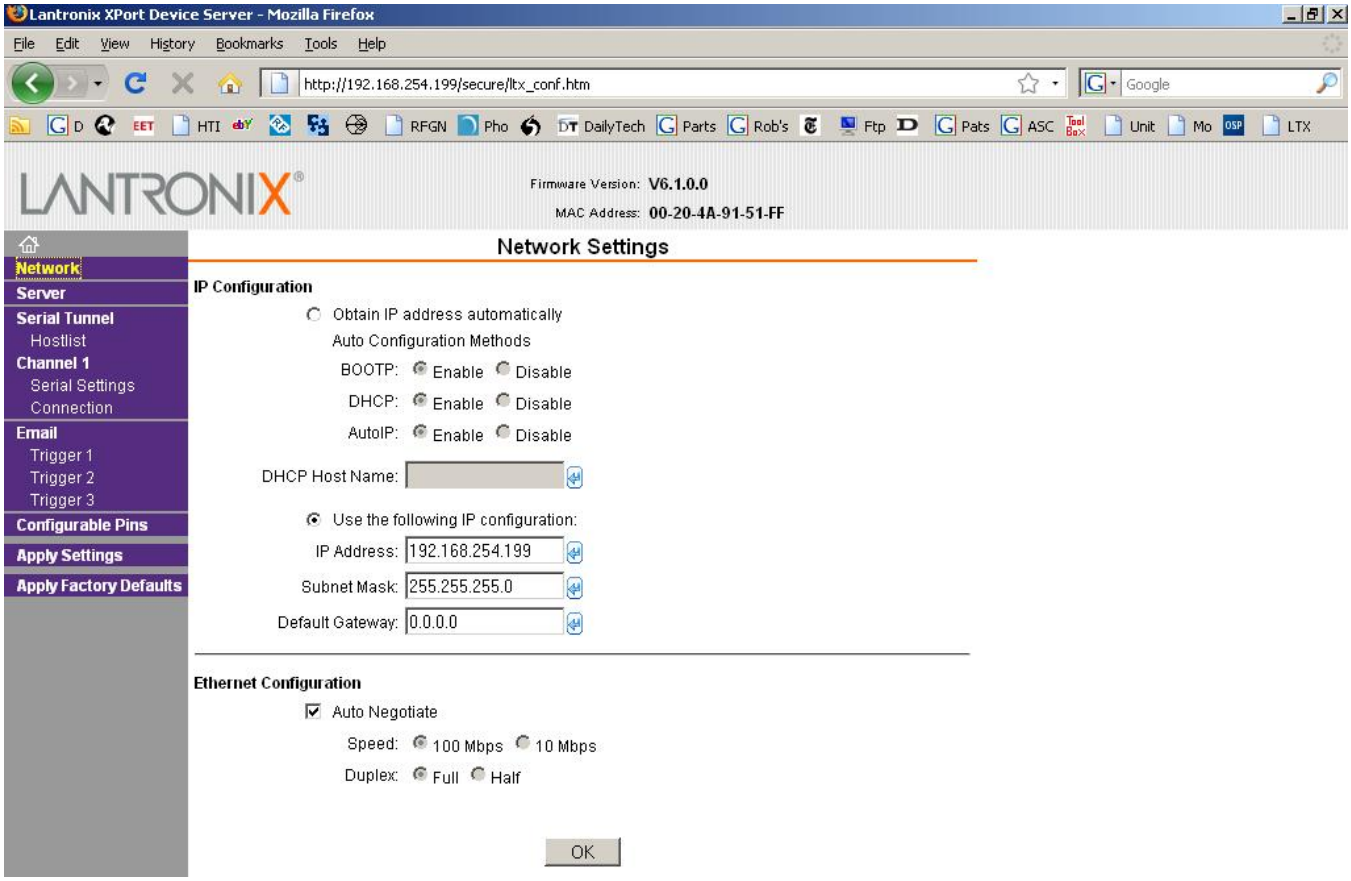
http://www.lantronix.com

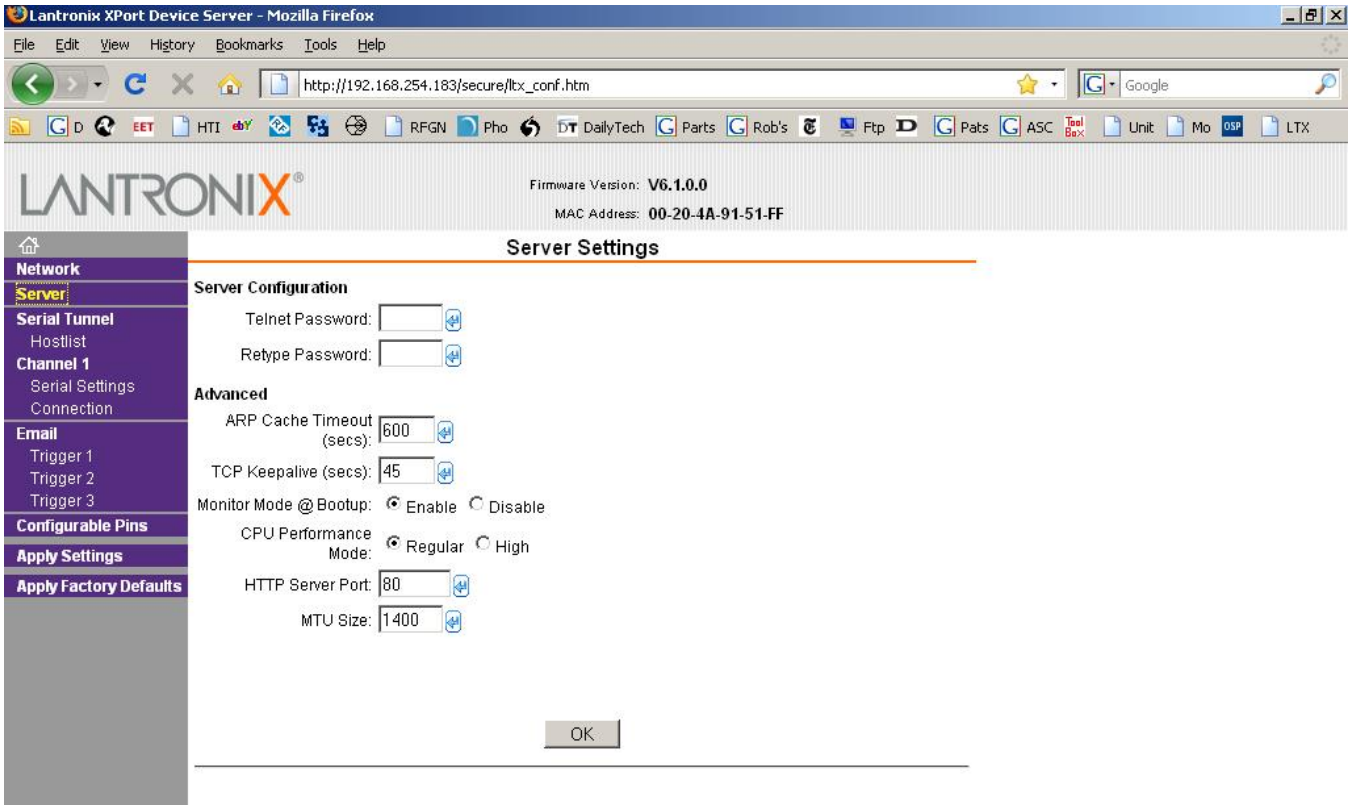
The XportInstaller IP address assignment pane looks like this:

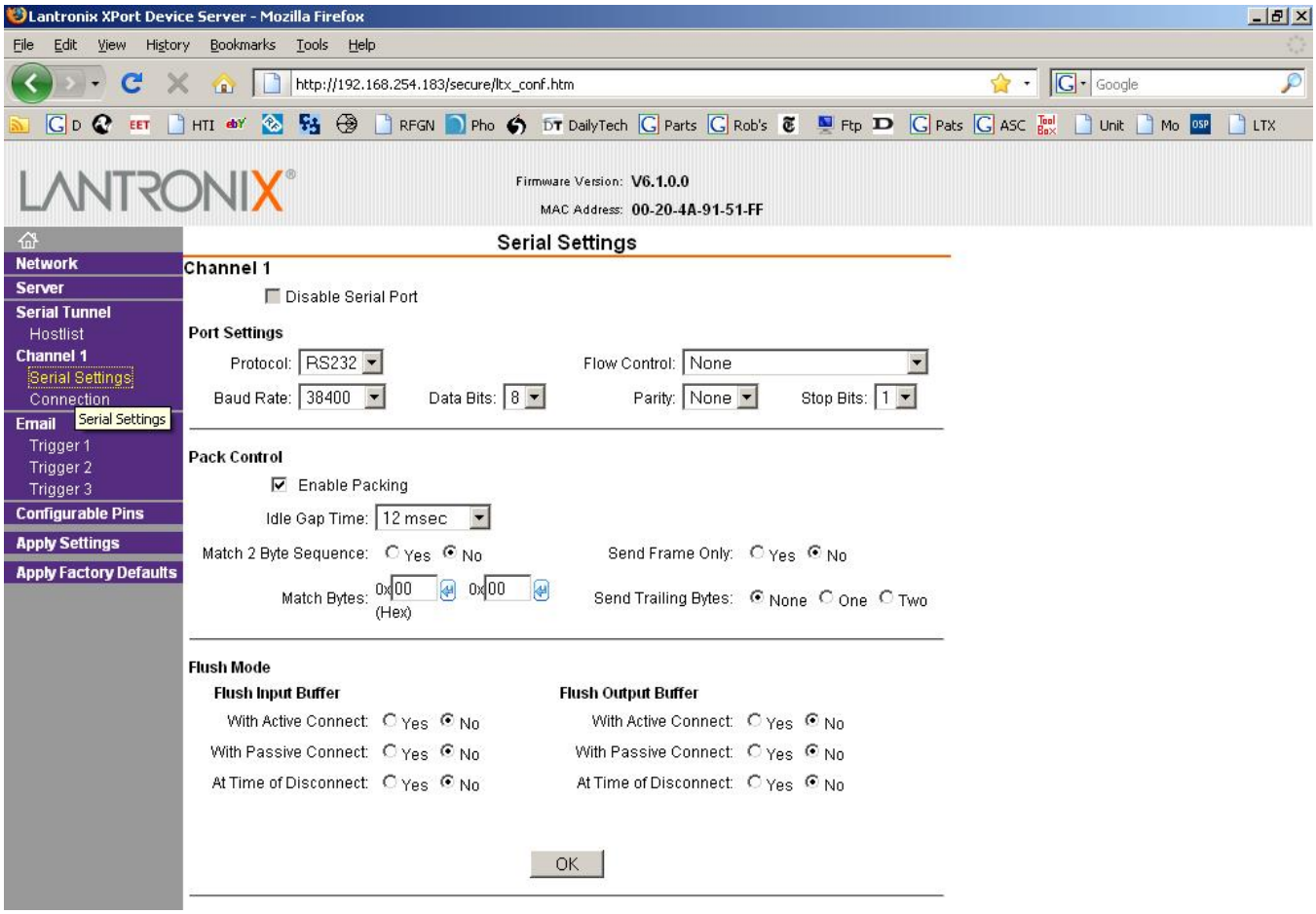


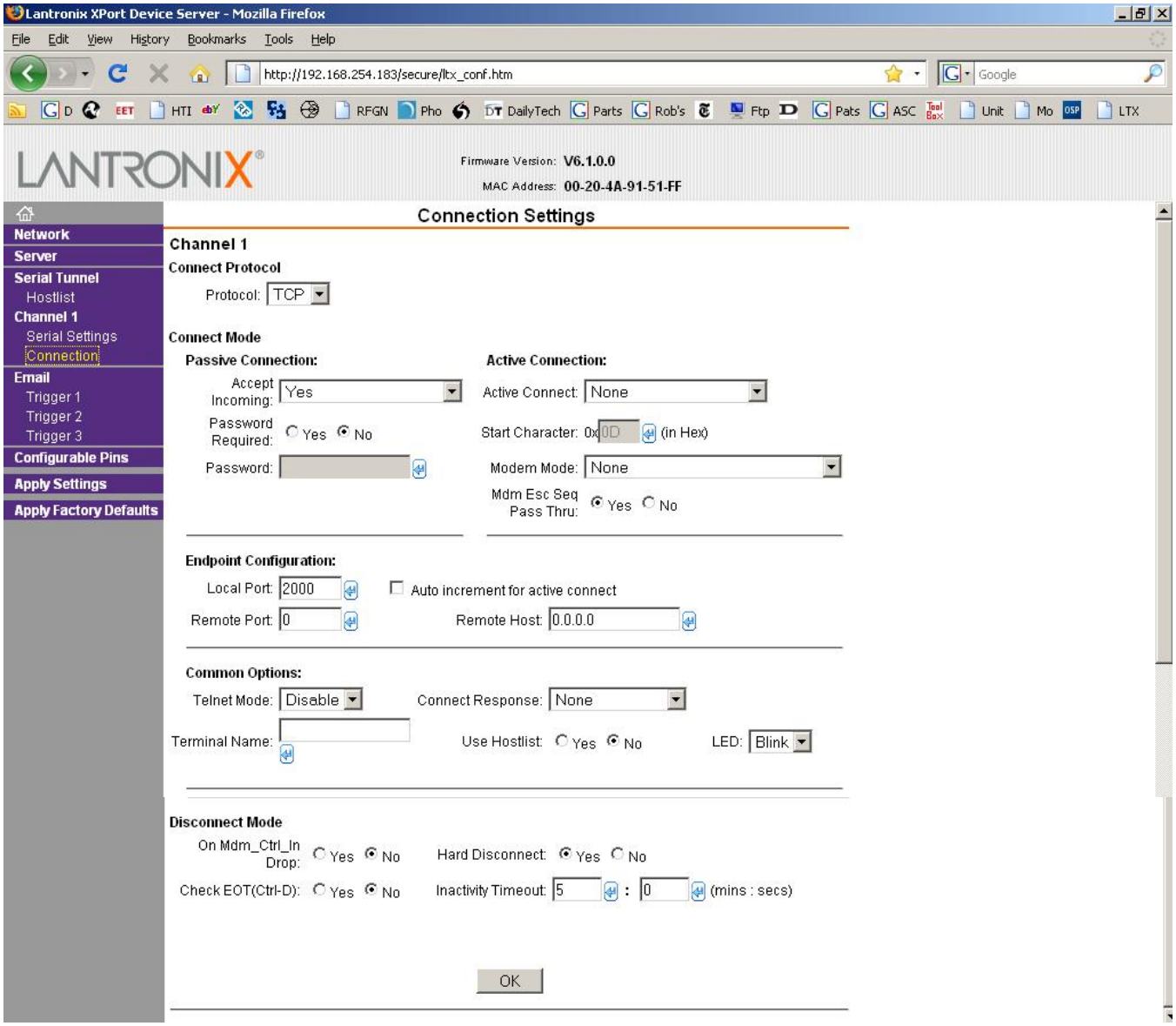
Once the Xport module has been assigned an IP address, a web browser can be used to access the Xport module as a web page; just type the IP address into the browser's address bar, after which settings may be edited. You need not initially enter a user name or password. The web page interface can also be used to change the IP address, so if your browser can access the Xport directly, you need not run the XportInstaller.

The following images represent the setup in which the Xports in the T344/T346 are normally shipped.




Lantronix XPort Device Server - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://192.168.254.183/secure/ltx_conf.htm
Google
LANTRONIX
Firmware Version: V6.1.0.0
MAC Address: 00-20-4A-91-51-FF
Network
Server
Serial Tunnel
Hostlist
Channel 1
Serial Settings
Connection
Email
Trigger 1
Trigger 2
Trigger 3
Configurable Pins
Apply Settings
Apply Factory Defaults
Server Settings
Server Configuration
Telnet Password:
Retype Password:
Advanced
ARP Cache Timeout (secs): 600
TCP Keepalive (secs): 45
Monitor Mode @ Bootup: Enable Disable
CPU Performance Mode: Regular High
HTTP Server Port: 80
MTU Size: 1400
OK


Lantronix XPort Device Server - Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://192.168.254.183/secure/ltx_conf.htm
Google
LANTRONIX
Firmware Version: V6.1.0.0
MAC Address: 00-20-4A-91-51-FF
Network
Server
Serial Tunnel
Hostlist
Channel 1
Serial Settings
Connection
Email
Trigger 1
Trigger 2
Trigger 3
Configurable Pins
Apply Settings
Apply Factory Defaults
Serial Settings
Channel 1
Disable Serial Port
Port Settings
Protocol: RS232
Flow Control: None
Baud Rate: 38400
Data Bits: 8
Parity: None
Stop Bits: 1
Pack Control
Enable Packing
Idle Gap Time: 12 msec
Match 2 Byte Sequence: Yes No
Send Frame Only: Yes No
Match Bytes: 0x00 0x00 (Hex)
Send Trailing Bytes: None One Two
Flush Mode
Flush Input Buffer
With Active Connect: Yes No
With Passive Connect: Yes No
At Time of Disconnect: Yes No
Flush Output Buffer
With Active Connect: Yes No
With Passive Connect: Yes No
At Time of Disconnect: Yes No
OK



Note that the Xport allows only one TCP/IP connection to be open at any one time, and will time out and disconnect after the time set for a hard disconnect. Enter 0 to disable automatic disconnect. It is usually prudent to set up the Xport to disconnect after some inactivity period, to avoid having an inactive connection lock out access.

A periodic ping, such as sending a single null character every minute or so, will keep a TCP/IP session open.

14 BIST

The T344/T346 feature an automatic self-test sequence to allow the user to test the functionality of the unit without external equipment and without the need to disconnect field wiring.

Note: BIST is primarily a functional test and checks only approximate quantitative performance limits. It cannot allow absolute verification of module accuracy, as external NIST-traceable standards are required for formal calibration.

Although the BIST operations can detect most module failures, certain errors can be missed. They include:

- Failure of a connector pin or associated printed-circuit traces.
- Failure of a channel test relay.
- Low-order DAC bit errors.

Items tested include:

- BIST a/d converter operation
- Synthesizer (128 MHz) clock frequency accuracy
- Channel full-scale output voltages
- Channel divided-by-10 output voltages
- Channel output frequency accuracy
- Filter response

To invoke BIST, send the serial command

`BIst 0`	or	**`BIst`**	to run tests and report error summary only
`BIst 1`			to run tests and report numeric results of any errors
`BIst 2`			to run tests and report all numeric results

During the test, the green LED will blink rapidly, and the red LED will come on solid for at least one second if any error is detected. Test time is about 7 seconds. After the self-test, all previous module settings will be restored, except that arbitrary waveform data is lost. If any error was detected, an error flag bit will be left up, so the red LED will continue to flash. **`ERrors 0`** will clear the BIST error flag.

15 Calibration Verification

To verify channel performance accuracy, the TEST connector of one or more modules may be connected to a precision voltmeter/frequency counter.

Route a selected channel output to the test connector with a command…

MOde 1	route channel 0 to the test connector
MOde 2	route channel 1 to the test connector
MOde 3	route channel 2 to the test connector
MOde 4	route channel 3 to the test connector
MOde 0	to resume normal operation

Now program the selected channel to some known frequency and amplitude, and check the values with the external instrument.

16 Operating Examples

16.1 Powerup

Connect the J12 power supply to the DC power connector. At powerup, all four LEDs should light and, about three seconds later, all should go out except that the green POWER led will blink about once a second.

16.2 Serial Communications

Connect the module to the serial port of a PC, using a straight-through RS-232 cable. Only the transmit, receive, and ground lines are used. See caution in section 4.8.

Run a serial communications program such as HyperTerminal. Set it up for local port connection, 38,400 baud, 8 bits, no parity, 1 stop, no handshaking. A simple ASCII TTY33 or VT100 mode is acceptable.

When you type <enter>, the T344 should respond with…

T344 <cr> <lf>

Any time a key is hit on the PC, the orange "com" LED on the T344 should flash. Any time the T344 replies, its green LED will flash.

Type

STATUS to display the setup and status report

HELP to show the main Help message

16.3 Demo Modes

Connect one or more channel outputs to an oscilloscope and type

DEmo 0

to invoke the first demo setup, basic sine wave outputs.

Now any of the channel control commands can be used to change the outputs. For example, typing **0Freq 20K** will change the channel 0 output to 20 KHz.

Type **HElp CHannels** for a summary of channel commands.

Type **`HElp DEmo`** for a list of other available demos.

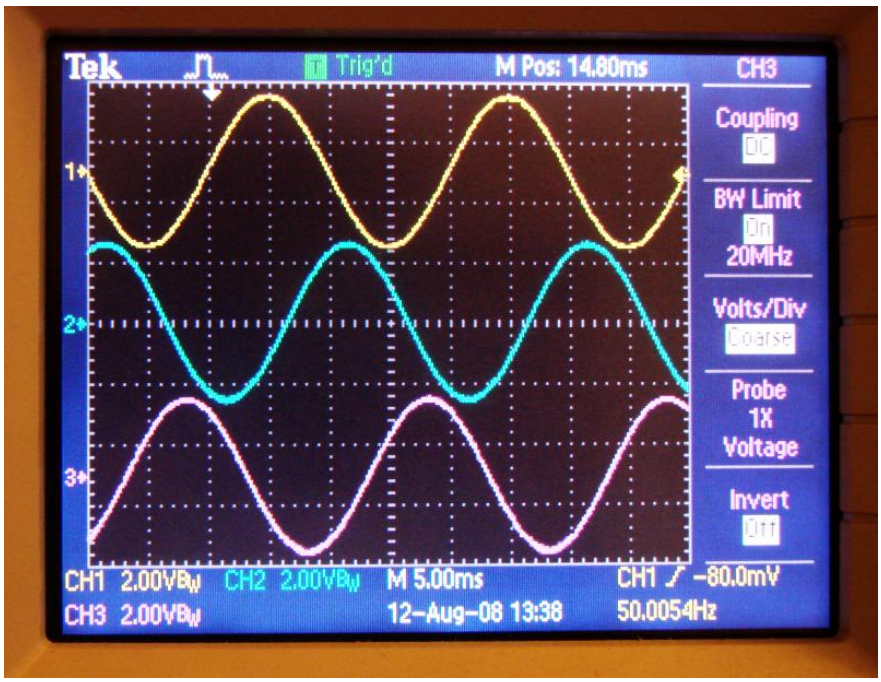
16.4 Synchronizing Channels and Phase Control

The default mode of the T344 is for the four channels operate as independent waveform generators. When any channel parameter is changed, such as amplitude or frequency, the internal microprocessor detects the change and loads the appropriate hardware as soon as possible but with no guaranteed timing. In this mode, channel synchronization is not possible and the values in the channel phase-control registers are essentially meaningless.

In order to coordinate channels, it is necessary to synchronize channels and make future frequency changes synchronously.

For example, to generate a 3-phase sine wave set using channels 0, 1, and 2, the command sequence could be:

`LOad DEfault`	load default setup as starting point
`QFreq 50`	set all 4 channels to 50 Hz
`QAmpl 2.5`	set all 4 channels to 2.5 volts peak
`1Phase 120`	set channel 1 to 120 degrees lag
`2Phase 240`	set channel 2 to 240 degrees lag
`SYnc`	synchronize channels



The frequency of the set may be changed at any time using another **QFreq** command. Channel phases, amplitudes, and offsets may be changed at any time without affecting phase coherence. Since **QFreq** changes frequencies of all channels atomically, the default auto-install mode is acceptable.

A basic frequency sweep can now be programmed using the **WAIT** command. To sweep the above setup from 50 to 70 Hz, send a command sequence like…

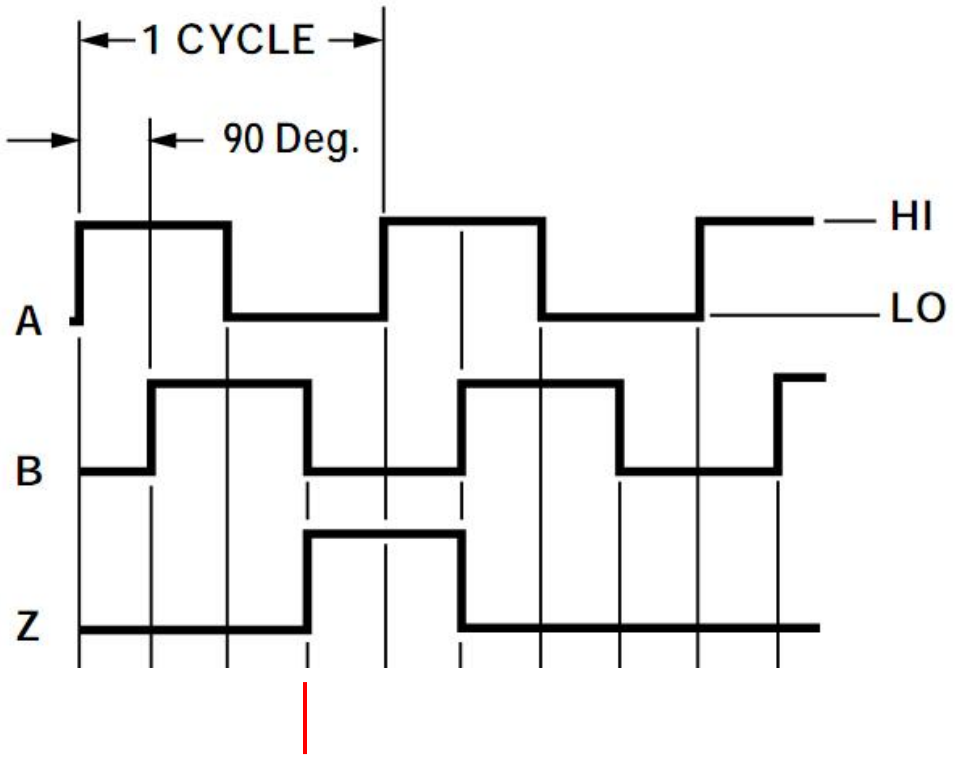
```
QF 51; IN; WA 250; QF 52; IN; WA 250; QF 53; IN, WA 250;
```

etc to 70 Hz. The command line, including the optional spaces, will be 360 characters long and will take about 5 seconds to execute.

This will step the frequency of all channels by 1 Hz every 250 milliseconds. Note that **INstall** commands are necessary after every frequency change to force updates within a command line. The T346 can also do smooth sweeps using the frequency modulation feature.

16.5 Bidirectional Encoder Simulation

The PWM mode can be used to simulate a quadrature encoder. As an example, we could simulate a typical quadrature encoder having 2000 counts per revolution. It would output a pair of quadrature square waves, each making 500 cycles per revolution, and would have a third index output that goes high once a rotation. A typical waveform set is shown below. We could use T344 channels 0 and 1 to make the A and B quadrature signals, and channel 2 to make the Z index pulse. We assume a "half cycle index" as shown below.



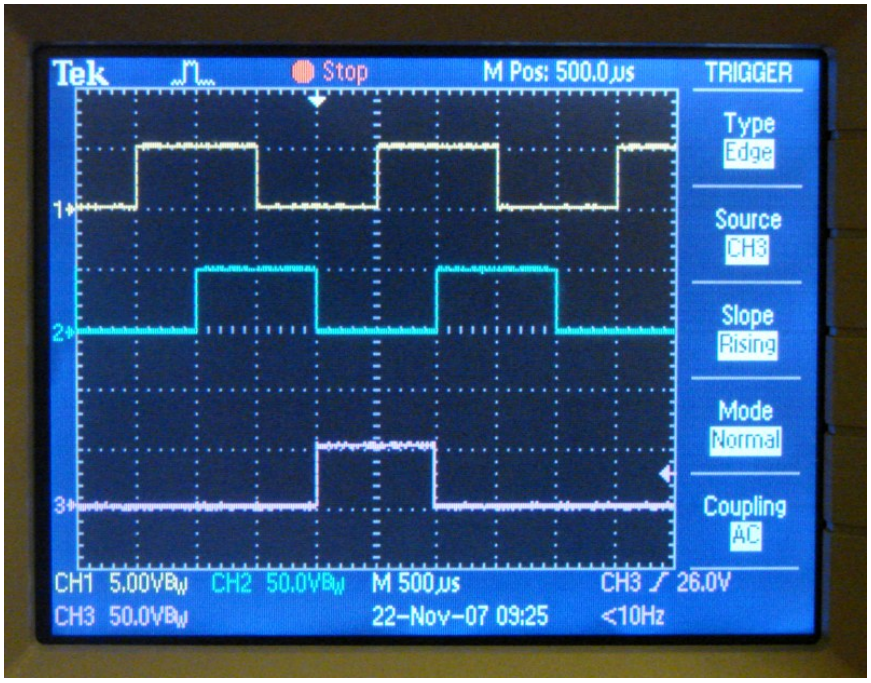
We could program the T344 as follows:

LOad DEfault	load default setup as starting point
QFreq 0	set all 4 channels to zero frequency
QSet BPwm	set all channels to bipolar PWM mode
0Wid 32768	set channels 0 and 1 (A and B) to 50% duty cycle
1Wid 32768	
2Wid 65	set channel 2 (index Z) 1/1000 duty cycle
0Phase 270	A leads index by 270 degrees
1Phase 180	B leads index by 180 degrees
QA 2.5; QD 2.5	set all 4 channels for TTL outputs
SYnc	install settings and synchronize channels

Now the encoder is "stopped" at the zero angle point indicated in red above. To begin rotation, program the frequency of the index channel, channel 2, to be the rotational speed in Hertz, and program 0 and 1 to be exactly 500 times higher. Use the "raw" frequency commands to keep this ratio exact.

To start running at 1 rev/second, 60 RPM, issue the command

```
0Raw 33500; 1Raw 33500; 2Raw 67
```



The resulting waveform set is shown above. Levels are TTL as programmed. Rise and fall times are about 9 ns.
The T344 has no direct mechanism for slewing channel phases to absolute angular positions. Users can implement algorithms which read channel phases, using the phase snapshot command, and dynamically adjust channel frequencies to converge on and stop at a desired absolute angular position.

The A and B channels could be used in sinewave mode by not setting their PWM control bits. This would simulate an encoder that has quadrature sine outputs.

16.6 DC DAC Outputs

Any T344 channel can be used as a simple DC output DAC. Program the channel waveform amplitude to zero, then use the **nDC** offset command set the output level.

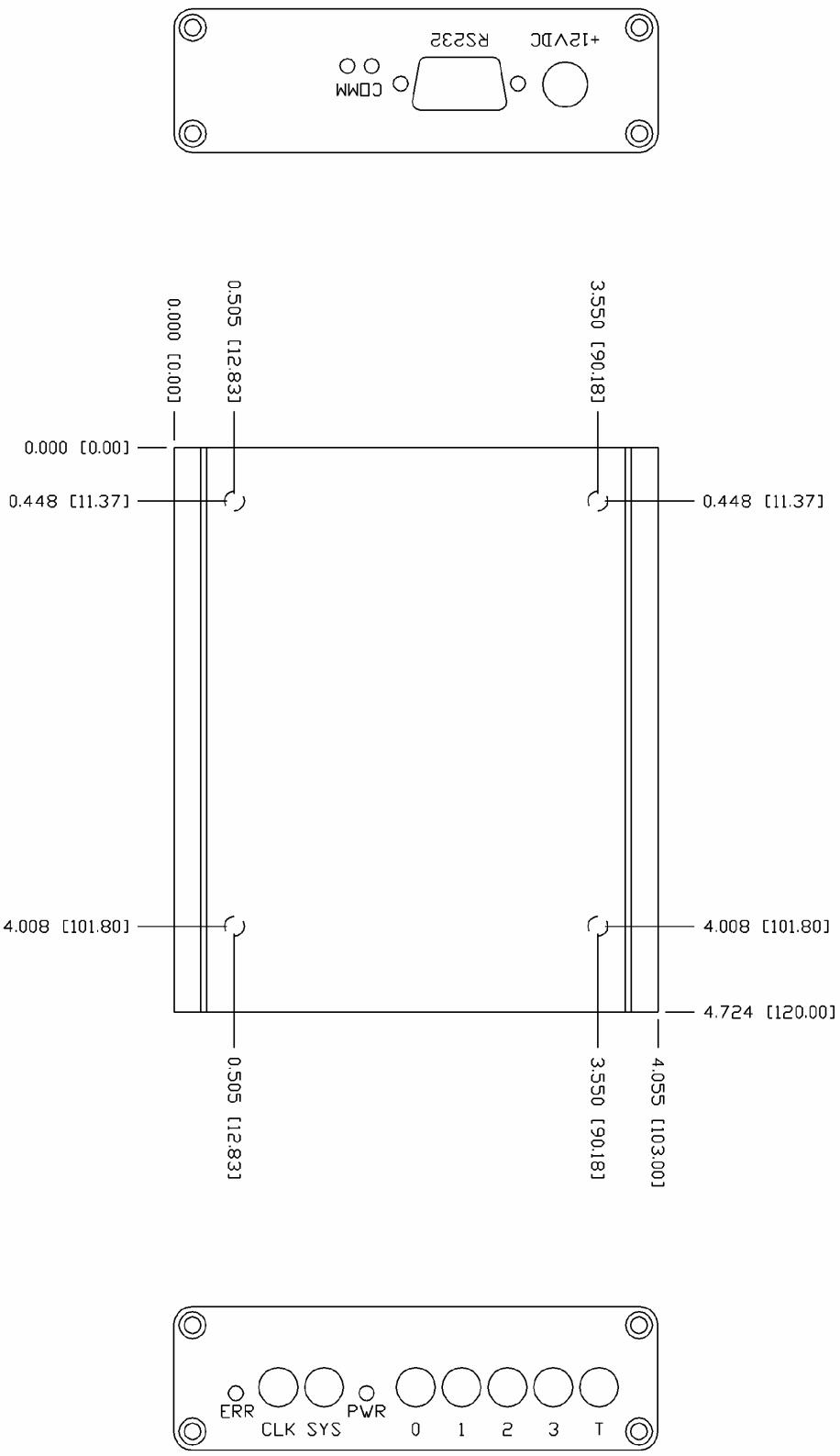
17 Dimensions and Mounting

T344/T346 mechanical dimensions are shown below. The evaluation versions are furnished with the T566 mounting flange bolted to the bottom of the extruded enclosure. This makes it easier to install on mounting surfaces which do not have rear access.

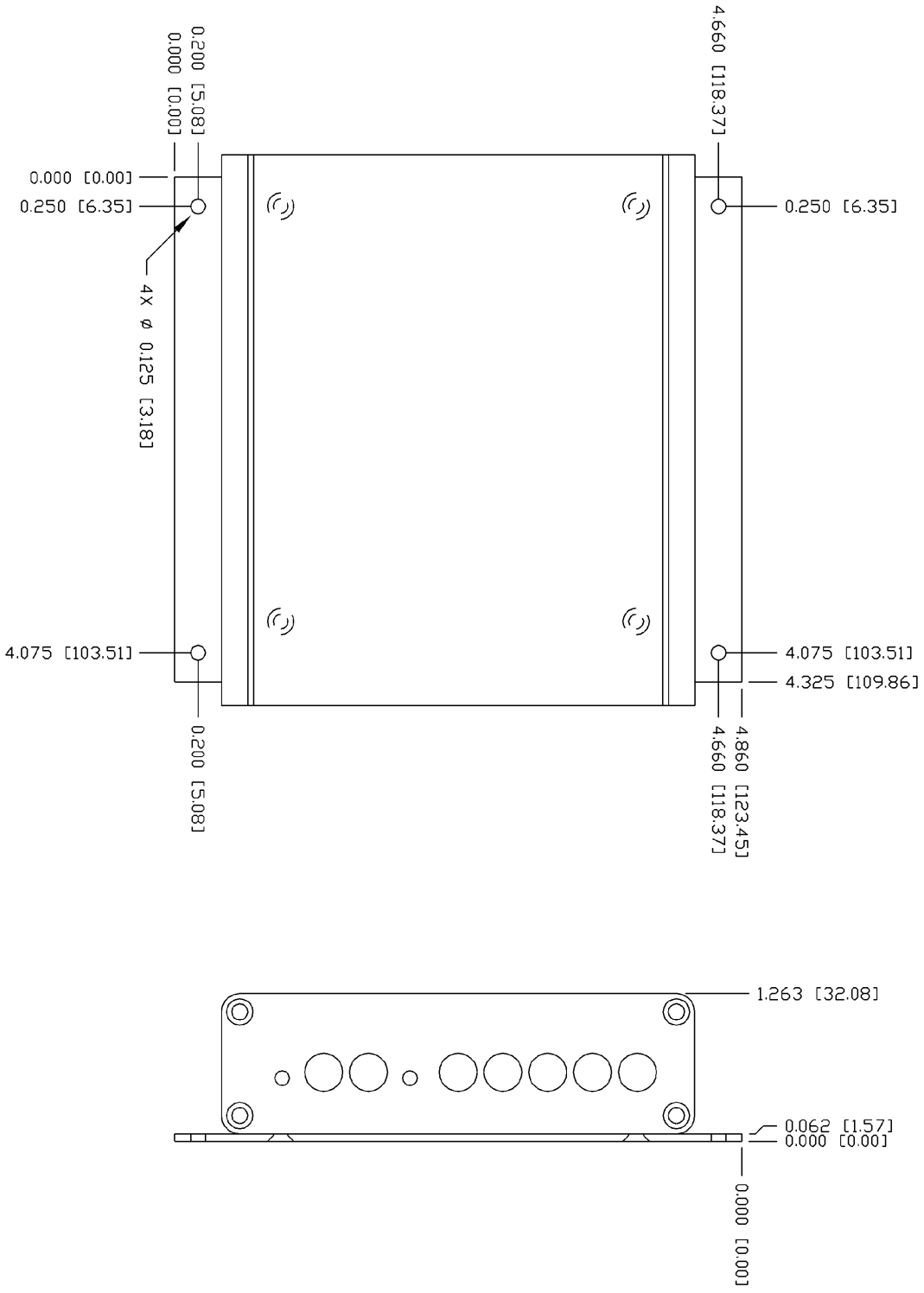
The T344/T346 may be mounted using the flange supplied, or the flange may be removed and the unit mounted with four 4-40 machine screws from below.

⚠ **CAUTION: Mounting screws may not penetrate more than 0.160 inches (4 mm) into the T344/T346 enclosure.**

See sections 19 and 22 for more on versions and accessories.



T344/T346 Outline and Mounting



Flange Mounting Dimensions

18 PC Support Software

A Java-based Windows/Linux virtual instrument control program is available. It can be downloaded from Dropbox here:

https://www.dropbox.com/s/v5371px7us1a6uh/T34x.zip?dl=0

The folder contains both the source code and the executable (which is under the dist folder). Java is required to run it, and there are instructions in the dist/README.TXT about installing librxtxserial.

19 Versions

The standard products are -1 versions:

T344-1	4-channel compact 32 MHz arbitrary waveform generator
T346-1	4-channel compact 32 MHz arbitrary waveform generator with complex modulation and ethernet

Evaluation kits are also available:

T344-9	4-channel compact 32 MHz arbitrary waveform generator (includes standard T344-1 factory installed on T566-1 removable mounting flange, one J12-1 power supply, one J57-1 6’ RS-232 cable, and four J53-1 3’ SMB to BNC cables)
T346-9	4-channel compact 32 MHz arbitrary waveform generator with complex modulation and ethernet (includes standard T346-1 factory installed on T566-1 removable mounting flange, one J12-1 power supply, one J57-1 6’ RS-232 cable, and four J53-1 3’ SMB to BNC cables)

20 Customization

Consult factory for information on additional custom versions.

21 Hardware and Firmware Revision History

21.1 Hardware Revision History

Revision D	June 2013 Reduces noise on switching power supplies
Revision C	December 2009 Replaces obsolete part- no functional changes
Revision B	October 2008 Separates TTL and SYS connectors (Revision A had a single, shared SYS/TTL connector) Revises serial commands associated with their management
Revision A	May 2008 Initial PCB release

21.2 Firmware Revision History

The standard T344/T346 firmware is version 28E346. The firmware is stored on a single plug-in Eprom chip and may be field-upgraded if required.

Revision C	October 2009 Adds the missing CStat command
Revision B	December 2008 Supports the separate SYS and TTL connectors
Revision A	September 2008 Initial firmware release

22 Accessories

J12-1	12 volt power supply (1 included with purchase)
J41-1	3’ SMB to SMB cable
J41-2	6” SMB to SMB cable
J53-1	3' SMB to BNC cable (4 included with evaluation kit purchase)
J53-2	6” SMB to BNC cable
J57-1	6′ D9 male to D9 female RS-232 cable (1 included with evaluation kit purchase)
J57-2	10′ D9 male to D9 female RS-232 cable
P10-1	19" rack mount shelf (four t-boxes per rack)
T566-1	mounting flange (1 included with evaluation kit purchase)