

T564

ADVANCED DIGITAL DELAY GENERATOR



Technical Manual

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1. Introduction

The T564 is a small, enclosed digital delay/pulse generator which is intended for use in embedded OEM applications. Given an internal or external trigger, it outputs four precisely-timed pulses.

Standard features include:

- Four TTL-level delay outputs, individually programmable for delay and pulse width
- 10 picosecond delay and width resolution, 10 second range
- 21 nanosecond insertion delay, 16 MHz max trigger rate
- < 35 picosecond typical jitter
- Highly accurate DSP phaselock system provides crystal-clock delay accuracy with zero indeterminacy from asynchronous external trigger
- Internal 10 MHz crystal oscillator timebase with external lock capability
- 0-16 MHz DDS synthesizer for internal trigger rates
- Programmable-level trigger input with divide/burst features and trigger enable GATE input
- Advanced QUEUE, TRAIN, and FRAMES functions
- Needs only +12 volt power from external universal power supply
- RS-232 serial interface standard; 10/100-mbps Ethernet interface optional
- Extruded enclosure with removable mounting flange

Customizable features include:

- OEM packaged or board-only custom versions
- Alternate timing algorithms
- Number of timing channels, 1 to 8
- Alternate connector types and locations
- OCXO timebase

- Low impedance outputs, 4 volts min into 50 ohms
- Extended temperature ranges and conformal coating

Highland can also provide benchtop pulse/delay generators or OEM timing packages that include picosecond-resolution time-interval measurement, ultrafast or high-voltage outputs, optical interfaces, and precision analog measurement.

Because creating new versions of the T564 involves hardware or firmware changes, customization is normally done under a contractual OEM agreement with associated purchase commitments.



2. Specifications: T564 Delay/Pulse Generator

FUNCTION	4-channel digital delay and pulse generator
GATE FUNCTION	Programmable as level sensitive enable input, edge triggered burst enable input, or divisor enabled output
GATE INPUT	Programmable termination, 50 Ω or 500 Ω to +2.5 V Logic low -0.3 V min, +0.7 V max Logic high +2 V min, +5 V max
GATE OUTPUT	Logic low +0.1 V typical, +0.4 V max @ 50 mA Logic high +5 V typical, +4 V min @ 50 mA
TRIGGER SOURCES	Internal DDS: 0 to 16 MHz, 0.02 Hz resolution Internal clock: 80 MHz Remote command or External signal
TRIGGER DIVISOR	1 to $2^{32}-1$, 125 MHz max input
EXTERNAL TRIGGER INPUT	Programmable termination, 50 Ω or 10 k Ω to ground Programmable trigger level (+0.25 to +3.3 volts) and slope
CHANNEL OUTPUTS A, B, C, D	Four pulse outputs, 5 V, 50 Ω source impedance, each programmable for delay, width, polarity
DELAY RANGE	0 to 10 seconds, 10 ps resolution
WIDTH RANGE	2 ns to 10 seconds, 10 ps resolution
INSERTION DELAY	21 ns \pm 400 ps, external trigger to any output
DIFFERENTIAL NONLINEARITY	< 200 ps
JITTER	< 35 ps typical (50 ps max) RMS, external trigger to any output or between any outputs Add clock jitter for delays > 500 μ s
TRIGGER RATE	0 to 16 MHz, limited to $1/(\text{delay}+\text{width}+60 \text{ ns})$ max
RISETIME	750 ps max
FALLTIME	750 ps max
CLOCK	Internal 10 MHz VCXO, 1 ppm initial accuracy, < 2 ppm/year drift Added jitter below 10 ns per second of delay TC below 0.2 PPM/ $^{\circ}$ C Connector provides clock in/out Locks to external source Clock jitter and delay errors are zero relative to external source Optional higher-performance OCXO
TIMING ACCURACY	\pm 400 ps \pm 7.5 ps/ $^{\circ}$ C \pm clock accuracy
BURST	Programmable to fire N times out of each M triggers where N and M are 1 to $2^{32}-1$
OPERATING TEMPERATURE	0 to 50 $^{\circ}$ C, non-condensing
STORAGE TEMPERATURE	-20 to 80 $^{\circ}$ C
CALIBRATION INTERVAL	One year
POWER	+12 \pm 0.25 volts, 0.3 amps max; 0.4 amps max with Ethernet Universal AC adapter supplied

COMMUNICATIONS	RS-232 standard, 38.4 kbaud Optional 10/100 Ethernet
CONNECTORS	7 SMB for trigger, gate, clock, outputs 2.5 mm stereo jack for RS-232 0.25" power connector Optional RJ45 for Ethernet
INDICATORS	LEDs indicate shot, communications
PACKAGING	4.75" (L) x 4.0" (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

3. Overview of the T564

The T564-1 is an embedded digital delay/pulse generator. It accepts a trigger pulse and generates up to four output pulses, with each pulse being individually programmable in delay and width. Triggers may be external, internal, or evoked through the communications interface. Timing has crystal-clock precision with picosecond jitter relative to an external trigger.

Each output is user programmable for delay (0-10 seconds) and width (0-10 seconds) with 10 ps resolution. When externally triggered, all delays are relative to the basic 20 ns insertion delay.

The T564 is fully backward compatible with the standard T560 DDG, but adds the following features:

- TRAIN facility generates multiple outputs from a single trigger.
- FRAME facility stores up to 8192 delay/width scenarios, with rapid reload.
- QUEUE installs new delay/width settings without disturbing ongoing cycles.
- Optional E and F outputs.
- Optional fast TTL-level isochronous serial communications.

3.1. Standard Packaging

The standard T564-1 unit is packaged in a small extruded aluminum enclosure. The Ethernet connector is provided on the T564-2 version. Section 7 of this manual provides detailed dimensions.

3.2. Overall Block Diagram

Figure 3.2 is the block diagram of the T564-1. OEM versions may include various features of the module. The optional Ethernet interface is not furnished on the standard T564-1 version.

The T564 digital delay generator creates delays by digitally counting a basic clock to create coarse delays to a resolution of 20 nanoseconds, and then adding a fine analog delay to interpolate the final times to picosecond resolution. The timing clock is derived from a 50 MHz gated oscillator which is started when an internal or external trigger is received. A DSP-based phaselock system digitizes and compares the waveforms generated by this oscillator to that of a precision 10 MHz crystal oscillator and servoes the gated oscillator to be as accurate as the crystal while still maintaining the timing relationship to the original trigger.

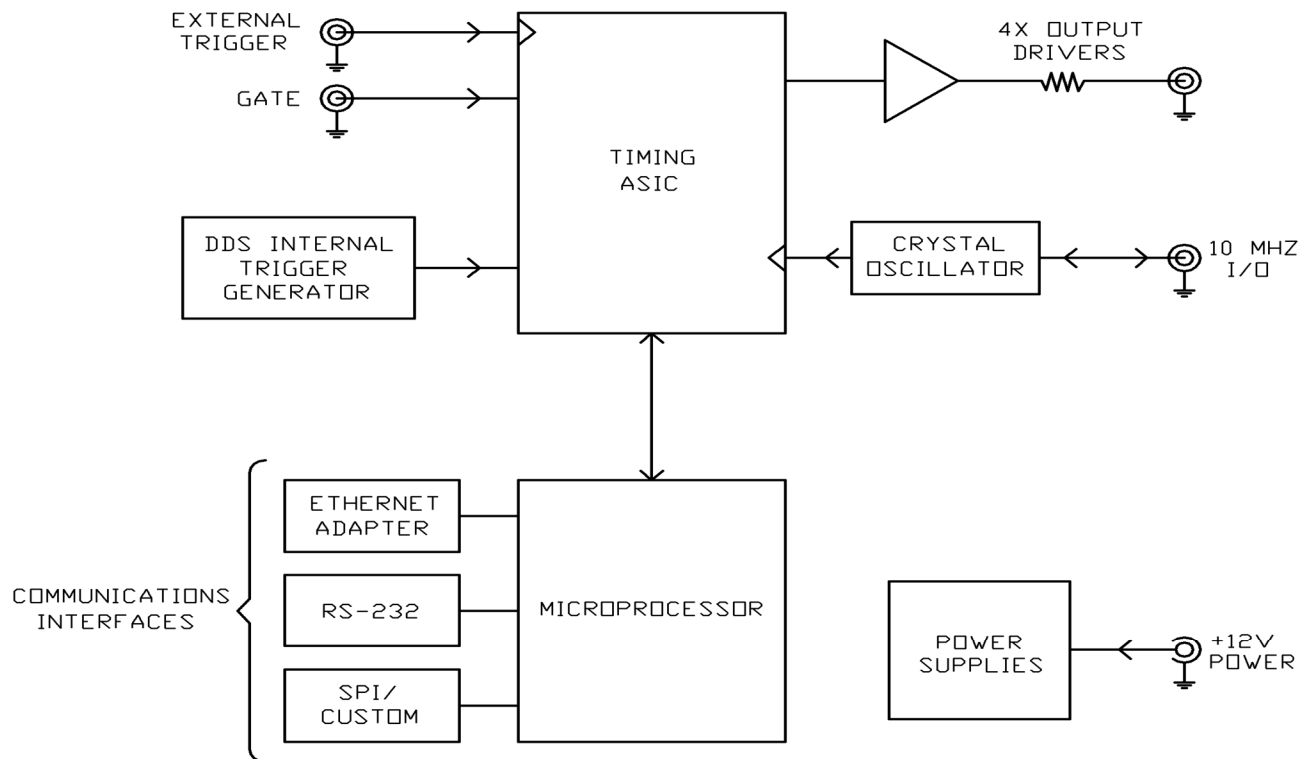


Figure 3-1 T564 Basic Block Diagram

The T564-1 supplies four TTL pulse outputs, each programmable in delay and width. Custom versions of the T564 can provide up to eight independent delay outputs.

Because the all-digital phaselock system uses no drift-prone analog signal storage elements, long-delay accuracy and jitter depend only in the quality of the internal or external 10 MHz timebase.

3.3. Crystal Oscillator Timebase

The standard T564 includes a 10 MHz VCXO crystal oscillator timebase. It is factory-set to an accuracy of ± 1 PPM and may be expected to drift less than 2 PPM per year. A trim DAC is provided to allow user commands to readjust the oscillator frequency as desired, with the setting stored in nonvolatile memory.

A connector is provided which allows the internal oscillator to provide a 10-MHz output, or allows an external 10-MHz source to be accepted. This allows multiple T564s to be synchronized to each other or to an external 10-MHz reference. The external clock levels are 3.3 volt square-wave CMOS logic levels. The T564 can lock to an externally-applied square wave of 10 MHz ± 50 PPM, 3.3 to 5 volt positive logic levels, or to a 1 volt RMS sine wave.

The long-delay (millisecond range) jitter performance of the T564 is dominated by the phase noise of the internal crystal oscillator or the equivalent phase noise of a user-provided external reference.

Custom versions may include a higher-precision OCXO timebase. Multiple T564 units may be locked to one another to ensure timing coherence.

3.4. Trigger Inputs

Figure 3.2 is a simplified diagram of the T564 trigger and sequence logic. Any one of five available trigger sources may be selected to fire the system: External+, External-, an internal 80-MHz clock, the internal 0-16 MHz DDS synthesizer, and the user software trigger. The selected trigger is divided by a programmable factor K from 1 to $2^{32}-1$ and supplied to the cycle-start HIT flipflop. The hit floplop is enabled by the gating/burst logic. Once the flipflop is fired, eight identical timing blocks generate delays A1 through D2, each programmable from 0 to 20 seconds in 10-ps steps. Pairs of delays are combined to result in four outputs, each a pulse whose delay and width are programmable with respect to the common trigger. When all delay blocks have timed out, the EOD (end-of-delay) logic resets the hit flipflop for about 50 ns, after which the system is enabled to accept another trigger.

The standard external trigger is a positive level, with trigger threshold programmable from +0.25 to +3.3 volts and selectable rising/falling edge. The trigger input may be programmed to be high impedance or a 50-ohm termination to ground. Maximum safe input levels are -0.3 to +5.0 volts.

The maximum allowed trigger rate is

$$R = 1 / (D + W + 60 \text{ ns})$$

where D + W is the greatest channel sum of programmed delay plus width, and R is limited to 16 MHz max. If a channel is programmed OFF, its time settings are not relevant. If the T564 receives an internal or external trigger while a timing cycle is still busy, that trigger will be ignored. Some additional timing restrictions apply in QUEUE, TRAIN, and FRAME modes.

An internal 80 MHz clock (exactly 8x the main 10 MHz clock) may also be selected as the trigger source. When it is used, a trigger divisor K must be programmed to keep the trigger rate at or below 16 MHz.

The internal DDS synthesizer allows internal triggering at rates from 0 to 16 MHz with 0.02-Hz resolution. The DDS synthesizer has a period jitter of about 1 part in 20,000, which can be substantial in absolute terms at lower requested frequencies. Both period jitter and resolution can be improved by keeping the DDS frequency in the 2-10 MHz range and using the internal trigger divisor facility to get lower trigger rates. The DDS trigger is not included on the T564-10.

External triggers up to 125 MHz can be accepted, given that a programmed divisor or the inherent busy-cycle limitation will restrict the actual trigger rate to some countdown fraction of the input frequency below 16 MHz.

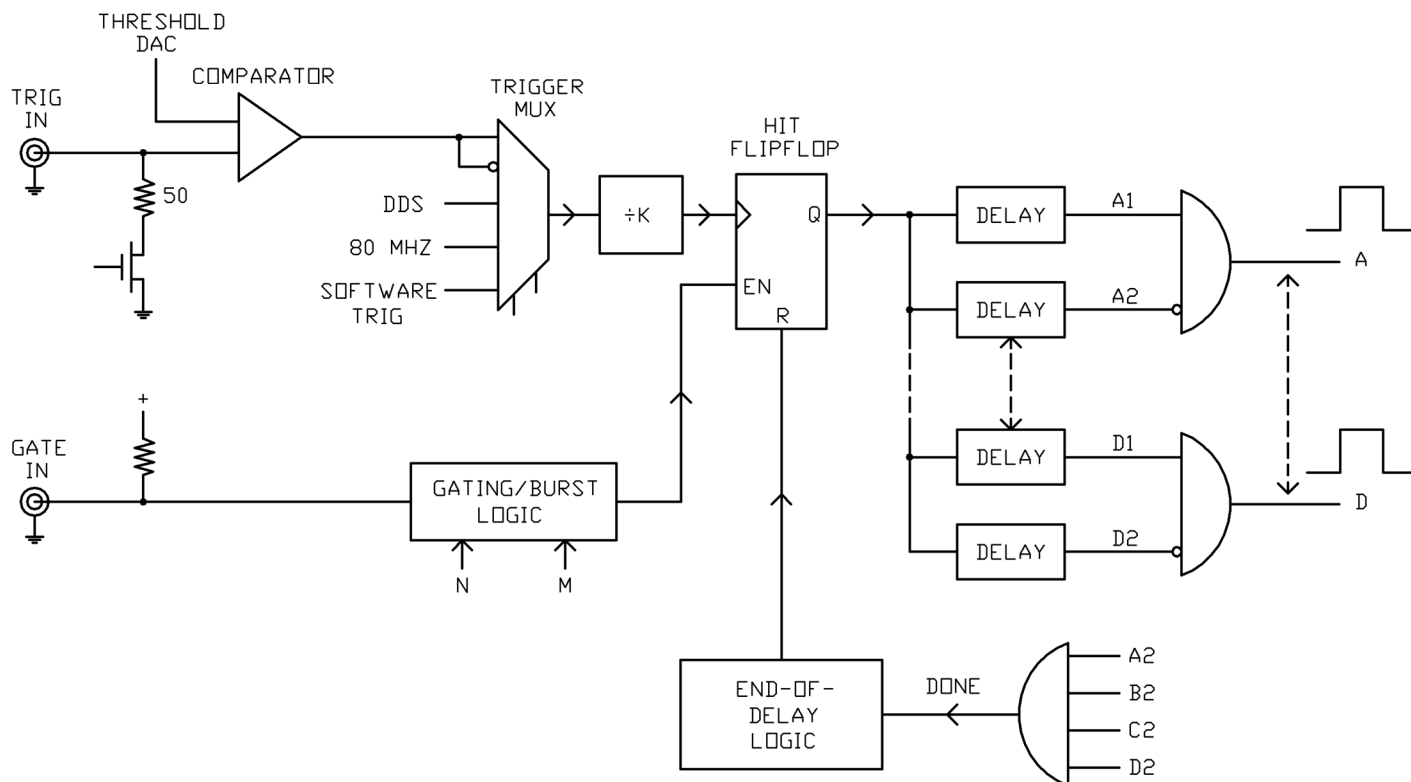


Figure 3-2 Trigger and Sequencing Logic

3.5. Burst Logic

The burst logic allows the user to define two integers N and M, each in the range of 1 to $2^{32}-1$. The T564, when triggered, will respond to a burst of N triggers every M triggers. For example, if N = 2 and M = 5, trigger response will be Fire, Fire, Skip, Skip, Skip, repeated indefinitely. N/M is thus the trigger duty cycle.

If either N or M is programmed to be 0, the burst logic is disabled.

Burst cycles may "free run", continuously generating N of every M possible cycles. The internal burst logic may be reset by a user command, so that the next trigger will start a new burst of N outputs.

A single burst of N cycles may be started under control of the GATE input or on software command. If GATE mode is set to BURST (command **GAtE BUrst**), the next active edge

of the GATE input will enable a single burst of N cycles. Similarly, the **GAtE REmote** mode enables a user-fired burst, started by the **GAtE FIrE** serial command. In both cases, M must be set greater than or equal to N. If M is greater than N, additional burst starts will be locked out until a full M triggers have been received.

3.6. Pulse Outputs

Four pulse outputs are provided, called channels A, B, C, and D. Outputs are +5 volt CMOS levels with a 50-ohm source impedance. They can drive 5 volts into a non-terminating load, or 2.5 volts into a 50-ohm load. Because they are source terminated, they may drive a 50-ohm coaxial cable any distance into any termination impedance without significant reflection problems. For example, a 100 ohm termination will provide a clean 0 to +3.3 volt logic swing, and a high-impedance (such as CMOS) load will swing 5 volts. External passive components can be used to convert to ECL or PECL levels.

Each output is programmable for pulse delay and width relative to the trigger. If an output is programmed for delay D, the actual output pulse will occur at D + 20 ns after the external trigger, where 20 ns is the basic insertion delay of the T564. Pulse outputs are normally active-high, but may be programmed to operate active-low.

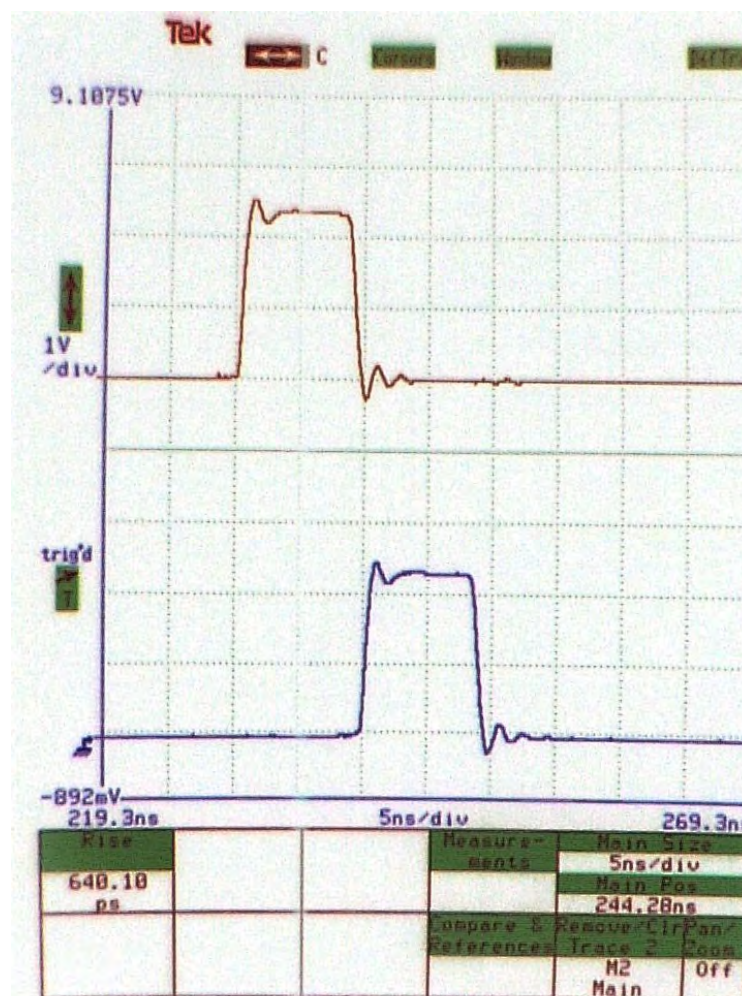


Figure 3-3 Typical T564 channel outputs into 50 ohms. Risettime is 640 ps.

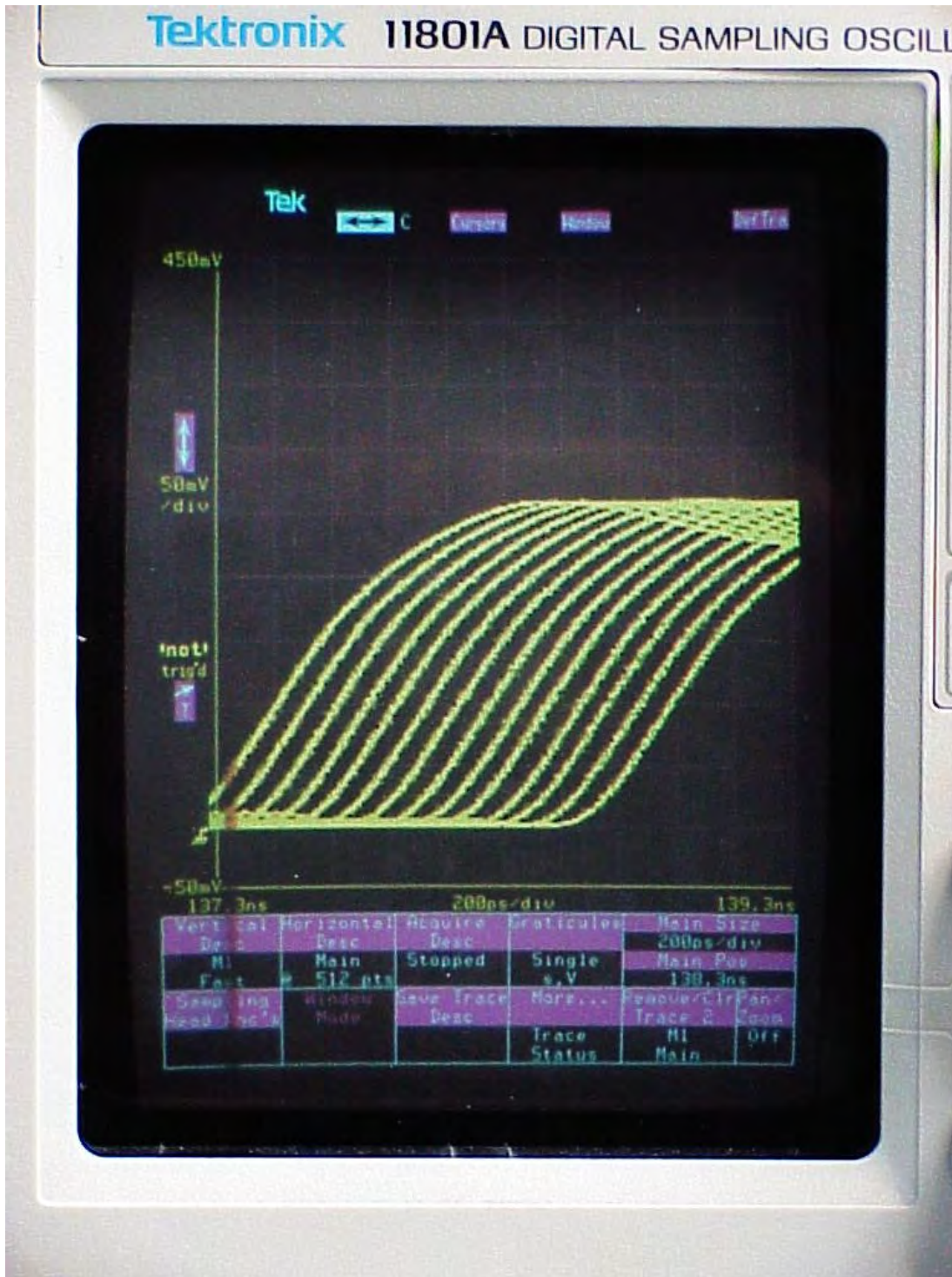


Figure 3-4 Output rising edge, 100 ps delay steps

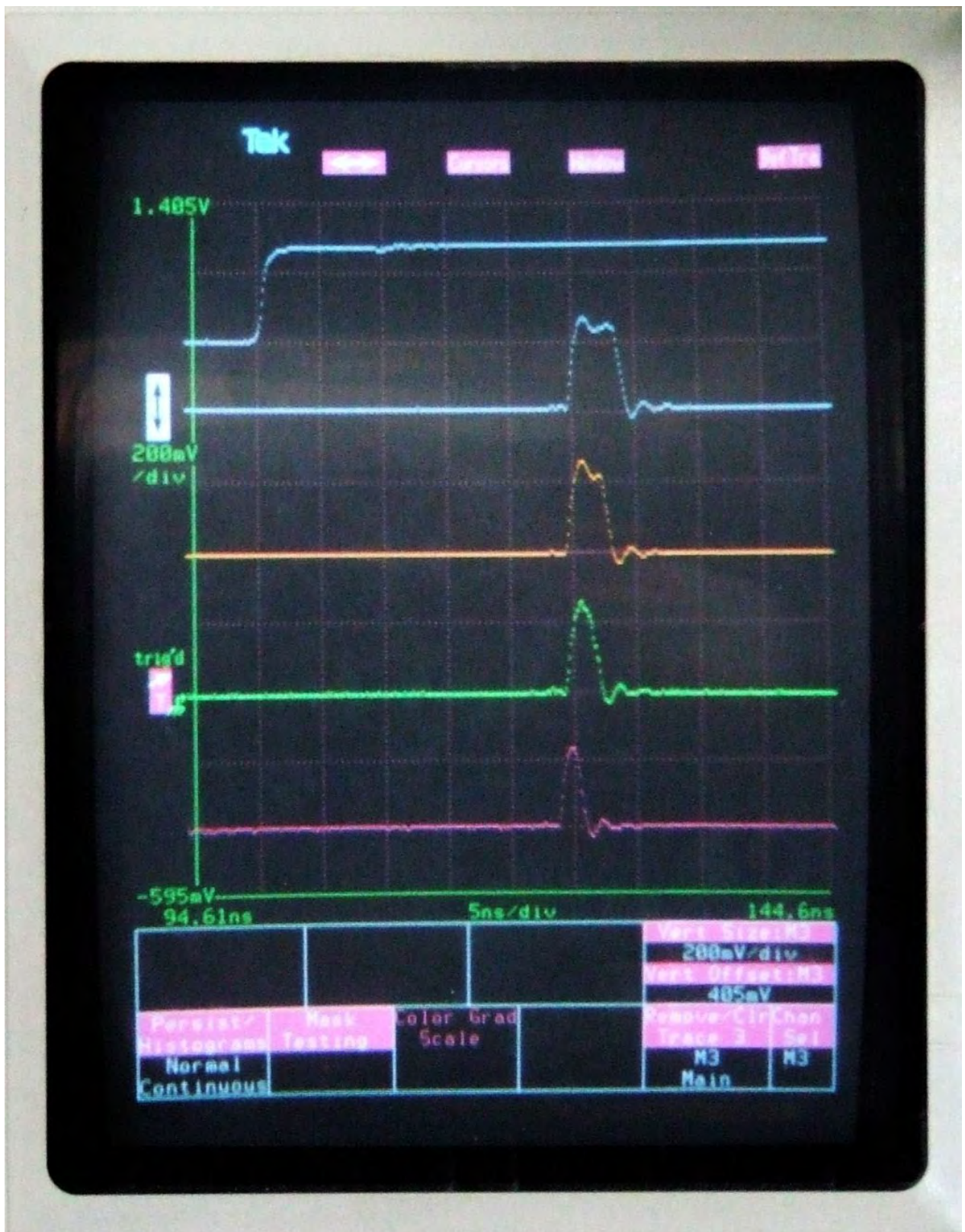


Figure 3-5 Trigger and output pulses, widths 4ns, 3 ns, 2 ns, and 1.5 ns

3.7. Gate I/O

A GATE coaxial connector is provided; it is pulled up to +5 volts through a 1K resistor or may, under software control, be terminated at 50 ohms to ground. GATE may be

programmed as an input or as an output. As an input, it may be programmed to enable triggers, with high or low being the active level. As an output, it will go true (selectable high or low) to indicate that the HIT flipflop is armed and ready to accept triggers. The gate logic may also be used to enable a single burst of N pulses, with the burst being evoked by a rising edge at the GATE connector input or by remote command.

3.8. Communications and Control

The standard T564-1 is equipped with a 38.4-kbaud RS-232 interface. The T564-2 version adds a 10/100 Ethernet interface. If the Ethernet option is installed, both the Ethernet and RS-232 ports will be functional, but commands should not be sent to the T564 through both ports simultaneously.

3.9. Connectors

Standard logic-level connectors are right-angle SMBs.

Other connector types are available on OEM versions. Connectors may be straight or right-angle, SMB, MCX, or LEMO, mounted topside or bottom. Hirose H.FL or U.FL surface-mount connectors can also be provided on either side of the circuit board. Because of the close spacing of the connectors, SMA types are not recommended.

A three-foot SMB-to-BNC cable is available as Highland part number J53-1.

A miniature 2.5-mm stereo phone jack is used for the RS-232 serial interface; a mating connector and cable is available, terminated with a female D9 connector, and may be plugged into the serial port of a standard PC. The RS-232 cable assembly is Highland part number T565-1, and one is included with every purchase.

Pinout of the serial connector is:

Tip	RXD	serial data to T564	to PC D9-3
Ring	TXD	serial data from T564	to PC D9-2
Ground			to PC D9-5

OEM versions can be furnished with the J8 (alternate power input) and J14 (auxiliary i/o) connectors.

3.10. Power Input

The T564 requires +12 volts DC at 0.3 amps max, 0.4 amps for the Ethernet version. A wall-plug universal power supply is furnished with the evaluation kit, or users may supply +11.75 to +12.25 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. OEM versions can alternately be provided with a Phoenix terminal block for power input, or a D9 combined power/RS232 connector.

The T564 power input is protected by a self-resetting polyfuse and a transzorb zener diode and will withstand reasonable overvoltage or polarity reversal.

On OEM versions, power can also be applied to connector J8 pin 3, with J8 pins 5 and 6 being grounds. J8 pin 1 is at board coordinate X 0.500, Y 1.890; see fig 12.3.

3.11. Custom Logic

Custom logic functions are available. Since the T564 incorporates eight internal delay generators, up to eight delay-only or delay-plus-fixed-width outputs can be provided.

3.12. Indicators

Three LED indicators are provided:

The green PWR LED indicates that power is available. It also blinks at a 1-Hz rate to indicate CPU heartbeat. Its color changes to yellow if any internal error conditions are sensed.

The blue TRIG LED flashes whenever the T564 is triggered.

The COMM LED flashes yellow when any serial character is received and green when the T564 formats a reply.

3.13. Train and Frame Features

The TRAIN feature allows a single trigger to invoke a sequence of as many as 2^{32} sets of programmed delays. See section 8.

The FRAME feature allows users to pre-load a list of up to 8192 delay and width settings, and enable the unit to rapidly reload these settings between shots, without realtime per-shot serial commands. See section 9.

TRAIN and FRAME may be used separately or together.

4. Programming

4.1. General Comments

The T564 accepts ASCII serial commands from the standard RS-232 interface or from the optional 10/100 Ethernet adapter. Refer to Section 6 for details about configuring the Ethernet interface.

For evaluation, serial commands may be typed using any common serial communications program, for example HyperTerminal (for RS-232) or the standard "Telnet" utility for the Ethernet version. A family of **HElP** commands is available, summarizing serial commands and operating modes. The **STatus** command will send back a summary of T564 settings.

The standard baud rate is 38,400. The receive buffer is limited to 256 bytes, and the T564 ignores serial input while it is processing the current command line.

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

TLevel <cr>

represents a command string sent to the T564, terminated with a carriage return character <cr>, and italic text...

1.25 <cr> <lf>

represents the reply from the T564. All commands must be terminated with semicolon or <cr>, and all reply lines are terminated by <cr> <lf>.

4.2. Command Strings

Users send serial ASCII command strings to the T564, to which the T564 immediately replies. Because the standard baud rate is high, and because the T564 may spend a millisecond 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 alpha or numeric argument. Multiple commands may be sent in a single line, separated by semicolons. When a full line is received, indicated 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 letters; only the first two letters 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 T564 protocol is case insensitive.

For example, **TRigger** indicates that the short form is **TR**, and the long form is **TRIGGER**, both of which are recognized commands.

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

A delay or width is sent as

```
ADelay 23.5u  
CWidth 40n
```

Acceptable suffixes are:

```
p - pico    (1E-12)  
n - nano    (1E-9)  
u - micro   (1E-6)  
m - milli   (1E-3)  
s - seconds
```

and exponential notation is not supported. Default is nanoseconds.

Trigger levels are sent in volts, as **TLevel 1.50**

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

```
ADelay          (no argument)
```

evokes the reply

```
02.123456789123
```

which represents the delay setting for the rising edge of the A output in seconds.

Since such long strings of numbers are difficult to read, a "verbose" mode is available, which will send times and other long numbers in the form

```
02.123,456,789,123
```

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.
- Colon is translated to semicolon, the command separator
- Most other characters, including + - , * ? and linefeed, are ignored.
- A "blank" input line, <cr> only, evokes the response **T564 <cr> <lf>**

The T564 does not support hardware or software flow control. Other baud rates are available on special order.

4.3. Command Structure

A command line begins with a command keyword (or its 2-letter abbreviation), followed by optional arguments. 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.

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

Time-set commands are expressed as channel delays and widths, with the four pulse outputs identified as A, B, C, or D, corresponding to the four output pulse connectors.

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

Since the T564 receive buffer is limited to 256 bytes, users should not program multiple commands per line that might exceed this length. If at any time the <backspace> character (ASCII code 8) is received, the T564 will flush its receive buffer and ignore any previous input.

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...

1.25; TLEVEL; TRIG POS

the reply will be of the form

OK;1.25;OK

All reply strings are terminated with carriage return/linefeed <cr> <lf> characters.

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.

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

4.4. 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 hundreds of microseconds, 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 longer **HElp** pages taking as long as 500 milliseconds.

When delay/width settings are changed via the **INStall** command (or an end-of-line autoinstall) or the trigger, burst, or gate parameters are changed, the firmware will immediately force the end-of-delay reset state, which will abort any timing cycles currently in progress. EOD will be asserted for about 350 microseconds, after which triggers will be re-enabled.

If aborting timing cycles is undesirable, one can disable triggers, wait until any possible timing cycle has finished, then do the desired operation. For example, if it were known that all delay+width settings total under 40 milliseconds, one could send the T564 the sequence...

```
TRIGGER OFF; WAIT 50000; CDELAY 2.5m; INSTALL; TRIGGER POS
```

to which it would reply

```
OK;OK;OK;OK;OK
```

with an additional 50 millisecond pause before the second **OK**.

One can also use the realtime USEC counter to measure actual command execution times in microseconds...

```
US 0; SY 3.579545M; US
```

which might respond

```
OK;OK;0,000,001,128
```

Again, command execution times are usually dominated by the 38 kbaud communications rate. If the isochronous interface is used, command execution can be much faster; see section 11.2

The T564 also features a **QUEUE** install mode, which allows delays to be reprogrammed without disrupting ongoing triggers; see section 4.6.2.

4.5. T564 Command Summary

The following is a summary of commands which may be sent to the T564.

<i>Long Form</i>	<i>Short Form</i>	<i>Function</i>
ADELAY 45u	AD 45u	set A delay
AWIDTH 25.5n	AW 25.5n	set A width
ADELAY	AD	delay A query
AWIDTH	AW	width A query
ASET ON	AS ON	enable A output
ASET OFF	AS OF	disable A output
ASET POS	AS PO	set A polarity positive (normal)
ASET NEG	AS NE	set A polarity negative (inverted)
ASET	AS	query channel A settings
APENDING	AP	query channel A pending settings
BDELAY 45u	BD 45u	set B delay
BWIDTH 25.5n	BW 25.5n	set B width
BDELAY	BD	delay B query
BWIDTH	BW	width B query
BSET ON	BS ON	enable B output
BSET OFF	BS OF	disable B output
BSET POS	BS PO	set B polarity positive (normal)
BSET NEG	BS NE	set B polarity negative (inverted)
BSET	BS	query channel B settings
BPENDING	BP	query channel B pending settings
CDELAY 45u	CD 45u	set C delay
CWIDTH 25.5n	CW 25.5n	set C width
CDELAY	CD	delay C query
CWIDTH	CW	width C query
CSET ON	CS ON	enable C output
CSET OFF	CS OF	disable C output
CSET POS	CS PO	set C polarity positive (normal)
CSET NEG	CS NE	set C polarity negative (inverted)
CSET	CS	query channel C settings
CPENDING	CP	query channel C pending settings
DDELAY 45u	DD 45u	set D delay
DWIDTH 25.5n	DW 25.5n	set D width
DDELAY	DD	delay D query
DWIDTH	DW	width D query
DSET ON	DS ON	enable D output
DSET OFF	DS OF	disable D output
DSET POS	DS PO	set D polarity positive (normal)
DSET NEG	DS NE	set D polarity negative (inverted)
DSET	DS	query channel D settings
DPENDING	DP	query channel D pending settings
QDELAY 45u	QDELAY 45u	set all four ("quad") delays
QD 45u	QD 45u	set all four ("quad") widths

<i>Long Form</i>	<i>Short Form</i>	<i>Function</i>
INSTALL	IN	apply pending channel settings immediately
INSTALL 24	IN 24	apply Frame settings immediately
QUEUE	QU	synchronous install at next EOD
QUEUE 24	QU 24	synchronous install Frame at next EOD
AUTOINSTALL 1	AU 1	apply pending settings at end of line
AUTOINSTALL 2	AU 2	queue pending settings at end of line
AUTOINSTALL 0	AU 0	cancel automatic mode
UNDO	UN	cancel all pending channel settings
TLEVEL 1.25	TL 1.25	set external trigger level
TLEVEL	TL	query trigger level
TRIGGER POS	TR PO	trigger on external rising edge
TRIGGER NEG	TR NE	trigger on external falling edge
TRIGGER INT	TR IN	select internal 80 MHz trigger
TRIGGER SYN	TR SY	select internal DDS synthesizer
TRIGGER REMOTE	TR RE	select remote trigger
TRIGGER OFF	TR OF	disable triggers
TRIGGER HIZ	TR HI	trigger input is 10K to ground
TRIGGER TERMINATE	TR TE	trigger input is terminated at 50 ohms
TDIV 5000	TD 5000	set trigger divisor
TDIV	TD	query trigger divisor
TRIGGER	TR	trigger setup query
TFREQ INPUT	TF IN	set TFREQ to count trigger input signal
TFREQ HITS	TF HI	set TFREQ to count actual triggers
TFREQ	TF	return trigger frequency, Hz
TPER	TP	return trigger period, in ns
FIRE	FI	fire remote trigger
FEOD	FE	force End Of Delay, abort timing cycle
SYNTHESIZE 3.579M	SY 3.579M	set optional DDS synthesizer rate
SYNTHESIZE	SY	query DDS synthesizer rate
CLOCK HIZ	CL HI	clock connector is unused
CLOCK OUT	CL OU	connector outputs 10 MHz
CLOCK IN	CL IN	external 10 MHz is accepted
CLOCK	CL	query clock settings and temperature
CTRIM 2048	CT 2048	set 10 MHz clock trim, 0...4095
CTRIM	CT	query clock trim value
CLOCK SAVE	CL SA	save clock trim to flash memory
BNUM 555	BN 555	set burst N, pulses output in burst
BMOD 2000	BM 2000	set burst M, total triggers/cycle
BURST ON	BU ON	enable burst mode
BURST OFF	BU OF	disable burst

<i>Long Form</i>	<i>Short Form</i>	<i>Function</i>
BURST RESET	BU RE	reset burst counters
GATE OFF	GA OF	disable gate functions
GATE OUTPUT	GA OU	make gate connector an output
GATE INPUT	GA IN	make gate an input
GATE POS	GA PO	gate in/out is active high (normal)
GATE NEG	GA NE	gate in/out is active low (inverted)
GATE TERMINATE	GA TE	gate input is terminated at 50 ohms
GATE HIZ	GA HI	gate input is 1K to +5 volts
GATE BURST	GA BU	enable single burst at gate input rise
GATE REMOTE	GA RE	enable single burst on command
GATE FIRE	GA FI	fire a single remote burst
TCOUNT OFF	TC OFF	cancel pulse Train mode
TCOUNT 2000	TC 2000	add N pulses per trigger
TSPACE 88U	TS 88U	set train pulse spacing
FRAME OFF	FR OF	cancel frame mode
FRAME 12	FR 12	store current settings into frame nnn
FA 4	FA 4	set start frame
FB 24	FB 24	set end frame
FC 999	FC 999	set frame repeat count
FN	FN	report frame load count. FN 0 clears
FP	FP	report realtime frame pointer
FRAME GO	FR GO	start frame operation
FRAME LAST	FR LA	report last available frame index
FRAME	FR	report frame system status
FDUMP 8190	FD 8190	display frame N contents, internal format
FX	FX	display frame diagnostic report
RTEST	RT	test frame memory
RZAP	RZ	clear frame memory
STATUS	ST	show T564 status report
SAVE	SA	save current setup
RECALL	RE	recall saved setup
LOAD DEFAULT	LO DE	load default setup
RUN DEMO	RU DE	run demonstration setup
RSET	RS	reset the T564
SHOTS	SH	query shot counter
SHOTS 0	SH 0	reset shot counter
USEC	US	query microsecond counter
USEC 0	US 0	reset microsecond counter
IRQ	IR	query 40 Hz interrupt counter
WAIT 3400	WA 3400	wait specified number of microseconds
IDENTIFY	ID	return ID string

<i>Long Form</i>	<i>Short Form</i>	<i>Function</i>
ERRORS	ER	return error status
ERRORS 0	ER 0	clear error flags
VERBOSE 1	VE 1	show long numbers with commas
VERBOSE 0	VE 0	show long numbers without commas
VERBOSE	VE	query verbose setting
COMMENT	CO	command is ignored
HELP	HE	return general HELP message
HELP CHANNELS	HE CH	return help on channel operations
HELP TRIGGER	HE TR	return Trigger help
HELP CLOCK	HE CL	return Clock help
HELP BURST	HE BU	return Burst help
HELP GATE	HE GA	return Gate help
HELP PULSETRAIN	HE PU	return Train help
HELP FRAMES	HE FR	return Frames help
HELP MISC	HE MI	return miscellaneous help
IS TX STRING	IS TX STRING	send string to isoch transmit interface
IS RX	IS RX	get string from isoch receive interface
IS LO STRING	IS LO STRING	isoch loopback test
IBLOCK 1	IB 1	set isoch test flags

4.6. Command Details

4.6.1. CHANNEL SET COMMANDS

The channel commands allow channel delays, widths, and modes to be set or queried.

Set a delay or width with the appropriate command, such as

ADelay 65.81n

DWidth 55.2u

where times may be specified with suffix characters s,m,u,n, or p for seconds, milliseconds, microseconds, nanoseconds, and picoseconds. The default is nanoseconds.

Interrogate a time setting with

ADelay which evokes the reply, in seconds,

00.000000065810 in terse mode, or

00.000,000,065,810 in verbose mode.

All channel settings are stored in a "pending" buffer until applied to the timing hardware. Two modes are available: INSTALL and QUEUE. See section 4.6.2.

The **UNdo** command cancels any pending channel settings.

ASet ON	enables channel A output
ASet OFF	disables channel A output. Its electrical output will stay low (or high, if channel is inverted) and its time settings are ignored
ASet POS	sets channel A polarity positive (normal)
ASet NEg	sets A polarity negative (inverted)
ASet	query channel A settings. A string will be returned <i>Ch A POS ON Dly 00.123456789012 Wid 01.234567890123</i>
APending	query channel A pending settings. This produces a response identical to ASet , except that the pending values are presented

The **QDelay** and **Qwidth** “quad” commands set all four delays or widths to the same value.

Note that the channel polarity and on/off settings must be installed before taking effect, just as the channel delays and widths.

4.6.2. *INSTALL AND QUEUE COMMANDS*

After one or more channel delay and width setting commands are transmitted, the new settings must be loaded into the delay generator hardware. This is inherently tricky, as delays may be in progress when the timing settings are changed.

When delay/width settings are changed via the **INStall** command (or an end-of-line autoinstall) or the trigger, burst, or gate parameters are changed, the firmware will immediately force the end-of-delay reset state, which will abort any timing cycles currently in progress. The EOD system reset will be asserted for about 300 microseconds, after which triggers will be re-enabled.

Use **INSTALL** when it is necessary to ensure that the very next trigger will use the latest-commanded timings.

The T564 also features a queued install mode, which allows delays to be reprogrammed without disrupting ongoing triggers. A **QUEUE** command will load the current time settings into the hardware at the next EOD, namely at the **end** of the next timing cycle. No cycles are lost or aborted.

QUEUE allows timings to be changed during ongoing triggers, without truncating timing cycles. The **QUEUE** operation requires a minimum delay from EOD until the next trigger of 10 microseconds, to allow vernier delay circuits to settle. Less delay may result in timing errors of as much as 20 ns.

The **AUTOinstall n** command enables either install or queue operations to be performed at the end of parsing the current command line.

AUTOinstall 1	enables "install" operation at end of line
AUTOinstall 2	enables "queue" operation at end of line

AUTOinstall 0	cancels automatic installs
----------------------	----------------------------

A typical command line might be

```
ADelay 45n; AWidth 130u; INstall
```

or

```
CDelay 33u; DWidth 500u; QUeue
```

where the final verbs are not needed if the appropriate autoinstall mode is enabled.

Both **INstall** and **QUeue** can accept an optional numeric argument to load frame data; see section 9.

4.6.3. TRIGGER SETUP COMMANDS

The **TRigger** family of commands select the T564 trigger source and associated parameters.

TLevel 2.50	Sets external trigger level; legal range is 0.25 to 3.30
TLevel	Queries trigger level. The response would be 2.50
TRigger POs	Trigger on external input, rising edge.
TRigger NEg	Trigger on external input, falling edge.
TRigger INT	Selects an internal 80 MHz trigger, 8x the internal 10 MHz clock. A divisor K of at least 5 is required to limit the trigger rate to the 16 MHz limit.
TRigger SYn	Selects optional internal DDS synthesizer as the trigger source. Its frequency may be set from 0.018 Hz to 16 MHz using the SYN command.
TRigger REmote	Enables software triggers, via the FIRE command.
Fire	Fires one remote trigger.
TRigger OFF	Disables triggers
TDivisor 80000	Sets a trigger divisor integer K, from 1 to $2^{32}-1$. When the divisor is loaded, the next trigger will fire the T564 (subject to other restraints) and then K-1 triggers will be skipped before another is enabled. TD 0 disables the divide function. Divide can be combined with BURST. CAUTION: a large trigger divisor can create the appearance of a triggering failure.
TRigger HIz	Trigger input is 10K to ground.
TRigger TErminate	Enables 50 ohms terminator on TRIGGER input.
TRigger	Trigger setup query, evokes a response of...
Trig REM 50R Level 1.250 Div 0000000000 SYN 00010000.00	

The frequency of the electrical trigger source, or the actual DDG hit frequency, may be measured. The hit frequency can be lower than the incoming trigger rate if a divisor is programmed, gating is in use, or long delays result in missed triggers. After switching the

measurement selection, wait at least two seconds for counts to settle. The frequency measurement timebase is one second.

TFreq INput	selects the trigger input for measurement
TFreq HIt	selects the actual DDG hit rate for measurement
TFreq	returns the current trigger or hit frequency, in Hz
TPer	returns the corresponding period, in ns

4.6.4. *SYNTHESIZE COMMAND*

The T564 is furnished with a direct-digital frequency synthesizer that may be used to generate internal triggers from 0 to 16 MHz with 0.018 Hz resolution. This is not functional on the T564-10.

SYn 123.456K sets the frequency. Suffix characters may be K (kilohertz) or M (megahertz). The default is Hertz.
SYn queries the current frequency

4.6.5. *BURST COMMANDS*

The **BURst** commands control the trigger burst logic. Burst allows a group of N pulses to be fired out of each group of M input triggers; that is, N successive triggers will be accepted, then M-N triggers will be skipped.

It is also possible to generate a burst of N triggers, invoked by the rising edge of the GATE input, or by remote command. See 4.6.6 - GATE COMMANDS

BNum 555	sets burst N, pulses output in burst
BNum	queries burst N value
BMod 2000	sets burst M, total triggers/cycle
BMod	queries burst M value
BURst ON	enables burst mode
BURst OFF	disables burst
BURst REset	reset burst counters; next trigger will be the first of N.
BURst	queries burst settings. This will return a string...
<i>Burst OFF N 000000555 of M 0000002000</i>	

4.6.6. *GATE COMMANDS*

The GATE coaxial connector may be used as an input or an output. As an input, it can enable or disable triggers under the control of an external TTL level. As an output, it can indicate when the internal hit flipflop is enabled to accept triggers.

If the gate is configured as an input, a true level allows triggers and a false level disables them. If BURST is also enabled, then whenever the input level is in the trigger disable state, the burst counter logic is reset; the next time gate goes true, the burst logic will immediately enable a group of N triggers.

4.6.8. FEOD COMMAND

The **FEod** (force end-of-delay) command briefly resets the timing hardware, aborting any timing cycle in progress. This is useful for terminating long delays.

4.6.9. SAVE, RECALL, LOAD COMMANDS

The **sAve** command will save the overall T564 setup into nonvolatile memory. This setup will be restored at powerup or may be installed via the **REcall** command.

SaVe	save current setup to nonvolatile memory
REcall	recall saved setup. Train and frame parameters are saved and recalled, but frame memory is not saved.
LoAd DEfault	load default setup; see Figure 4-1 Typical T564 Status Report
RUn Demo	run demonstration setup. This is the default setup, except that the T564 self-triggers at 20 KHz

4.6.10. USEC, WAIT, IRQ, SHOTS, TEMP COMMANDS

The **uSec** command returns the value of a free-running 32-bit counter that increments once each microsecond. **uSec 0** resets the counter.

The **WAit nnn** command pauses command execution for a specified number of microseconds, up to $2^{32}-1$, or about 4294 seconds.

The **IRq** command returns the value of the internal 40 Hz interrupt counter.

The **sHots** query returns the 32-bit shot counter. This counter increments every time the T564 is fired. **sHots 0** will clear the shot counter.

The following command line will return the approximate trigger rate in Hz:

```
SHOTS 0; WAIT 1000000; SHOTS
```

4.6.11. IDENTIFY COMMAND

The **IDentify** command returns a string which identifies the T564 firmware version. The returned form is **T564-1 Firmware 28E560-A**

4.6.12. ERRORS COMMAND

The **ERrors** command returns a string which identifies any T564 errors. The returned form is...

```
Errs None
```

Or

Errs 00127 XTRIM RECAL CALIB LOGIC XLOCK TUNE DPLL

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

<i>Bit</i>	<i>Value</i>	<i>Flag</i>	<i>Meaning</i>
0	1	XTRIM	VCXO trim value lost
1	2	RECAL	saved setup recall failed
2	4	CALIB	calibration table lost; default cals are used
3	8	LOGIC	internal logic error
4	16	XLOCK	VCXO failed to lock to external source
5	32	TUNE	powerup DPLL calibration error
6	64	DPLL	DPLL stability error

If any error bits are set, the string will also explicate the error bits in text. The "power" LED will turn yellow if any error bits are up.

The **ERrors 0** command will clear the error flags word.

4.6.13. VERBOSE COMMAND

The **vErbose 1** command places the T564 in verbose mode, where commas are included in all long numeric strings that are returned. This mode makes time 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.

4.6.14. HELP COMMANDS

The **HElp** command, with no arguments, will display a short command summary, listing top-level commands. Specific commands will be explained with requests of the form **HElp TRigger** and such.

HElp	return general HELP message
HElp CHannels	return help on channel operations
HElp TRigger	return Trigger help
HElp CLock	return Clock help
HElp BUrst	return Burst help
HElp GAtE	return Gate help
HElp PULsetrain	return Train help
HElp FRames	return Frames help
HElp MIsc	return miscellaneous help

4.6.15. STATUS COMMAND

The **sTatus** query returns a full report of T564 settings. A typical report is shown below. Verbose mode was enabled. The status shown is the default setup.

```
Highland Technology Model T564 Digital Delay Generator

Firmware 28E560-A 1034                      Cal date January 31, 2014

Trig REM 50R Level 1.250 Div 0,000,000,000 SYN 00,010,000.00
Hit Freq Hz 0,000,000,000 Period ns 0,000,000,000

Gate OFF POS HIZ Shots 0,000,000,066
Burst OFF N 0,000,000,016 of M 0,000,000,064

Verbos ON Autoinstall FEOD Usec 0,306,931,240 DPLL 00000
Clock OUT Trim 02048 Temp +35.6

Errs None

Train count 0,000,000,000 Train spacing 0,000,000,003

Frames OFF FA 00000 FB 00009 FC 00000 FN 0,000,000,000

Ch A POS ON Dly 00.000,000,000,000 Wid 00.000,002,000,000
Ch B POS ON Dly 00.000,002,000,000 Wid 00.000,002,000,000
Ch C POS ON Dly 00.000,004,000,000 Wid 00.000,002,000,000
Ch D POS ON Dly 00.000,006,000,000 Wid 00.000,002,000,000
```

Figure 4-1 Typical T564 Status Report

Since the report is subject to change of both format and contents, it is recommended that it not be parsed to extract T564 parameters.

4.6.16. RSET COMMAND

The **rSet** command performs a hardware reset/restart of the T564, equivalent to a power off/on cycle. The reset takes about 4 seconds, after which the T564 will respond with the string *Highland Technology T564 DDG* <cr> <lf>

The last-saved setup will be installed.

4.6.17. PTRAIN, PSPACE, FRAME, AIM, GET COMMANDS

See sections 8-Pulse Trains and 9-Frames.

4.7. Firmware Upgrade Procedure

T564 firmware may be field-upgraded, from a Windows PC with an RS-232 serial-port connection to the unit.

The PC must have the following Highland-provided files in a common folder:

Flash1.bat	batch file for COM1 port
Flash2.bat	batch file for COM2 port
28E560z.flc	script file to flash version 28E564z
28E560z.rom	application file to be loaded
Flash560_Win.exe	Windows flash manager program

To reflash the T564 firmware, connect PC serial port COM1 or COM2 to the T564 using Highland cable part number T565 or equivalent, and start the appropriate Flash1.bat or Flash2.bat batch file.

The flash procedure should now run, reporting progress. At the end, verify that the displayed file and actual flash checksums are equal.

Powerup States and Saved Setups

Users may program the T564 as desired and then use the **save** command to copy all setups to nonvolatile flash memory. That saved setup may be recalled at any time via the **recall** command. The saved setup is also recalled and installed at powerup, allowing the T564 to resume operation without any serial commands.

The powerup sequence takes about 4 seconds. During this time, channel outputs are electrically low and terminations are high-Z.

If the saved configuration programs channels to be inverted polarity, those outputs will transition from low to high when the initial powerup sequence is over.

5. *Powerup States and Saved Setups*

Users may program the T564 as desired and then use the **SAve** command to copy all setups to nonvolatile flash memory. That saved setup may be recalled at any time via the **REcall** command. The saved setup is also recalled and installed at powerup, allowing the T564 to resume operation without any serial commands.

The powerup sequence takes about 4 seconds. During this time, channel outputs are electrically low and terminations are high-Z.

If the saved configuration programs channels to be inverted polarity, those outputs will transition from low to high when the initial powerup sequence is over.

6. Xport Ethernet Module Setup

The T564-2 and T564-32 use a Lantronix Xport module as the Ethernet/TCP-IP interface. It can be accessed by connecting to the device via either its IP address or DHCP-provided hostname, on TCP port 2000. The interface is the same line-oriented ASCII interface as provided over the serial interface, but can be accessed through a standard telnet client such as TeraTerm, puTTY, or the OS-provided telnet command.

To confirm that the T564 has been connected successfully, type `st` followed by <Enter>. You should see the status report as defined in 4.6.15.

6.1. DHCP

The factory default setting for the T564 has its IP address assigned by the network's DHCP server. The T564 can be accessed by either IP address or hostname, which will be in the form: t564-xxxxx, where the xxxxx is the 5-digit unit serial number. If the serial number is fewer than five digits long, pad it on the left with zeros.

6.2. Static IP Assignment

The XPort also supports static 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>.

To find the IP address of a T564 unit, the T564 should be connected to the local network. The Lantronix DeviceInstaller software should be started from a Windows PC connected to the same network.

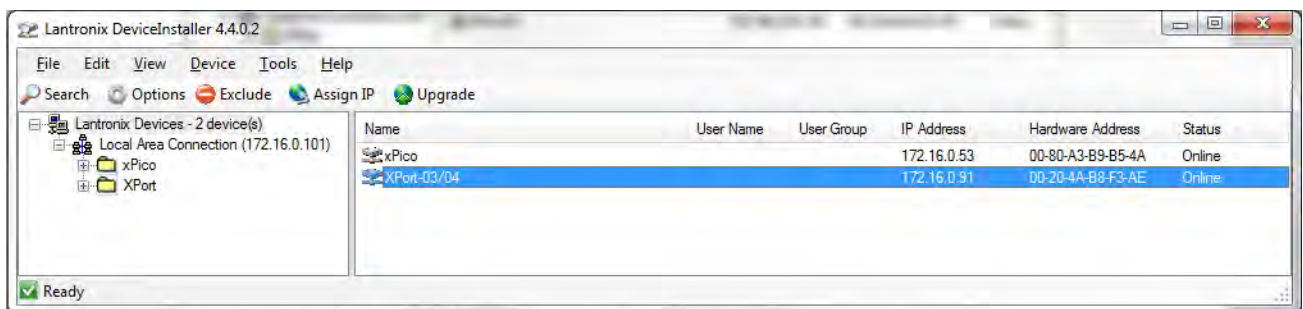


Figure 6-1. Lantronix DeviceInstaller Main Screen

Find the T564 in the software by its hardware MAC address. The MAC address can be found on one of the sides of the T564 and will follow the form xx-xx-xx-xx-xx-xx. In the above image, the MAC address is 00-20-4A-B8-F3-AE. The IP address will appear in the software next to the MAC address.

To assign a static IP address, click on the T564, and then click on the Assign IP button. After clicking the button, the Lantronix DeviceInstaller IP address assignment pane should appear:

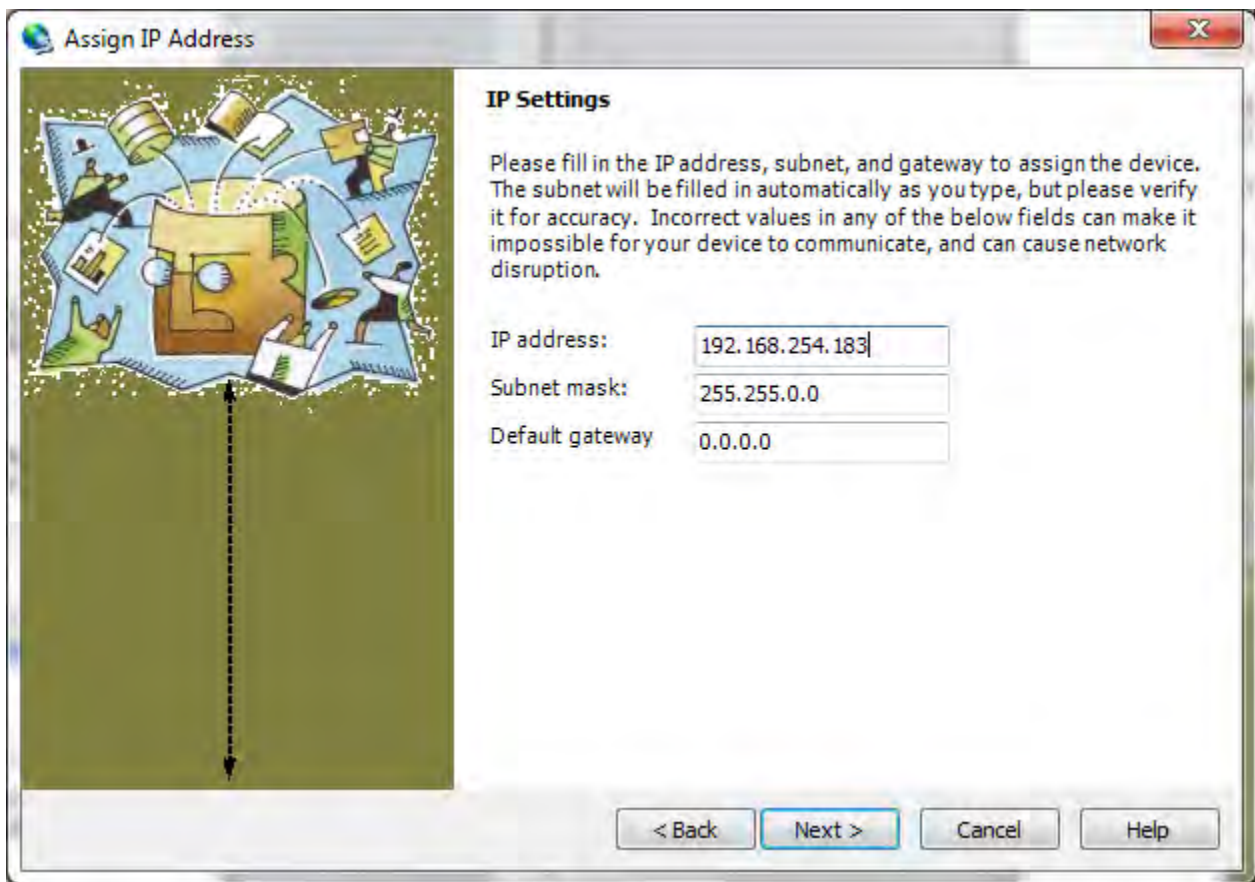


Figure 6-2. IP address assignment pane

Once the IP address has been identified or assigned, a web browser (preferably the web browser provided by DeviceInstaller) 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. Initially, no user name or password need be entered; simply leave both fields blank and hit Enter. The web page interface can also be used to change the IP address.

6.3. *Factory XPort Settings*

The following images represent the setup in which the XPort in the T564 is shipped.



Figure 6-3. XPort Home Web Page

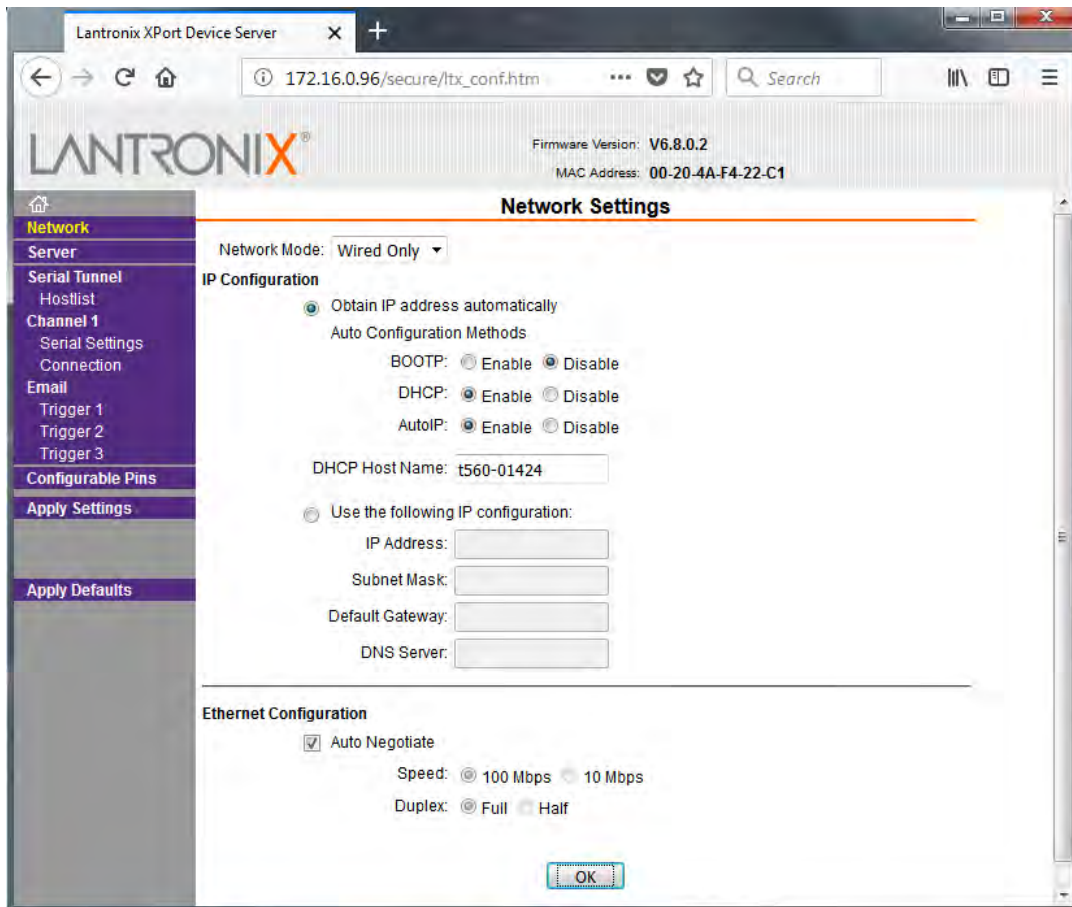


Figure 6-4. XPort Network Settings

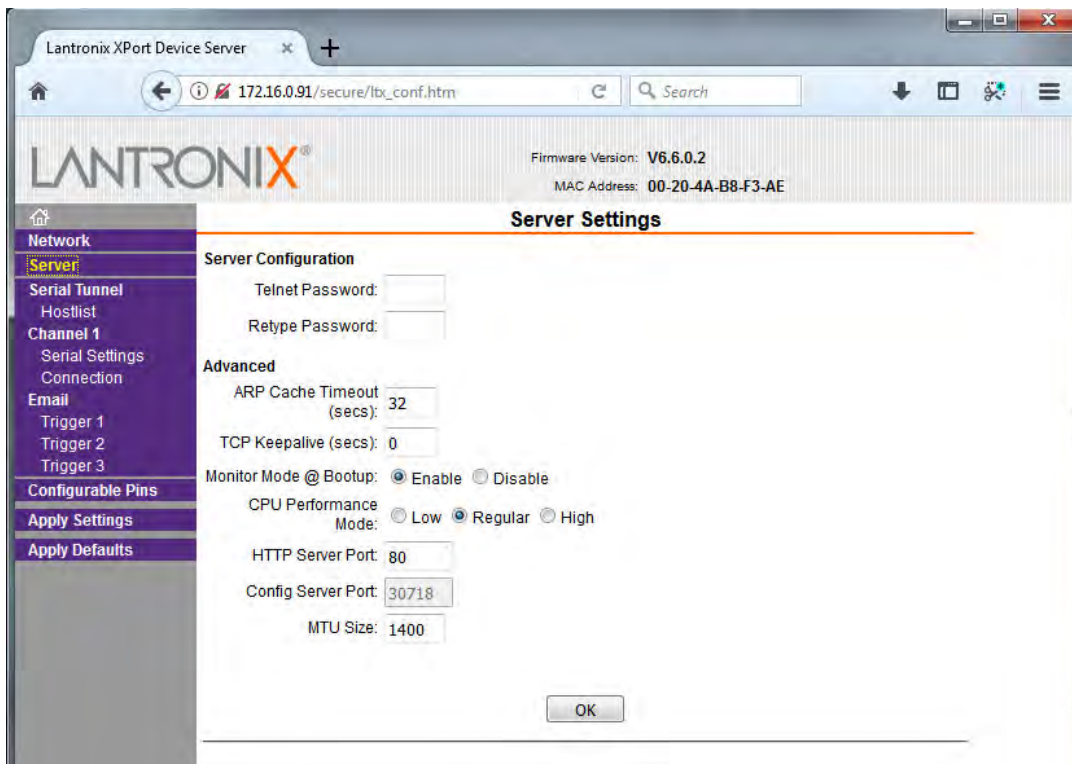


Figure 6-5. XPort Server Settings

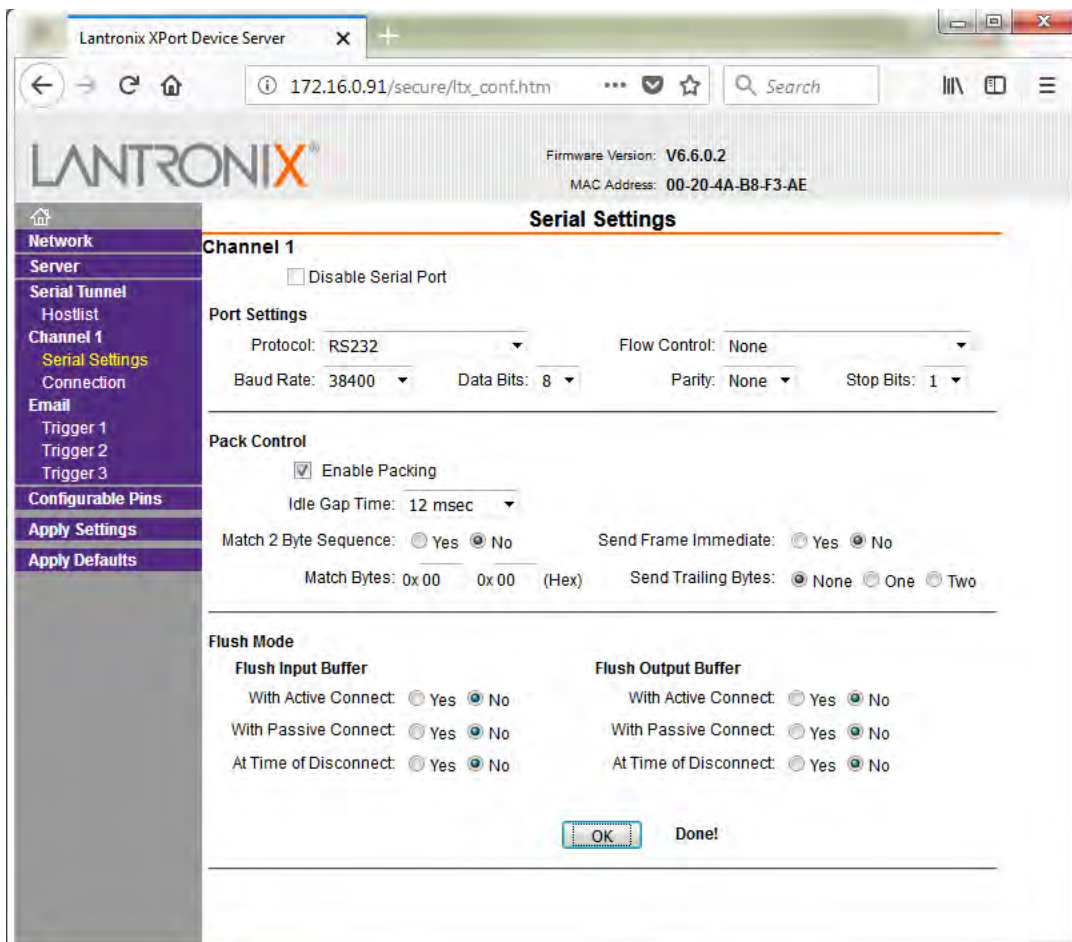


Figure 6-6. XPort Serial Settings

The screenshot shows the Lantronix XPort Device Server web interface. The browser address bar displays '172.16.0.91/secure/tx_conf.htm'. The page title is 'Lantronix XPort Device Server'. The firmware version is V6.6.0.2 and the MAC address is 00-20-4A-B8-F3-AE. The left sidebar contains the following links: Network, Server, Serial Tunnel, Hostlist, Channel 1, Serial Settings, Connection (highlighted), Email, Trigger 1, Trigger 2, Trigger 3, Configurable Pins, Apply Settings, and Apply Defaults. The main content area is titled 'Connection Settings' and shows the configuration for 'Channel 1'. The 'Connect Protocol' is set to 'TCP'. The 'Connect Mode' section includes 'Passive Connection' and 'Active Connection' settings. The 'Passive Connection' settings are: 'Accept Incoming' (Yes), 'Password Required' (No), 'Password' (empty), 'Modem Escape Sequence Pass Through' (Yes), and 'Modem Mode' (None). The 'Active Connection' settings are: 'Active Connect' (None), 'Start Character' (0x0D), 'Show IP Address After RING' (Yes), and 'Modem Mode' (None). The 'Endpoint Configuration' section includes 'Local Port' (2000), 'Remote Port' (0), 'Remote Host' (0.0.0.0), and 'Auto increment for active connect' (unchecked). The 'Common Options' section includes 'Telnet Com Port Cntrl' (Disable), 'Connect Response' (None), 'Terminal Name' (empty), 'Use Hostlist' (No), and 'LED' (Blink). The 'Disconnect Mode' section includes 'On Mdm_Ctrl_In Drop' (No), 'Hard Disconnect' (Yes), 'Check EOT(Ctrl-D)' (No), and 'Inactivity Timeout' (5 mins, 0 secs). An 'OK' button is at the bottom.

Figure 6-7. XPort Connection Settings

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.

7. Jitter Notes

Jitter is defined as the 1-sigma standard deviation of delay. It is the shot-to-shot time uncertainty from the external trigger to any output's rising or falling edge, or the uncertainty between edges of channel outputs. Jitter is measured in RMS picoseconds. Visual peak-to-peak jitter is roughly 5 times that of RMS.

"Jitter" is usually accepted to indicate time variance as observed over an interval of 0.1 seconds, with the term "wander" used to describe slower changes of delay. Wander thus encompasses changes in delay driven by temperature changes and other slow effects. The T564 jitter specs are valid for observation periods up to 10 seconds in the absence of radical temperature changes. Note that coaxial cable propagation delay can change considerably with temperature and can contribute to observed timing variance.

Uncorrelated jitters add trigonometrically, as the square root of the sum of the squares of all jitter contributors.

Jitter can be difficult to measure. The trigger input to the T564 must be clean and fast (< 2 ns risetime) and the measuring instrument must have a jitter noise floor well below that of the T564. Most oscilloscopes and counters are not capable of resolving T564 jitter performance, especially so for longer delays. For example, a Tektronix 11801C sampling oscilloscope (or the newer DSA8200 without the optional phaselock module) has a short-delay jitter well below that of the T564 but has added jitter on the order of 20 microseconds per second of delay, whereas the T564 starts with a greater basic jitter but typically adds about 4 ns of jitter per second of delay.

For lowest jitter from an external trigger, the T564 trigger level should be set to the steepest part of the input edge, typically 1/3 to 1/2 of the peak amplitude.

Jitter is a function of the generated time delays. Very short delays have a baseline jitter that depends on fundamental triggered-oscillator phase noise. After about 500 ns, the DSP stabilization loop becomes active and disciplines the triggered oscillator, limiting its jitter accumulation.

Long delays, in the milliseconds range, become dominated by the phase noise of the internal crystal oscillator, typically about 4 ns per second of delay. Long-delay effects are zero relative to a user-provided 10 MHz reference clock.

Jitter between successive triggers, referred to as "period jitter", depends on the quality of the trigger source. The internal DDS trigger synthesizer has jitter typically about one part in 20,000 of the trigger period. DDS jitter is best if its frequency is in the 2-10 MHz range, where the period jitter, measured at a channel output, is typically about 25 ps RMS. For lowest DDS jitter at lower rates, keep the DDS synthesizer frequency in this range and use a trigger divisor to get lower trigger rates.

Dividing down the internal 80 MHz clock results in period jitter in the neighborhood of 40 ps RMS, until millisecond-range periods when crystal oscillator phase noise again becomes important.

The graph below summarizes typical T564 jitter versus delay. Here, "delay" refers to the time from an external trigger to any output edge. The rise which begins at about 1 millisecond is caused by internal crystal oscillator phase noise, and will not be present relative to an external 10 MHz reference. The T564 is also available with optional, lower phase-noise OCXO oscillators. The graphed data includes jitter contributed by the P400 trigger source and the 11801C oscilloscope, so actual T564 jitter is somewhat less.

Jitter between outputs is similar.

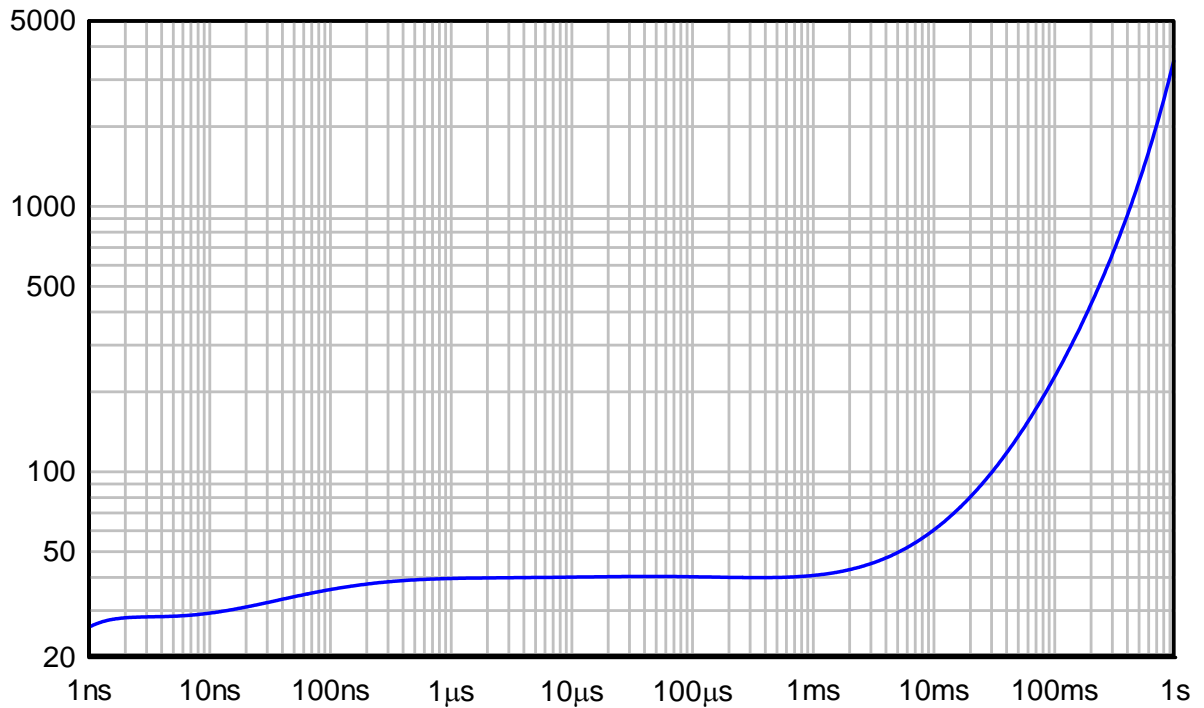


Figure 7-1 Typical T564 jitter in ps RMS versus delay

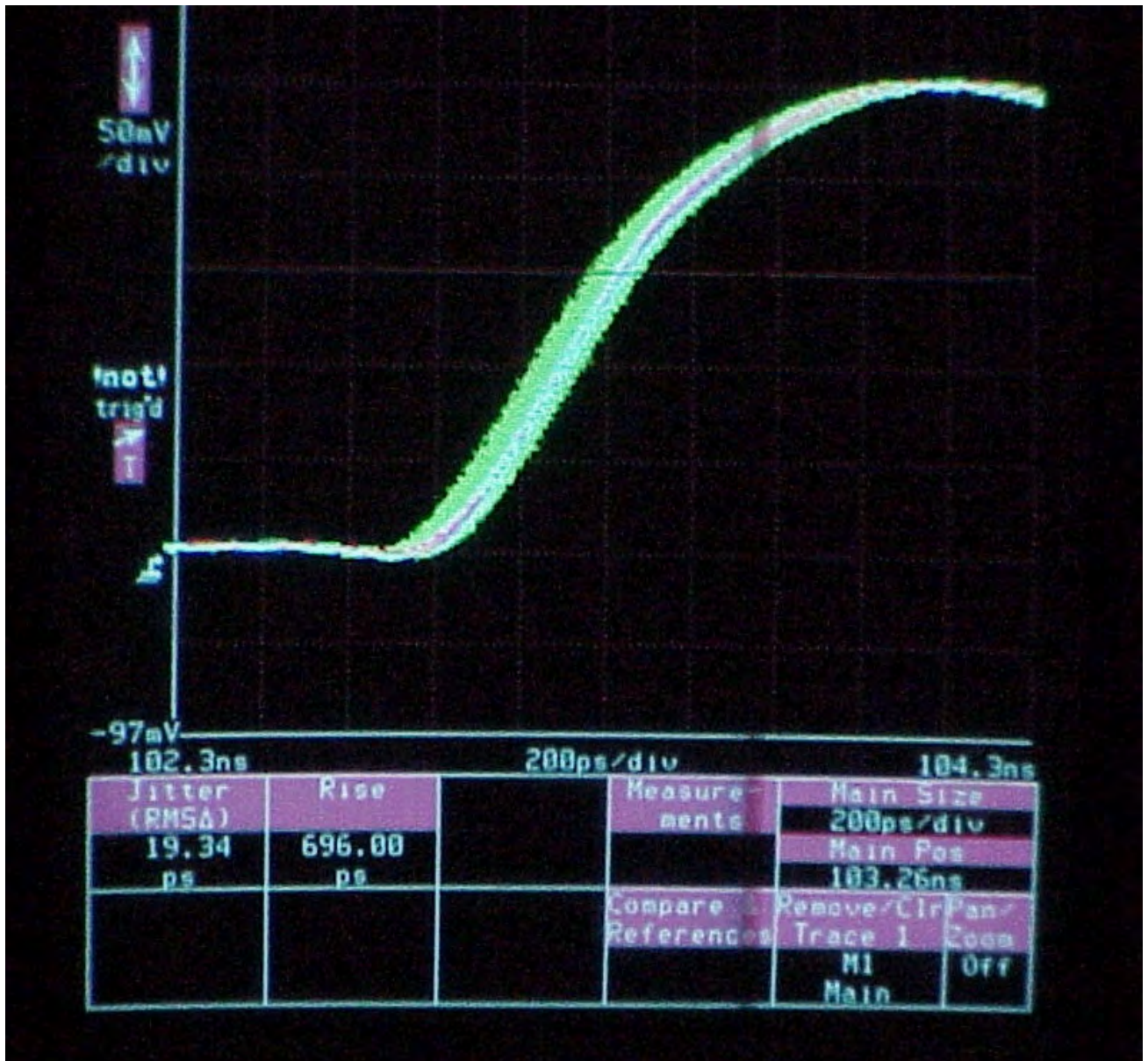
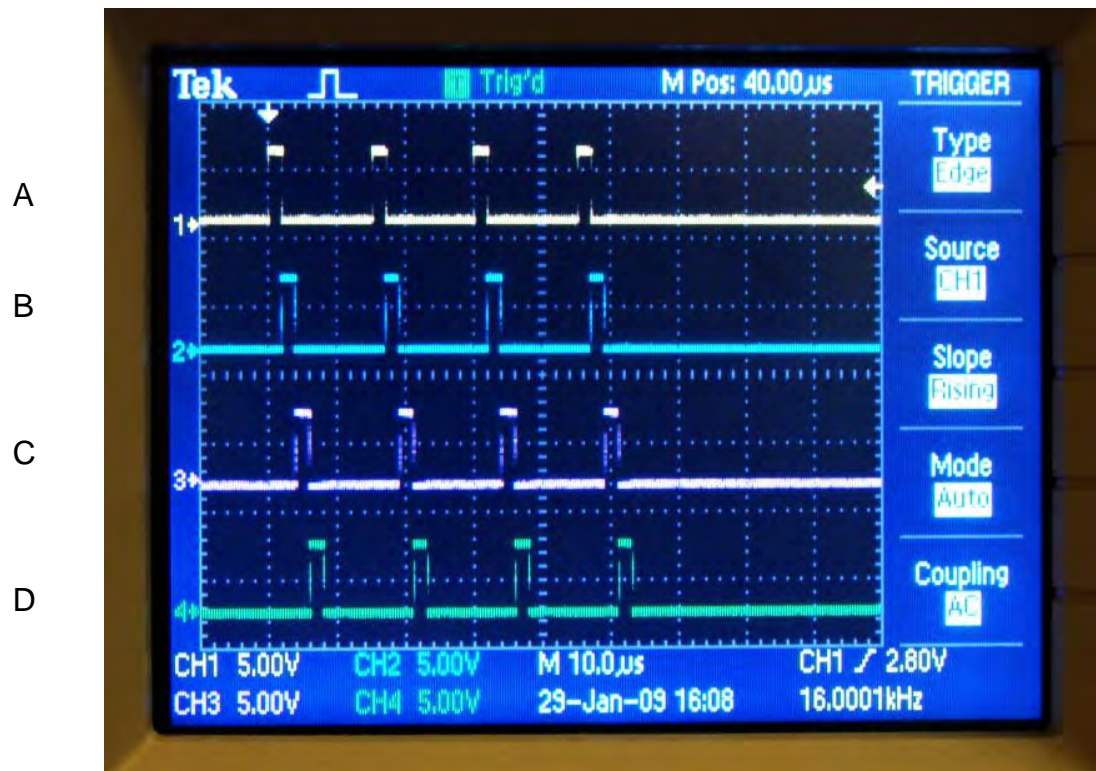


Figure 7-2 Typical T564 Rising Edge, Externally triggered, delay = 100 ns

This was measured on a Tektronix 11801A sampling oscilloscope, with the scope and the T564 triggered by a Highland P400 digital delay generator. Indicated jitter is 19.3 ps RMS, risetime 696 ps.

8. Pulse Trains

The T564 may be programmed to produce pulse trains, namely to make a sequence of delay cycles starting with a single trigger. The associated waveforms are shown below...



The first set of A/B/C/D outputs are the usual ones, as programmed by the standard channel delay and width commands. After these are finished, additional sets are generated, spaced from the original set by time T2. This particular sequence was invoked by the **TCount 3** command. Note that the numeric argument to the **TCount nnn** command is the number of additional pulses added to the normal pulse output.

The pulse spacing T2 is set by the **TS ddd** command, **TS 750** for a 15 us group spacing in this example. The time is expressed in units of 20 ns. Up to $2^{32}-1$ pulses can be generated by the train facility, with spacing T2 from 80 ns to 10 seconds. T2 must be set to time W+80 ns minimum, where W is the time from the first edge (here, the rise of A) to the last edge (here, the fall of D.)

The T2 intervals are quantized to 20 ns and are exact to the accuracy of the internal crystal oscillator timebase.

After all pulses are over, the standard EOD (end-of-delay) system reset occurs.

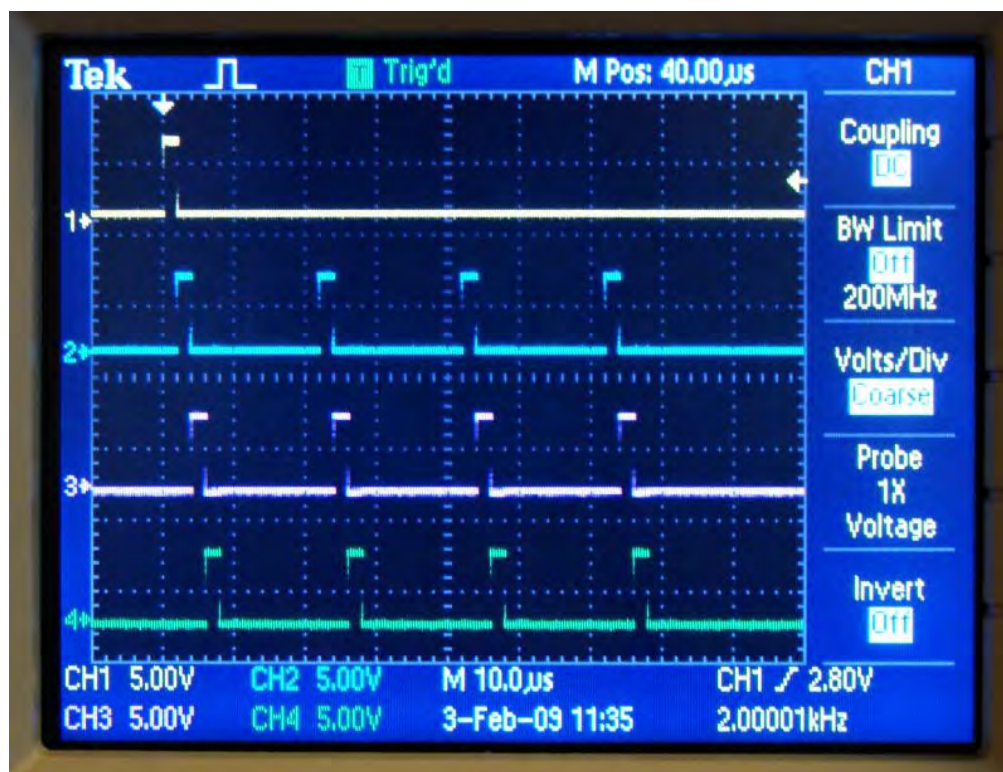
The associated serial commands are...

TCOUNT	OFF	TC OFF	cancel Train mode
TCOUNT	2000	TC 2000	make a train of 2001 pulses per trigger
TSPACE	88	TS 88	set train T2 spacing to 1760 ns

TCOUNT OFF resets the train subsystem. This immediately clears the pending, actual, and hardware Tcount values. **TCOUNT 0** disables train operation but operates like a normal timing parameter, requiring an **INSTALL** or **QUEUE** command to become effective.

The train parameters must be installed before becoming active, using the **INSTALL** or **QUEUE** commands, or their autoinstall equivalents. Train parameters are saved in Frames.

If any channel is programmed for a delay below 20 ns in Train mode, only the first, single pulse will appear. This is defined as a feature, as it allows a single "train start" output pulse to be generated. In the example below, the channel A delay is set to zero, so it makes only one initial pulse in Train mode.



9. Frames

The T564 allows a schedule of multiple delay setups to be stored in local volatile memory, with new settings loaded rapidly after each trigger/delay sequence.

Delay setups are compiled and stored in "frames". Each frame includes channel delays, widths, channel enable bits, channel polarities, and TRAIN parameters. Users may program a group of settings and store that setup to a numbered frame.

At runtime, initializing the frame system will allow a number of DDG shots to be fired, using parameters extracted from sequential frames. The T564 can store up to 8192 frames.

The frame controller logic has three states:

- OFF frame system is disabled. DDG operates normally.
- RUN frames are being loaded at each end-of-delay, namely at the end of each timing cycle.
- DONE last frame has been loaded and run, and triggers are inhibited.

The associated serial commands are...

FRAME OFF	disable frame mode
FRAME nnn	save current settings to frame nnn, in range 0 to 8191.
FA nnn	set first frame to execute. FA with no argument is a query.
FB nnn	set last frame to execute. FB must be greater than FA
FC nnn	set frame loop count, 0 to 65534. Value 65536 sets infinite loop.
FRAME GO	enter RUN state and start frame execution, from first to last.
FRAME LAST	report maximum available frame index, usually 8191
FN	report number of frames loaded into hardware. FN 0 clears count
FP	report realtime frame pointer
FRAME	report frame system state
INSTALL nnn	unpack frame nnn and load immediately into DDG hardware
QUEUE nnn	unpack frame nnn and queue into DDG hardware

The **FRAME GO** command loads the start (FA) frame into the hardware and queues the next sequential frame to be installed into the timing registers at the next EOD, namely at the end of the next shot sequence. Subsequent triggers use the timings extracted from sequential frames. After the last (FB) frame is used, triggers are disabled until another **FRAME GO** or **FRAME OFF** command is issued.

FRAME GO will produce the error response ?? if FB is not greater than FA.

The **FRAME** command, with no argument, returns **OFF** or **DONE** if frame execution is not active, or an integer from 0 to 8191 identifying the next frame to be executed if the sequence is active.

The **FRAME OFF** command returns the DDG to normal operating mode. The last-sent group of channel settings is re-installed, and triggers will be re-enabled if the trigger settings allow. One can issue the **TRIGGER OFF** command before the **FRAME OFF** command if this sequence might produce undesired outputs.

If the FC parameter is zero, a **FRAME GO** command will load frames FA through FB into the hardware then stop, responding to (FB-FA+1) triggers. If the FC loop parameter is in the range of 1 to 65534, that sequence will be repeated FC times, responding to $(FB-FA+1) * (FC+1)$ triggers, about 536 million triggers in the extreme case. If FC is set to 65535 and **FRAME GO** is executed, the frame system will loop forever, executing frames FA through FB until terminated by **FRAME OFF**.

To speed up loading frames, it is recommended that Autoinstall be off (zero), and it is not necessary to issue an **INSTALL** command before saving a frame.

The FA, FB, and FC parameters may be queried at any time, but it is illegal to change them while frames are actively running. The command **FB 222** will invoke the ?? response if frames are running.

There are some realtime limitations to frame performance. Trigger rate may not exceed 15 KHz, and there must be a minimum delay between EOD and the next trigger of 10 microseconds, where EOD is the time of the trailing edge of the last active channel. Violating these limits may cause triggers to be missed.

Another note is that calibration and delay temperature compensation math is performed at the instant a frame is compiled and saved, so later playback of frames may result in more than normal temperature drift, as much as 20 ps per degree C. So it is best to load "fresh" frames for maximum accuracy.

If frames have been loaded but frame operation is inactive, one can issue the **INSTALL nnn** or **QUEUE nnn** commands to load the setup of frame nnn into the DDG timing hardware. This allows the frame buffer to be used to store up to 8192 saved timing setups, any of which can be recalled with a relatively short serial command. These commands are also useful for testing frame setups. Set Autoinstall mode to zero when using these commands; otherwise an end-of-line autoinstall will override any recalled frame settings.

After such an **INSTALL nnn** or **QUEUE nnn** command, queries of channel delay or width settings will reflect the last values sent by normal **DELAY** or **WIDTH** commands, and not the values just recalled from frame memory.

Since channel on/off and pos/neg polarity states are saved in frames, it is possible to have channels selectively fire on a frame-by-frame basis. One can also program a channel to be off, but still flip its polarity on a per-frame basis, effectively creating a static TTL output that is controllable in each frame.

Some diagnostic commands are...

FDUMP 8190	FD 8190	display frame N contents, internal format
FX	FX	display frame diagnostic report
FM	FM	display frame trigger down-counter
RTEST	RT	test frame memory
RZAP	RZ	clear frame memory

The following is a simple example of frame operation. The following serial commands are sent to the T564:

```

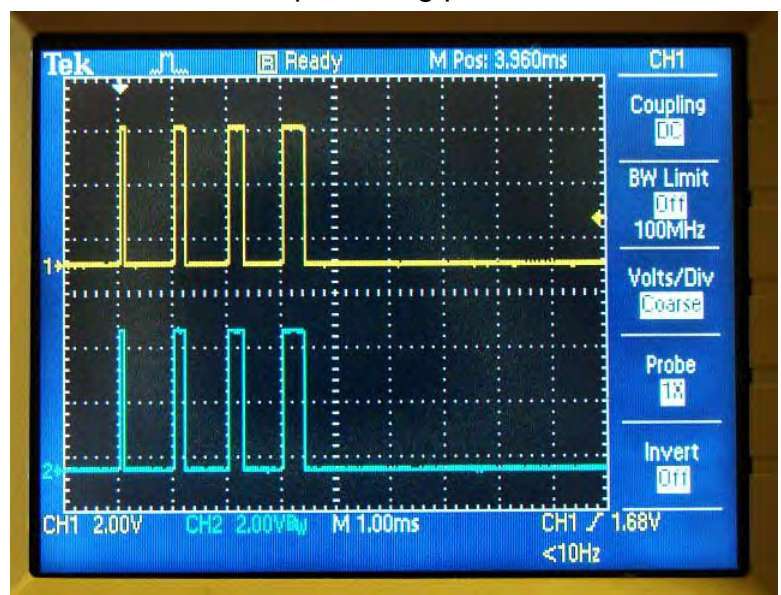
LOAD DEFAULT
QDELAY 0
QWIDTH 100U; FRAME 1
QWIDTH 200U; FRAME 2
QWIDTH 300U; FRAME 3
QWIDTH 400U; FRAME 4
FA 1; FB 4
TDIV 80000
FRAME GO
TRIGGER INTERNAL

```

This will result in four triggers being fired at a 1 KHz rate, producing pulses of 100, 200, 300, and 400 microseconds on all four output connectors. The **LOAD DEFAULT** command cleared the frame loop counter FC, so frames 1 through 4 are scanned only once. The FN counter is incremented by five, the number of triggers plus one.

The resulting waveform is shown left, with the A and B outputs displayed.

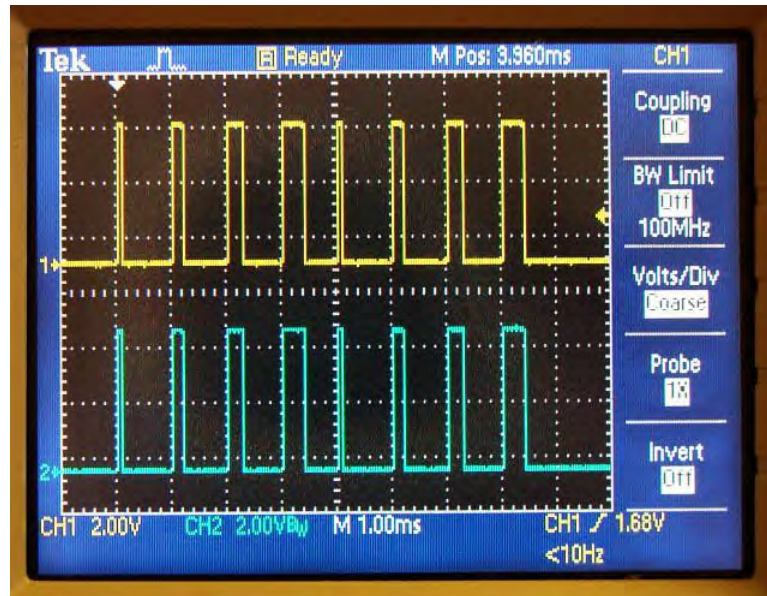
Another **FRAME GO** command will repeat this sequence.



If we then issue the commands

```
FC 1  
FRAME GO
```

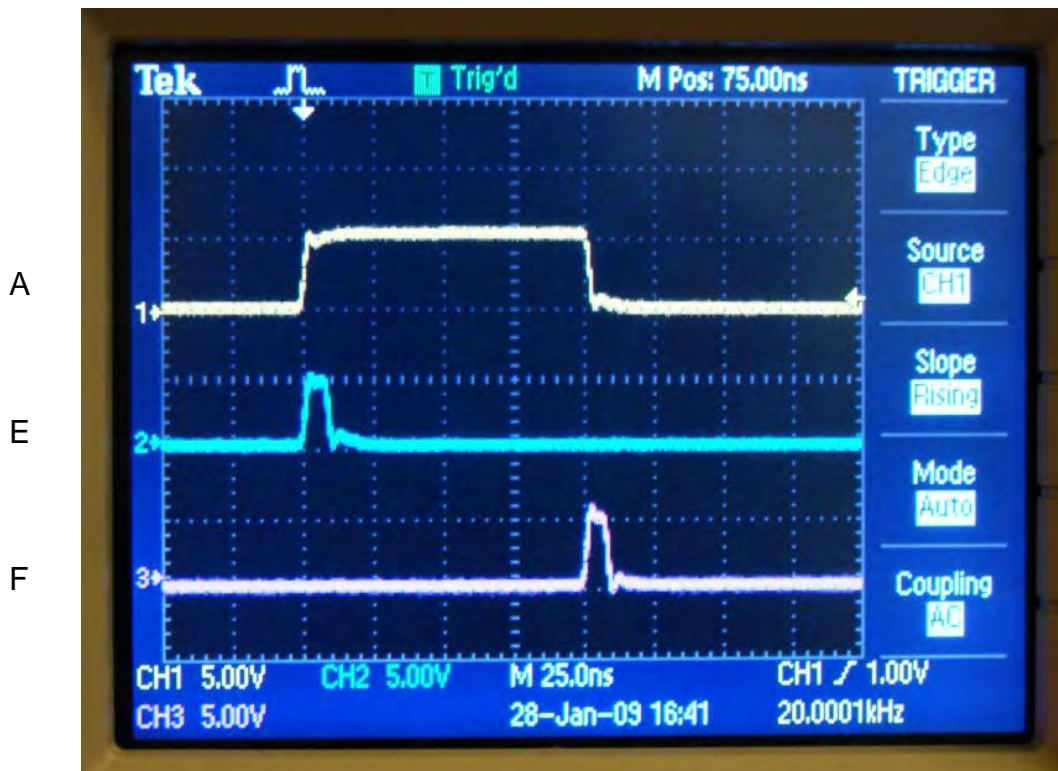
the four programmed frames will be executed twice, accepting a total of 8 triggers. The FN count will increment by 9.



10. Optional E and F Outputs

The T564 can be furnished with optional E and F electrical outputs.

E produces a short (8 ns nom) positive pulse at the rising edge of the standard channel A output, and F produces a similar pulse at the falling edge of A.



In figure 12.3, the E output connector is in the position to the left of the D output, and F is immediately to the right of the A output.

11. J14 Auxiliary Connector

The T564-10 version is provided with a bottom-side single-row female box connector which provides additional control and communications features.

11.1. J14 Pinout

J14 pinout is as follows:

<i>Pin</i>	<i>Name</i>	<i>Description</i>
1	TRIGMON	Buffered copy of the trigger comparator output. If the T564 is triggered by an external falling edge, this is inverted; otherwise it is true.
2	ARM	Logic level input to the T564, with an internal pull up resistor. When pulled low, triggering is disabled. When pulled up or left floating, triggering is enabled.
3	SRD	Isochronous serial reply data from the T564
4	AUXTRIG	Auxiliary trigger
5	SPD	Isochronous serial command data to the T564
6	SCLK	Externally-generated isochronous serial clock, in the 1-5 MHz range
7	NC	No connection
8	NC	No connection
9	GND	Signal ground
10	GND	Signal ground
11	NC	No connection
12	NC	No connection
13	NC	No connection
14	GND	Signal ground

Logic levels are 3.3 volt CMOS.

11.2. Isochronous Serial Interface

The T564 is available with an optional SPI-like fast, TTL-level serial command interface. This interface is in addition to, and operates concurrently with, the standard RS-232 serial interface. The command protocol is identical to the RS-232.

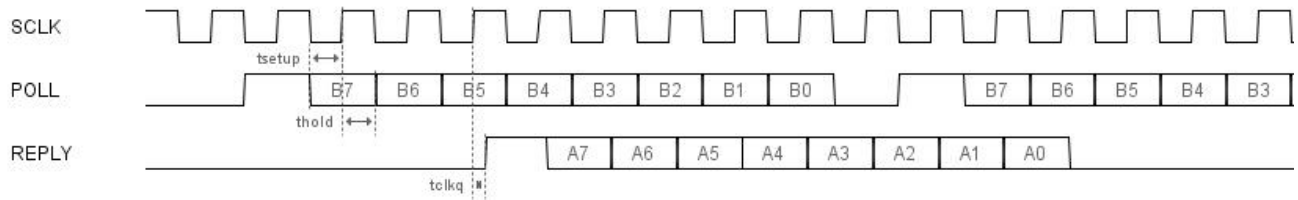
The interface uses three TTL-level signals:

SCLK continuous serial clock, user-furnished, 4 MHz nom

SPD poll (command) serial data, from user to T564; T564 "receive"

SRD reply serial data, from T564 to user; T564 "transmit"

Serial data lines idle electrically low. A byte is sent as a single high "start" bit, eight data bits, and a low stop bit.



f_{clk}	SCLK frequency	5 MHz recommended max
t_{clkw}	SCLK high/low pulse width	65 ns min
t_{setup}	POLL change to SCLK rising edge	30 ns min
t_{hold}	SCLK rising edge to POLL change	10 ns min
t_{clkq}	SCLK rising edge to REPLY change	30 ns min 80 ns max
V_{ip}	Logic high input voltage	2.4V min
V_{il}	Logic low input voltage	0.6V max
V_{oh}	Logic high output voltage	2.9V min ($I_L = 100 \mu A$) 2.3V min ($I_L = 24 \text{ mA}$)
V_{ol}	Logic low output voltage	0.1V max ($I_L = 100 \mu A$) 0.55V max ($I_L = 24 \text{ mA}$)

The SPD (serial poll data) signal is the serial data from the master to the T564. The SRD (serial reply data) signal is the serial data from the T564 to the master. Logic input circuitry (SCLK, SPD) is a 1K series resistor, a 33pF capacitor to ground, and a 3.3V Schmitt trigger input. Logic output SRD is a 3.3V LVC series output.

At frequencies below the recommended maximum f_{clk} of 5 MHz, a serial master may read SRD at the same time the rising edge of SCLK is generated and update SPD at the same time the falling edge of SCLK is generated with no timing concerns.

When no data is being transmitted, the data lines idle low. Data is transmitted in 8 bit frames, starting with a logic high start bit, then the data (MSB first), then a logic low stop bit. Data follows the same rules described in the Programming chapter of the manual, i.e. ASCII characters followed by a carriage return (0x0D) to mark the end of transmission. The T564 will process the commands normally, and respond with an ASCII string, terminated by a carriage return.

Four RS-232 port serial commands are provided to test the isochronous interface.

IS TX STRING	send string to isoch transmit (reply) interface
IS RX	get string from isoch receive (poll) interface
IS LO STRING	isoch loopback test
IBLOCK 1	don't parse incoming isoch command strings
IBLOCK 2	send isoch receive (poll) data to the RS232 interface
IBLOCK 256	suppress all command reply data, isoch or RS232

The **IS TX TEXT** command sends the remainder of the line " TEXT" out the isoch transmit (reply) interface.

The **IS RX** command essentially empties the receive (poll) FIFO and sends any non-null bytes to the RS232 transmit interface. This allows inspection of the contents of the isoch receive buffer.

The **IS LO** command combines **IS TX** and **IS RX**.

Because the command parser is normally trying to absorb and execute commands coming into the isoch receive port, it can interfere with testing. The **IBLOCK 1** command will disable such parsing.

If a loopback tester is connected to the T564 isoch interface connector, one can set the **IBLOCK 1** state; now the command **IS TX HELLO** will send " HELLO" out, and a subsequent **IS RX** will fetch the looped-back " HELLO" string which will be returned by the RS232 interface.

The **IBLOCK 2** command will divert any characters that would normally go out the isoch transmit interface into the RS232 transmit port.

If a loopback tester is operating and the **IBLOCK 2** state is in effect, an RS232 command such as **IS TX ST** will loop back the " ST" into the isoch receive interface, the parser will interpret the command and generate the T564 status report, and the resulting report will be diverted to the RS232 port.

IBLOCK 0 will restore normal operation. Any command error will clear the **IBLOCK** parameter.

The interface uses connector J14.

J14 pin 6 is the externally-generated clock SCLK, in the 1-5 MHz range

J14 pin 5 is command/poll data SPD to the T564

J14 pin 3 is reply data SRD from the T564

J14 pins 9 and 10 are ground.

Logic levels are 3.3 volt CMOS.

J14 pin 1 is at board coordinate X 1.770, Y 0.530. J14 pins are spaced at 0.1 inch centers. See fig 12.3.

With Autoinstall off, some typical command execution times, are, in microseconds,

AD 1	102
AD 123.456N	164
AD	160
AD 1;AW 1	198
AD 1.234M;AW 1.234M	370
DD 1	116
QD 123.456U	202
IN	312
QU	312
FEOD	74
FIRE	72
CO	72
TL 1.25	256
TL	160
TS 1234	190
TS	206
ST	4.2 MSEC
ST	230 MSEC RS232 OUTPUT

Each extra character in a command, beyond the required first two, adds about 6 microseconds to command execution.

12. Dimensions and Mounting

T564 mechanical dimensions are shown below. The evaluation T564 is furnished with the T566 mounting flange bolted to the bottom of the extruded enclosure to make it easier to install on mounting surfaces which do not have rear access.

The T564 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 T564 enclosure.

The T564-1 does not include the Ethernet connector



T564-2 includes Ethernet and the 2.5 mm RS-232 connector



Further customization information is in Versions on page 60.

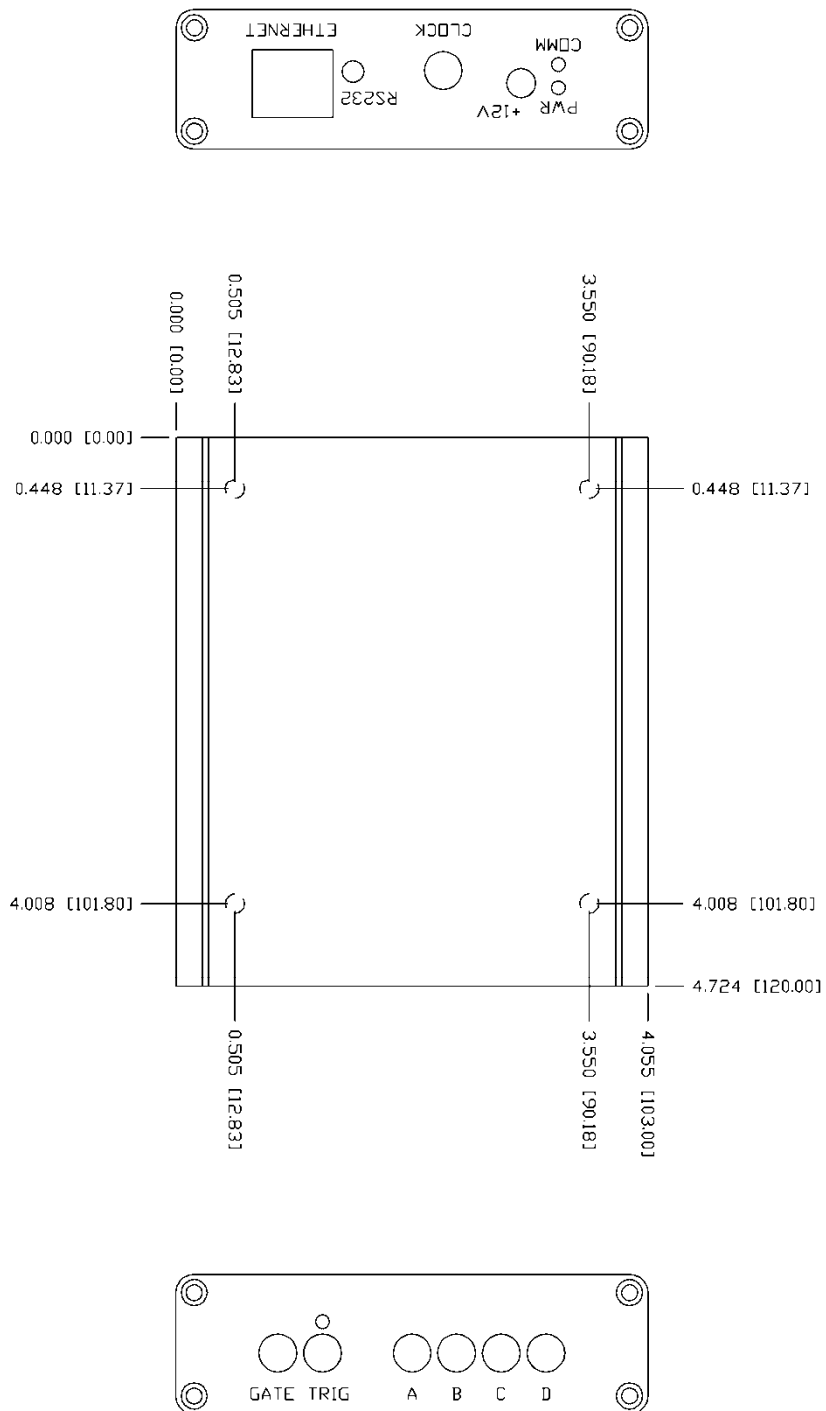


Figure 12-1 T564 Outline and Mounting

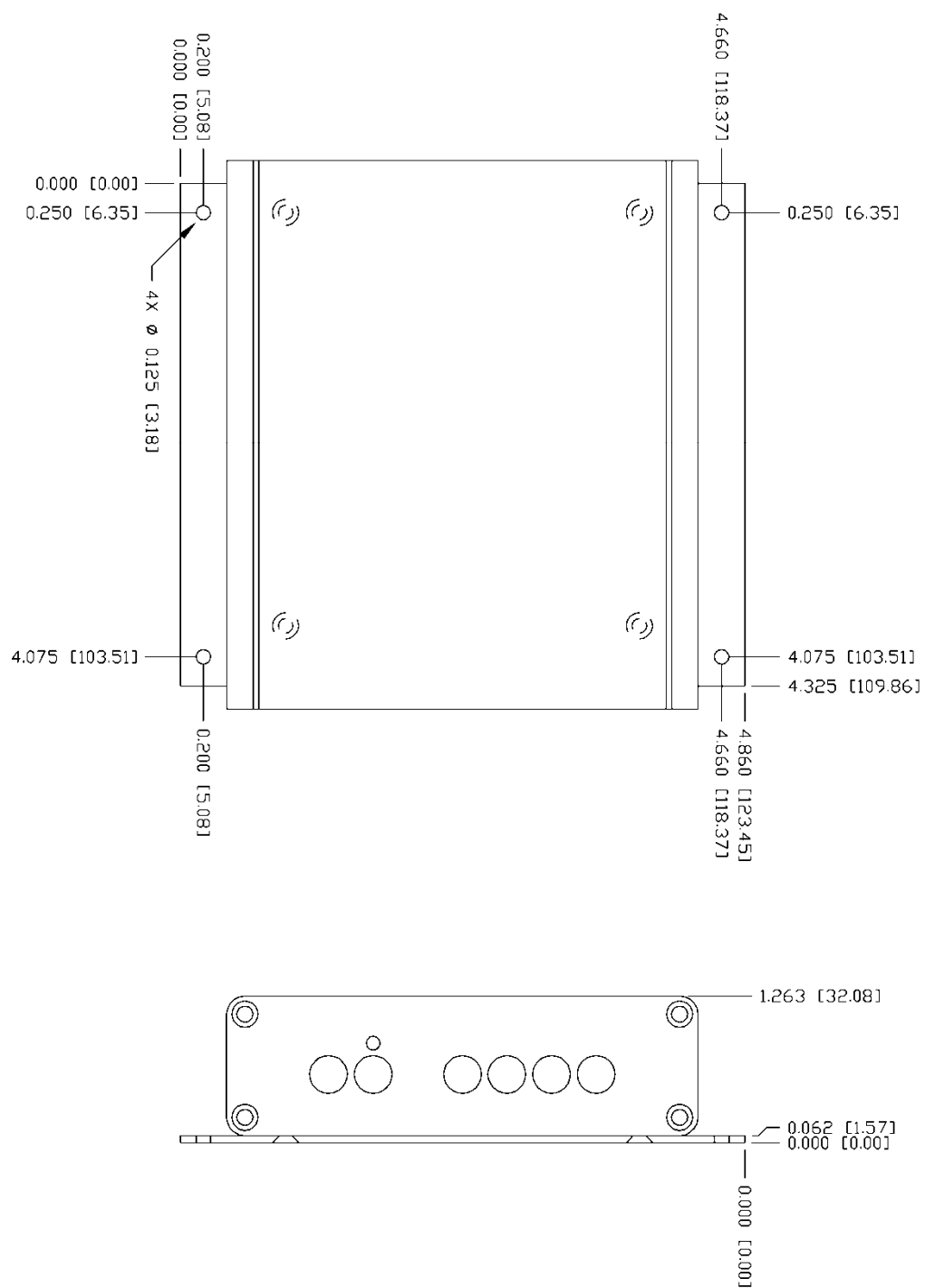


Figure 12-2 Flange Mounting Dimensions

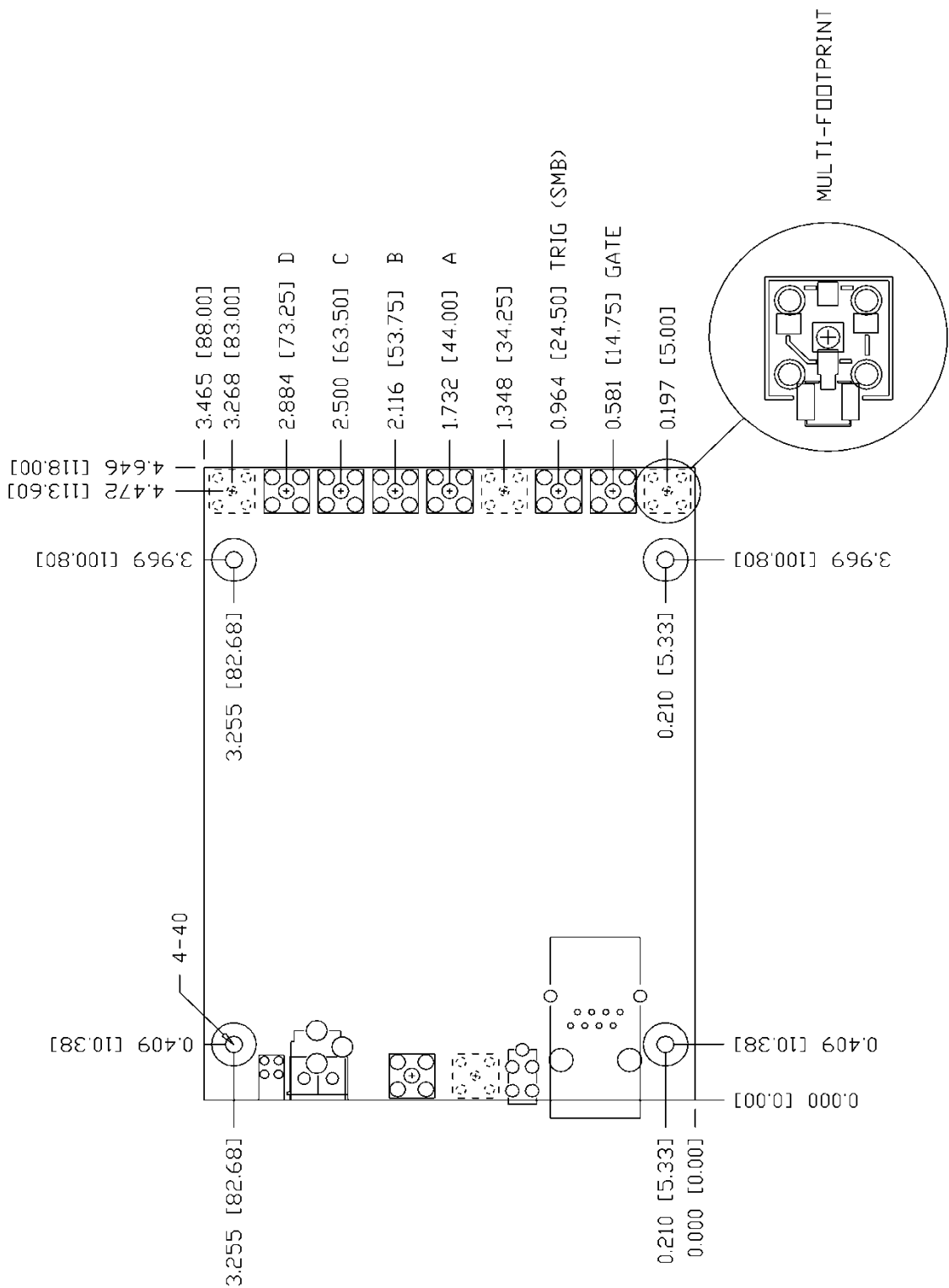


Figure 12-3 Printed-Circuit Board Dimensions

13. Demo Software

Win560.EXE is a Windows program that communicates with the T564 using serial commands. Device settings are displayed on screen, and can be sent to the T564 all at once or refreshed all at once in the program. Communications access to the T564 is available via RS-232 or the Ethernet port.

Further information on running the program is available via the in-program Help screens. Win560 requires Windows 2000 or later.

14. Versions

- T564-1: stand-alone 4-channel compact advanced digital delay and pulse train generator
- T564-2: stand-alone 4-channel compact advanced digital delay and pulse train generator with Ethernet interface
- T564-9: evaluation kit (includes T564-2 factory installed on mounting flange with Ethernet interface, power supply, two 3' SMB cables, and one RS-232 cable)
- T564-31: stand-alone 4-channel compact advanced digital delay and pulse train generator with OCXO option
- T564-32: stand-alone 4-channel compact advanced digital delay and pulse train generator with Ethernet interface and OCXO option

Consult factory for information about additional custom versions.

15. Revision History

15.1. Hardware Revisions

Revision L	June 2021 Replaced obsolete parts. Improved manufacturability. Functionally equivalent to Revision J
Revision K	Sep 2014 Functionally equivalent to Revision J
Revision J	Jan 2014 Replaced timing element with GaAs FETs to improve timing accuracy and reduce crosstalk Requires switch to 28A560 series firmware
Revision H	Feb 2012 Improved manufacturability Functionally equivalent to Revision C
Revision G	Dec 2011 Improved manufacturability. Functionally equivalent to Revision C
Revision F	Dec 2010 Replaced obsolete regulator package Functionally equivalent to Revision C
Revision E	Jul 2009 Improved manufacturability Functionally equivalent to Revision C
Revision D	Jan 2008 Improved manufacturability Functionally equivalent to Revision C
Revision C	Apr 2007 Reduced jitter to 50 ps RMS Reduced insertion delay to 20 ns Reduced minimum pulse width to 2 ns Increased maximum trigger input rate to 125 MHz
Revision B	Jan 2007 Initial production release. Worst case jitter of 80 ps RMS Insertion delay 25 ns Maximum trigger input rate 80 MHz

15.2. Firmware Revisions

28E560-E	June 2021 For hardware revision L Modified for revision L hardware
28E560-D	February 2016 For hardware revisions J-K Fixed TUNE error when powering up unit above room temperature. Fixed missing pulse in gate burst mode when the trigger is very near the gate.
28E560-C	January 2016 For hardware revisions J-K Fixed bug with occasional loss of PLL lock during long delays.
28E560-B	Aug 2015 For hardware revisions J-K Fixed bug with T564 identification on some models
28E560-A	Jan 2014 For hardware revision J Improved timing calibration linearity
28E563-B	Apr 2007 For hardware revision C-H Modified for revision C hardware
28562-A	Jan 2007 Hardware revision B Initial release

16. Accessories

- J12-1: 12 volt power supply (1 included with purchase)
- J53-1: 3' SMB to BNC cable (2 included with evaluation kit purchase)
- J53-2: 6" SMB to BNC cable
- P10-1: 19" rack mount shelf (four t-boxes per rack)
- T565-1 : RS-232 cable (1 included with purchase)
- T566-1 : mounting flange (1 included with evaluation kit purchase)