HIGHLAND TECHNOLOGY

T560

DIGITAL DELAY GENERATOR

Technical Manual

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1. Introduction

The T560 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 indeterminancy 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
- 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 T560 involves hardware or firmware changes, customization is normally done under a contractual OEM agreement with associated purchase commitments.

2. Specifications: T560 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 kΩ 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 ± 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 µs
TRIGGER RATE	0 to 16 MHz, limited to 1/(delay+width+60 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/°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	± 400 ps ± 7.5 ps/°C ± 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°C, non-condensing
STORAGE TEMPERATURE	-20 to 80°C
CALIBRATION INTERVAL	One year
POWER	+12 ± 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 T560

The T560-1 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.

3.1. Standard Packaging

The standard T560-1 unit is packaged in a small extruded aluminum enclosure. The Ethernet connector is provided on the T560-2 version. Section 7 of this manual provides detailed dimensions.

3.2. Overall Block Diagram

Figure 3-1 T560 Basic Block Diagram is the block diagram of the T560-1. OEM versions may include various features of the module. The optional Ethernet interface is not furnished on the standard T560-1 version.

The T560 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.

The T560-1 supplies four TTL pulse outputs, each programmable in delay and width. Custom versions of the T560 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.

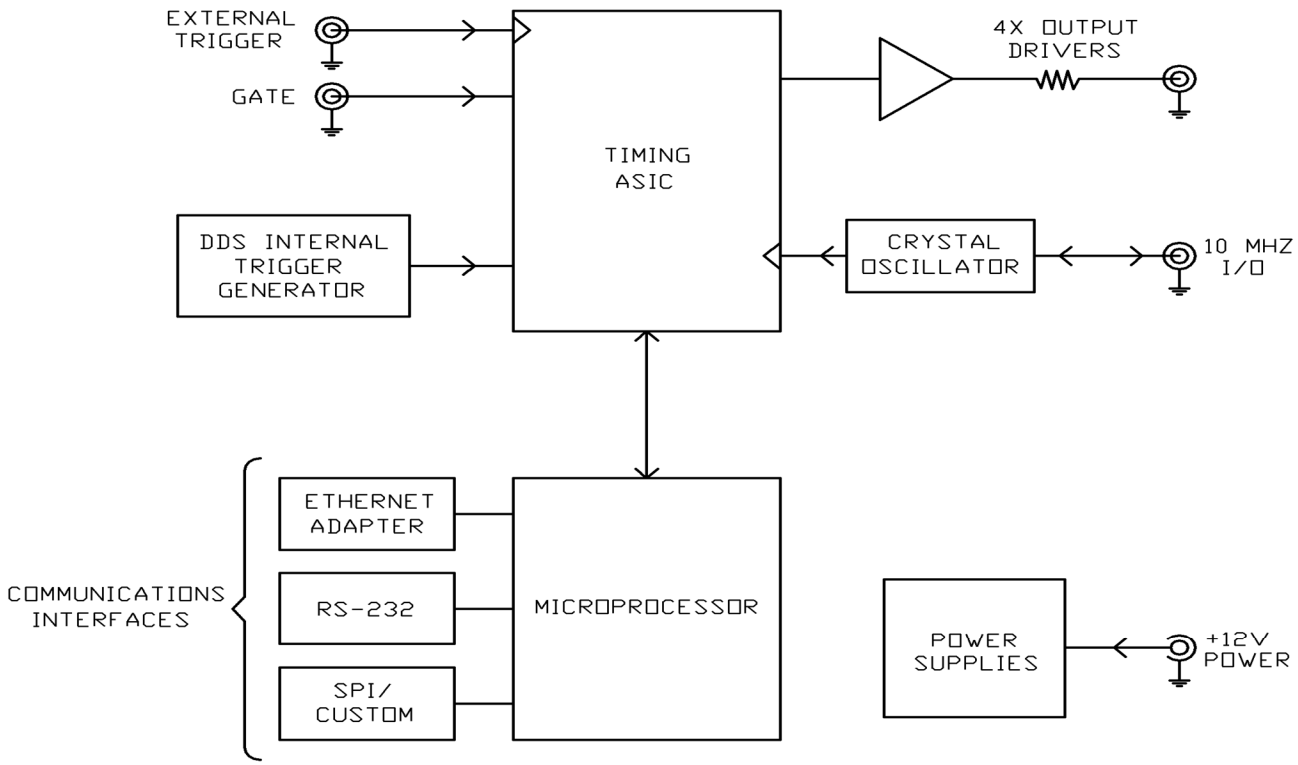

Figure 3-1 T560 Basic Block Diagram

3.3. Crystal Oscillator Timebase

The standard T560 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 T560s 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 T560 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 T560 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 T560 units may be locked to one another to ensure timing coherence.

3.4. Trigger Inputs

Figure 3.2 is a simplified diagram of the T560 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 flopflop 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

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

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 T560 receives an internal or external trigger while a timing cycle is still busy, that trigger will be ignored.

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.

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.

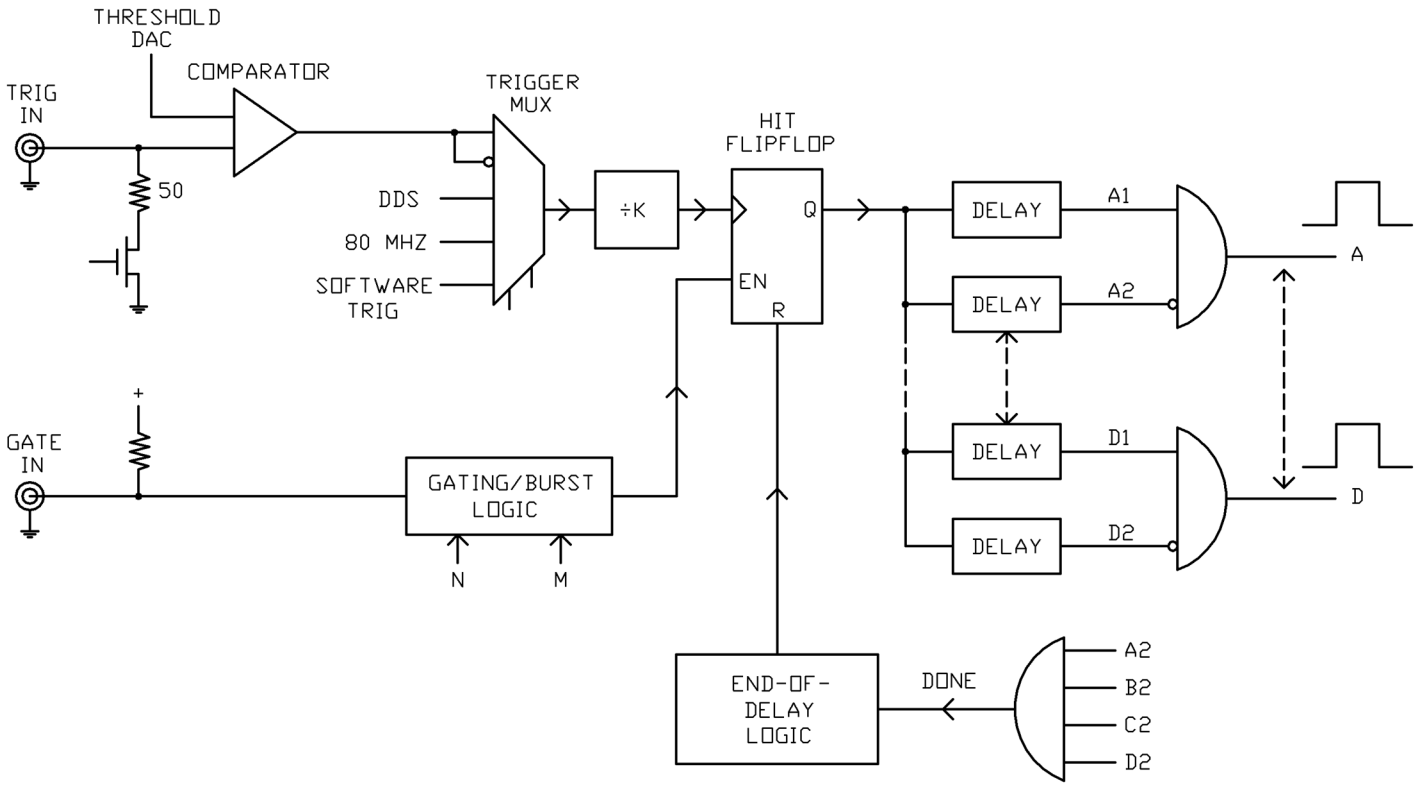

Figure 3-2 Trigger and Sequencing Logic

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 T560, 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. 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 T560. Pulse outputs are normally active-high, but may be programmed to operate active-low.

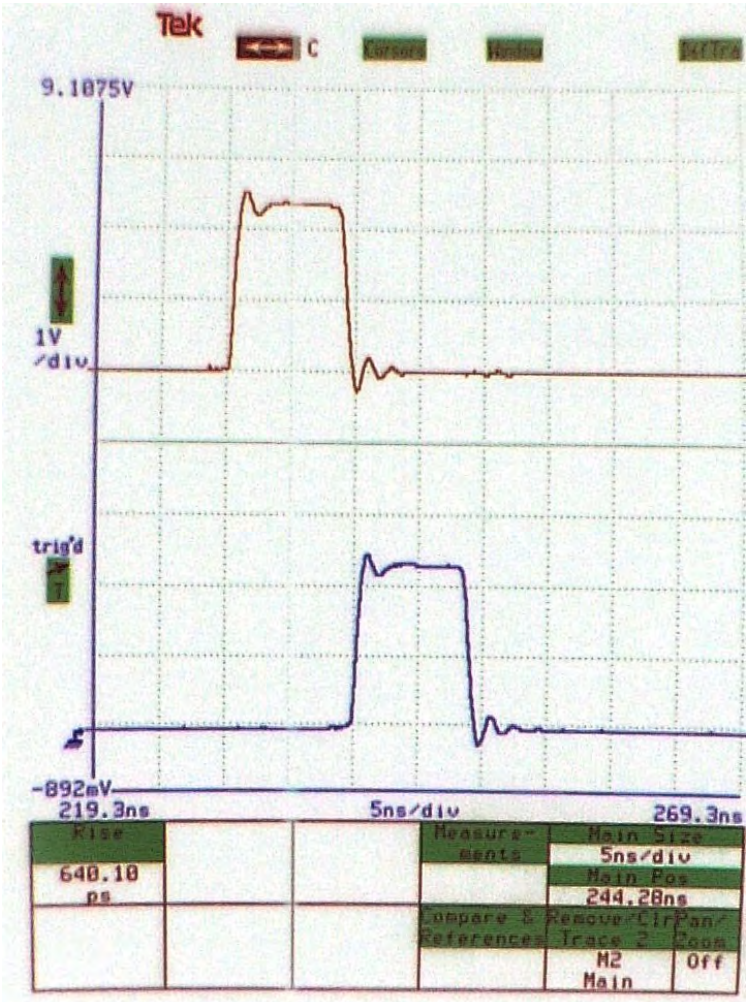

Figure 3-3 Typical T560 channel outputs into 50 ohms. Risetime is 640 ps.

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

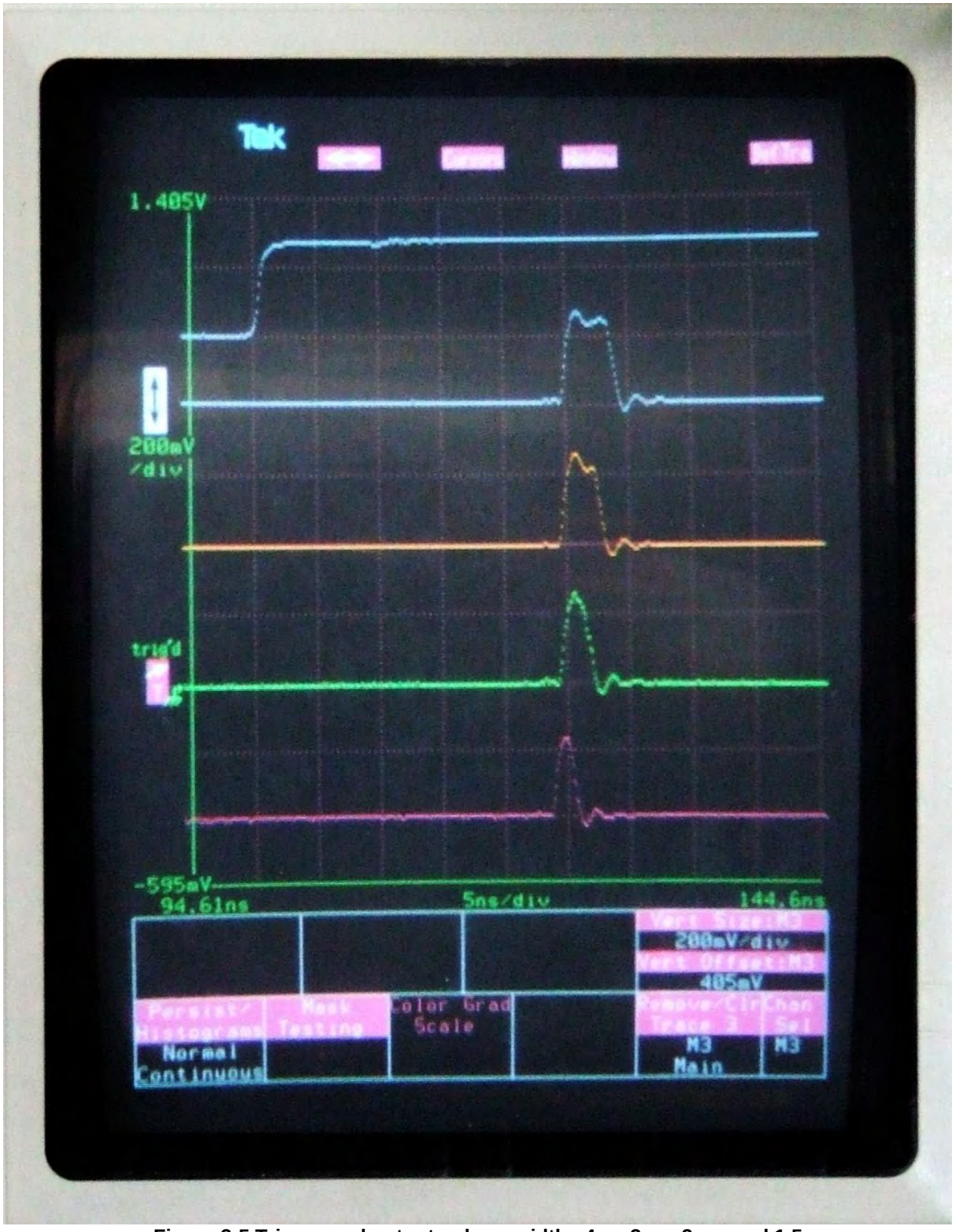

Figure 3-5 Trigger and output pulses, widths 4ns, 3 ns, 2 ns, and 1.5 ns

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 T560-1 is equipped with a 38.4-kbaud RS-232 interface. The T560-2 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 T560 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 T560	to PC D9-3
Ring	TXD	serial data from T560	to PC D9-2
Ground			to PC D9-5

3.10. Power Input

The T560 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 T560 power input is protected by a self-resetting polyfuse and a transzorb zener diode, and will withstand reasonable overvoltage or polarity reversal.

3.11. Custom Logic

Custom logic functions are available. Since the T560 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 T560 is triggered.

The COMM LED flashes yellow when any serial character is received and green when the T560 formats a reply.

4. Programming

4.1. General Comments

The T560 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 T560 settings.

The standard baud rate is 38,400. The receive buffer is limited to 256 bytes, and the T560 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 T560, terminated with a carriage return character <cr>, and italic text...

1.25 <cr> <lf>

represents the reply from the T560. 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 T560, to which the T560 immediately replies. Because the standard baud rate is high, and because the T560 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 T560 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)

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 ***T560 <cr> <lf>***

The T560 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 T560 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 T560 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 T560 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.

4.5. T560 Command Summary

The following is a summary of commands which may be sent to the T560.

Long Form	*Short Form*	*Function*
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

Long Form	*Short Form*	*Function*
QDELAY 45u	**QDELAY 45u**	set all four (“quad”) delays
QD 45u	**QD 45u**	set all four (“quad”) widths
INSTALL	**IN**	apply all pending channel settings
AUTOINSTALL 1	**AU 1**	automatically apply pending settings
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
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
BURST RESET	**BU RE**	reset burst counters
GATE OFF	**GA OF**	disable gate functions
GATE OUTPUT	**GA OU**	make gate connector an output

Long Form	*Short Form*	*Function*
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
STATUS	**ST**	show T560 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 T560
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
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 MISC	**HE MI**	return miscellaneous help

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 by an **INstall** command. If the **AUtoinstall** mode is set to 0, users must send the discrete **INstall** command to apply pending time settings. If **AUtoinstall** is set to 1, any new settings are installed when the <cr> command line terminator is seen, after all commands on that line have been processed.

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 ***Ch A POS ON Dly 00.123456789012 Wid 01.234567890123***
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.

4.6.2. TRIGGER SETUP COMMANDS

The **TRigger** family of commands select the T560 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 4194304	Sets a trigger divisor integer K, from 1 to 2^{32}-1. When the divisor is loaded, the next trigger will fire the T560 (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.
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	

4.6.3.SYNTHESIZE COMMAND

The T560 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.

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

4.6.4.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 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...
Burst OFF N 0000000555 of M 0000002000	

4.6.5.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.

If gate is set to be an output, it will go active (high or low, as programmed) whenever the hit flipflop is armed to accept triggers. So in burst mode, it will go true during the active “N” pulses of the burst sequence. If a trigger divisor is programmed, it will go high only when the divisor enables triggers.

GAte OFf	disable gate functions
GAte OUtput	make gate connector an output. The output level will be true when the hit flipflop is enabled to accept triggers
GAte INput	make gate an input. When the external TTL level is true, triggers will be enabled.
GAte POs	gate in/out is active high (normal)
GAte NEg	gate in/out is active low (inverted)
GAte TErminate	gate input is terminated at 50 ohms
GAte HIz	gate input is 1K to +5 volts
GAte BUrst	enable single burst at gate input rise
GAte REmote	enable single burst on **GATE FIRE** command
GAte FIre	fire a single burst
GAte	gate setup query. Returns...
Gate OFF POS HIZ Shots 0000000066	

4.6.6.CLOCK COMMANDS

T560 timings are based on an internal 10 MHz crystal oscillator clock. The function or the CLOCK coaxial connector is controlled by this group of commands. If the connector is declared to be an input, the T560 accepts a 10 MHz TTL square wave input, or a sine wave of about 1 volt RMS, and will lock its crystal oscillator to this source. If the connector is set to be an output, the local 10-MHz oscillator frequency will be output from this connector.

The value used to trim the internal oscillator frequency is an integer in the range 0 to 4095, with 2048 being roughly the nominal center frequency. Since the internal crystal oscillator might be expected to drift 1-2 ppm per year, users may wish to occasionally trim its frequency if precise delays are required.

Clock-group serial commands are...

CLock HIz	clock connector is unused
CLock OUt	connector outputs internal 10 MHz oscillator
CLock IN	external 10 MHz is accepted; oscillator phaselocks
CTrim 2048	sets 10 MHz clock trim, 0...4095, about 0.1 ppm/lsb
CTrim	queries clock trim value
CLock SAve	save clock trim to flash memory. This value will be restored at powerup
CLock	query clock settings; returns...
Clock OUT *Trim* 02048 Temp +32.4	

The ***Temp*** item is circuit board temperature in degrees C. It is typically about 10 degrees above ambient.

4.6.7.FEOD COMMAND

The **FEod** command briefly resets the timing hardware, aborting any timing cycle in progress. This is useful for terminating long delays.

4.6.8.SAVE, RECALL, LOAD COMMANDS

The **SAve** command will save the overall T560 setup into nonvolatile memory. This setup will be restored at powerup or may be loaded via the **REcall** command.

SAve	save current setup to nonvolatile memory
REcall	recall saved setup
LOad DEfault	load default setup; see Figure 4-1 Typical T560 Status Report
RUn DEmo	run demonstration setup. This is the default setup, except that the T560 self-triggers at 20 KHz

4.6.9.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.

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 T560 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
```

4.6.10. IDENTIFY COMMAND

The **IDentify** command returns a string which identifies the T560 firmware version. The returned form is ***T560-1 Firmware 28E563-A***

4.6.11. ERRORS COMMAND

The **ERrors** command returns a string which identifies any T560 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...

Bit	*Value*	*Flag*	*Meaning*
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.

4.6.12. VERBOSE COMMAND

The **VErbose 1** command places the T560 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.

4.6.13. 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 MIsc	return miscellaneous help

4.6.14. STATUS COMMAND

The **STatus** query returns a full report of T560 settings. A typical report is shown below. Verbose mode was enabled. The status shown is the default setup.

```
    Highland Technology  Model T560  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
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 4,009,459,010  DPLL 00000
Clock  OUT  Trim 02048         Temp +36.3

Errs   None

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 T560 Status Report

4.6.15. RSET COMMAND

The **RSet** command performs a hardware reset/restart of the T560, equivalent to a power off/on cycle. The reset takes about 4 seconds, after which the T560 will respond with the string ***Highland Technology T560 DDG <cr> <lf>***

The last-saved setup will be installed.

4.7. Firmware Upgrade Procedure

T560 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.fls	script file to flash version 28E564z
28E560z.rom	application file to be loaded
Flash560_Win.exe	Windows flash manager program

To reflash the T560 firmware, connect PC serial port COM1 or COM2 to the T560 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.

5. *Powerup States and Saved Setups*

Users may program the T560 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 T560 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 T560-2 and T560-32 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 T560 has been connected successfully, type **ST** followed by <Enter>. You should see the status report as defined in 4.6.14.

6.1. DHCP

The factory default setting for the T560 has its IP address assigned by the network's DHCP server. The T560 can be accessed by either IP address or hostname, which will be in the form: t560-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 T560 unit, the T560 should be connected to the local network. The Lantronix DeviceInstaller software should be started from a Windows PC connected to the same network.

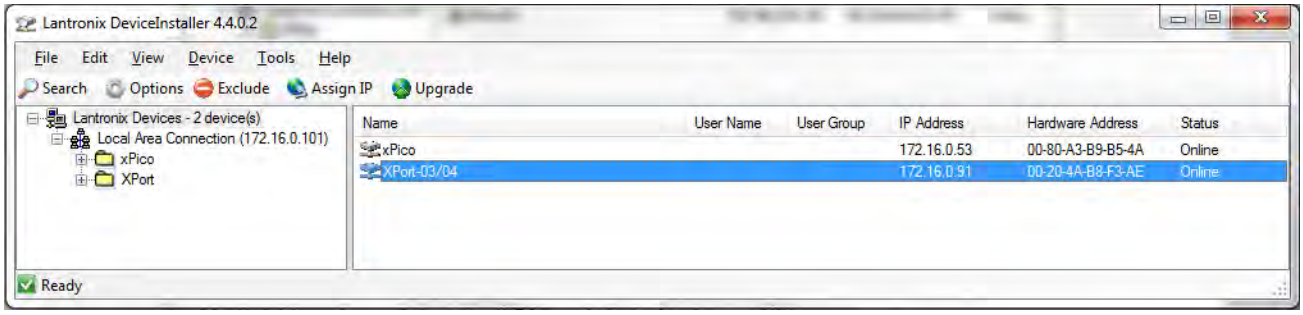

Figure 6-1. Lantronix DeviceInstaller Main Screen

Find the T560 in the software by its hardware MAC address. The MAC address can be found on one of the sides of the T560 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 T560, and then click on the Assign IP button. After clicking the button, the Lantronix DeviceInstaller IP address assignment pane should appear:

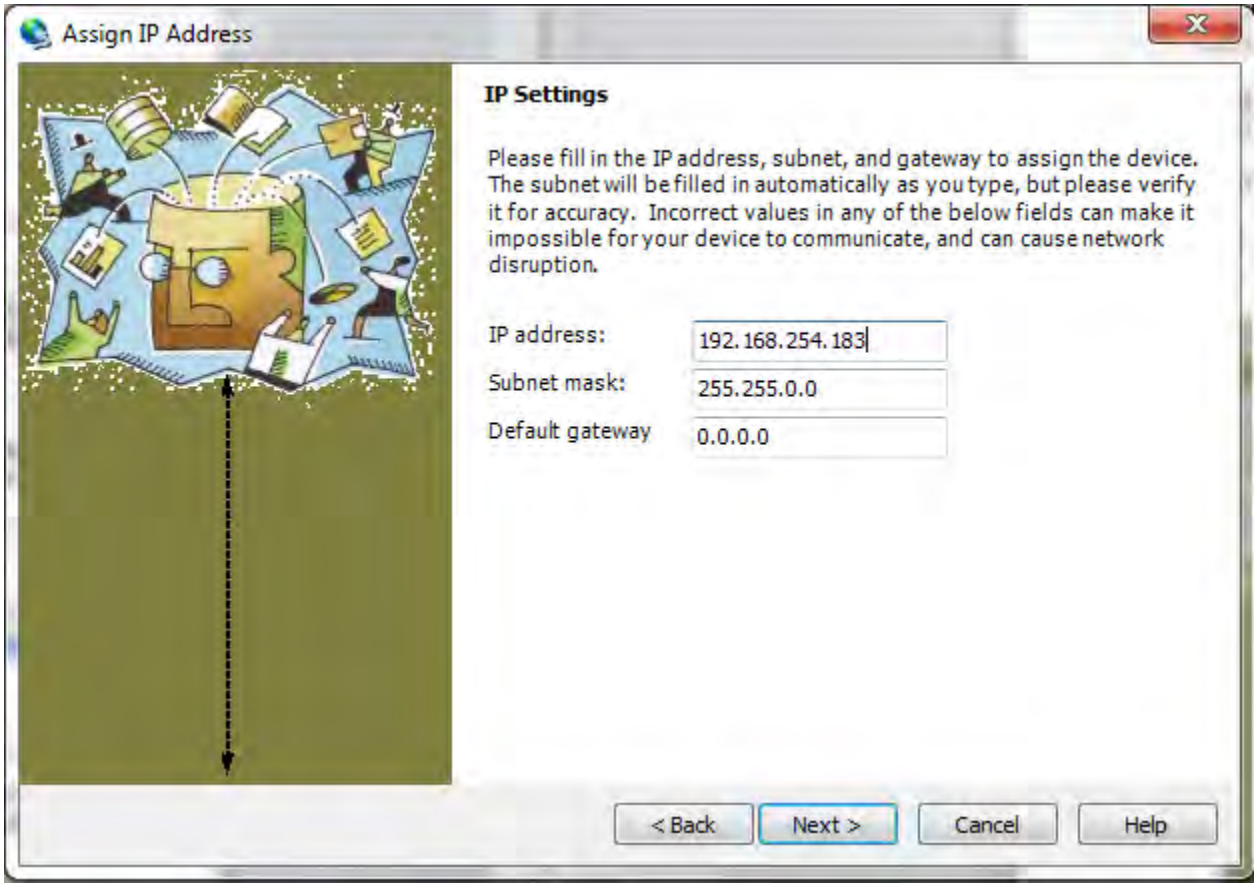

Figure 6-2. IP address assignment pane

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 T560 is shipped.

Figure 6-3. XPort Home Web Page

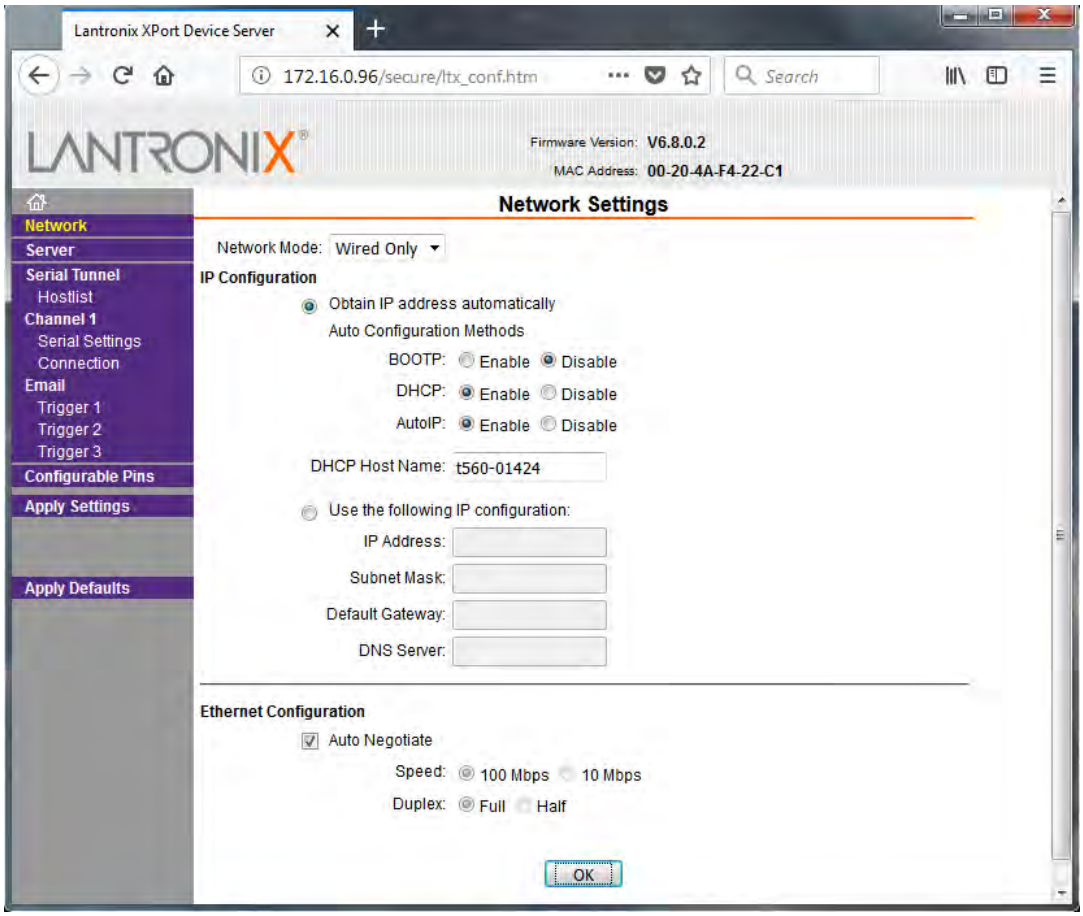

Figure 6-4. XPort Network Settings

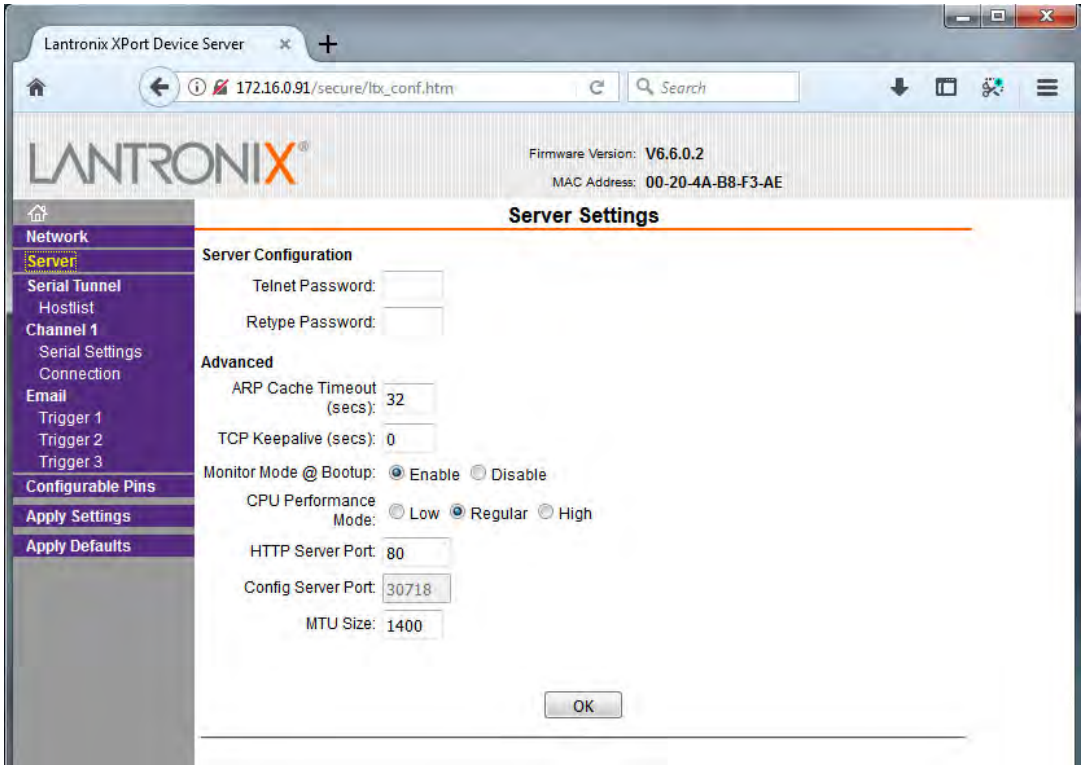

Figure 6-5. XPort Server Settings

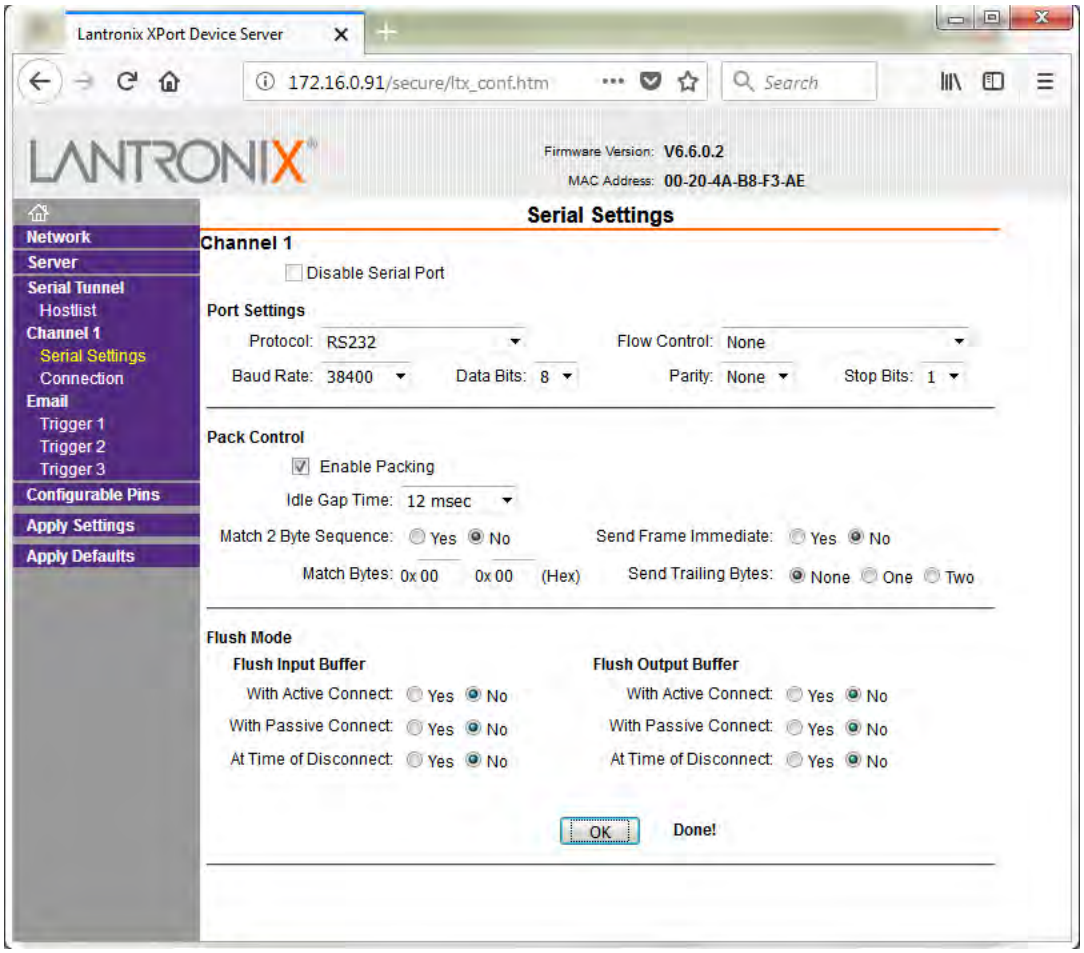

Figure 6-6. XPort Serial Settings

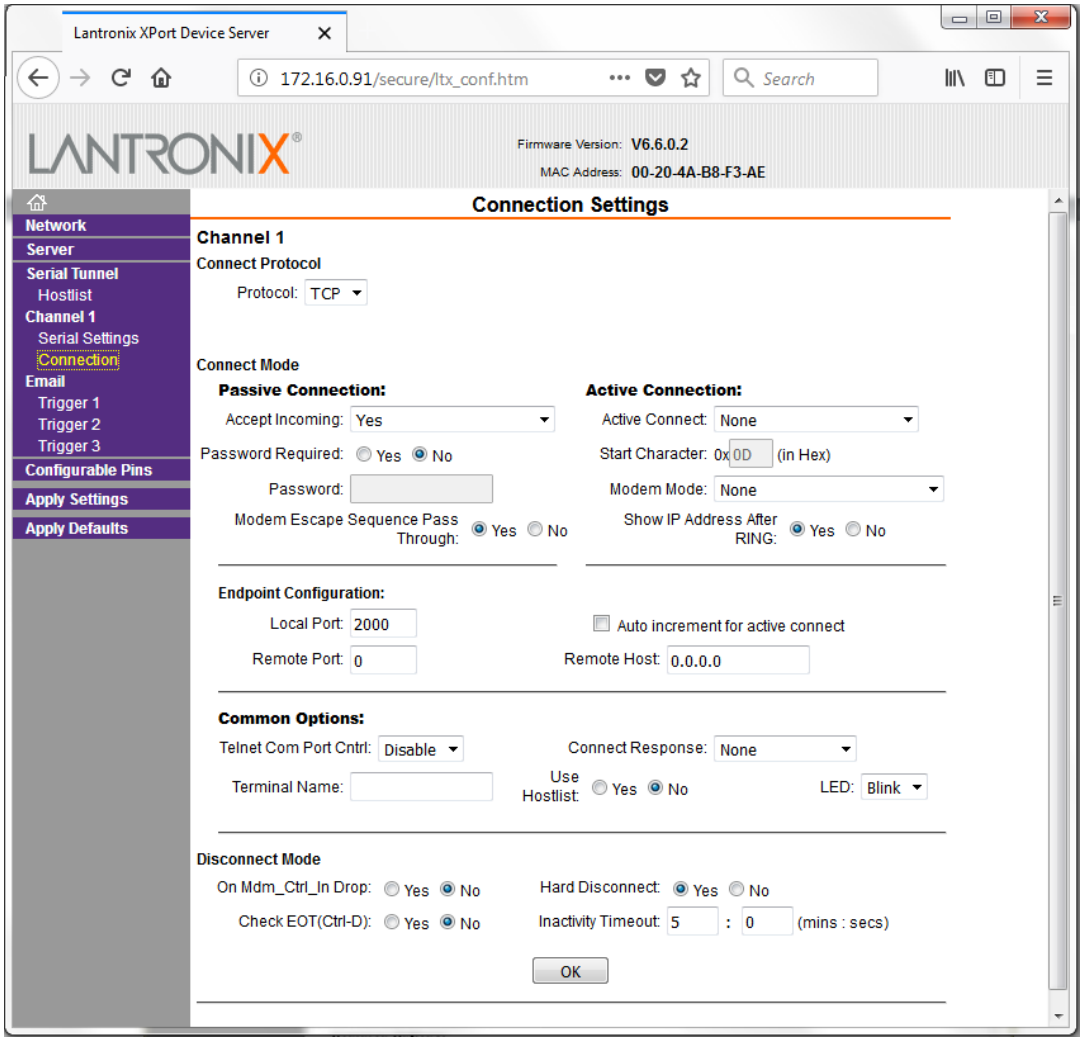

Figure 6-7. XPort Connection Settings

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 T560 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 T560 must be clean and fast (< 2 ns risetime) and the measuring instrument must have a jitter noise floor well below that of the T560. Most oscilloscopes and counters are not capable of resolving T560 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 T560, but has added jitter on the order of 10 microseconds per second of delay, whereas the T560 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 T560 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 T560 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 T560 is also available with optional, lower phase-noise OCXO oscillators. The graphed data includes jitter contributed by the P400 trigger source and the 11801A oscilloscope, so actual T560 jitter is somewhat less.

Jitter between outputs is similar.

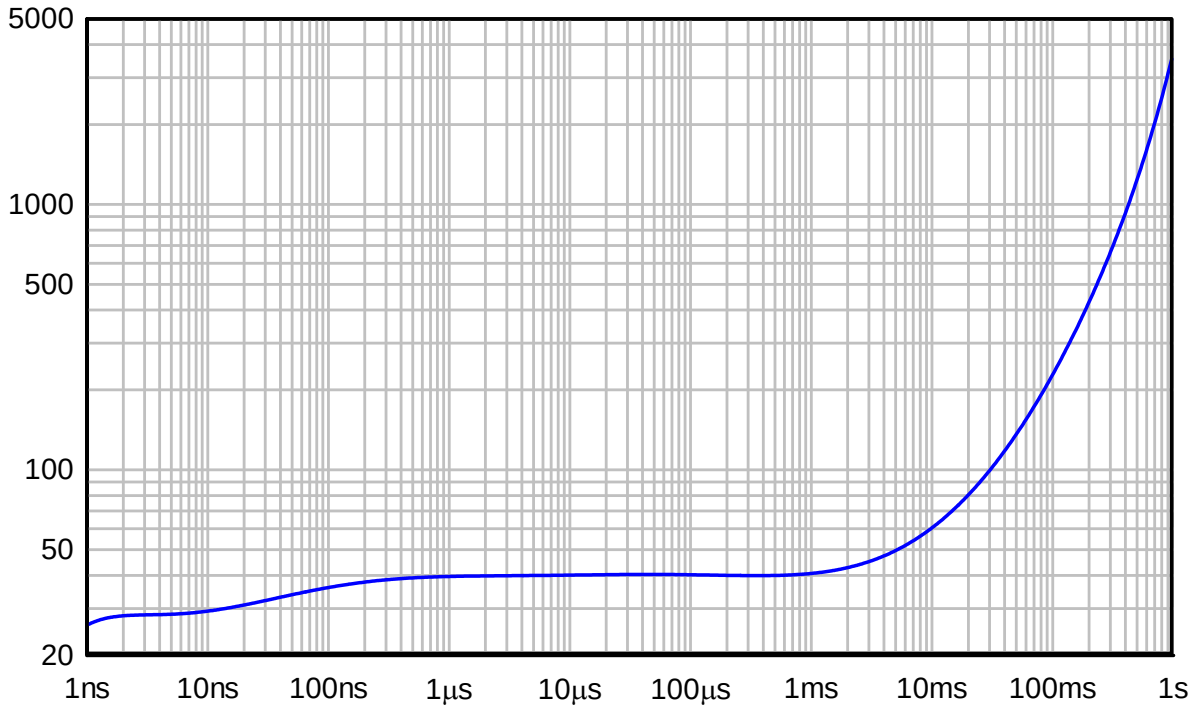

Figure 7-1 Typical T560 jitter in ps RMS versus delay

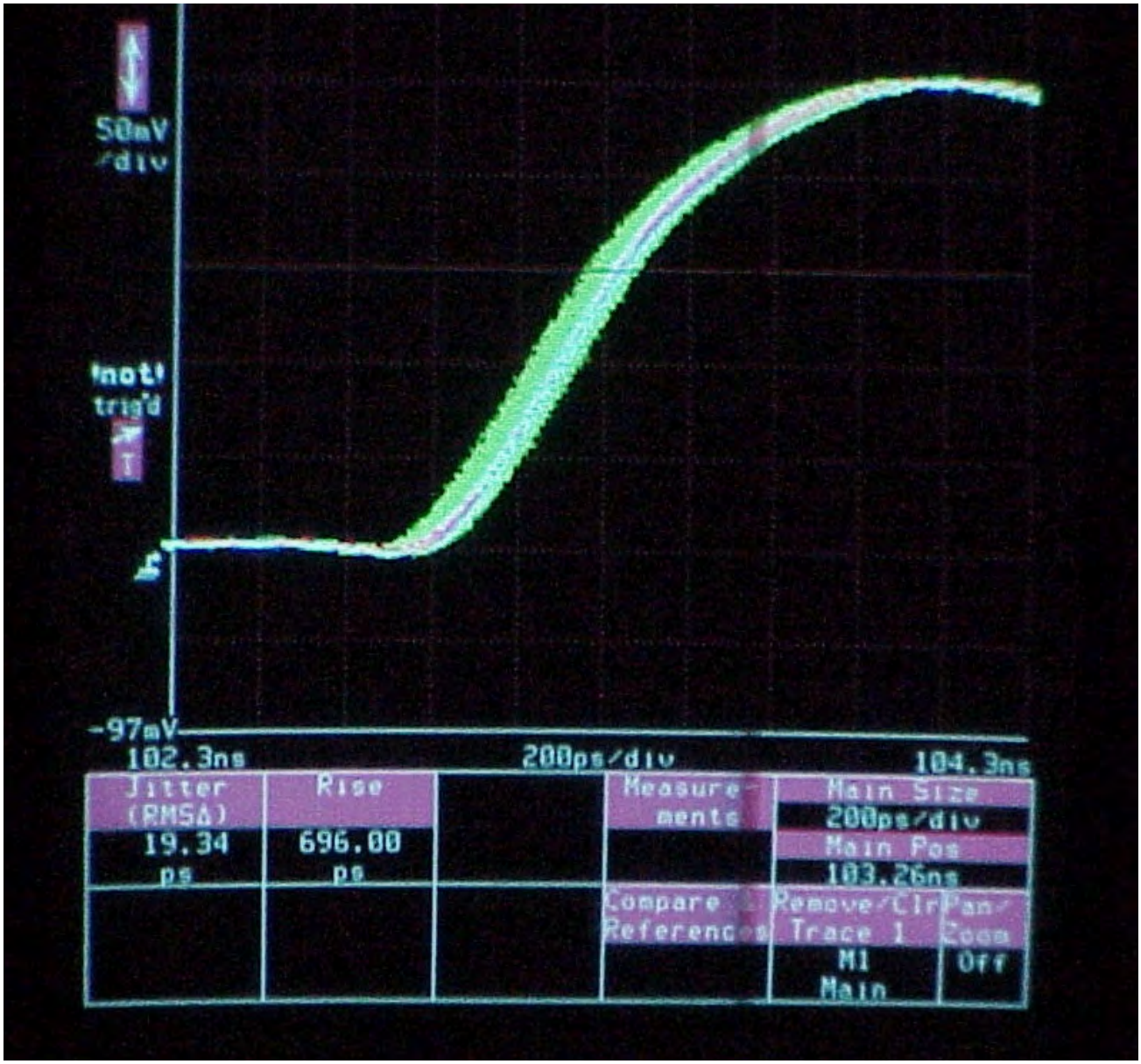

Figure 7-2 Typical T560 Rising Edge, Externally triggered, delay = 100 ns

This was measured on a Tektronix 11801A sampling oscilloscope, with the scope and the T560 triggered by a Highland P400 digital delay generator. Indicated jitter is 19.3 ps RMS, risetime 696 ps.

8. Dimensions and Mounting

T560 mechanical dimensions are shown below. The evaluation T560 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 T560 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 T560 enclosure.**

The T560-1 does not include the Ethernet connector

T560-2 includes Ethernet and the 2.5 mm RS-232 connector

Further customization information is in Versions on page 46.

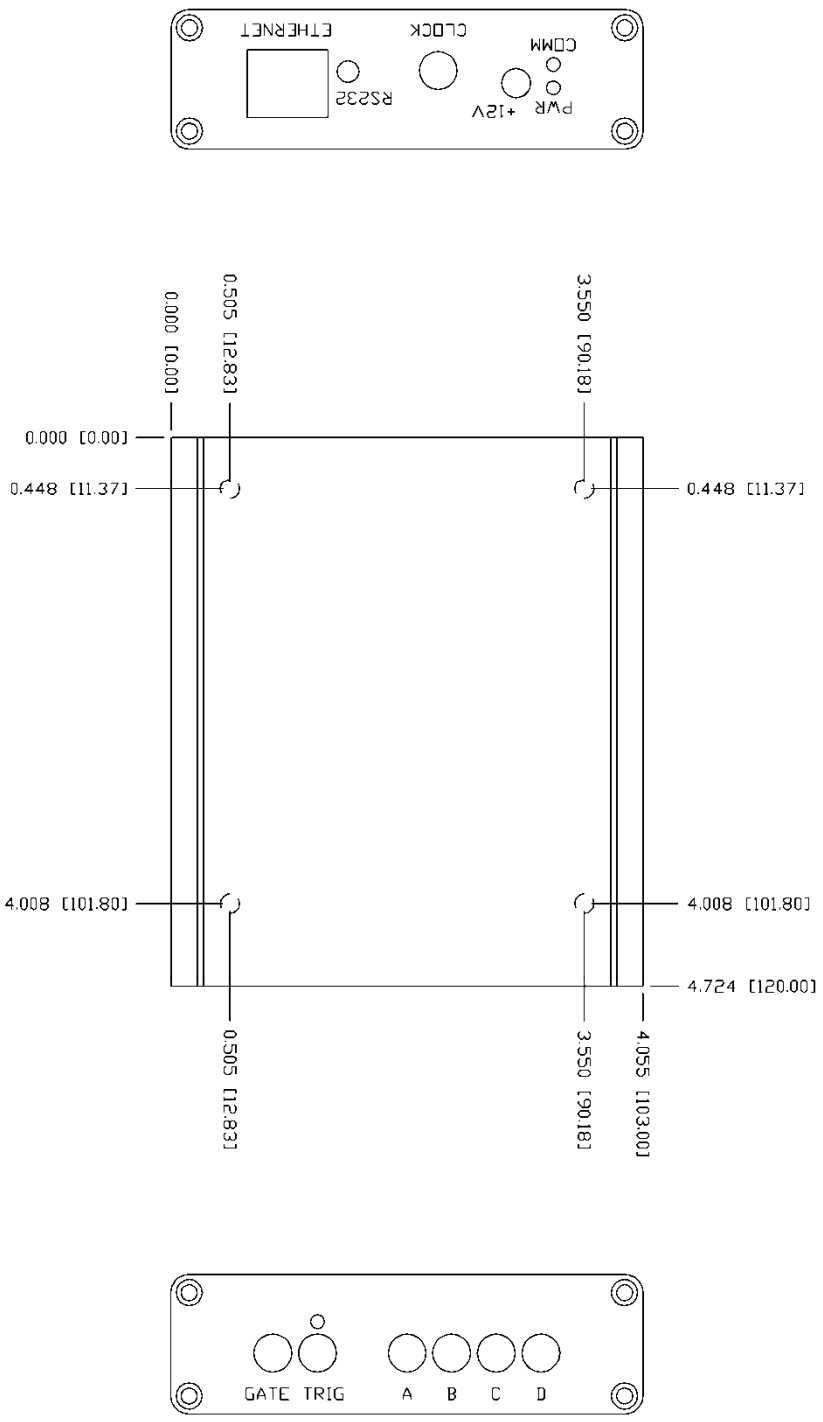

Figure 8-1 T560 Outline and Mounting

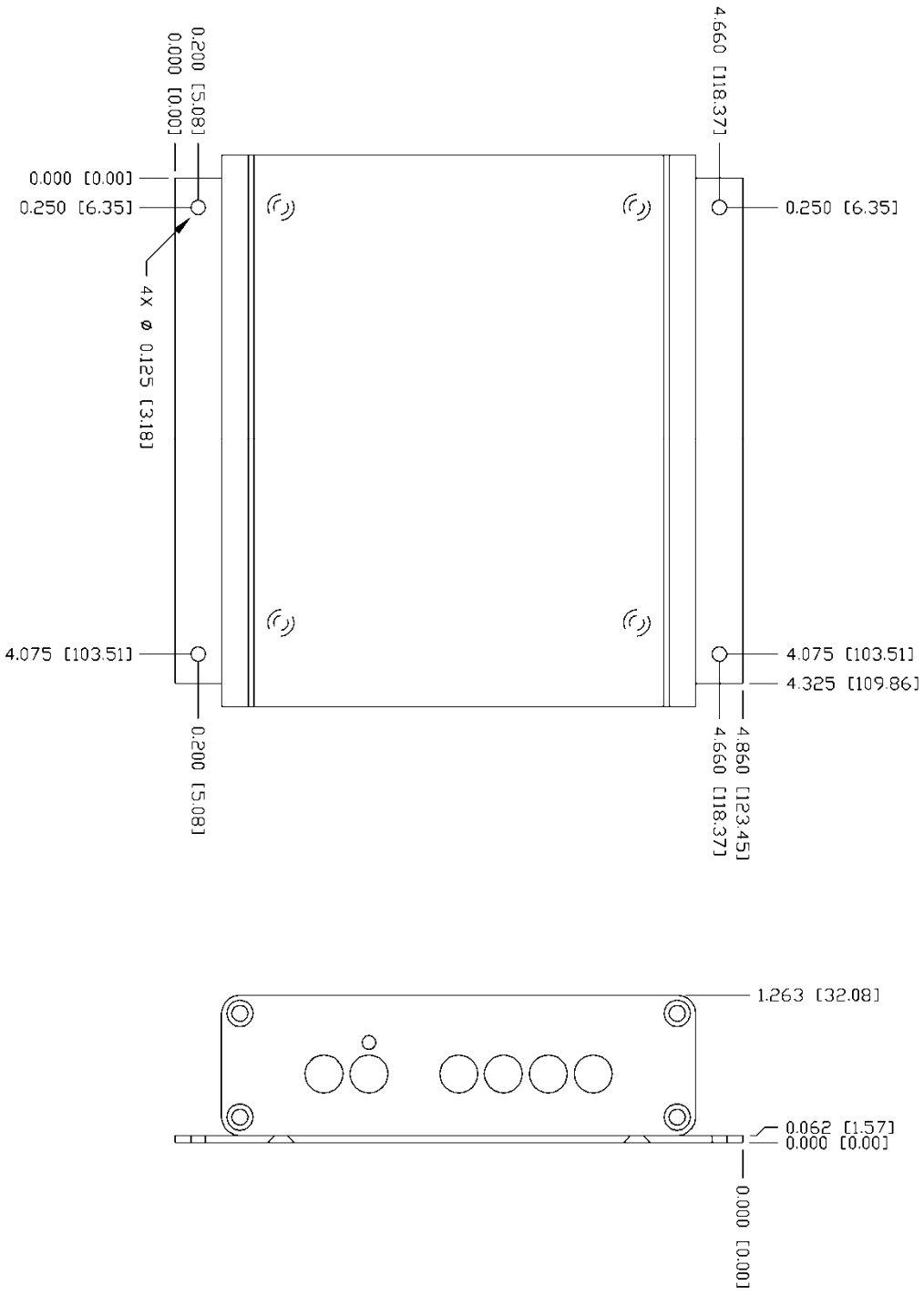

Figure 8-2 Flange Mounting Dimensions

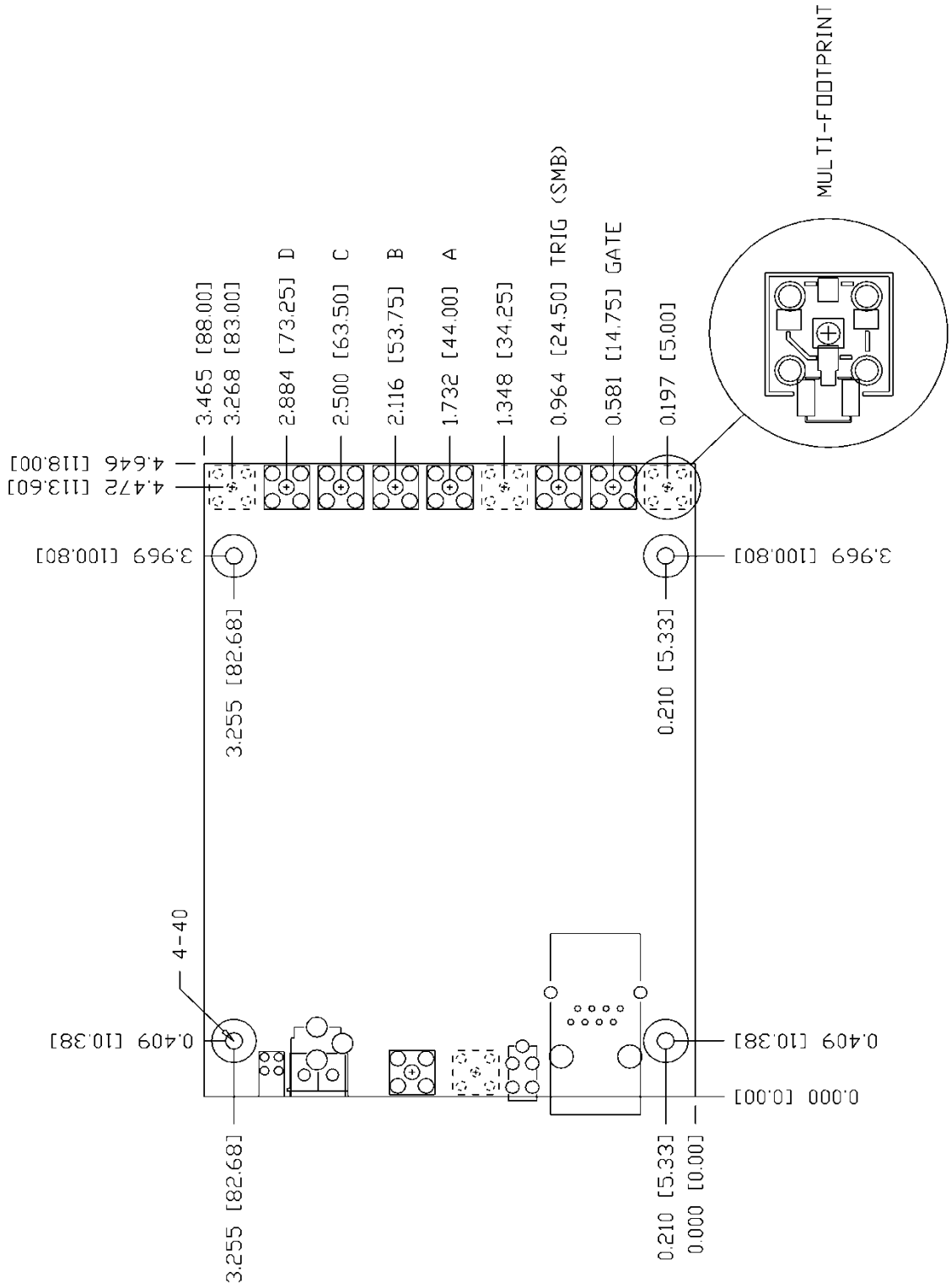

Figure 8-3 Printed-Circuit Board Dimensions

9. Demo Software

Win560.EXE is a Windows program that communicates with the T560 using serial commands. Device settings are displayed on screen and can be sent to the T560 all at once or refreshed all at once in the program. Communications access to the T560 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.

10. Versions

T560-1: stand-alone 4-channel compact digital delay and pulse generator

T560-2: stand-alone 4-channel compact digital delay and pulse generator with Ethernet interface

T560-3: board only 4-channel compact digital delay and pulse generator (10 piece minimum order quantity)

T560-4: board only 4-channel compact digital delay and pulse generator with Ethernet interface (10 piece minimum order quantity)

T560-9: evaluation kit (includes T560-2 factory installed on mounting flange with Ethernet interface, power supply, two 3’ SMB cables, and one RS-232 cable)

T560-31: stand-alone 4-channel compact digital delay and pulse generator with OCXO option

T560-32: stand-alone 4-channel compact digital delay and pulse generator with Ethernet interface and OCXO option

Consult factory for information about additional custom versions.

11. Revision History

11.1. 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

11.2. 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

12. 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)