HIGHLAND TECHNOLOGY

MODEL T500

Amplitude Modulator Chassis

Technical Manual

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1 Introduction

This is the manual for the Highland model T500 Amplitude Modulator Chassis. The AMC was designed to drive a 2-stage lithium niobate electro-optical modulator.

The AMC is a 3U rackmount box that includes:

- A main controller with Ethernet and USB interfaces, an LCD and LEDs and EOM bias supplies.
- A trigger manager board.
- A slicer module which generates rectangular pulses for one EOM section,
- An amplifier module for an externally generated arbitrary waveform, with impulse generator.
- A temperature-controlled enclosure for the customer-supplied EO modulator.
- An "optical bench" for mounting customer-supplied fiberoptic components.

The T500 operates in conjunction with a Highland model V880 timing module and a Tektronix AWG5208 arbitrary waveform generator.

CAUTIONS

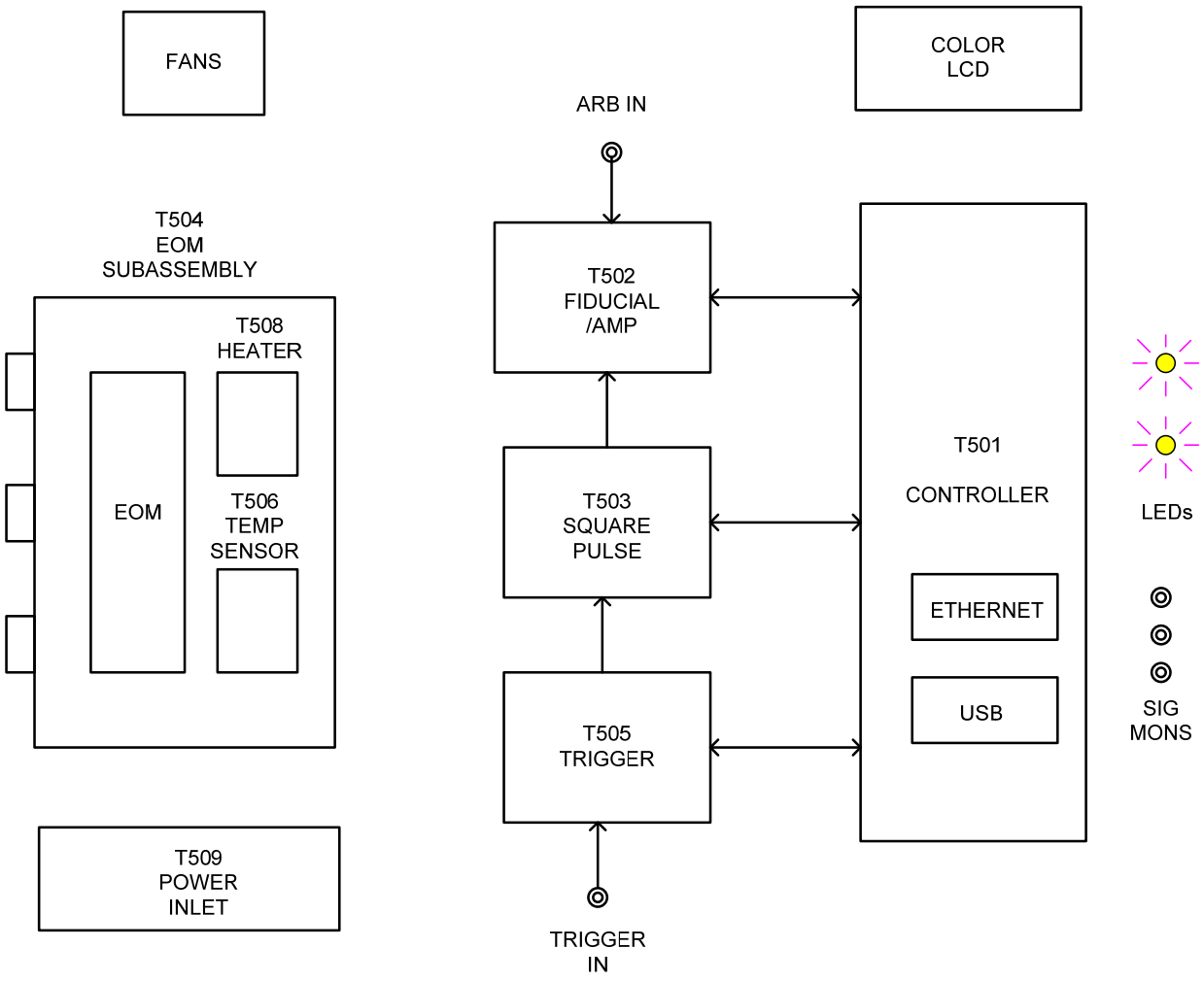
Note that the T500 and the Tek AWG are both susceptible to ESD damage. Follow the ESD rules in the Tek AWG manuals.

Always use proper tools to mate and unmate internal and external SMA connectors. Semi-hardline cables can be damaged by applying torque to the cables.

When shipping a T500, use the original custom shipping boxes. Remove the heater top cover and place it in the separate compartment provided.

2 Architecture and Key Subassemblies

The block diagram of the T500 is as follows:



The T500 main subassemblies are:

- T501 Control Board
- T502 Amplifier/Impulse board
- T503 Slicer Board
- T504 EOM Oven Assembly, including:
    - T506 EOM temperature sensor board
    - T508 EOM heater and temperature controller
- T505 Electrical Trigger Board
- T509 DC Inlet board

The T501, T502, T503, and T508 boards each carry their factory calibrations in local EEPROM nonvolatile memory.

The T500 is powered by an external +24-volt, 65-watt laptop-type power supply furnished with each unit, a Phihong model PPL65U-240.

Air enters the unit from the rear panel and exits through two speed-controlled fans on the front panel.

2.1 System wide specifications

Parameter	Specification
Delay between AWG/Impulse Generator (tIG) and Slicer's earliest Leading edge (tSL)	1 ns ≤ tIG-tSL ≤ 2ns
Delay from Trigger Input to Slicer's earliest Leading edge (tSL)	< 20 ns
Mean Time Before Failure (excluding fans)	>10 years
Mean Time Before Failure (including fans)	>5 years
Warm-up time after power up or reset command	≤ 1 hour

2.2 T501 Controller

The T501 includes:

- Voltage regulators, from the +24-volt prime supply
- 120 MHz ARM microprocessor
- Ethernet and USB interfaces
- Program and cal table flash memories
- EOM bias generators
- LEDs and LCD driver
- BIST multiplexers/ADC
- Ribbon cables to all other boards

- The bias monitors are 1:1 to the EOM bias voltages. View with a HiZ scope.
- BIAS-1 and BIAS-2 Output pulses generators

2.2.1 BIAS-1, BIAS-2 Output Specifications

Parameter	Specification
Amplitude Output, into 1MΩ	Max. Positive Polarity: • +8.00V Max. Negative Polarity: • -4.00V Min. Positive Polarity: • +0.001V Min. Negative Polarity: • -0.001V
Pulse Width	2 µs to 15 µs
Pulse Delay	0 to 1.05 ms
Pulse Rate	960 Hz to 9.6kHz

2.3 T502 Amplifier/Fiducial Impulse Board

The T502 accepts the external arb waveform and generates the fiducial reference impulse. The external arb input is mixed with the fiducial impulse and applied to the final distributed amplifier. The fiducial impulse is generated by a fast pulser, programmable for time delay from trigger and for pulse width and amplitude.

The final stage is a Hittite distributed amplifier. It is actively biased to low current, high voltage at its output to minimize power dissipation and maximize pulse dynamic range; this is similar to the output stage of Highland's Technology T130 EOM driver.

The monitor pickoff is a resistive voltage divider followed by an amplifier with gain of 5 and 2.4 GHz bandwidth. The voltage into a 50 ohm oscilloscope is 0.037 of the voltage at the e/o modulator.

A switchable attenuator is located after the final distributed amplifier. When engaged, the gain is reduced to 0.77 of its normal value.

The cable from the front-panel ARB input to the T502 input includes a coaxial DC block, MiniCircuits BLK-89. This removes any DC offset current from the Tek AWG output.

2.3.1 ARB Waveform Generator Output Specifications

Parameter	Specification
AWG Output Amplitude (V), out of RF-2, into 50 Ω	4.0 ± 0.1 V to 5.4 ± 0.1 V
AWG Output Amplitude, tuning bits	≥ 1 bit
AWG Input to AWG Output bandwidth (GHz)	≥ 10 GHz
AWG Output P1dB (dBm)	≥ 23 dBm (≥ 4.467V)

2.3.2 Impulse Generator Output Specifications

Parameter	Specification
Amplitude Output (V) into 50 Ω	0 V, tunable from ≤ 2.9 to ≥ 6.25 V
Amplitude Output polarity	Negative Polarity
Pulse width (FWHM)	90ps to 110ps
Temporal jitter (rms) over 10 s	≤ 7 ps
Temporal drift (rms) over 8 hrs	≤ 7 ps

2.4 T503 Square Pulse Driver

The T503 board generates the dual square slicer pulse into the first EOM section. It accepts the stretched electrical trigger from the T505 and outputs the trigger to the impulse generator on the T502.

The square pulse timing allows for programming of all four pulse edges to better than 1 ps resolution. The first pulse normally straddles the fiducial impulse and the second pulse gates the arbitrary waveform. A single pulse may also be selected.

A programmable DAC sets the common amplitude of both pulses.

Its final output stage and monitor are similar to the T502. The monitor ratio is 0.122 into a 50 ohm scope.

2.4.1 Square Pulse Driver (Slicer) Output Specifications

Parameter	Specification
Number of pulses	User programmable: 1 or 2 pulses
Delay range between slicer pulses with respect to trigger	≥ 36 ns

Amplitude Output Voltage Range (into 50 Ω)	0V ≤ 2.9 V to ≥ 6.5 V
Amplitude Output polarity	Negative OK
Minimum Pulse Width (ps)	≤ 500 ps
Maximum Pulse Width (ns)	≥ 37 ns
Shortest time in between two pulses (ns)	Min ≤ 5 ns
Rise & Fall time (10% to 90%)	≤ 110 ps
Temporal Jitter (rms) over 10 s	≤ 5 ps
Temporal Drift (rms) over 8 hrs	≤ 5 ps

2.5 T505 Electrical Trigger Board

The T500 accepts an electrical rising-edge trigger from a marker output of the Tek AWG, which is in turn derived from Highland Technology V880 timing module. The T505 accepts a rising edge and generates a fixed 150 ns pulse that triggers the T503 Slicer and the T501 controller.

T505 terminates the external trigger in 50 ohms to ground. Trigger level is programmable from 0 to +3 volts. Max safe input is low-duty-cycle pulsed +5 volts. T505 will also accept an internal test trigger from the T501 controller.

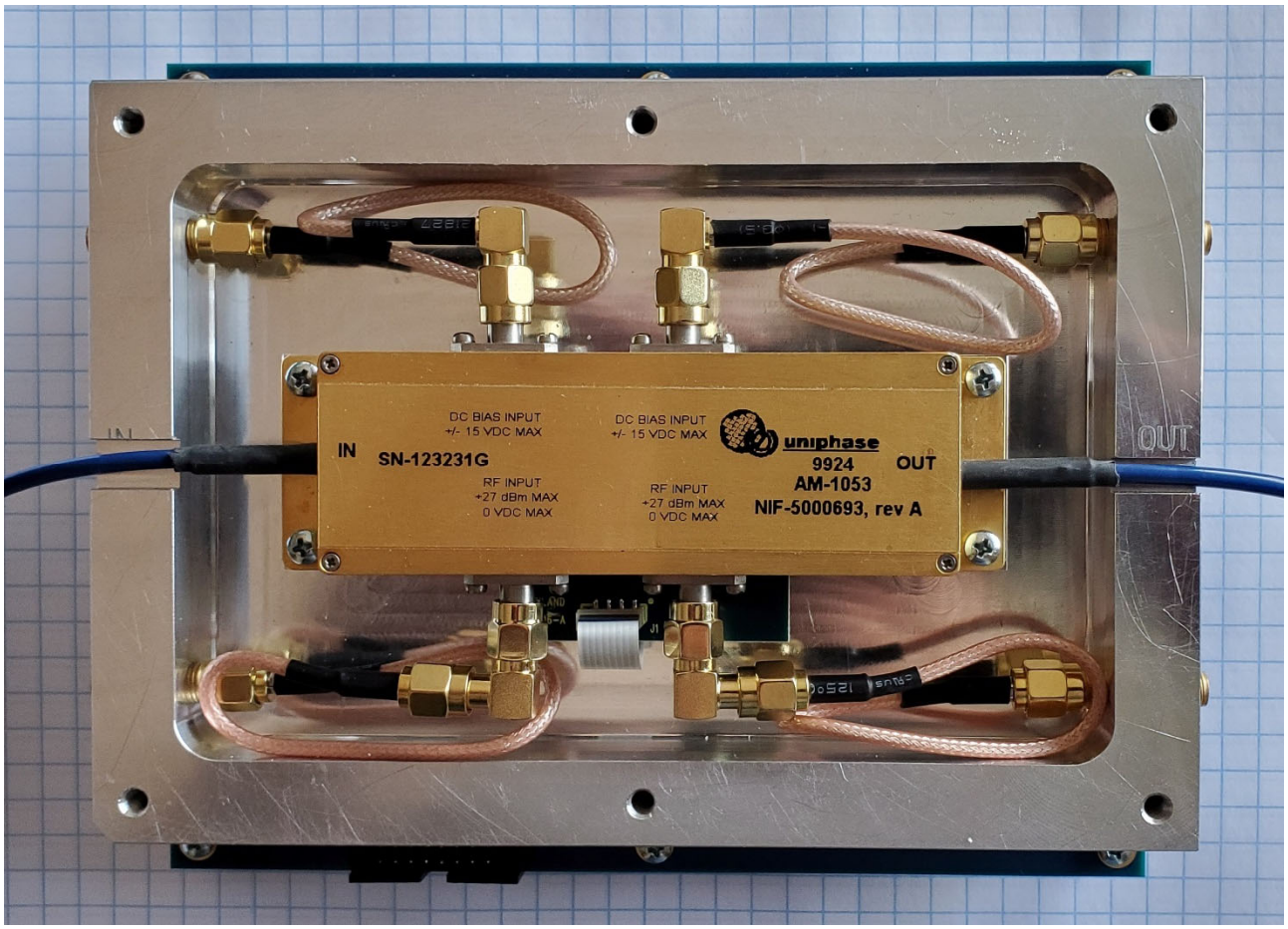
2.5.1 Trigger Input Specifications

Parameter	**Specification**
Input trigger amplitude, minimum acceptable range (V)	Between 1.5 V and 4 V
Input trigger rise time (20%-80%), minimum (ns)	700 ps
Input trigger pulse width (ns)	150 ns

2.6 T504 EOM Oven Enclosure

The EOM is mounted on a platform in the T504 machined aluminum oven enclosure. T504 includes the T506 and T508 sensor and heater boards.

The platform is machined to support a JDSU modulator. Changes may be required for the alternate ixblue device.



The oven assembly is shipped with its heavy top cover removed and secured in a separate section of a custom foam-insert box. This reduces the assembly mass and the likelihood of shipping damage. It is recommended that all units be shipped this way.

Be careful to not damage the semi-hardline cables when installing the EOM. Use two wrenches to avoid twisting the cables, and use the recommended SMA torque; typical values are 5 in-lbs, 0.56 N-m.

2.7 T506 Temperature Sensor Board

The T506 is a small board that mounts inside the oven assembly, on the underside of the EOM platform.

The T506 has three independent Wheatstone bridges, each composed of two precision thermistors and two Susumu precision thinfilm resistors. The bridge outputs go back to the temperature controller, to a differential-input 24-bit delta-sigma ADC. The bridges and ADC operate from 25 to 45º C with micro-degree resolution. The center bridge is used for temperature control and the others as checks.

2.8 T508 Heater/Controller

The T506 board is mounted on the bottom of the EOM oven box. It includes six heater mosfets. An analog multiplexer and 24-bit A/D converter acquire temperatures from the T506 board and also monitor supply voltages, heater currents, and PCB local temperature.

2.9 T509 DC Inlet Board

T509 is a small board that accepts +24 volts from the external power supply and feeds it to the control board. It includes a self-resetting polyfuse, transient and EMI filters, a power switch, and a rear-panel LED.

Current requirement is < 2 amps during heater warmup and < 1 amp steady-state. Warmup takes less than one hour.

3 Mechanical Arrangement

3.1 Front Panel

The front panel includes

Two fans. Fan speeds are adjustable by SCPI command and are shipped at 90%. Lower speeds will reduce noise but may compromise internal cooling.

Five LEDs

POWER	green, lights when 24V power is on
TRIG	blue, flashes when the T500 is triggered
COMM	orange, flashed when a serial command is accepted
BIST	green, blinks to indicate that self-test is running
ERR	red, indicates a BIST error

USB is a type-B (printer style) USB connector. The USB interface emulates a serial port.

MONITORS. Six SMA female connectors

TRIG	a 150 ns pulse, at each trigger. About +0.6 volts into 50 ohms
GATE	reflects the RF1 square pulse into the EOM.

GATE BIAS reflects the Bias 1 square pulse bias.

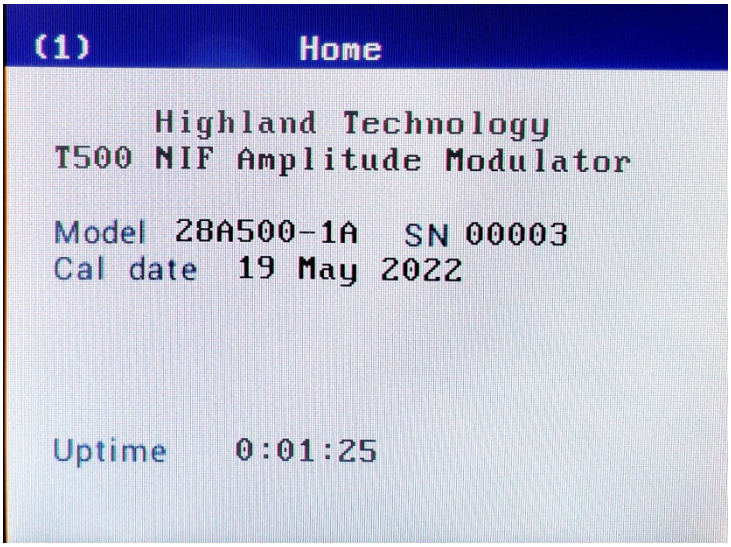
AWG reflects the RF2 AWG pulse into the EOM.

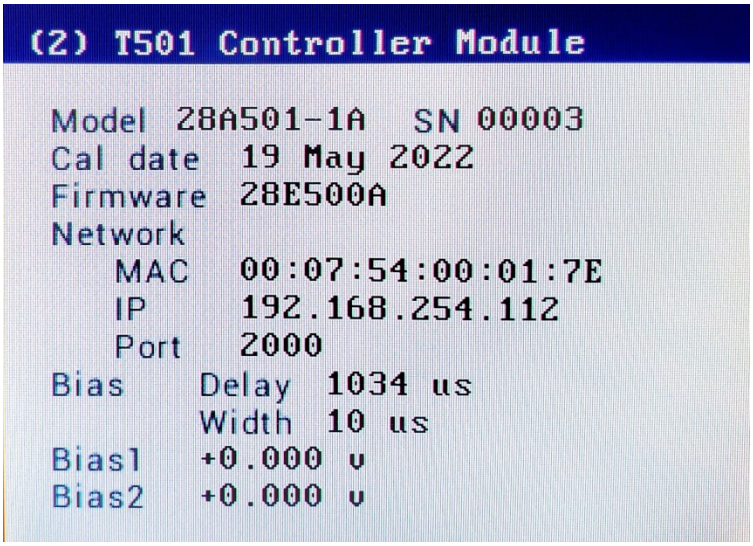
AWG BIAS reflects the RF2 bias pulse into the EOM. Gain is 1:1 into a HiZ scope.

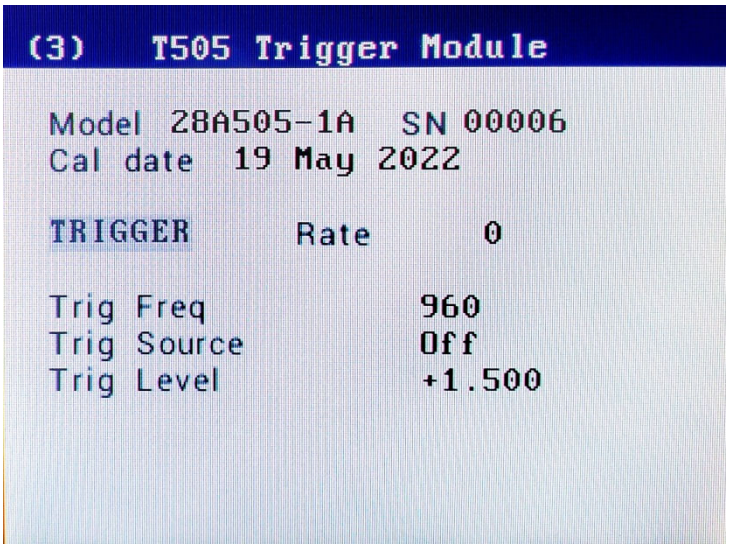
AWG IN arb waveform input from the Tek AWG5208

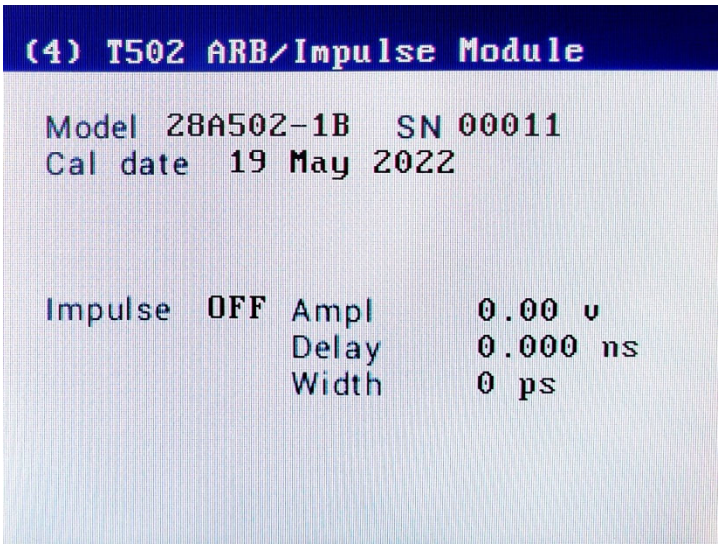
Color LCD

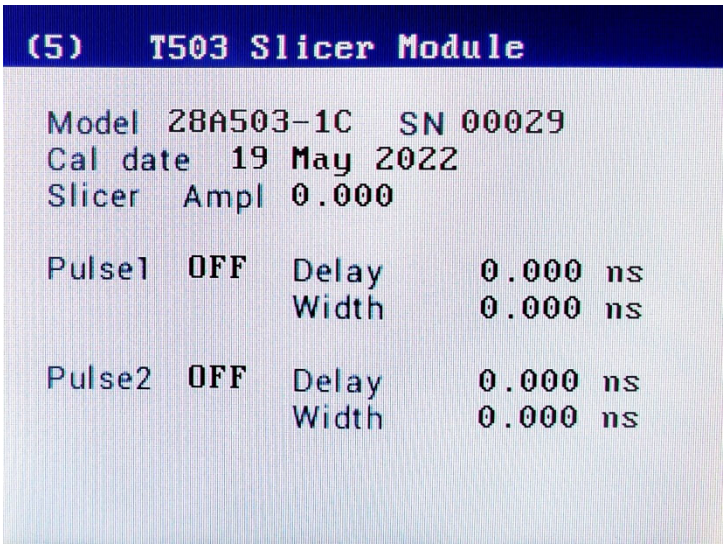
The LCD displays eight pages of T500 status. The rocker switch to the right of the LCD steps up and down through the display pages. Pages are

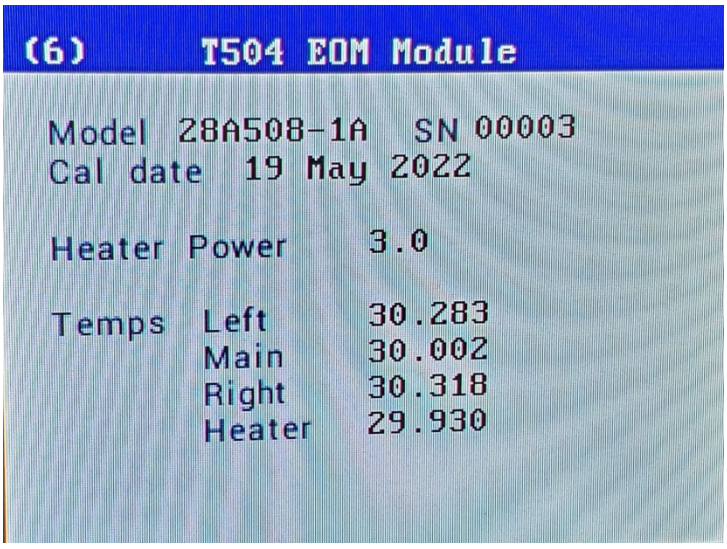


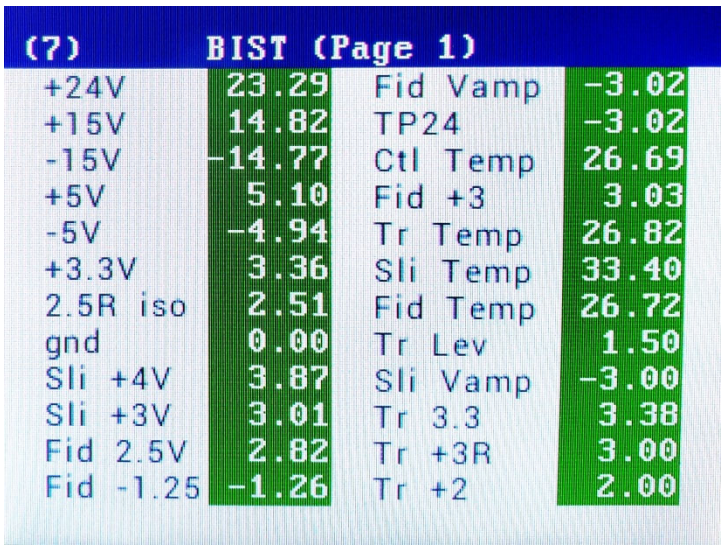


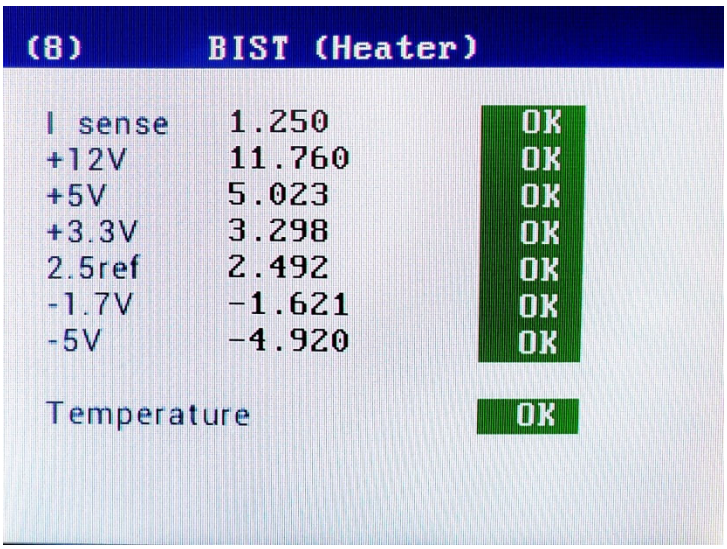





(5) T503 Slicer Module
Model 28A503-1C SN 00029
Cal date 19 May 2022
Slicer Ampl 0.000
Pulse1 OFF Delay 0.000 ns
Width 0.000 ns
Pulse2 OFF Delay 0.000 ns
Width 0.000 ns


(6) T504 EOM Module
Model 28A508-1A SN 00003
Cal date 19 May 2022
Heater Power 3.0
Temps Left 30.283
Main 30.002
Right 30.318
Heater 29.930


(7) BIST (Page 1)
+24V 23.29
+15V 14.82
-15V -14.77
+5V 5.10
-5V -4.94
+3.3V 3.36
2.5R iso 2.51
gnd 0.00
Sli +4V 3.87
Sli +3V 3.01
Fid 2.5V 2.82
Fid -1.25 -1.26
Fid Vamp -3.02
TP24 -3.02
Ctl Temp 26.69
Fid +3 3.03
Tr Temp 26.82
Sli Temp 33.40
Fid Temp 26.72
Tr Lev 1.50
Sli Vamp -3.00
Tr 3.3 3.38
Tr +3R 3.00
Tr +2 2.00


(8) BIST (Heater)
I sense 1.250 OK
+12V 11.760 OK
+5V 5.023 OK
+3.3V 3.298 OK
2.5ref 2.492 OK
-1.7V -1.621 OK
-5V -4.920 OK
Temperature OK

3.2 Rear Panel

The rear panel includes

24 volt input barrel connector

Power switch and LED

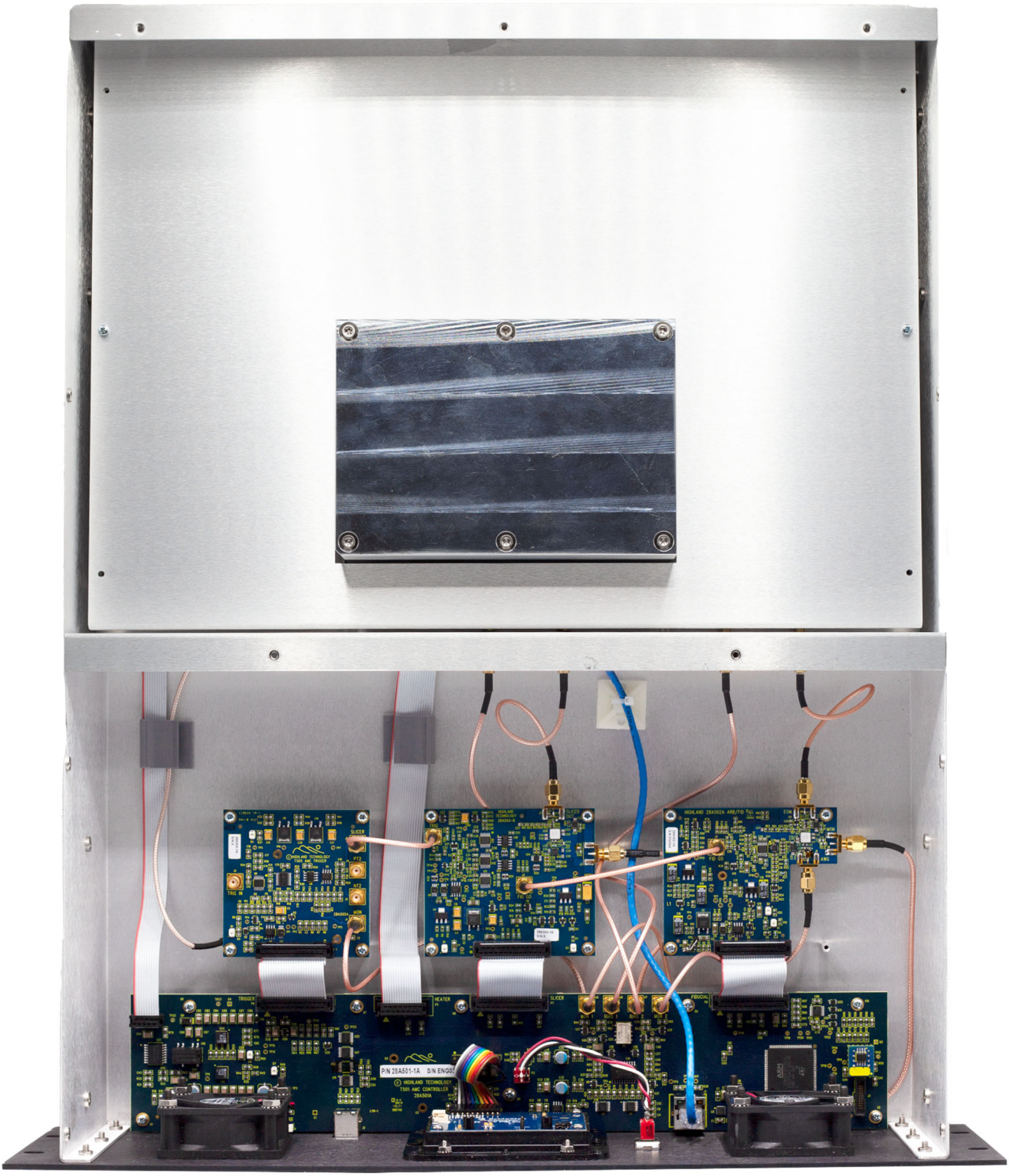
SMA trigger input connector, from a Tek marker channel

Ethernet connector. RJ45, 10/100 ethernet.

Three Diamond 1015584 circular fiber feedthrus and three Diamond 1047201 rectangular feedthrus.

Grounding lug

3.3 T500 Top View



4 Communications and Programming

4.1 USB Interface

All of the T500's ASCII serial commands can be sent through the USB interface.

The T500 emulates a serial port using the FTDI FT230XS USB interface chip. This is the most common USB/serial interface chip, so many operating systems will include appropriate drivers.

Documentation and drivers are available at http://www.fdtichip.com.

The serial port protocol is:

Baud	115200
Data Bits	8
Stop Bits	1
Parity	None

4.2 TCP/IP Interface

By default the T500 uses a DHCP client to request an IP address from the network's DHCP server. This may be changed to a static IP address using the SYST:COMM:SOCK subsystem of commands described below.

The T500 has a default hostname of "T500-xxxxx", where xxxxx is the serial number of the unit padded with zeroes on the left to 5 digits, for example "T500-00001".

The T500 uses raw TCP for ASCII serial commands. It listens on port 2000 by default. (This port number may be changed with the SYST:COMM:SOCK:PORT command, described below.) The port is configured to permit up to six simultaneous connections (in particular so that multiple user programs may monitor or control the T500's main subsystems separately.)

4.3 General Syntax

The commands follow SCPI syntax. If a command takes multiple arguments, the arguments are delimited from each other by a comma ','. The T500 replies to query commands (commands which end with a question mark '?') but not set commands. Replies to queries in compound commands (multiple commands on the same line) are delimited from each other by semicolons and terminated by a newline. No command in a compound command will be executed until an end-of-line character

(ASCII 10 or 13) is received. After the end-of-line character is received, the compound commands on the line will be executed in the order in which they are received.

If any error is encountered during a compound command, execution of the remainder of the compound command will be aborted. If any reply had already been sent due to previous queries on the same line, then end-of-line will be replied; otherwise no reply will be made.

Commands described in the following subsections are written such that their short form mnemonic is in upper-case and the remaining letters of their long-form mnemonic is in lower-case. For example, a command mnemonic written as SLICer may be sent to the T500 as either SLIC or SLICER.

Regardless of how they are written in this manual, all commands are case-insensitive. Any command arguments whose type is Character Program Data (text not escaped by quotes, for example ON, OFF, MAX, or MIN) are also case-insensitive.

4.4 Note About Critical Systems

SCPI does not reply to non-query commands. To ensure that a command was received and executed without error, we recommend appending the *OPC? query to every non-query command line. If the reply to *OPC (‘1’ followed by a newline) is not received within a timeout period, the error may be queried using the SYST:ERR? query. (As noted above, all compound commands on a line are executed in the order in which they are written.)

For example, to save the calibration table and ensure that the command was executed, send

```
CAL:SAVE;*OPC?
```

and test for a reply of 1.

4.5 Command Detailed Description

4.5.1 Common and Miscellaneous Commands

HEADer <ON/OFF>
VERBose <ON/OFF>

The HEADer command controls whether or not command mnemonics are included with the replies to serial command queries. If VERBose ON is used, then the long form of these mnemonics will be replied. Whether verbose or not, the command will be stated from the top-level mnemonic. For example, if HEADer and VERBose are both set to on, a reply to

```
:FID:AMP?;DEL?
```

might be:

:FIDUCIAL:AMPLITUDE 1.234;:FIDUCIAL:DELAY 5.678

***IDN?**

The query-only *IDN? command returns the company, model, serial number, and firmware version. E.g.:

```
*IDN?
```

HTI,T500-1A,SN 123,28E500A

***OPC?**

The query-only *OPC? command waits until all pending operations are complete, then responds with '1'. This is useful as a handshaking mechanism to ensure previous commands have completed before proceeding.

***RST**

The *RST command reboots the T500.

SYSTem:DISPlay "<message>"

Display a message on the front panel for three seconds before returning front panel to normal display. The argument is string program data; it must be encapsulated by single or double quotes. The case of the text will be preserved.

SYSTem:DISPlay:BRIGhtness <brightness>
SYSTem:DISPlay:BRIGhtness?

Control the brightness of the front panel display. <brightness> is a PWM duty cycle, in percent (0 to 100). The power-up default is 100 percent.

SYSTem:DISPlay:TEST

Run a test of the front-panel LCD by setting the screen various full color displays for about a second at a time, before returning to normal operation. This may be useful for detecting stuck pixels. The order of colors are: white, blue, red, green, and black.

SYSTem:LEDs:TEST

Cause the front-panel TRIG, COMM, BIST, and ERR leds to spend the next approximately four seconds toggling on and off, before returning to normal operation. (The PWR led is not controlled by the firmware, and should remain on while the unit is powered on regardless of LED test state.)

SYSTem:ERRor?
SYSTem:ERRor:NEXT?

The SYST:ERR command returns the top-most error message in the SCPI error queue, in the form <error code>, <error string>, and removes it from the queue. If the queue is empty it returns 0. If the error queue is full and an additional error occurs, the last entry in the error queue will be replaced with -350, “queue overflow”. The NEXT form of this command is a synonym for the shorter, and behaves identically. Example:

```
SYST:ERR?
-222,”Parameter Data Out of Range”
SYST:ERR?
+0,”No Error”
```

SYSTem:IDENtify:SLICer?
SYSTem:IDENtify:TRIGger?
SYSTem:IDENtify:CONTrol?
SYSTem:IDENtify:HEATer?
SYSTem:IDENtify:FIDucial?

The SYST:IDENT set of serial commands are convenience wrappers that reply calibration data from the requested subassembly. The reply is in the form <serial>,<dash>,<rev> for example:

```
SYST:IDENT:SLIC?
123,1,A
```

If the subassembly’s calibration table failed to load, its serial number will be zero.

SYSTem:IDENtify:BIAS?

SYSTem:IDENtify:BIAS? is an alias for SYSTem:IDENtify:CONTrol?

SYSTem:FAN <percent>
SYSTem:FAN?

Set or query the T500 fan power. <percent> is a percentage of the full DAC value powering the fan, 0 to 100. The power-on default is 100. Users may elect to reduce fan speed to reduce noise; consult Highland as regards internal cooling.

4.5.2 Status Commands

STATus:BIST?
STATus:BIST:LONG?

STATus:BIST replies 1 for a passing background-BIST state, 0 for BIST errors.

STATus:BIST:LONG replies a full BIST report, consisting of 105 comma-delimited parts:

"<name1>",<value1>,<result1>,...,"<name35>",<value35>,<result35>

<name> is a brief text string naming the item being tested.

<value> is the measurement of the item being tested. It will be degrees Celsius if it is a temperature. Otherwise it will be a voltage.

<result> will be 0 if <value> is not within the testable limits. Otherwise it will be 1. Some items, such as test points, are informative only; <result> will be 1 for those as well.

The full result list is as follows:

Item	<name> text	Units	Additional Notes
1	+24V	Volts	
2	+15V	Volts	
3	-15V	Volts	
4	+5V	Volts	
5	-5V	Volts	
6	+3.3V	Volts	
7	2.5R iso	Volts	
8	gnd	Volts	Calibration reference for ADC offset.
9	Sli +4V	Volts	
10	Sli +3V	Volts	
11	Fid 2.5V	Volts	
12	Fid -1.25V	Volts	
13	Fid Vamp	Volts	Approx. zero until power-up sequence complete
14	TP24	Volts	Test point. Not tested by BIST.
15	Ctl Temp	°Celsius	Control board thermistor. Not tested by BIST. 29 typ.
16	Fid +3	Volts	
17	Tr Temp	°Celsius	Trigger board thermistor. Not tested by BIST. 29 typ
18	Sli Temp	°Celsius	Slicer board thermistor. Not tested by BIST. 35 typ
19	Fid Temp	°Celsius	Fiducial board thermistor. Not tested by BIST. 29 typ
20	Tr Lev	Volts	Expected value is trigger level as set by user
21	Sli Vamp	Volts	Approx. zero until power-up sequence complete
22	Tr 3.3	Volts	

Item	<name> text	Units	Additional Notes
23	Tr +3R	Volts	
24	Tr +2	Volts	
25	EOM I sense	Volts	Expected value is EOM DAC voltage divided by 2. The tolerance is 5% of the DAC setting plus 5% full scale.
26	EOM +12V	Volts	
27	EOM +5V	Volts	
28	EOM +3.3V	Volts	
29	EOM 2.5ref	Volts	
30	EOM -1.7V	Volts	
31	EOM -5V	Volts	
32	EOM Left temp	°Celsius	See note below
33	EOM Ctr temp	°Celsius	See note below
34	EOM Right temp	°Celsius	See note below
35	EOM Oven temp	°Celsius	See note below

Note: All EOM temperatures share a single pass/fail state: If “Oven” temperature deviates from “Ctr” temperature by more than 20 degrees, or if “Left” or “Right” temperature deviate from “Ctr” temperature by more than 10 degrees, all temperatures are considered to be in an error state.

STATus:UPTime?

STATus:UPTime reports the number of seconds of the current boot cycle. This value is derived from a 32-bit millisecond counter which will roll over every 49 consecutive days of uptime.

4.5.3 Network Commands

Note: All changes to the network settings must be saved with SYST:COMM:SOCK:SAVE and the system must be reset before the changes take effect.

SYSTem:COMMunicate:SOCKet:ADDress "<ip-address>"
SYSTem:COMMunicate:SOCKet:ADDress?

The ADDress subcommand sets or queries the T500’s IP address. <ip-address> must be wrapped in single or double quotes. It must be expressed as one of the folloing:

- A period-delimited static IP address, e.g. “192.168.0.123”
- An all-zeros IP address, to indicate that a DHCP client should be used: “0.0.0.0”
- “dhcp” (case-insensitive) to use the T500’s DHCP client.

Replies to queries will always be the last user-requested IP address. If DHCP is used, an address of "0.0.0.0" will be replied. To see the actual IP address provided by a DHCP server, use SYST:COMM:SOCK:NST (described below).

SYSTem:COMMunicate:SOCKet:SMASk "<ip-address>"
SYSTem:COMMunicate:SOCKet:SMASk?

The SMASk subcommand sets or queries the T500's subnet mask. This value will only be used if the ADDress subcommand is configured for a static IP address. If using DHCP, use SYST:COMM:SOCK:NST? to query the server-provided subnet mask currently used by the T500. The <ip-address> argument must be wrapped in single or double quotes. It must be expressed as four decimal-delimited numbers, e.g. "255.255.255.0".

SYSTem:COMMunicate:SOCKet:DGATeway "<ip-address>"
SYSTem:COMMunicate:SOCKet:DGATeway?

The DGATeway subcommand has the same rules as the SMASk subcommand, except that it is for the default gateway. This is a placeholder setting. Currently the only network client on the T500, the DHCP client, does not use it.

SYSTem:COMMunicate:SOCKet:MAC?

The MAC subcommand queries the T500's MAC address.

SYSTem:COMMunicate:SOCKet:HNAMe?

The HNAMe subcommand queries the T500's hostname. If the T500's DHCP client is being used and has connected with a DHCP server on the network, it can be reached using this hostname, which is "t500-" followed by a five-digit serial number, e.g. "t500-00123".

SYSTem:COMMunicate:SOCKet:NSTat?

The NSTat subcommand queries the "real" network settings. If a static IP address is being used, then these values will be the same as the reply to SMASk, ADDress, and DGATeway queries. The reply will be three comma-delimited addresses. The first is the IP address; the second is the subnet mask; the third is the default gateway. For example the reply might look like:

192.168.0.123,255.255.255.0,192.168.0.0

SYSTem:COMMunicate:SOCKet:PORT <port>
SYSTem:COMMunicate:SOCKet:PORT?

The PORT subcommand sets the port number that its serial command server will use to accept TCP connections. The default port number is 2000.

SYSTem:COMMunicate:SOCKet:SAVe

The SAVe subcommand will store the network settings into the T500's non-volatile RAM.

This action may take up to three seconds to execute. Do not run it during normal operations.

SYSTem:COMMunicate:SOCKet:DEFault

Load the hard-coded default network settings.

4.5.4 Slicer (Square Pulse) Commands

SLICer:AMPlitude <voltage>
SLICer:AMPlitude?
SLICer:DELay<chan> <time>
SLICer:DELay<chan>?
SLICer:WIDTh<chan> <time>
SLICer:WIDTh<chan>?
SLICer:ENABled<chan> <ON/OFF>
SLCIer:ENABled<chan>?

<chan> is a command suffix, and it must be either 1 or 2. If no suffix is given, the default is 1.

<time> and <voltage> may be expressed as any SCPI-valid numerical expression: for example, numbers like 1.2, 2.3E02, #H16, and so on are all valid, so far as they are within valid range.

<time> may have the following numerical suffixes S, MS, US, NS, PS. If no suffix is provided, then NS will be assumed.

<voltage> may have the following numerical suffixes: V, MV. If no suffix is provided, then V will be assumed.

The programmable limits for <time> are 0 to 36 nanoseconds. The programmable limits for <voltage> are 0 to 6.5 volts. Arguments MIN and MAX may be used as substitutes for these values.

4.5.5 Impulse (Fiducial Pulse) Commands

FIDucial:AMPlitude <voltage>
FIDucial:AMPlitude?
FIDucial:DELay <time>

FIDucial:DELay?
FIDucial:WIDTh <time>
FIDucial:WIDTh?
FIDucial:ENABled <ON/OFF>
FIDucial:ENABled?

<time> and <voltage> have the same format as with the SLICer subsystem.

The programmable limits for delay <time> are 0 to 36 nanoseconds. The programmable limits for width <time> are 0 to 150 picoseconds. The programmable limits for <voltage> are 0 to 6.5 volts.

FIDucial:ATTenuator:ENABled <ON/OFF>
FIDucial:ATTenuator:ENABled?

Enable or disable the T502 AWG-path attenuator. The attenuator will be turned off while the fiducial is enabled.

BIAS Pulser Commands

BIAS:DELay <time>
BIAS:DELay?
BIAS:WIDTh <time>
BIAS:WIDTh?
BIAS:AMPlitude<chan> <voltage>
BIAS:ENABled<chan> <ON/OFF>
BIAS:ENABled<chan>?

<time>, and <voltage> have the same format as with the SLICer subsystem of commands.

<chan> 1 and 2 refer to EOM sections 1 and 2. Section 1 is the slicer, 2 is the ARB/fiducial.

The programmable limits for <time> are 0 to 1.092 milliseconds. The delay factory default, is 1.036 ms and the width is 10.000 us.

The programmable limits for <voltage> are -5 to +10 volts. Arguments MIN and MAX may be used as substitutes for these values.

4.5.6 Trigger Commands

TRIGger:LEVel <voltage>

<voltage> has the same format as with the SLICer subsystem of commands. The programmable limits are 0.1 to 3 volts. Arguments MIN and MAX may be used as substitutes for these values.

TRIGger:SOURce <EXTL/INTL/OFF>
TRIGger:SOURce ?

Select the trigger source.

WARNING: Do not use an external trigger source greater than 100 kHz. The T500 was designed to expect a trigger source of either 9600 Hz or 960 Hz.

TRIGger:FREQuency <960/9600>
TRIGger:FREQuency?

Set the internal trigger frequency. If the frequency argument expressed in floating-point notation, then the argument will be cast to an integer. If the expression does not evaluate to either 960 or 9600, it will be considered an argument error. This setting will only be implemented when the trigger source is INTL.

Replies to queries will be the current setting. To query the measured trigger rate, use TRIG:RATE? instead.

Note that the Bias delay and width settings will not be changed when changing the internal trigger frequency. If triggering internally, users should also update the Bias settings with BIAS:DELAY and BIAS:WIDTH.

TRIGger:RATE?

The TRIG:RATE query returns the actual, measured trigger frequency.

4.5.7 Calibration Commands

CALibrate:DATa <offs>,<value>
CALibrate:DATa? <offs>

Set or query a 32-bit value stored in the calibration table. <value> should be expressed as an integer; if not, it will be converted to the nearest integer value. The reply will always be expressed as an unsigned base-10 integer.

<offs> is the byte offset in the calibration table. It must be a multiple of 4 and it may not be greater than or equal to the size of the calibration table.

CALibrate:MAC "<mac>"
CALibrate:MAC?

Set or query the MAC address in the calibration table. This is a convenience wrapper for CAL:DATA specific to the MAC address field, since it is 48 bits wide.

“<mac>” is SCPI string program data (ie. encapsulated by quotation marks) expressing the MAC address using the convention of six colon-delimited hexadecimal numbers, e.g. “00:04:A3:02:EA:01”. The digits A-F are case-insensitive.

This change will not take effect until the calibration table has been saved and the device has been rebooted. Use the SYST:COMM:SOCK:MAC? query to determine the currently implemented MAC address.

The MAC address is saved during factory calibration. End-users should not change this from the address on the product sticker.

CALibrate:LOAD

Reload the calibration table from nonvolatile memory. If the calibration table in nonvolatile memory has been corrupted, then the default calibration table will be loaded in its place and an error will be stored in the error queue.

CALibrate:STATus?

Query the status of the calibration table. The reply is one of the following:

Reply:	*Meaning:*
OK	The active calibration table in RAM is valid
DIRTY	The active calibration table in RAM has been edited but not saved.
DEFAULT	The default calibration table has been loaded into RAM.
PARTIAL	One or more of the subassemblies’ calibration data failed to load. You can check which one by querying the ID fields at addresses 0, 256, 512, 768, and 1024. A value of 57084 indicates that the default data was loaded in its place. See section “Calibration.”

CALibrate:DEFault

Set the calibration table to hard-coded default values.

CALibrate:SAVE

Save the active calibration table to nonvolatile memory. ***Caution:*** This will halt T500 operations for up to twenty seconds.

4.5.8 Firmware Upgrade Commands

Note: The following are a detailed description of the serial commands. See section “Remote Firmware Upgrade” for an overview of how to apply these commands.

FLASh:LOCK
FLASh:UNLock

FLASh:UNLock enables FLASh:ERASe and FLASh:WRITe. This is a redundant measure to prevent accidental modification of the flash. This state will remain in effect until either the next boot cycle (*RST or power-cycle) or the next FLASh:LOCK command.

FLASh:LOCK will prevent future uses of FLASh:ERASe and FLASh:WRITe. This is the power-on default state.

FLASh:ERASe

FLASh:ERASe erases the portion of the flash that will store the upgrade image. FLASh:ERASe should be executed before writing a new binary into the flash.

Note: This may halt some of the T500’s functionality, including the processing of any serial commands, for up to thirty seconds. Remove the T500 from normal operation before conducting a remote upgrade.

FLASh:WRITe “<srec>”

FLASh:WRITe writes a line from an S-Record into the serial flash.

<srec> must be wrapped by single or double quotes. It must be a valid S-Record line whose encoded address is within the upgrade image portion of the T500’s on-board flash. If the line is valid but not a data type (S1, S2, or S3), then the command will be treated as valid but no action will take place.

FLASh:CHECksum?

FLASh:CHECksum runs a checksum of the images in the T500’s on-board flash and replies the result. This does not modify the flash images.

The reply will be a line of the form:

FF:<res>,FP:<res>,FH:<res>,UF:<res>,UP:<res>,UH:<res>

For the two-letter headings, the first letter means:

F Factory image
U Upgrade image

The second letter means:

F Firmware (microprocessor) image
P FPGA image, *if applicable*
H Additional files used by firmware, *if applicable*

<res> is one of:

OK Image is present and checksum passed, or image is not applicable
NP Image was expected but not found
ER Image was found but its checksum failed

The result for the factory images should always be OK. The result for the upgrade images should either be NP (if erased or never upgraded) or OK. The expected result for a new T500 is:

```
FF:OK,FP:OK,FH:OK,UF:NP,UP:NP,UH:NP
```

If any of the *upgrade* images' results are ER, this indicates an incomplete or failed upgrade procedure. If any of the *factory* images' results are not OK, this should be treated as a critical failure.

Note: This may halt some of the T500's functionality for up to five seconds. Remove the T500 from normal operation before running this test.

4.5.9 Heater Commands

HEATer:AUTO
HEATer:POWer <power>
HEATer:POWer?
HEATer:STATe?

The HEATer commands start, stop, or query the EOM control loop algorithm.

HEATer:AUTO starts the temperature control algorithm using parameters in the calibration table. The T500 starts up in this state.

HEATer:POWer disables the temperature control algorithm and sets it to a static setting. <power> is in units of Watts. HEATer:AUTO or a reboot will be required to restore the temperature control algorithm.

HEATer:STATe? will reply AUTO if the temperature control algorithm is being used, and POWER if a static setting is used.

4.5.10 Debug/Development Serial Commands

WARNING! **The following serial commands were created for development purposes. They are deprecated, and should not be used for normal operations. Some may be modified or removed in later firmware revisions, others may violate SCPI syntax rules in their replies, and still others may confuse the normal system state.**

FIDucial:DAC<which> <raw_dac_codes>

Write raw DAC codes directly to the fiducial's DAC. <which> is one of the following:

0	Width DAC
1	VGG
2	Amplitude DAC
3	Attenuator DAC

BIAS:CALibrate <ON/OFF>

Turning BIAS:CAL to OFF (the default setting) will cause the Bias gate to be controlled by the trigger input and the BIAS:DELAY and BIAS:WIDTH settings. Turning it ON will cause the Bias gate to be on continuously.

BIAS:DAC<channel> <raw_dac_codes>

Write raw codes directly to one of the two BIAS DACs. <channel> is 1 or 2. <raw_dac_codes> should be between zero and 1048575.

BIAS:MONitor<channel> <state>

Select what goes out the MON1 or MON2 connector on the T501 control board. <channel> is 1 or 2. State is 1 to select the signal BIAS*n*_DC, 0 to select the signal OUT_BIAS*n*.

TRIGger:DAC <raw_dac_codes>

Write raw codes directly to the trigger-level DAC. <raw_dac_codes> should be between zero and 65535.

SYSTem:COMMunicate:SOCKet:ENET?

This query will reply low-level debug information about the status of the Ethernet controller, e.g.

STATE:7,LINK:1,CONNECTED:0,"KST8081"

SYSTem:DISPlay:DATA <offset>,<value>
SYSTem:DISPlay:DATA? <offset>

Read or write a register in the FT800 display driver.

DBG:FAN?

Query the DAC output that drives the front-panel fans. Reply will be an integer, 0 to 4095.

DBG:HEATer:ADC?

Query the 16 multiplexed ADC inputs on the EOM. The reply will be sixteen comma-delimited values. The first four are in degrees Celcius. The remaining twelve are in volts.

DBG:MUX <mux>

Stop the BIST background scan and hold it on a single MUX input. ADC conversions will continue to take place, but the multiplexed input will not change. <mux> is one of the following:

Argument	Reference designator (rev. A T501)
0…7	U13 "MUX0" inputs 0-7
8…15	U22 "MUX1" inputs 0-7
16…23	U17 "MUX2" inputs 0-7
-1	Unfreeze and restore scan loop

DBG:SOCKet?

Query the socket state. The reply will be human-readable, multi-line text containing information about the current connection state of the TCP "transmission control blocks" managed by the firmware. *WARNING: The reply to this command violates SCPI syntax, and could break parsers. It was intended for manual use only.*

DBG:CLK?

Query the frequency of the microcontroller's core clock.

5 Remote Firmware Upgrade

The T500's firmware may be upgraded using the :FLASh subsystem of serial commands. An upgrade file is an S-Record with a name of the form "28E500<rev>_upgrade.s28," where <rev> is the revision letter. If the revision letter is followed by a number, e.g. A1, then the file is a pre-release draft of the revision.

Caution: FLASH:ERASE, FLASH:WRITE, and FLASH:CHECKSUM? will prevent the T500 from conducting most of its operations until the operation is complete. The T500 should be removed from its normal operating environment for this procedure.

The upgrade procedure is as follows:

1. Send the FLASH:UNLOCK command to the T500, to enable modifying the flash.
2. Send the FLASH:ERASE command to the T500. This may take up to thirty seconds. No additional serial commands will be processed during this time, so you can be certain that the erasure has completed by appending the *OPC? query to the command and waiting for the reply '1'.
3. Open the S-Record file. Perform the following subroutine until you reach end-of-file.
    a. Read a line from the S-Record.
    b. Send the FLASH:WRITE command, with the line from the S-Record as an argument to the T500.
    c. Normal operations will be delayed during execution of the FLASH:WRITE command, so it is adviced to append the *OPC? query to the command and wait for the reply '1'.
4. Send the FLASH:CHECKSUM? query to the T500. Wait up to five seconds for the reply. The expected reply is: `FF:OK,FP:OK,FH:OK,UP:OK,UH:OK`. This indicates that the upgrade image is now present and its firmware checksum tests passed.
5. Either power-cycle the T500 or send a *RST serial command to reboot it. Aproximately the first second of the next boot cycle will be spent finalizing the firmware upgrade. *Once this begins, do not power-off the T500 until its new firmware has loaded and begun running again.*

6 Calibration

6.1 Storage of the Calibration Table

There calibration table has five parts, each of which is stored in a different location:

Location	Portion in active calibration table (offsets)	Description
Microcontroller's on-chip flash	0-255	Bias DACs, MAC address, and overall module information
T505 (Trigger PCB) EEPROM	256-511	Trigger level
T504 (EOM) EEPROM	512-767	Heater algorithmic parameters and conversions into DAC codes
T502 (Fiducial) EEPROM	768-1023	Fiducial calibration factors
T503 (Slicer) EEPROM	1024-1279	Slicer calibration factors

At power-up, the *saved calibration table* is read into a single array in memory, the *active calibration table*. This array can be modified with the CAL:DATA serial command, and saved back in their respective nonvolatile memories with the CAL:SAVE serial command.

If any subassembly's calibration table cannot be loaded, either because it was never calibrated or because the subassembly is not connected, default values will be loaded instead. The remaining subassemblies' calibration tables will still be loaded, but this will be considered an error condition; the CAL:STAT? query will reply PARTIAL.

6.2 Full Layout of the Calibration Table

In the "Type" column of the table below, "Float" refers to a IEEE-754 single-precision floating point number. The CAL:DATA command evaluates its arguments as integers, so express the value in the form of its *bitwise* conversion to an integer. For example, to change EOM_KI to a value of 0.12,

DO send one of CAL:DATA 580,#H3DF5C28F
CAL:DATA 580,1029516303

DO NOT send CAL:DATA 580,0.12

In the latter case, the argument will be incorrectly evaluated as zero. In the former case, the exponent, sign, and mantissa bits are such that the number will be evaluated as +1.91999996 x 2^{-4}, the value nearest to 0.12 that can be stored in a single-precision float.

Tip: In C++, this decoded value can easily be converted using `std::bit_cast` from the standard `<bit>` header.

In C, it can be converted by using a `union` type whose fields are a `float` and a `uint32_t`, as in the following example:

```
unsigned long bitcast_ftoul(float f)
{
        union {
                uint32_t u32;
                float f;
        } x = { .f = f };
        return (unsigned long)x.u32;
}
```

The full calibration table in RAM is 1280 bytes.

For polynomials, the 0^{th}-order coefficient is the lowest-offset value. Most polynomials exist as reserved space in case a simple gain and offset won't do.

End-users should only calibrate the date fields and fields whose type is "Float". Modifying serial numbers and dash numbers may cause confusion if troubleshooting is necessary.

Name	Byte Offset	Size (bits)	Type	Units	Default	Description
Control board cals						
CTL_ID	0	16	integer	NA	57084	Identification. When saving, firmware will overwrite this will value 28501.
CTL_SERIAL	4	16	Integer	NA	0	T500 serial number
CTL_DASH	6	16	Integer	NA	1	T500 board dash number
CTL_REV	8	16	Integer	NA	65 ('A')	T500 revision letter, ASCII 'A', 'B', etc.
CTL_YCAL	12	16	Integer	NA	0	Year calibrated

Name	Byte Offset	Size (bits)	Type	Units	Default	Description
CTL_DMCAL	14	16	Integer	NA	0	Bits 1-15 are the day calibrated (1-21). Bits 16-31 are the month calibrated (1-12)
MAC	16	48	6-Byte array	NA	00:0a:35:00:01:22	Ethernet MAC address. *TIP: Use CAL:MAC instead of CAL:DATA, to prevent confusion about byte order*
BIAS1	32 36 40 44	32 32 32 32	Float Float Float Float	DAC codes Codes/Volts $Codes^2/Volts^2$ $Code^3/Volts^3$	349.5253e3, 69.9057e3, 0.0, 0.0	BIAS1 DAC cal factor, polynomial. Probably only need gain and offset
BIAS2	48 52 56 60	32 32 32 32	Float Float Float Float	DAC codes Codes/Volts $Codes^2/Volts^2$ $Codes^3/Volts^3$	349.5253e3, 69.9057e3, 0.0, 0.0	BIAS2 DAC cal factor…
CTL_CSUM	252	32	Integer		NA	Fletcher's 32-bit checksum of control portion of calibration table. Overwritten by firmware when saving.
Trigger Board Cals						
TRIG_ID	256	16	integer	NA	57084	Like CTL_ID, but set to 28505 when saved
TRIG_SERIAL	260	16	Integer	NA	0	Trigger subassembly serial number
TRIG_DASH	262	16	Integer	NA	1	Trigger subassembly dash number
TRIG_REV	264	16	Integer	NA	65 ('A')	Trigger subassembly revision letter, ASCII 'A', 'B', etc.
TRIG_YCAL	268	16	Integer	NA	0	Year trigger module was calibrated

Name	Byte Offset	Size (bits)	Type	Units	Default	Description
TRIG_DMCAL	270	16	Integer	NA	0	Day/month trigger module was calibrated, same format as CTL_DMCAL
TLEV	272 276 280 284	32 32 32 32	Float Float Float Float	DAC codes Codes/V $Codes^2/V^2$ $Codes^3/V^3$	0, 21845.333, 0, 0	Trigger level.
TRIG_CSUM	508	32	Integer	NA		Like CTL_CSUM but for trigger subassembly
EOM Cals						
EOM_ID	512	16	integer	NA	57084	Like CTL_ID, but set to 28504 when saved
EOM_SERIAL	516	16	Integer	NA	0	EOM serial number
EOM_DASH	518	16	Integer	NA	1	EOM dash number
EOM_REV	520	16	Integer	NA	64 (‘A’)	EOM revision, ASCII letter ‘A’, ‘B’, etc.
EOM_YCAL	524	16	Integer	NA	0	Year EOM assembly was calibrated
EOM_DMCAL	526	16	Integer	NA	0	Day/month EOM assembly was calibrated, same format as CTL_DMCAL
EOM_POWER	544 548 552 556	32 32 32 32	Float Float Float Float	DAC Codes Codes/Watt $Codes^2/Watt^2$ $Codes^3/Watt^3$	0.0 2730.67 0.0 0.0	EOM Power-to-dac cals. Uniform across all three dacs. Probably only linear needed.
EOM_TOFF_LEFT	560	32	Float	Deg. Celcius	0.0	Left temp. sensor offset correction
EOM_TOFF_CTR	564	32	Float	Deg. Celcius	0.0	Center temp. sensor offset correction
EOM_TOFF_RIGHT	568	32	Float	Deg. Celcius	0.0	Right temp. sensor offset correction

Name	Byte Offset	Size (bits)	Type	Units	Default	Description
EOM_TOFF_PCB	572	32	Float	Deg. Celcius	0.0	PCB (“oven”) temp. sensor offset correction
EOM_P_MAX	576	32	Float	Watts	24.0	Maximum power to set.
EOM_KI	580	32	Float		0.1	
EOM_KP	584	32	Float		25.0	
EOM_KD	588	32	Float		0.0	
EOM_SLEW_RATE	592	32	Float		8e-3	
EOM_SET_POINT	596	32	Float	Deg. Celcius	30.0	Target temperature for EOM
EOM_CSUM	764	32	Integer	NA		Like CTL_CSUM but for EOM subassembly
Fiducial Cals						
FID_ID	768	16	integer	NA	57084	Like CTL_ID, but set to 28502 when saved
FID_SERIAL	772	16	Integer	NA	0	Fiducial board serial number
FID_DASH	774	16	Integer	NA	1	Fiducial board dash number
FID_REV	776	16	Integer	NA	64 (‘A’)	Fiducial board revision, ASCII letter ‘A’, ‘B’, etc.
FID_YCAL	780	16	Integer	NA	0	Year fiducial board was calibrated
FID_DMCAL	782	16	Integer	NA	0	Day/month fiducial board was calibrated, same format as CTL_DMCAL
FID_DELAY	800 804 808 812	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	49152.0 1213.63 0.0 0.0	Fiducial delay. Dac is D5 on the slicer PCB.
FID_WIDTH	816 820 824 828	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	14700.0 110000.0 -658.0 4669.0	Fiducial WIDDAC cals for fiducial width
FID_AMPL	832 836 840 844	32 32 32 32	Float Float Float Float	DAC Codes Codes/V $Codes^2/V^2$ $Codes^3/V^3$	-658.0 4669.0 0.0 0.0	Fiducual MODDAC cals for fiducial amplitude

Name	Byte Offset	Size (bits)	Type	Units	Default	Description
FID_ATT	848	16	Integer	DAC Codes	43690	***Deprecated***, not used with T502 rev. B. For rev. A, this was the ATTDAC value to set when enabling the attenuator.
FID_DLYDAC	850	16	Integer	DAC Codes	32767	DLYDAC value to set at power-up. Formerly called FID_VGG2.
FID_CSUM	1020	32	Integer	NA		Like CTL_CSUM but for fiducial board
Slicer Cals						
SLIC_ID	1024	16	integer	NA	57084	Like CTL_ID, but set to 28503 when saved
SLIC_SERIAL	1028	16	Integer	NA	0	Slicer board serial number
SLIC_DASH	1030	16	Integer	NA	1	Slicer board dash number
SLIC_REV	1032	16	Integer	NA	64 (‘A’)	Slicer board revision, ASCII letter ‘A’, ‘B’, etc.
SLIC_YCAL	1036	16	Integer	NA	0	Year slicer board was calibrated
SLIC_DMCAL	1038	16	Integer	NA	0	Day/month slicer board was calibrated, same format as CTL_DMCAL
SLIC_RISE1	1056 1060 1064 1068	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	5461.3 1213.6 0.0 0.0	Slicer D2 dac cals
SLIC_FALL1	1072 1076 1080 1084	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	Same as SLIC_RISE1	Slicer D1 dac cals
SLIC_RISE2	1088 1092 1096 1100	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	Same as SLIC_RISE1	Slicer D4 dac cals

Name	Byte Offset	Size (bits)	Type	Units	Default	Description
SLIC_FALL2	1104 1108 1112 1116	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	Same as SLIC_RISE1	Slicer D3 dac cals
SLIC_AMPL	1120 1124 1128 1132	32 32 32 32	Float Float Float Float	DAC Codes Codes/ns $Codes^2/ns^2$ $Codes^3/ns^3$	-658.0 4669.0 0.0 0.0	Slicer MIDDAC dac cals
SLIC_CSUM	1276	32	Integer	NA		Like CTL_CSUM but for slicer board

7 Timing Notes

The T500 is triggered by a rising edge on the rear-panel TRIG connector. The front-panel trigger monitor will show a positive pulse with rising edge about 4 ns later, with width of about 150 ns.

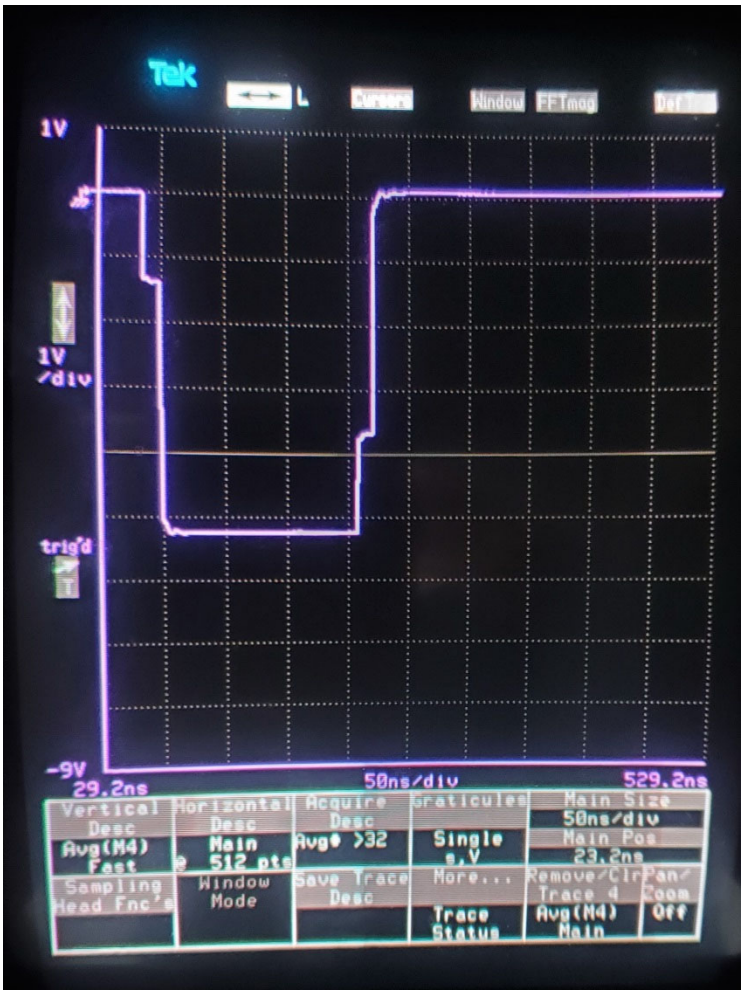
SCPI commands specify "SCPI times". The T500 has a calibrated 18 ns insertion delay, so an event specified for zero SCPI time arrives at the EOM RF connector 18 ns after the external trigger. SCPI times for the slicer and impulse edges may range from 0 to 36 ns.

The T502 arb/impulse module switches between its impulse generator and the Tek AWG signal about 8 ns after the impulse. When the impulse is turned off, it selects the Tek full-time.

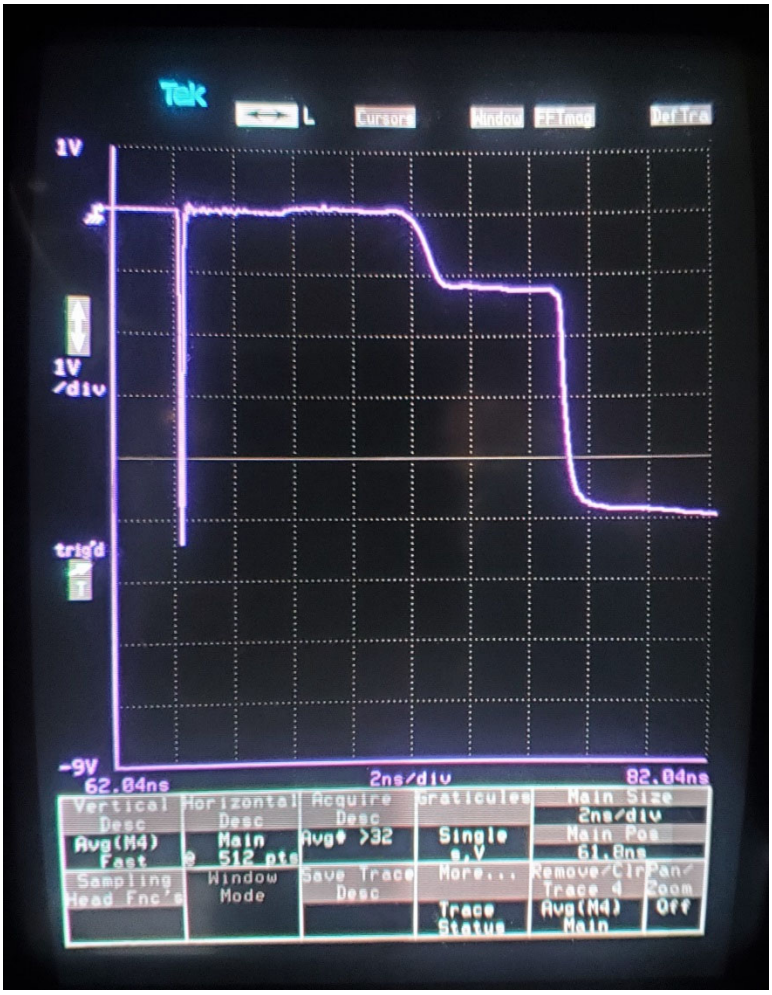
The bias supplies are intended to come up some microseconds before a shot and stay up for a few microsecond after. What is important is that the bias voltage be settled and flat during the 36 ns shot window. The pulsed bias supplies are essentially flat within 5 us of their rising edge.

The default bias time settings are 1036 microseconds delay and 10 us width. At a 960 Hz trigger rate, which is a 1042 us period, the bias will assert at 8 microseconds before the next trigger, staying on until 2 us after the trigger. The edges of the bias pulses are quantized to a clock that is asynchronous to the external trigger, with jitter about 60 ns p-p.

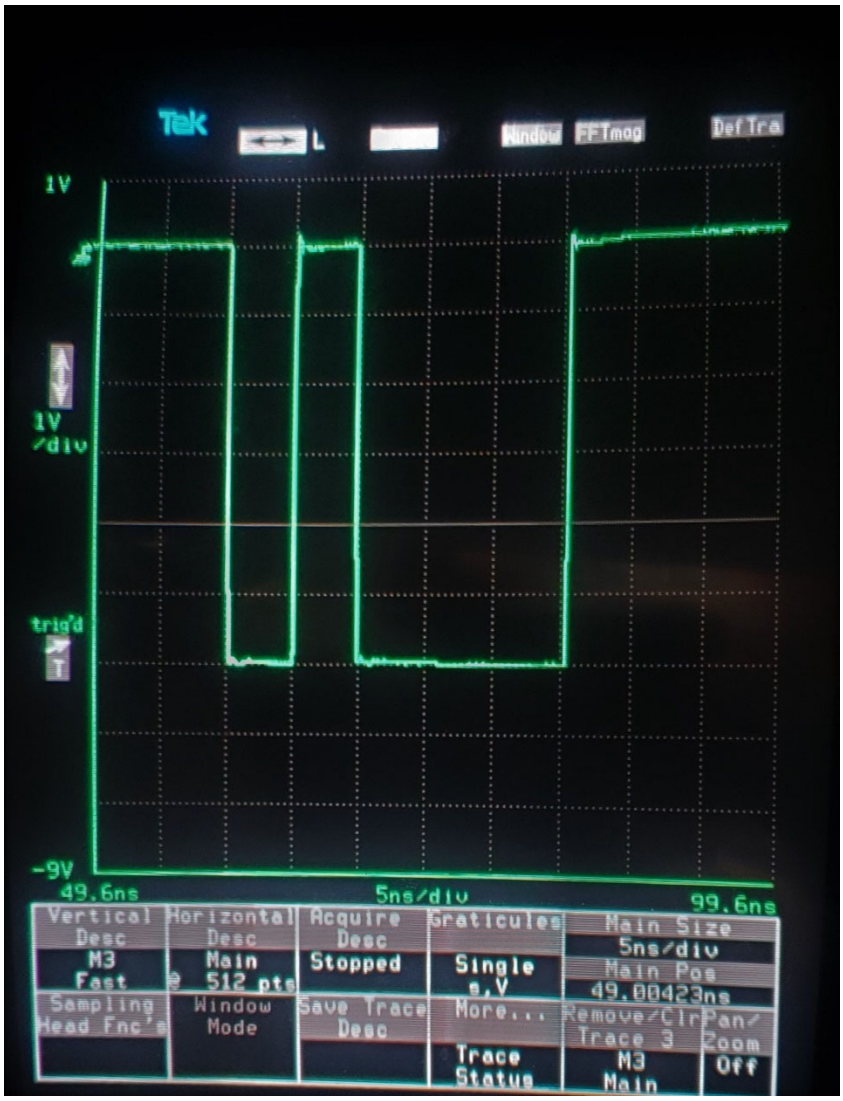
8 Typical Waveforms



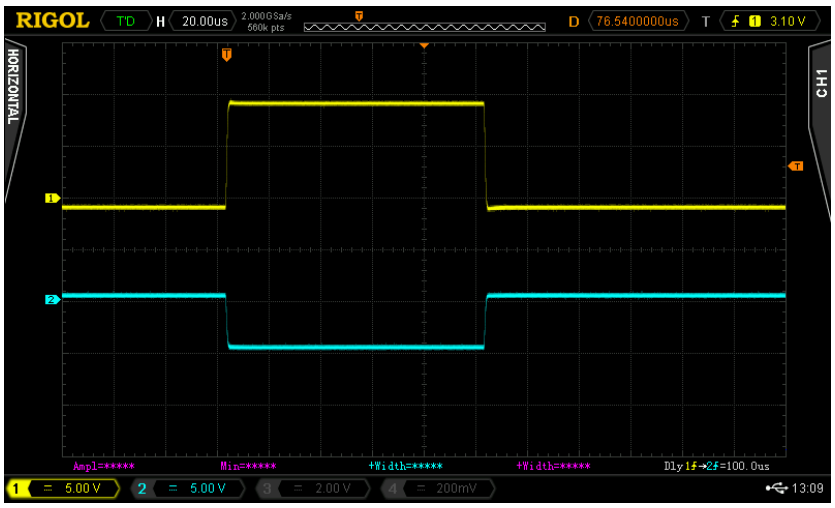
AWG test waveform measured at EOM



AWG test waveform with impulse enabled



Slicer pulses at EOM



Bias waveforms at EOM sections

9 Versions

T500-1: amplitude modulator chassis

10 Customization

Consult factory for information about additional custom versions.

11 Revision History

11.1 Hardware Revision History

Revision A February 2022
Initial Release

11.2 Firmware Revision History

Revision A April 2022
Initial Release

Revision B June 2022
Changed power supply BIST limits.
Allows the T502 attenuator to be enabled when the impulse is enabled.

12 Accessories

J25-1: 24 volt 65W power supply (furnished with purchase)

J95-1: 3U rack slide (set furnished with purchase)