MODEL P350 MULTICHANNEL WAVEFORM PROCESSOR

Technical Manual

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Contents

1 Introduction

This is the technical manual for the Highland model P350 Wayback Machine, a standalone instrument intended to play stored waveform files for aerospace simulations.

Features of the P350 include:

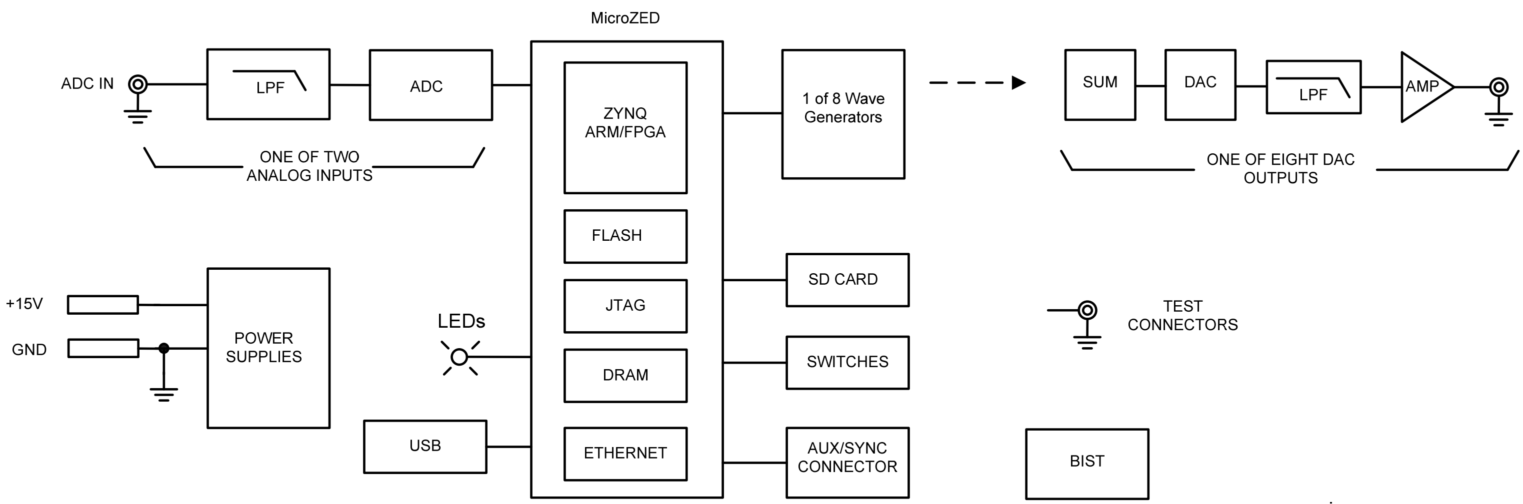
- Eight channels of independent or synchronized 16-bit waveform generation
- Two auxiliary ADC analog inputs for summing or modulation
- File playback and repetitive arbitrary wave generation modes
- 32 Gbytes of internal waveform file storage
- Realtime programmable sample rates, amplitudes, phase, time shift
- Two bandwidth-programmable Gaussian noise generators
- Includes modulation, filtering, channel summing, noise generation
- Multi-box phase locking and waveform synchronizations
- Embedded Linux with Gbit Ethernet and USB interfaces
- Includes built-in self-test, signal monitor connectors, and LEDs

2 Specifications

FUNCTION	Analog waveform playback box
WAVE GENERATORS	8 internal waveform generators, 16 bits 32K sample FIFO / Wavetable memory per channel File Playback/FIFO mode, 2 channels up to 1M samples/sec per channel 4 channels up to 500 K samples/sec per channel 8 channels up to 350 K samples/sec per channel Wavetable mode, up to 50 MHz sample rate Programmable filtering: off, short, advanced, $sinc^3$
ANALOG OUTPUTS	8 DAC channels, 16 bit resolution, DC coupled ± 10.24 volts range, 50 ohm source impedance 500 KHz analog bandwidth, risetime 700 ns nom
ANALOG INPUTS	2 channels, DC coupled, 14 bits ± 10.24 volts, 2 MHz sample rate, 100 KHz bandwidth
ACCURACY	Analog outputs, ± 1% Frequency, ± 20 PPM
DIGITAL I/O	One programmable digital monitor output One multibox SYS sync connector One AUX logic i/o
WAVEFORM MEMORY	32 Gbytes, FAT32, fast class 10 SD card 4 Gbytes maximum file size
OS	embedded Linux
COMMUNICATIONS	Gigabit Ethernet, USB
COMPUTE PLATFORM	MicroZed board with Xilinx ZYNQ 7020 SoC FPGA with dual-core 600 MHz ARM processors
CALIBRATION INTERVAL	One year
POWER	model J350, 15 VDC, 22 watts max, external supply furnished
TEMPERATURE	0 to 60°C operating range

3 Architecture

The figure below is a simplified block diagram of the P350:



The primary functions of the P350 are to play waveform files which were previously acquired from sensors on operating machinery, or to generate periodic waveforms from a standard or user-supplied waveform table. The major functional blocks include

MicroZED board with Xilinx ZYNQ system-on-chip, DRAM, gigabit Ethernet, and SD card flash storage. The ZYNQ chip includes an extensive FPGA architecture and dual 600 MHz hard-core ARM processors.

Eight wave generator channels, GenA through GenH, each usable in file Playback FIFO mode or in Wavetable periodic mode.

Two analog input channels, AdcX and AdcY, each with input signal conditioner, anti-alias lowpass filter, and 14 bit ADC.

Two random noise generators NP and NQ.

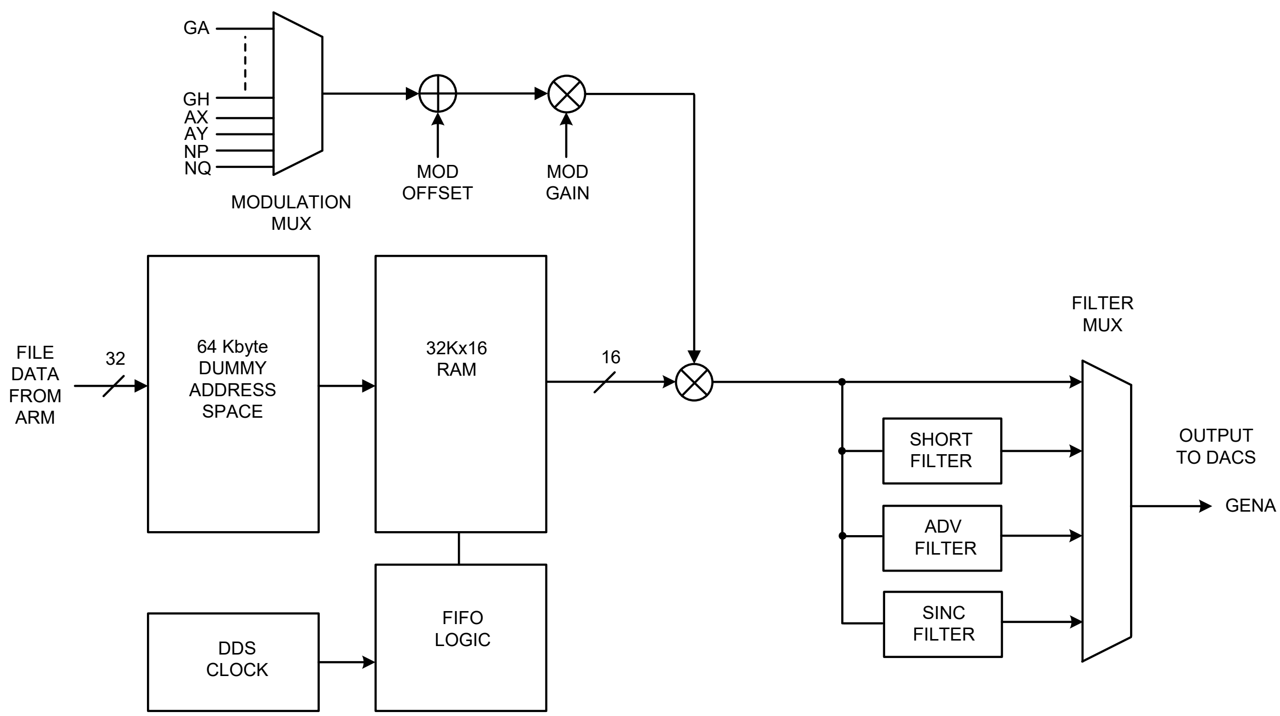
Eight analog output channels Dac0 through Dac7, each with arbitrary signal source summing, 16-bit DAC, anti-alias lowpass filter, and output amplifier.

3.1 Waveform Generators

There are eight waveform generator blocks, named GenA through GenH. Each may be used in Playback or in Wavetable modes.

3.1.1 Playback Mode

In Playback mode, the GEN signal processing is as follows:



The 32 Ksample wave generator RAM is configured as a FIFO buffer. The ARM processor streams user-supplied waveform files directly into the FPGA, and the FIFO hardware unloads those 16-bit samples at a user-programmable clock rate.

The channel's DDS clock generator determines the rate at which samples are extracted from the FIFO. The range is 0 to 1 MHz, and is always programmed to exact multiples of 1 milliHertz. See the Specifications section for multi-channel rate limits.

The SHIFT parameter allows realtime forward/backward time shift up to ± 999.99 samples, which allows dynamic high-resolution channel-to-channel time offsets.

Users can select one other signal (wave generators GENA...H, ADCs AX or AY) as a signed amplitude modulator. Rev B firmware does not support noise sources as modulators.

The DDS sample-rate frequency may be changed in real time, with the STROBE mechanism allowing simultaneous update of new settings across multiple channels.

Signal amplitude scaling and DC offset are done downstream, in the DAC output channels.

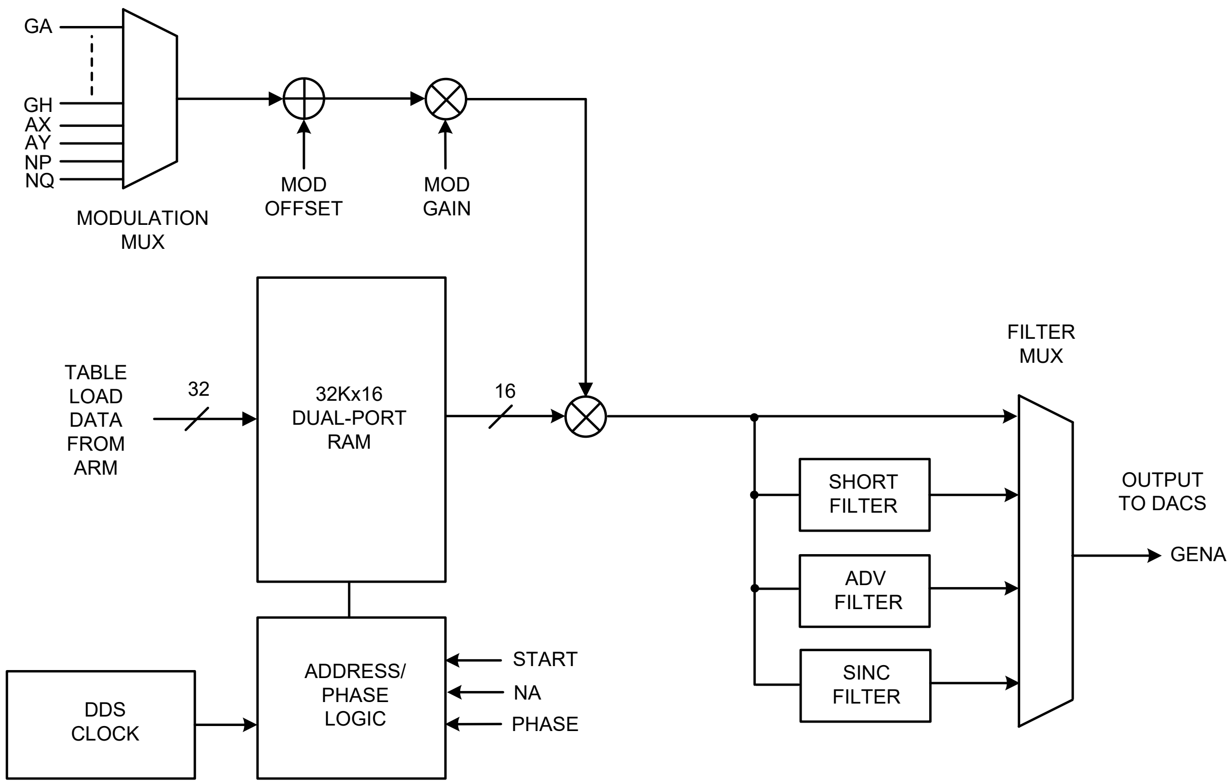
Note that a Playback session normally ends at end-of-file of the file selected to play. At that time, the Status report will show "EOF". Samples in the FIFO will continue to stream out until the FIFO buffer is empty, at which time the generator output will be forced to zero.

After a Playback session is over, users should issue a `gen -c xx -mode off` command to shut down the generator logic, or `gen -c xx -mode play` to begin playback of another file. Do not issue another `-file` command without first declaring a new mode.

The command `gen -c xx -mode off` can be used to abort a Playback session.

3.1.2 Wavetable Mode

In Wavetable mode, a repetitive waveform is generated from data in a selected region of the waveform RAM. The signal processing is



The 32K sample RAM is directly addressable by the ARM processor, which can load waveforms into one or more arbitrarily-sized regions. The region to be played by the FPGA hardware is defined by the START (start address) and NA (point count) parameters. The region from START to START+NA-1 is looped through at the point-step rate generated by the DDS clock. The sample clock range is 0 to 50 MHz, in units of 1 milliHertz. The sinc^3 filter option enables time resolution better than implied by the wavetable entries or the 500 ns DAC update rate.

The realtime address can be modified by the optional PHASE parameter, allowing phase shifts up to 360 degrees. Phase shift resolution is finer than 360/NA degrees.

The START, PHASE, and FREQUENCY parameters may be changed in real time, with provision for simultaneous update of new settings across multiple channels. Signal amplitude scaling and DC offset are done downstream, in the DAC output channels

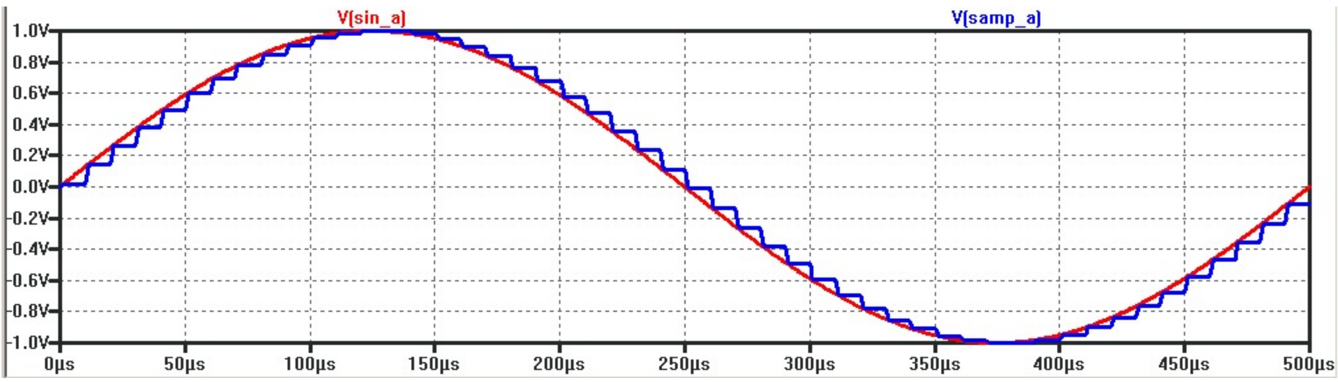
Waveform data can be loaded into any region of the RAM from a file, using the `-file` command. Or individual points can be loaded with the `-data` command.

The command `gen -c xx -mode off` can be used to abort Wavetable operation.

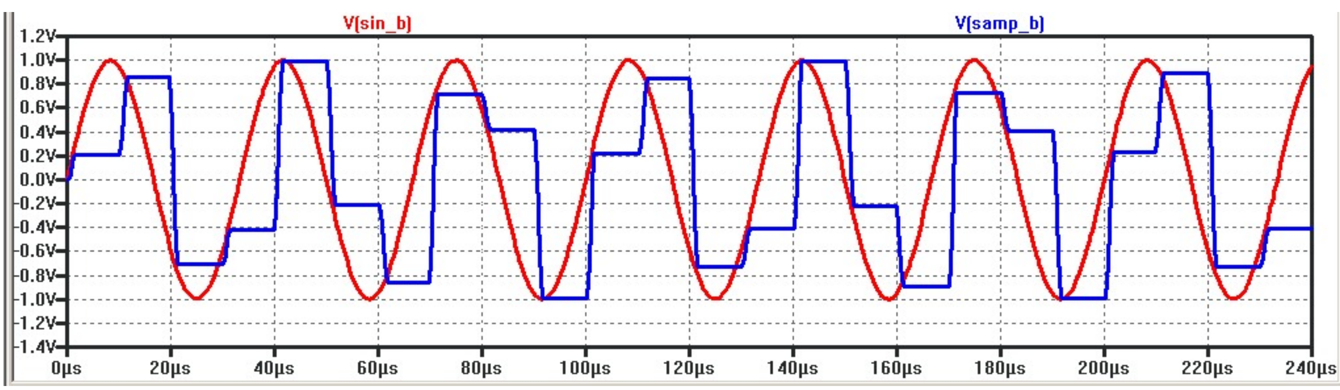
3.1.3 Wave Generator Filters

Points in a user-provided waveform file are played into the P350 digital-to-analog converters at a specified sample rate, often the rate at which it was originally recorded.

When a signal, such as a sine wave, is played at a relatively high sample rate, the DAC output will be a reasonable representation of the original signal. For example, here is a 2 KHz sine wave (red trace), and the resulting waveform after the signal is sampled and reproduced at a sample rate of 100 KHz (blue trace.)



If the signal frequency is high relative to the sample rate, the waveform distortion is more severe. This is a 30 KHz sine wave sampled at 100 KHz:



Not only is the blue reproduced signal very choppy, with spurious high frequency content and jitter, there is also distinct amplitude modulation.

If either of those signals is followed by a lowpass filter, a good sine waveform can be recovered.

The P350 allows unfiltered playback and also includes three selectable digital lowpass filters.

The available filters selections are:

OFF	No digital filtering. The 500 KHz post-DAC analog filter is still functional.
SHORT	A 5-tap digital FIR lowpass filter provides good waveform reconstruction in most situations, with minimal added time delay. This filter automatically adapts to the sample rate.
ADVANCED	A 15-tap digital FIR lowpass filter provides good waveform reconstruction when the signal frequency is closer to the sample rate, with more time delay than the short filter. This filter also adapts to the sample rate.
$SINC^3$	The sinc filter is used in Wavetable mode when the sample rate is expected to exceed 2 MHz. It decimates (merges) wavetable entries that would otherwise be skipped by the 2 MHz DAC rate limit and provides time resolution below the 500 ns DAC update period. This filter has a fixed bandwidth of 500 KHz.

The Short and Advanced filters can be used in Playback mode up to 1 M sample/second, or Wavetable mode at sample rates up to 2 MHz.

In Wavetable mode, when it is expected to operate above 2 MHz, the sinc filter can be enabled to improve waveform reproduction and pulse timing resolution.

See section 6 for details of filter operation.

3.1.4 Wayback Registers

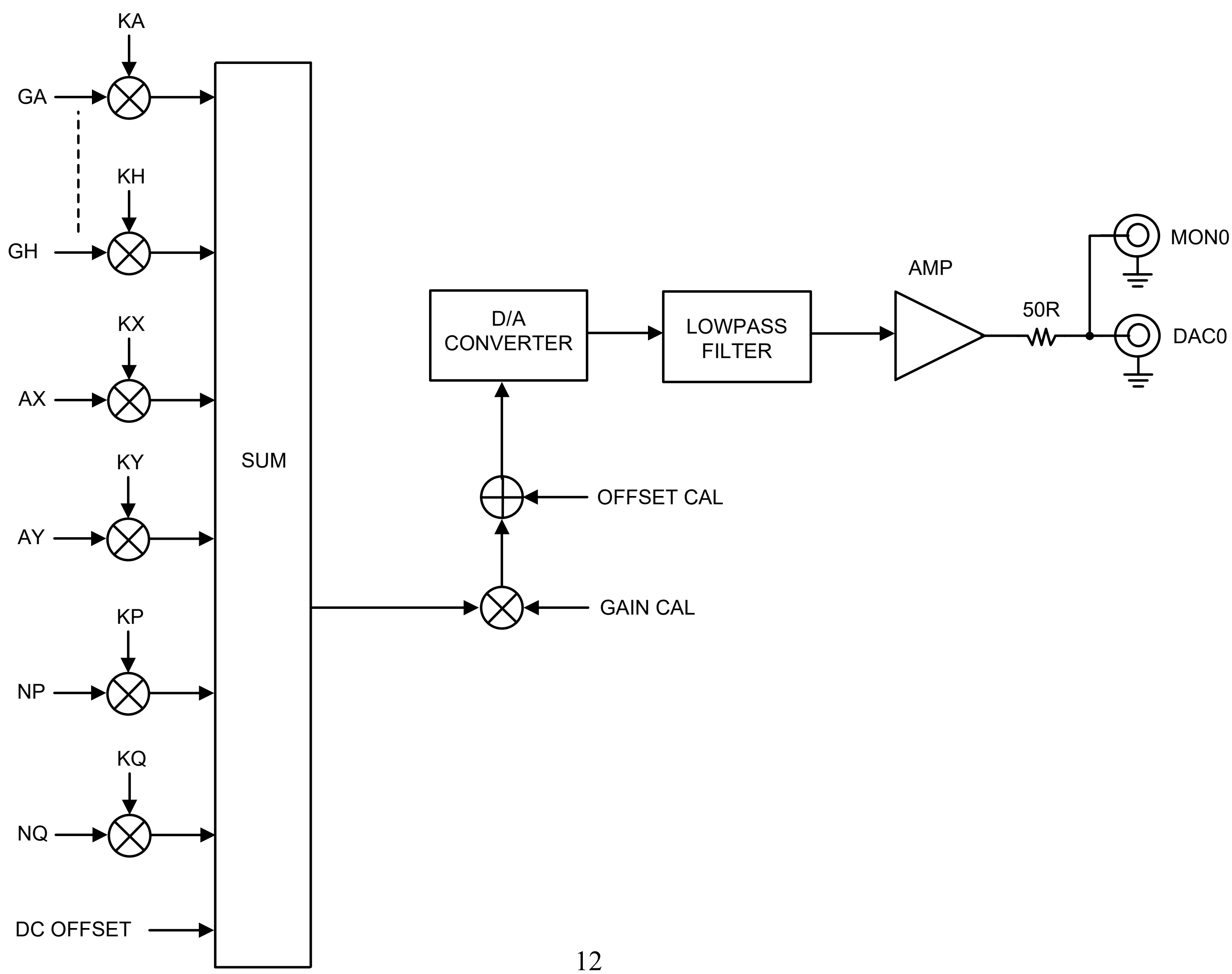
Each GEN channel has a Wayback Register. This is a 64-bit extension of the DDS frequency generator. It is incremented every time the DDS rolls over, namely every time a new sample is extracted from the FIFO or from the wavetable RAM. Data is latched at STROBE time.

If, in Playback mode, some equipment is being stimulated by waveforms from the P350, and some device event or fault is detected, a STROBE operation can be issued to freeze the wayback values. The resulting value is equivalent to a pointer into the waveform file near the time of the fault.

`status -wayback d` returns the 64-bit wayback register for GenD

3.2 DAC Output Channels

There are eight DAC output channels, named Dac0 through Dac7. Each has an input summer, a DC offset adder, a 16-bit D/A converter, lowpass filter and an output amplifier.



Each DAC channel can be programmed to sum any combination of signal sources: waveform generators GenA through GenH, ADCs AX and AY, and the noise generators NP and NQ. Each signal source has its own amplitude scaler, with gains set by gain parameters KA through KQ. These gain scalers can have magnitudes from +99.999 to −99.999.

For example, this structure allows one signal source to be output to multiple DACs at different amplitudes; GenC could be output to Dac1 and Dac2 with opposite-signed gain scalers, to create a differential output. Or one signal could be presented on two outputs, one with ADC or noise summing, and one without.

Complex pulse trains can be generated by summing multiple GEN channels, with the SHIFT or PHASE parameters used to move the timing of features within the overall structure.

The unloaded output of a DAC channel is +10.239 volts for full-scale (0x7FFF) digital data received from a signal source with a gain setting of 1.00. The effective data value can be increased by increasing gain or by summing additional signals or by adding DC offset. Such situations can cause the output to increase to the electrical clipping limit of the output amplifier, typically about ± 12 volts.

3.3 ADC Input Channels

There are two 14-bit ADC input channels, AdcX and AdcY. Each is sampled at 2 MHz and has an analog bandwidth of 100 KHz. The electrical input range is ± 10.24 volts. ADCs can be used to modulate waveform generators, and can be summed into DAC outputs.

Input impedance is about 4K, and open inputs float at about +1.8 volts.

3.4 Noise Generators

There are two random noise generators, NP and NQ. Each generates band-limited Gaussian noise at the equivalent of 1 volt RMS amplitude. Users can program the -3 dB bandwidth of the generated noise, up to 100 KHz. The noise sources have no gain or offset parameters; any required scaling is performed in GEN or DAC blocks.

The noise waveform is nearly Gaussian, with a crest factor of about 4.2.

Noise generators can be summed into DAC output blocks.

3.5 Power Supply

The P350 is powered by an external 15 volt supply. With light external loads, nominal supply current is about 750 mA. Worst case, with all outputs at -10.24 volts DC and external 50 ohm loads, supply current will be about 1.5 amps.

4 Software Interface

4.1 Overview

The Xilinx ZYNQ FPGA includes FPGA programmable logic and two hard 600 MHz ARM processor cores. The P350 runs GNU/Linux to provide standard interfaces to control its functionality.

The operating system, file system, and applications are stored on a plugin microSD card. At power-up, the ARM boots the OS and configures the FPGA from files on this card. These files may be remotely replaced, and the microSD could be physically replaced if ever required, to reinitialize system software.

Once the system is running, commands are executed from the BusyBox “ash” program (a scaled down shell comparable to “bash”) via an SSH remote login session. Files are transferred to and from the device using the SCP protocol.

The factory default IP address is 192.168.XXX.YYY, where XXX and YYY are set by the IP address rotary switches. See section 4.15.

If the IP address of a P350 is 192.168.0.0, log in with the shell command:

```
$ ssh root@192.168.0.0
```

The user name is always “root”. When prompted for a password, the factory default is "highland". A user may change this password with the “passwd" program during the ssh session.

The file system is in volatile memory, except for the directory "/mnt", where the microSD card is mounted. Changes made to any other directory are lost when the P350 reboots. For this reason the Linux password file “passwd” is stored in “/mnt” rather than “/etc”.

The default base IP address of 192.168.0.0 can be changed by using the "ipset" command. Changes to the base address or switches will not affect the actual IP address until the P350 reboots.

Waveform files are pure binary, one signed 16-bit integer per waveform sample. 0x7FFF is +10.239 volts out with unity gain scaling. They are generally stored in "/mnt/". Users can store files in other directories, and include the full path in a -file command.

Once the system has initialized, control of the waveform generators and associated logic is usually done by executing high-level commands. These commands invoke Linux programs which parse and execute the ASCII command lines. Lower-level commands are provided to allow direct access to FPGA registers.

4.2 Command Syntax

Commands are ASCII text, terminated by an end-of-line character. Long commands may be extended onto the next line with the backslash '\' escape. Blank lines and excess whitespace are ignored.

The pound character, "#", starts a comment anywhere on the line. The comment is terminated by the end of the line, and may not be extended onto the next line.

The general command syntax is

```
gen -c abc -mode wave -freq 25000 -start 0x2000 -na 1024
```

The overall high-level command set is:

`default`		restore powerup settings
`strobe`		Load buffered settings into GEN or DAC channels
`gen`		GenA...GenH waveform generator controls
	`-c`	name one or more applicable gen channels
	`-mode`	set Off, Play or Wavetable mode
	`-file`	open waveform file
	`-freq`	set DDS sample rate in Hz
	`-filt`	filter selection
	`-mult`	select modulation/multiplier source
	`-moff`	set modulation offset
	`-mgain`	set modulation gain
	`-shift`	set time shift, Playback mode, range ± 999.99 samples
	`-pointer`	declare RAM address for Wavetable file load or `-data`
	`-count`	set load size for Wavetable file load
	`-start`	Start address, Wavetable mode
	`-na`	Number of points/blocksize, Wavetable mode
	`-phase`	Phase lead, degrees, Wavetable mode
	`-data`	single write into wave RAM, Wavetable mode
	`-sine`	loads sine wave, Wavetable mode
	`-square`	loads square wave, Wavetable mode
	`-tri`	loads triangle wave, Wavetable mode
	`-saw`	loads sawtooth wave, Wavetable mode
	`-go`	enables GEN channel waveform output

`dac`		Dac0...Dac7 analog output controls
	`-c`	name one or more applicable DAC channels
	`-sumz`	selects signal sources to sum
	`-offset`	set DC offset
	`-off`	disable DAC channel; output = 0.
`noise`		program a noise generator
	`-c`	name one or two noise generators
	`-freq`	program the -3 dB noise bandwidth
`relays`		load BIST relays
`monitor`		select digital monitor signal
`aux`		control AUX connector
`sys`		control SYS connector
`status`		send status report
`bist`		initiates self-test
`ipset`		set IP base address

4.3 DEFAULT

The `default` command restores all GEN and DAC settings to their powerup states.

At powerup, or at the `default` command, the following are set:

Waveform generators GenA...GenH

mode	off
GO	0
filter	off
modulation	off, gain=1, offset=0
Frequency	1 KHz
shift	0
phase	0
start	0
NA	1024
pointer	0

count 1024

DAC outputs Dac0...Dac7

DC offsets 0

summing gains 0

Noise sources NP and NQ:

bandwidths 1 KHz

Whenever a GEN is set to `-mode off` or a DAC is set `-off` these defaults are also installed on that channel.

4.4 STROBE

The `strobe` command installs certain buffered GEN or DAC control settings, and snapshots realtime registers for readback. Multiple GEN and DAC commands may be executed to set parameters, and can then be simultaneously installed by a `strobe` operation. This maintains phase coherence across multiple outputs.

`strobe` strobes everything; same as `strobe 0xFFFFFFFF`

`strobe mask` strobes selectively. The mask is

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D7	D6	D5	D4	D3	D2	D1	D0	GH	GG	GF	GE	GD	GC	GB	GA

Where '1' strobes the named GEN or DAC.

`strobe -c CHAN` strobes enumerated channel; CHAN may be a-h, 0-7, x, y, p, q, or some combination, eg. strobe `-c ab01`.

To maintain "gear ratio" frequency and phase coherence between channels, program channel frequencies to be precise integer multiples or ratios, and start waveforms, or modify realtime channel parameters, using the `strobe` mechanism.

4.5 GEN Waveform Generator Controls

The `gen` command controls the eight waveform generators GenA through GenH.

A `gen` command for waveform generator A might look like:

```
gen -c a -mode play -freq 8000 -filt adv -file /mnt/waves.dat
```

or

```
gen -c a -mode wave -freq 25e6 -filt sinc -start 1024 -na 750
```

One `gen` command can apply to multiple waveform generator channels

```
gen -c abcf -freq 200e3
```

Many settings are buffered until the `strobe` operation is executed, as noted below. The `strobe` mechanism allows critical realtime parameters to be coherently changed across multiple channels.

Generators are usually initialized and loaded when mode<>off but GO is not yet set.

A `gen` command line may include the following parameters. They are applied to all the named generator channels.

`-c` names the generators, a through h, to be affected by this command line. This must be first on the `gen` command line.

```
-c a
-c bcdh
```

`-mode` sets the GEN channel operating mode. The command performs basic channel initializations and puts the channel FPGA logic into the proper configuration.

```
-mode off           channel inactive, output zero
-mode play          sets channel to Playback/FIFO mode
-mode wave          sets channel to Wavetable/loop mode
```

`-mode off` closes any open files, clears the FIFO, zeroes the channel control register, and forces the GEN data output to zero.

any `-mode` command sets

start = 0	NA = 1024
pointer = 0	count = 1024
phase = 0	shift = 0
filter = off	modulation = off
frequency = 1 KHz	

Does not require `strobe`.

`-file` In Playback mode, `-file` opens a waveform file to play, and loads the FIFO in anticipation of a `-go` command. Does not require `strobe`.

```
-file /mnt/blades.dat
```

`-pointer`
`-count` In Wavetable mode, `-file` opens a file and loads a region of the waveform RAM. Users must also declare the `pointer` and `count` parameters.

```
-pointer 0x1000 -count 1250 -file /mnt/sensor2.dat
```

The file is closed as soon as the RAM load is complete. Premature EOF (file too short) is an error.

See `-data` as an alternate way to load the wavetable RAM.

`-go` enables a waveform generator to begin output. Requires `strobe`.

```
-go
```

`-freq` is the sample playback frequency in Hz. The max is 1 MHz for Playback mode, 50 MHz for Wavetable mode. Frequencies are quantized to 1 milliHertz. Requires `strobe`.

```
-freq 500000
-freq 30e6
```

`-freq 0` freezes a generator output

`-filt` selects channel digital filtering. Requires `strobe`.

```
-filt off          filtering off

-filt sho          short filter
-filt spl          equivalent to "sho"
-filt short

-filt adv          advanced filtering
-filt advanced

-filt sinc         500 kHz sinc³ filter
```

`-mult` selects one source to AM modulate this channel. Sources are a...h, x, y, p, or q. Does not require `strobe`.

```
-mult off        disable modulation
-mult y          modulate this channel by AdcY input
```

```
-moff  1.00      set modulation offset to 1 volt
-mgain 2.50      set modulation gain to 2.5
```

The above sequence would result in an AdcY input of 1 to 5 volts varying the GEN output amplitude from 0 to 100%.

`-shift` In Playback mode, `-shift` sets a channel time shift, measured in sample times. Range is ± 999.999 samples. If playback frequency is 100 KHz,

`-shift 240.5` shift output 2.405 msec forward in time; samples come out sooner

`-shift -15.2` shift output 152 usec later in time

Requires `strobe`.

The following `gen` options apply in Wavetable mode:

`-phase` In Wavetable mode, `-phase` sets added waveform phase lead, in degrees.

```
-phase 45.00
```

Range is ± 359.99 degrees. Negative values specify phase lag. The entire waveform buffer of NA points is the equivalent of 360 degrees. If NA were equal to 1000, `-phase 45.00` would advance the realtime waveform address by 125 table locations and shift a sine wave left on an oscilloscope. Requires `strobe`.

`-sine` loads the wavetable RAM, beginning at address `pointer`, with an integer number of full-amplitude sine wave cycles, into `count` sequential memory locations.

```
-pointer 0x2000 -count 3000 -sine 3
```

`-tri` like `-sine`, but loads a triangle wave
`-saw` like `-sine`, but loads a sawtooth
`-square` like `-sine`, but loads a square wave

`-start` sets the waveform-generation start address in wavetable RAM, 0 to 32767. Requires `strobe`.

```
-start 0x1000
```

For an already-running wavetable generator, the sequence

```
gen -c h -start 0x4000
strobe
```

performs a block jump of the active GenH wavetable region.

`-na` sets the number of wavetable points to play (i.e., block size) 1 to 32768. N must be set once after the -mode command, and should not be changed while waveforms are active. Requires `strobe`.

```
-na 2000
```

`-data` loads data into the wavetable RAM, starting at address `pointer`.

```
-pointer 2000 -data 0x4000 -data 0x7FFE
```

`Pointer` is incremented mod 32768 at each data point load.

The `-data` operation can load the wavetable RAM, as alternate to `-file`.

4.6 DAC Output Channel Controls

The DAC command controls the eight electrical output channels Dac0 through Dac7. This example

```
dac -c 3 -off -suma 0.52 -sumy −3.582 -offset 2.5
strobe
```

enables the summing of two named signal sources, GenA and AdcY, into the Dac3 output. Sources a...h are GEN channels, x and y are ADCs, and p and q are noise sources. Up to 12 signal sources can be summed and up to 8 DACs can be named. Each summed source has an associated amplitude scaler, in the range of ± 99.999. The above example command could be executed as five lines,

`dac -c 3 -off`	zero all summing multipliers and offset
`dac -c 3 -suma 0.52`	sum in GenA, gain = 0.52
`dac -c 3 -sumy −3.582`	sum in AdcY, gain = -3.582
`dac -c 3 -offset 2.5`	add +2.5 volts offset
`strobe`	install all that

with the same result. The command:

```
dac -c 01234567 -off
```

returns all DACs to their default states; it clears all summing gains and clears the DC offset for all eight DACs. Output goes to zero volts.

`-off` should be used whenever the current DAC setup might be unknown.

The command line

```
dac -c 2 -offset -5.25
```

sets the DC offset of Dac2 to −5.25 volts. The allowed offset range is ± 10.0 volts.

If the data output of a GEN channel is positive full scale (0x7FFF waveform file data) and that source is summed alone into a DAC output with gain scaler of 1.00, the electrical output without added offset will be +10.2397 volts.

Similarly, if an ADC with gain of 1.00 is summed into a DAC output,

```
dac -c 5 -sumy 1.00
```

the electrical gain from the AdcY input connector to the Dac5 output connector will be 1. If Dac5 were loaded by 50 ohms, the gain would be 0.5.

4.7 ADC Controls

There are two analog inputs, AdcX and AdcY. Users can see the realtime digitized values in the STATUS report. There are no other controls. Any required gain and offset factors are programmed in the downstream GEN or DAC channels.

4.8 Noise Generator Controls

The `noise` command programs the NP and NQ noise generator -3 dB bandwidths:

`noise -c p -freq 5000`	set bandwidth of NP to 5 KHz
`noise -c pq -freq 1e4`	set the bandwidth of NP and NQ to 10 KHz

The allowed frequency range is 0 to 100 KHz. The amplitude is always the equivalent of 1 volt RMS. If NP is summed into Dac0 with a summing gain of 1.00, the noise at the Dac0 connector will be 1 volt RMS.

4.9 Relay Controls

The "relays" command connects a DAC output and/or one or both ADCs to the BIST bus. This allows DAC-to-ADC loopback testing. The BIST bus is also available externally on the BIST connector.

Command options are

`-c CHAN`	CHAN is x or y for ADCs, or 0 to 7 for DACs.
`-z`	apply a 50-Ohm load to the BIST bus

`-off`	remove everything from the BIST bus

Only one DAC relay may be enabled at a time, but any combination of ADCs with or without a DAC is permitted.

Examples:

`relays -c xy1 -z`	Apply ADCs X and Y, DAC channel 1, and a 50-Ohm load to the BIST bus.
`relays -off`	Removes everything from the BIST bus.
`relays -12`	Illegal. Returns an error.

4.10 Digital Monitor Control

The `monitor nnn` command

selects one FPGA logic signal to drive the front-panel digital monitor connector. Selections are:

0x00	Ground
0x01	High
0x02	2 MHz clock
0x03	reserved
0x04	64 MHz clock
0x05	ARM software timing flag
0x06	FPGA register access flag
0x07	STROBE pulse
0x08	SYS bus level
0x09	File demon flag
0x0A	Ram write flag
0x10	GenA DDS MSB
0x11	GenB DDS MSB
0x12	GenC DDS MSB
0x13	GenD DDS MSB
0x14	GenE DDS MSB
0x15	GenF DDS MSB
0x16	GenG DDS MSB
0x17	GenH DDS MSB
0x20	GenA GO bit
0x21	GenB GO bit
0x22	GenC GO bit
0x23	GenD GO bit
0x24	GenE GO bit

0x25	GenF GO bit
0x26	GenG GO bit
0x27	GenH GO bit

The electrical output at the digital monitor connector is +1 volt nominal high, 50 ohm source impedance.

The GO bits can be used to trigger external equipment when a waveform output begins.

The `monitor 0` and `monitor 1` commands can be used to generate a user-controlled logic level or output trigger.

4.11 AUX Connector Control

`aux`	controls AUX connector. The currently supported values of the command are 0 and 1
`aux 0`	AUX is unused
`aux 1`	a rising-edge TTL input on the AUX connector generates a global STROBE operation

4.12 SYS Connector Control

`sys`	controls the SYS connector

SYS is reserved for future multi-box synchronization.

4.13 Status Report

`status` returns a status report

A typical status report looks like:

```
p350-09999# status
Highland Technology Model P350-99990 SN 09999
Firmware 23E354A17  Build 1430428740
IP 192.168.0.0      MAC 00:0A:35:00:01:22
Gen mode go     freq     filt mul  start   na   ph/shift file
  0  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  1  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  2  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  3  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  4  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  5  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  6  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
  7  OFF  X    +1000.000  OFF OFF      0   1024   +0.00
Dac offset suma   sumb   sumc   sumd   sume   sumf   sumg   sumh
  0 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  1 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  2 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  3 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  4 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  5 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  6 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
  7 +0.00 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000 +0.000
Dac  sumx   sumy   sump   sumq     Wayback regs
  0 +0.000 +0.000 +0.000 +0.000      0 0x0000000000000000
  1 +0.000 +0.000 +0.000 +0.000      1 0x0000000000000000
  2 +0.000 +0.000 +0.000 +0.000      2 0x0000000000000000
  3 +0.000 +0.000 +0.000 +0.000      3 0x0000000000000000
  4 +0.000 +0.000 +0.000 +0.000      4 0x0000000000000000
  5 +0.000 +0.000 +0.000 +0.000      5 0x0000000000000000
  6 +0.000 +0.000 +0.000 +0.000      6 0x0000000000000000
  7 +0.000 +0.000 +0.000 +0.000      7 0x0000000000000000
ADCs        Noise
  X +1.892    P +0.000 Hz
  Y +1.882    Q +0.000 Hz
BIST: not run   Cal: OK       power: OK
p350-09999#
```

Other `STATUS` commands include:

`status -free`	returns eight FIFO free counts
`status -wayback m`	returns one 64-bit wayback register
`status -ipswitch`	returns realtime combined IP base + switch setting (future IP address after reboot)
`status -d`	returns dash number
`status -s`	returns serial number
`status -S`	returns 5-digit serial number
`status -dflag`	returns eight DFLAG file demon flags
`status -power`	returns internal power supply report

4.14 BIST

Built-In-Self-Test can be invoked by pressing the front-panel BIST button or by issuing the `bist` serial command.

BIST tests internal power supplies, all eight DAC outputs, and both ADC channels. This is a functional test and cannot verify P350 calibration. BIST ends with the P350 in its default powerup state.

The front-panel BIST LED will flash orange during the tests, and settle red or green at the end, to indicate error or success.

If BIST is invoked by the pushbutton, a log file will be created to report test results. If BIST is invoked by a shell command, the report will be returned.

4.15 IP Address Set

`ipset 192.168.0.0` sets the IP base address

The low 12 bits of the declared base address are masked out and replaced by the 12 bits from the three IP Address rotary switches. The base value is saved in the cal table. The full IP address appears in the STATUS report. The system must be rebooted to install the new base+switch address.

`ipset 0.0.0.0` uses DHCP regardless of the switch settings.

`ipset DHCP` uses DHCP regardless of the switch settings.

`ipset DEFAULT` sets the base IP address to 192.168.0.0.

In DHCP mode, the host name is "P350-xxxx" where xxxx is the unit serial number.

4.16 Waveform Files

Waveform files are generally stored in Linux directory /mnt/, but can be stored elsewhere, as long as the full path is included in a `gen -file` command.

A waveform file is pure binary, a number of signed 16-bit integers, with no headers or overhead data. Data 0x7FFF is positive full scale, and will output +10.239 volts through a DAC channel that is programmed for gain = 1.000. Data 0x8000 is negative full scale, -10.24 volts. DAC block gain settings can scale output voltages as needed.

The FAT32 file structure limits each file to 4G bytes, or 2G waveform samples. That corresponds to about 5.5 hours of file playback at 100K samples/second.

Short waveform files can be used to load all, or segments of, the waveform RAM in Wavetable mode.

4.17 USB Notes

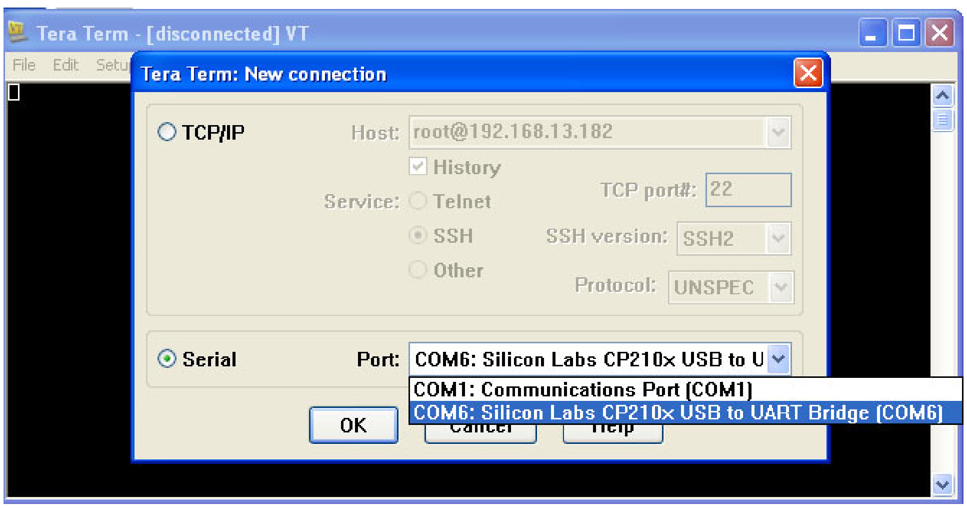
To connect to the P350 a terminal program is required. For Windows machines Tera Term is recommended, which can be downloaded from the Tera Term Project http://ttssh2.sourceforge.jp.

For Linux machines use the terminal program of your choice, Kermit or GtkTerm for example.

Windows USB example

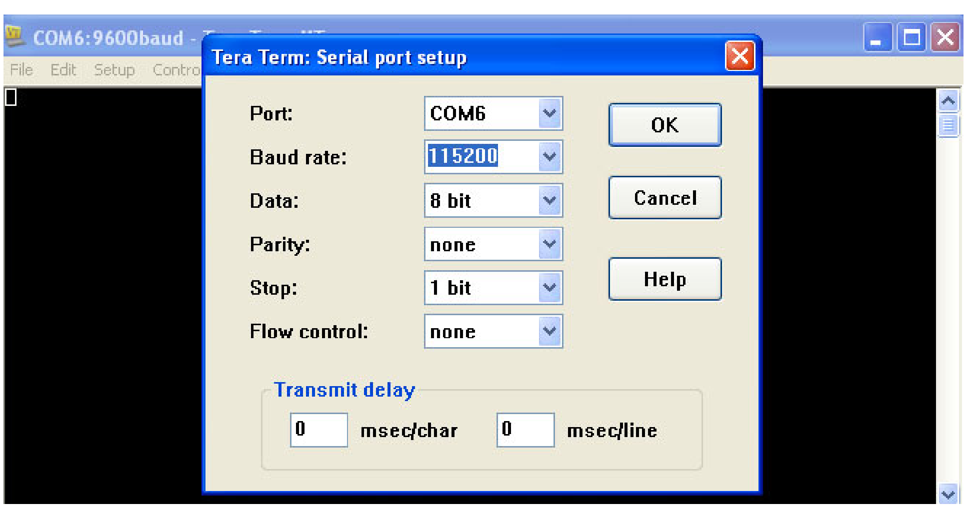
Connect the P350 USB port to a PC, using a MicroUSB to USB cable.

Open Tera Term, and choose serial communication. In the port section choose the COM port that shows the Silicon Labs CP210x USB to UART Bridge. Click OK.



Go to the Setup menu on the top of the terminal and from the drop down menu choose Serial port.

Choose the Baud rate to be 115200, leave everything else as is. Click OK.



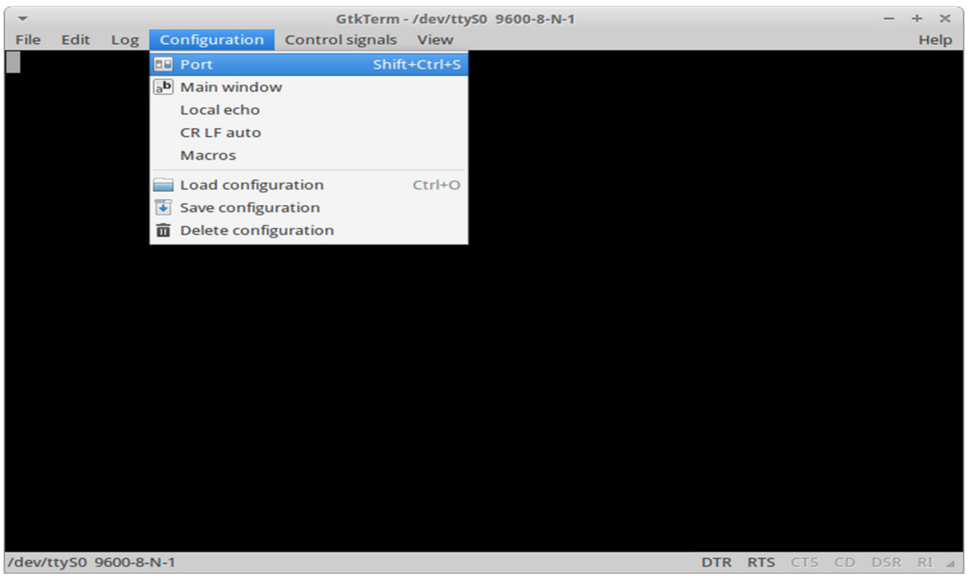
Press "enter" and the P350 prompt should appear. Type "status" and the P350 status report should appear.

Linux USB example

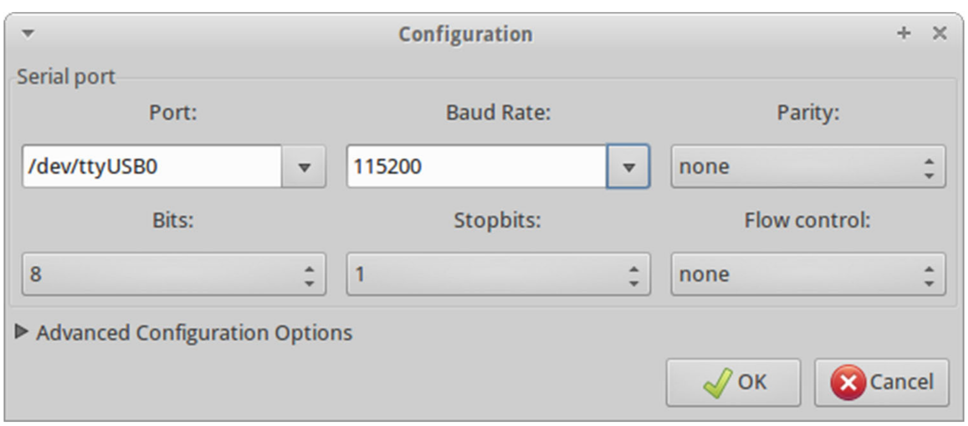
Connect the P350 USB port to a PC, using a MicroUSB to USB cable.

Open a serial terminal program, GtkTerm in this example.

Go to the configuration menu and from the drop down menu choose Port.



In the configuration window choose the USB port that corresponds to the P350 and the Baud Rate: 115200.



Press "enter" and the P350 prompt should appear. Type "status" and the P350 status report should appear.

Kermit users may create a .kermitrc setup file as follows:

```
set line /dev/ttyUSB0    (or appropriate serial port)
set baud 115200
set carrier off
set parity none
set flow none
connect
set local on
```

5 Examples

5.1 Quickstart Example

The following example is a simple way to output a 1 KHz sine wave on the Dac0 output.

`default`	initialize; NA=1024 start, pointer = 0
`gen -c a -mode wave -filt sho`	set GenA to wavetable mode, short filter
`gen -c a -freq 1024000 -sine 1`	set play rate, load one sine cycle
`dac -c 0 -suma 1`	route GenA data into Dac0 output
`gen -c a -go`	enable GenA
`strobe`	begin output

Use

```
gen -c a -mode off
```

to shut off the sinewave.

5.2 Basic File Playback Example

The following example initializes GenD in Playback mode, and streams file "demo.dat" at 40000 samples per second. The output appears on the front-panel Dac4 connector.

`gen -c d -mode play -file /mnt/demo.dat`	GenD to Playback mode, GO=0 begin streaming file data into FIFO
`gen -c d -filt spl -freq 40000 -go`	set GenD sample rate and filter; enable GO bit of GenD
`dac -c 4 -off -sumd 1.00 -offset 0`	clear Dac4 summing, select GenD, unity gain, no DC offset
`strobe`	STROBE to install above settings and begin output

Terminate that Play session with the command

```
gen -c d -mode off
```

The playback frequency and summing gain can be changed at any time during playback, and require another `strobe` to install settings.

5.3 Multichannel Playback Example

To start multiple channels synchronously, repeat the channel setup sequence as above, but wait until all setups are done before executing the `strobe` command. For example,

`gen -c abc -mode play -freq 2e4`	GENs a,b,c Playback mode, 20KHz
`gen -c a -file /mnt/wavea.dat`	open waveform file for GenA
`gen -c b -file /mnt/waveb.dat`	open waveform file for GenB
`gen -c c -file /mnt/wavec.dat`	open waveform file for GenC
`dac -c 0 -off -suma 1.00`	pipe GenA to Dac0 output
`dac -c 1 -off -sumb 1.00`	pipe GenB to Dac1 output
`dac -c 2 -off -sumc 1.00`	pipe GenC to Dac2 output
`gen -c abc -go`	enable the generators
`strobe`	and start waveforms

5.4 Basic Wavetable Example

The following example initializes GenB in Wavetable mode, and loads waveform RAM from a file. Wave generation is begun at RAM address 0, looping through 2000 points at 250 KHz point rate, sweeping the entire set at 125 Hz.

`gen -c b -mode wave -na 2000`	GenB: Wavetable mode, 2000 points
	sets filtering/modulation off, GO off
`gen -c b -pointer 0 -count 2000 -file /mnt/waves.dat`	
	load binary data from file into first 2000 points of GenB memory
`gen -c b -start 0 -freq 250e3 -filt adv`	
	set runtime start address, sample frequency, advanced filtering
`dac -c 7 -off -sumb 1.00 -offset 0`	sum signal into Dac7, no offset
`gen -c b -go`	enable GenB
`strobe`	begin output on connector 7

While the generator is running, new waveform data can be loaded into another region of the waveform memory, using either the `-file` or `-data` functions.

A realtime jump can be made, to output waveforms from another region of the waveform RAM. The block size NA may be changed if desired.

`gen -c fgh -start 4000`	jump the start address of three GENs
`strobe`	simultaneously

6 Digital Filtering Notes

The available GEN lowpass filter selections are:

OFF	No digital filtering. The 500 KHz post-DAC analog filter is still functional.
SHORT	A 5-tap digital FIR lowpass filter provides good waveform reconstruction in most situations, with minimal added time delay. This filter automatically adapts to the sample rate.
ADVANCED	A 15-tap digital FIR lowpass filter provides good waveform reconstruction when the signal frequency is closer to the sample rate, with more time delay than the short filter. This filter also adapts to the sample rate.
SINC[3]	The sinc filter is used in Wavetable mode when the sample rate is expected to exceed 2 MHz. It decimates (merges) wavetable entries that would otherwise be skipped by the 2 MHz DAC rate and extends time resolution below the 500 ns DAC quantization. This filter has a fixed bandwidth of 500 KHz.

The Short and Advanced filters can be used in Playback mode at sample rates up to 1 MHz, or Wavetable mode at sample rates up to 2 MHz. In wavetable mode, when it is expected to operate above 2 MHz, the sinc filter can be enabled to improve waveform reproduction.

Filter mode 0 is "off". Waveform generator data is presented to DAC blocks at 2 Msps, so there can be 500 ns peak-to-peak jitter (about 200 ns RMS). Unfiltered data steps will be distinct, so sine waves will look noisy and distorted unless the sample rate is much higher than the signal frequency.

Filter modes 1 and 2 are "sho" (short) and “adv” (advanced). Both settings use a heavily oversampled FIR filter to calculate the continuous time response of the waveform generator data followed by an anti-aliasing filter tracking the waveform sample rate. That continuous time data is then resampled at 2 Msps for DAC output. Both filters are linear-phase, with a constant delay and some slight overshoot. The short filter uses 5 waveform points at a time and has a delay of 2 samples at the original waveform sample rate. The advanced filter has better alias rejection and less attenuation through the passband of the original signal, but uses 15 waveform points, with a corresponding delay of 8 samples.

The risetime of the short and advanced filters scales with the bandwidth, which itself tracks the playback sample rate. The 10:90 risetime is about one sample period.

These filters reject the high-frequency aliases that would otherwise distort waveform components of high frequencies relative to the sample rate. Such distortion could show both jagged edges and beat frequencies, which can appear as a wobble in either the amplitude of the signal or in the zero baseline. This appears at startlingly low frequencies; a 10V peak 90 Hz sine wave sampled at 1 ksps will appear to have roughly 180mV of that amplitude transferred down to 10 Hz instead, i.e. 9.82 V * sin(2πt*(90 Hz)) + 0.18 V * sin(2πt*(10 Hz)). The short filter will reduce this amplitude transfer to about 8 mV. The advanced filter will reduce the amplitude transfer to under 0.5 mV.

The rate-tracking FIR filters (short and advanced) are only capable of operation up to 2 Msps. This accommodates all cases for the Playback mode, but not for Wavetable mode. If the sample rate of a Wavetable mode channel is expected to exceed 2 Msps, then neither the short nor advanced filters should be enabled on that channel.

Filter mode 3 is “sinc”, a 500 kHz $sinc^3$ filter. This is meant primarily for decimation of Wavetable channels that will exceed 2 Msps. In Wavetable mode, points are read from the waveform RAM at a programmable rate of up to 50 Msps. If the programmed point step frequency is above 2 Msps, leaving the filter off will mean that some samples are skipped over and not output. For instance, at 6 Msps, only one out of each 3 samples in the wavetable will reach the output. By using the sinc filter, the output will instead reflect a weighted average of all the wavetable samples. This is particularly useful in pulse generation applications, where the weighted averaging serves to improve the effective time resolution of the pulse below the 500 ns implied by the 2 Msps DAC rate. Note that unlike the rate-adaptive FIRs, where the response is a function of programmed DDS rate, the sinc filter has a fixed frequency response regardless of channel programming.

The sinc filter will continue to work properly at any sample rate, no matter how slow, but the smoothing effect on the waveform will diminish below 1 Msps.

The sinc filter can be used to generate low-jitter pulse trains with sub-100 ns time resolution, as might be used to simulate shaft torque transducers. With sinc enabled, the values of points in waveform memory, or the Wavetable `-phase` option, can be used to trim pulse positions to high resolution.

In general, filter selection should be based on the following guidelines:

- Use no filter to ensure that each data point emitted by the DAC is the one in the wave file with no interpolation, or to hit the absolute maximum signal bandwidth possible.

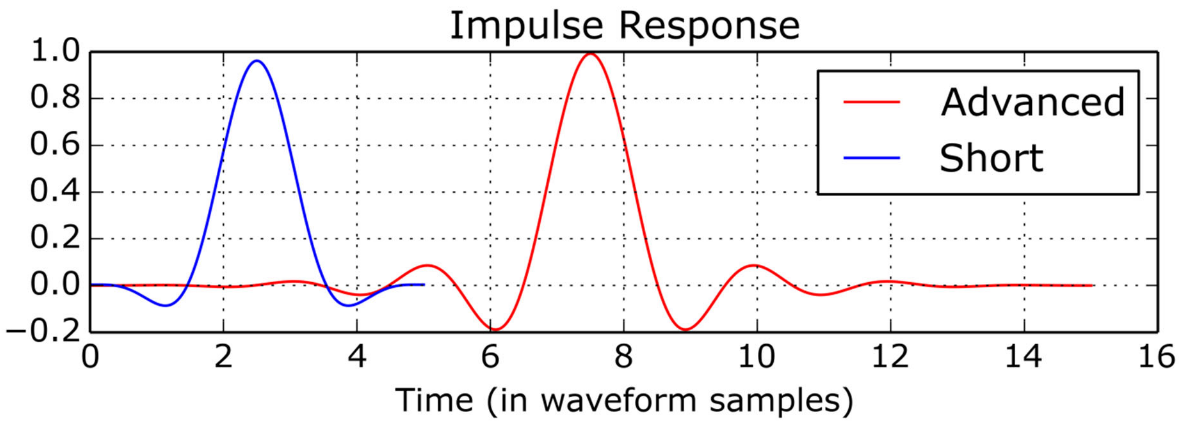
- Use the sinc filter for the best time resolution on primarily rectangular waveforms such as encoder simulations, or when the DDS rate will exceed 2 MHz.

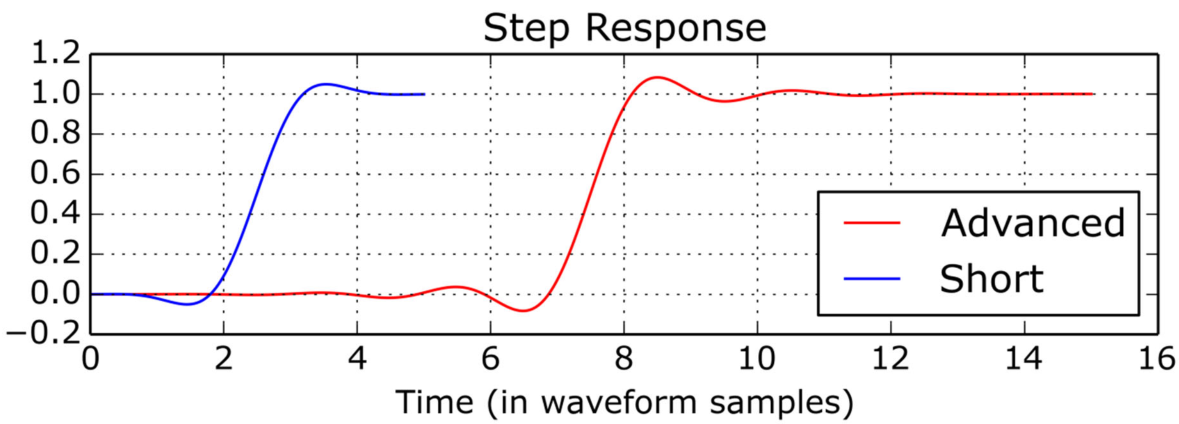
- Use the short filter below 2 Msps when relative signal delay matters, such as when using multiple waveform generator channels at different frequencies, but signal/sample frequency ratios are low, perhaps 1:10.

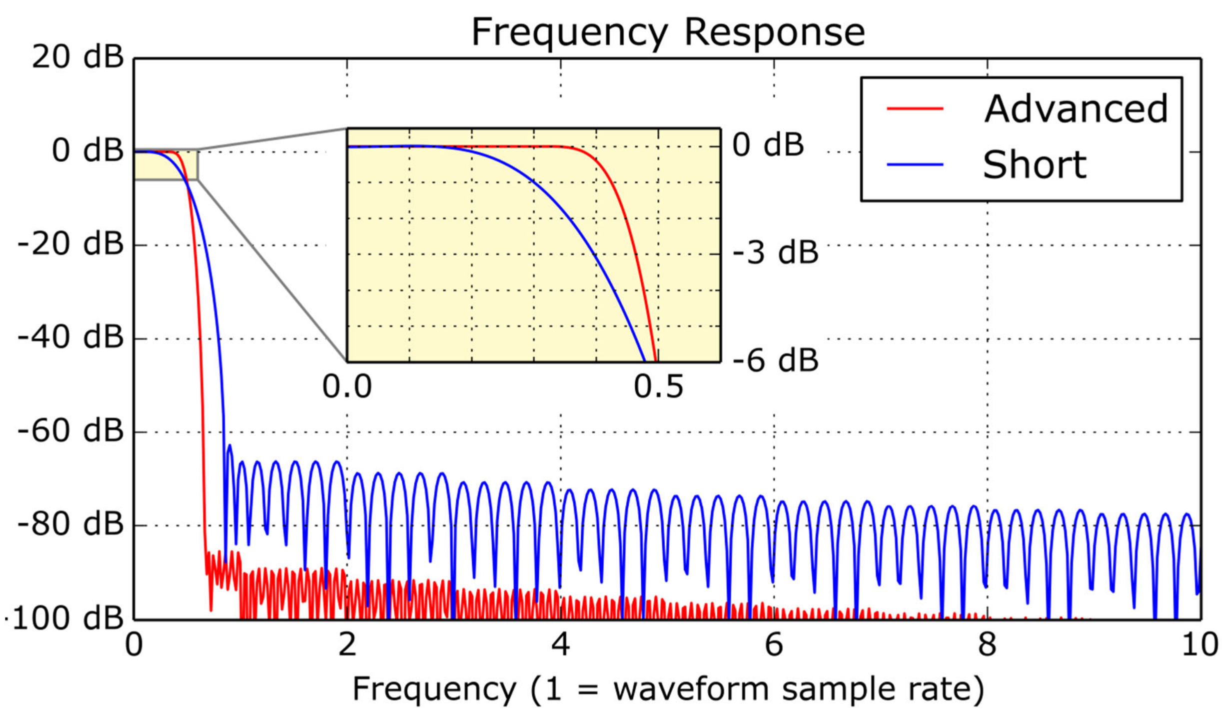
- Use the advanced filter below 2 Msps when the waveform may have significant components fairly close to the Nyquist rate of $F_{samp}/2$. The advanced filter will have superior reconstruction and less frequency rolloff than the short filter.

- As a general rule, use the advanced filter below 2 Msps, and the sinc filter above this rate.

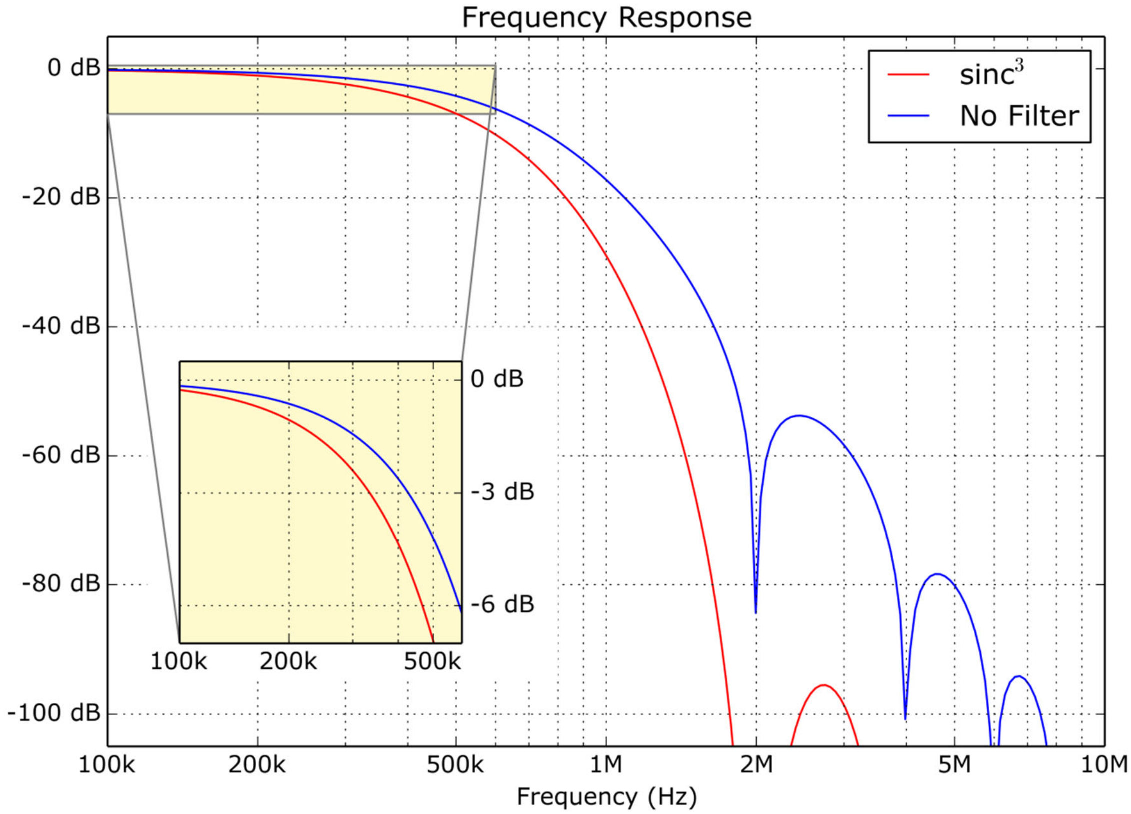
Short and Advanced Filter Responses





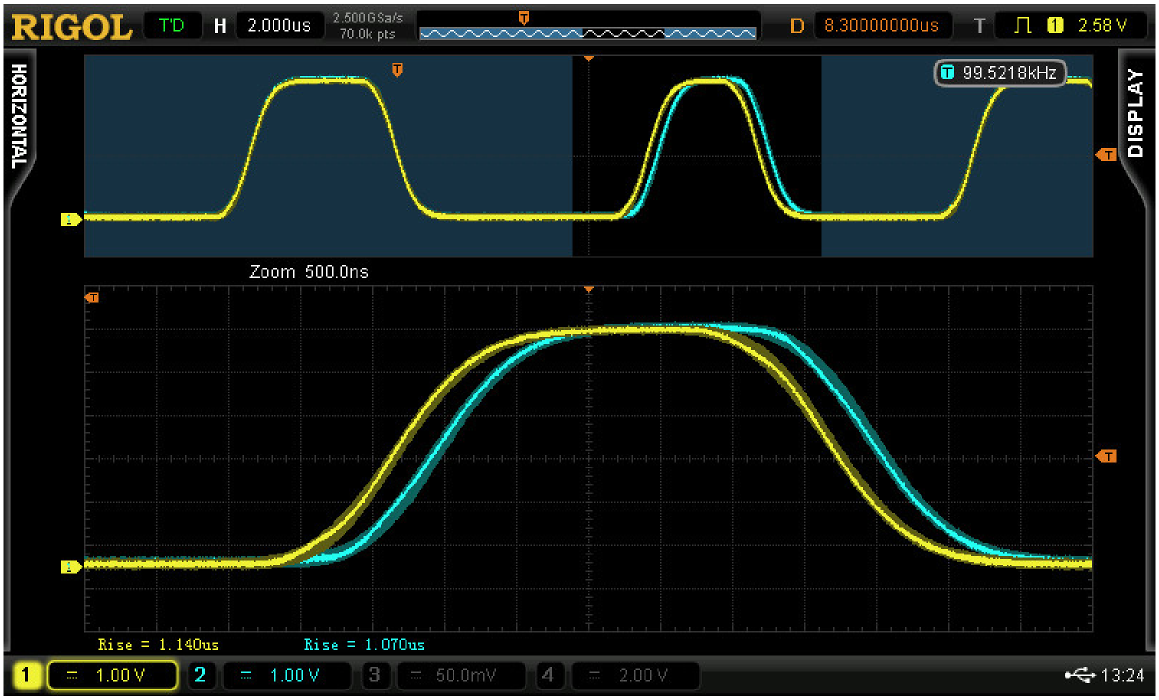


Sinc Filter Response



The following scope screen shows two waveforms created by two separate GEN channels, shown in yellow and blue. Both have NA=400, with a programmed sample rate of 19.9 MHz. The wide pulses are identical, and the narrow pulses are offset by 15 samples, about 300 nanoseconds. With the sinc filters off, pulse edges are quantized to the 2 MHz DAC clock rate, so the edges have jitter and the 300 ns offset is not resolved.

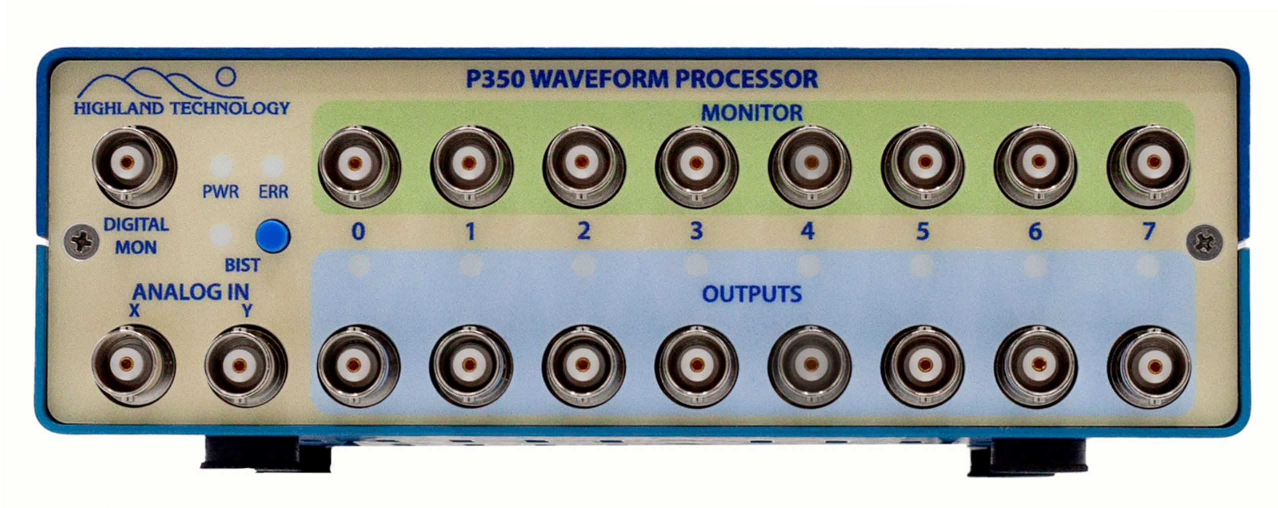
In the following case, the sinc filters are enabled on both GEN channels.



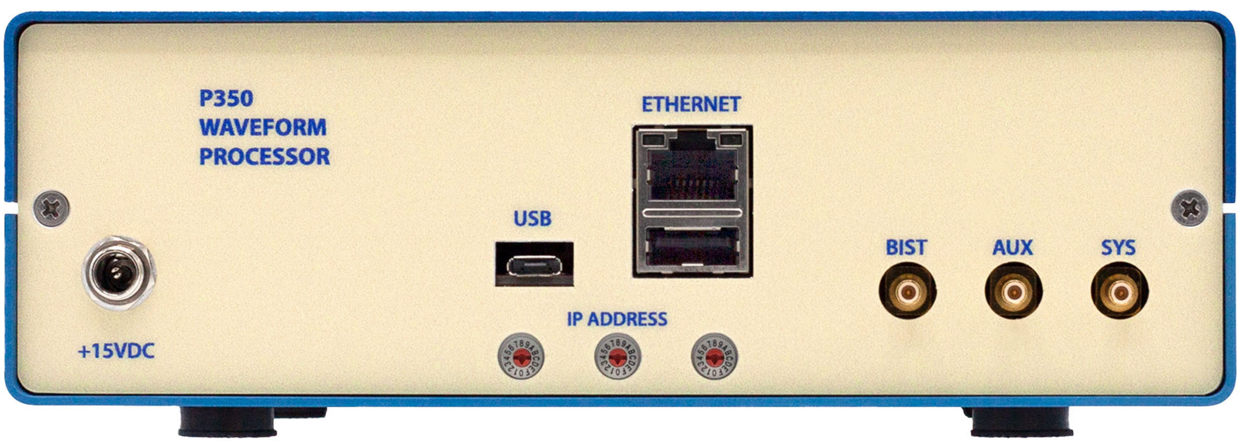
The 500 ns DAC quantization is removed, and the 300 ns pulse offset is clearly resolved.

For a step transition in the wavetable memory, the output risetime is about 1 microsecond.

7 Packaging



Front Panel



Rear Panel

8 Versions

P350-1 8-channel waveform playback/ARB module

9 Customization

Consult factory for information about additional custom versions.

10 Hardware and Firmware Revision History

10.1 Hardware Revision History

23A350 Revision B	August 2019 Improved manufacturability Functionally equivalent to Revision A
23A350 Revision A	Feb 2015 Initial release

10.2 Firmware Revision History

23E350 Revision B	June 2015 Corrects an incorrect display on the status report Corrects FIFO management bug, Play mode Does not support noise generators as modulation sources
23E350 Revision A	May 2015 Beta software release

11 Accessories

J43-1: 3' BNC to BNC cable

J53-1: 3' SMB to BNC cable

J53-2: 6” SMB to BNC cable

J350-1: 15 volt, 2 amp power supply (furnished with purchase)

P10-1: 19" rack mount shelf (two p-boxes per rack)

P51-1: mounting flange