Description:

The XScopes (Xminilab and Xprotolab) are a combination of three electronic instruments: a mixed signal oscilloscope, an arbitrary waveform generator, and a protocol sniffer; all housed in a small breadboard friendly module. The XScopes can also be used as development boards for the AVR XMEGA microcontroller.

Main Features:

- **Mixed Signal Oscilloscope**: Simultaneous sampling of 2 analog and 8 digital signals.
- **Arbitrary Waveform Generator** with advanced sweep options on all the wave parameters.
- **Protocol Sniffer**: SPI, I²C, UART
- **Advanced Triggering System**: Normal / Single / Auto / Free, with many trigger modes; adjustable trigger level, and ability to view signals prior to the trigger.
- **Meter Mode**: VDC, VPP and Frequency readout.
- **XY Mode**: For plotting Lissajous figures, V/I curves or checking the phase difference between two waveforms.
- **Spectrum Analyzer** with different windowing options and selectable vertical log and IQ visualization.
- **Channel Math**: add, multiply, invert, and average.
- **Horizontal and Vertical Cursors** with automatic waveform measurements, and waveform references.

![XScopes Block Diagram](figure2.png)
About this manual

This manual targets both novice and advanced users, providing a full resource for everyone. However, for a full understanding of the operation of the XScopes, the user should be familiar with the operation of a regular oscilloscope.

The features documented in this manual are for the Xminilab hardware version 2.1+ or Xprotolab hardware version 1.7+, with firmware version 2.00+.

Conventions

XScope: Xprotolab or Xminilab
CH1: Analog Channel 1
CH2: Analog Channel 2
CHD: Logic Inputs
Fast Sampling: 10ms/div or faster
Slow Sampling: 20ms/div or slower

Helpful tip

Technical Detail

Revision History

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Notes</th>
</tr>
</thead>
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<tr>
<td>1.0</td>
<td>September 2011</td>
<td>First revision</td>
</tr>
<tr>
<td>1.1</td>
<td>December 2011</td>
<td>Firmware upgrade for HW 1.7</td>
</tr>
<tr>
<td>1.2</td>
<td>January 2012</td>
<td>Updated AWG maximum frequency to 125kHz</td>
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<tr>
<td>1.3</td>
<td>January 2012</td>
<td>Added vertical sensitivity on specifications</td>
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<tr>
<td>1.5</td>
<td>January 2012</td>
<td>Changed seconds units from S to s</td>
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<tr>
<td>1.6</td>
<td>February 2012</td>
<td>Corrected discrepancies in the interface protocol</td>
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<tr>
<td>1.7</td>
<td>March 2012</td>
<td>Added maximum screen refresh rate</td>
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<tr>
<td>1.8</td>
<td>June 2012</td>
<td>Merged Xprotolab and Xminilab manual, added new features</td>
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<tr>
<td>1.9</td>
<td>August 2012</td>
<td>Documented latest features</td>
</tr>
<tr>
<td>2.0</td>
<td>August 2012</td>
<td>Added a chapter with examples</td>
</tr>
<tr>
<td>2.1</td>
<td>September 2012</td>
<td>Documented the Frequency Counter</td>
</tr>
<tr>
<td>2.2</td>
<td>September 2012</td>
<td>Updated Frequency Counter</td>
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1. General Overview

1.1 Xprotolab Pin Description

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>+5V</td>
<td>+5V Input voltage</td>
<td>Do not apply +5V if using the USB port</td>
</tr>
<tr>
<td>-5V</td>
<td>-5V Output voltage</td>
<td>50mA max output</td>
</tr>
<tr>
<td>GND</td>
<td>Ground</td>
<td>It is recommended use all ground pins to reduce voltage offset errors.</td>
</tr>
<tr>
<td>+3.3V</td>
<td>+3.3V Output voltage</td>
<td>200mA max output</td>
</tr>
<tr>
<td>Logic 0</td>
<td>Digital Channel 0</td>
<td>I2C Sniffer signal: SDA</td>
</tr>
<tr>
<td>Logic 1</td>
<td>Digital Channel 1</td>
<td>I2C Sniffer signal: SCL</td>
</tr>
<tr>
<td>Logic 2</td>
<td>Digital Channel 2</td>
<td>UART Sniffer signal: RX</td>
</tr>
<tr>
<td>Logic 3</td>
<td>Digital Channel 3</td>
<td>UART Sniffer signal: TX</td>
</tr>
<tr>
<td>Logic 4</td>
<td>Digital Channel 4</td>
<td>SPI Sniffer signal: /SS</td>
</tr>
<tr>
<td>Logic 5</td>
<td>Digital Channel 5</td>
<td>SPI Sniffer signal: MOSI</td>
</tr>
<tr>
<td>Logic 6</td>
<td>Digital Channel 6</td>
<td>SPI Sniffer signal: MISO</td>
</tr>
<tr>
<td>Logic 7</td>
<td>Digital Channel 7</td>
<td>SPI Sniffer signal: SCK</td>
</tr>
<tr>
<td>EXT. T</td>
<td>External Trigger</td>
<td>Digital input, max 5.5V</td>
</tr>
<tr>
<td>AWG</td>
<td>Arbitrary Waveform Generator</td>
<td>Output range: +/- 2V</td>
</tr>
<tr>
<td>CH2</td>
<td>Analog Channel 2</td>
<td>Input range: -14V to +20V</td>
</tr>
<tr>
<td>CH1</td>
<td>Analog Channel 1</td>
<td>Input range: -14V to +20V</td>
</tr>
<tr>
<td>PWR</td>
<td>Power up output signal</td>
<td>3.3V signal, 10mA max output</td>
</tr>
<tr>
<td>RX</td>
<td>Interface RX input</td>
<td>Connect to host’s TX</td>
</tr>
<tr>
<td>TX</td>
<td>Interface TX output</td>
<td>Connect to host’s RX</td>
</tr>
<tr>
<td>LNK</td>
<td>Interface link input</td>
<td>3.3V level input, with internal pull up</td>
</tr>
</tbody>
</table>

Table 1: Pin description
1.2 Xminilab Pin Description

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH1</td>
<td>Analog Channel 1</td>
<td>Input range: -14V to +20V</td>
</tr>
<tr>
<td>CH2</td>
<td>Analog Channel 2</td>
<td>Input range: -14V to +20V</td>
</tr>
<tr>
<td>AWG</td>
<td>Arbitrary Waveform Generator</td>
<td>Output range: +/- 2V</td>
</tr>
<tr>
<td>EXT. T</td>
<td>External Trigger</td>
<td>Digital input, max 5.5V</td>
</tr>
<tr>
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<td>Digital Channel 0</td>
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</tr>
<tr>
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<td>Digital Channel 1</td>
<td>I2C Sniffer signal: SCL</td>
</tr>
<tr>
<td>Logic 2</td>
<td>Digital Channel 2</td>
<td>UART Sniffer signal: RX</td>
</tr>
<tr>
<td>Logic 3</td>
<td>Digital Channel 3</td>
<td>UART Sniffer signal: TX</td>
</tr>
<tr>
<td>Logic 4</td>
<td>Digital Channel 4</td>
<td>SPI Sniffer signal: /SS</td>
</tr>
<tr>
<td>Logic 5</td>
<td>Digital Channel 5</td>
<td>SPI Sniffer signal: MOSI</td>
</tr>
<tr>
<td>Logic 6</td>
<td>Digital Channel 6</td>
<td>SPI Sniffer signal: MISO</td>
</tr>
<tr>
<td>Logic 7</td>
<td>Digital Channel 7</td>
<td>SPI Sniffer signal: SCK</td>
</tr>
<tr>
<td>+3.3V</td>
<td>+3.3V Output voltage</td>
<td>200mA max output</td>
</tr>
<tr>
<td>+5V</td>
<td>+5V Input voltage</td>
<td>Do not apply +5V if using the USB port</td>
</tr>
<tr>
<td>GND</td>
<td>Ground</td>
<td>It is recommended use all ground pins</td>
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<td>PWR</td>
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<td>3.3V signal, 10mA max output</td>
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<td>RX</td>
<td>Interface RX input</td>
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<td>Interface TX output</td>
<td>Connect to host’s RX</td>
</tr>
<tr>
<td>LNK</td>
<td>Interface link input</td>
<td>3.3V level input, with internal pull up</td>
</tr>
</tbody>
</table>

Table 2: Xminilab Pin Description
1.3 Specifications

General Specifications:
- ATXMEGA32A4 36KB Flash, 4KB SRAM, 1KB EEPROM.
- Graphic OLED display, 128x64 pixels.
  - Xprotolab display size is 0.96” and with 10,000 hours minimum life time (to 50% original brightness).
  - Xminilab display size is 2.42” and with 40,000 hours minimum life time (to 50% original brightness).
- Module size: Xprotolab: 1.615” x 1.01”. Xminilab: 3.3” x 1.75”
- PDI interface, an optional 2x3 headers can be soldered for programming and debugging.
- 4 tactile switches.
- Micro USB.

Logic Analyzer specifications:
- 8 Digital Inputs, 3.3V level
- Maximum sampling rate: 2Msps
- Frequency Counter: 12Mhz, +/- 1Hz resolution, +/-100ppm accuracy
- Protocol Sniffer: UART, I2C, SPI
- Internal pull up or pull down
- Buffer size: 256

Oscilloscope specifications:
- 2 Analog Inputs
- Maximum Sampling rate: 2Msps
- Analog Bandwidth: 200kHz
- Resolution: 8bits
- Input Impedance: 1MΩ
- Buffer size per channel: 256
- Input Voltage Range: -14V to +20V
- Vertical sensitivity: 80mV/div to 5.12V/div
- Maximum Screen Refresh Rate: 128Hz

AWG specifications:
- 1 Analog Output
- Maximum conversion rate: 1Msps
- Analog Bandwidth: 44.1kHz
- Resolution: 8bits
- Output current > +/- 7mA
- Buffer size: 256
- Output Voltage: +/- 2V

1.4 Dimensions

Figure 7: Xprotolab Dimensions

Figure 8: Xminilab 2.1 & 2.2 Dimensions

Figure 9: Xminilab 2.3 Dimensions
1.5 Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage (+5V)</td>
<td>-0.5</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Analog Inputs</td>
<td>-30</td>
<td>30</td>
<td>V</td>
</tr>
<tr>
<td>Digital Inputs</td>
<td>-0.5</td>
<td>3.8</td>
<td>V</td>
</tr>
<tr>
<td>External Trigger</td>
<td>-2.2</td>
<td>5.5</td>
<td>V</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-40</td>
<td>70</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-40</td>
<td>80</td>
<td>°C</td>
</tr>
</tbody>
</table>

Table 3: Absolute Maximum Ratings

1.6 Factory Setup

The device can enter factory options if the MENU key is pressed during power up. The following options are available:

1) **Offset calibration**: The unit is calibrated before being shipped, but calibration is required again if the firmware is updated. During calibration, two graphs are shown that represent the calibration on each channel.

2) **Sleep timeout**: Sets the time to shut down the display and put the microcontroller to sleep after the last key press. Shutting down the OLED extends its life. The current consumption is also reduced.

3) **Restore defaults**: Select this function to restore to the default the settings. There are many settings on the device, if you are not familiar with them, this function is useful to set the device to a known state.

1.7 Quick Start Guide

- Take the device out of the packaging. There is a protective film on the display which can be removed.
- The device can be powered with either the USB or with an external power supply, by applying +5V on the corresponding pin. Double check your connections because the device WILL get damaged if applying power on the wrong pin.
- Connect the AWG pin to CH1.
- The tactile switches are named (from left to right) K1, K2, K3 and K4. The K4 is the Menu button.
- Press and hold the K1 key (auto setup). The screen should look like figure 10.
- Pressing K2 or K3 will change the sampling rate.

**TIP** Additional examples on how to use the Xprotolab are presented in chapter 8.
1.8 User Interface

The K4 button is the MENU button, used to navigate thru all the menus. The K1 - K3 buttons action depend on the current menu. The green arrows represent the flow when pressing the MENU button. When the MENU button is pressed on the last menu, the device settings are saved and the menu goes back to the default. Figure 11 shows the main menus in blue and some secondary menus in yellow. Further ramifications are shown on the respective chapters.

1.9 Saving the settings

All the settings are stored to non-volatile memory only when exiting from the last menu (Miscellaneous Menu). This method is used to reduce the number of write cycles to the microcontroller’s EEPROM.
2. Mixed Signal Oscilloscope

The XScope is a mixed signal oscilloscope; it has 2 analog channels and 8 digital channels. This chapter will focus on the analog signals. More information about the digital channels is presented in chapter 3.

2.1 Horizontal Settings

The horizontal settings are controlled on the default menu. The menu is shown on figure 12.

2.1.1 Time Base

The time base can be varied from 8μs/div to 50s/div. Table 4 shows all the possible time bases. One time division consists of 16 pixels. Example: 8μs / division = 8μs / 16 pixels → 500ns / pixel.

<table>
<thead>
<tr>
<th>Time Base (s / div)</th>
<th>Fast</th>
<th>*8μ</th>
<th>16μ</th>
<th>32μ</th>
<th>64μ</th>
<th>128μ</th>
<th>256μ</th>
<th>500μ</th>
<th>1m</th>
<th>2m</th>
<th>5m</th>
<th>10m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow</td>
<td>20m</td>
<td>50m</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Time divisions

- At 8μs/div, CH2 is not displayed.

2.1.2 Technical Details

There are two distinct sampling methods: Fast Sampling and Slow Sampling.

- **Fast Sampling** (10ms/div or faster): All samples are acquired to fill the buffer, and then they are displayed on the screen.
  - Pre-trigger sampling (ability to show samples before the trigger) is available only with fast sampling.
  - Only 128 samples are visible at a time, varying the horizontal position allows exploring the full buffer.

- **Slow Sampling** (20ms/div or slower): Single samples are acquired and simultaneously displayed on the display.
  - The ROLL mode (waveform scrolls to the left during acquisition) is only available with the slow sampling.
  - All 256 samples are visible on the display (each vertical line will have at least two samples)

2.1.3 Horizontal Position

The horizontal position can be varied on the Fast Sampling time bases. There are 256 samples for each channel, but only 128 are displayed on the screen. When the acquisition is stopped, the full sample buffer can be explored with the K2 and K3 buttons. Pressing K2 and K3 simultaneously on the default menu will center the horizontal position.

2.1.4 Auto Setup

The Auto Setup feature will try to find the optimum gain and time base for the signals being applied on CH1 and CH2.
2.2 Vertical Settings
The analog channel controls are discussed in this section. Figure 13 shows the Vertical menu flow.

![Vertical menus](image)

2.2.1 Disable Channel
Any channel can be disabled; this is useful to reduce clutter on the display.

2.2.2 Channel Gain
Table 5 shows the possible gain settings for the analog channels. One gain division consists of 16 pixels. The current gain settings for the analog channels are shown in the top right part of the display (If the SHOW setting of the display is enabled).

2.2.3 Channel Position
The position of the waveform can be moved up or down in the Channel Position menu.

2.2.4 Channel Invert
The channel can be inverted. The displayed waveform and channel calculations will be affected.

2.2.5 Channel Math
- Subtract: The channel trace will be replaced with the difference.
- Multiply: The channel trace will be replaced with the product.
- Average: The channel samples will be averaged to reduce aliasing. (See Figure 14).

Channel Math Examples:

![Channel Math Examples](image)

TIP: To display CH1+CH2, first invert CH2 and then select the SUBTRACT function.

![Gain Settings](image)

Table 5: Gain Settings

<table>
<thead>
<tr>
<th>Gain Settings (Volts / Division)</th>
<th>CH1 and CH2 have identical settings.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.12</td>
<td></td>
</tr>
<tr>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>1.28</td>
<td></td>
</tr>
<tr>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>80m</td>
<td></td>
</tr>
</tbody>
</table>

Figure 14: Number of samples averaged when enabling the channel AVERAGE option. The device’s sampling rate is normally faster than needed to be able to average samples.
2.3 Trigger Settings

The XScope has an advance triggering system, it has most of the trigger controls of a professional oscilloscope. Figure 18 shows the trigger menus.

2.3.1 Trigger Types

There are four different trigger types, which determine when to display the trace on the screen:

- **Normal**: Trace only when the trigger event occurs.
- **Single**: Only one trace is displayed when the trigger event occurs.
- **Auto**: Trace when the trigger event occurs, or after a timeout.
- **Free**: Trace continuously ignoring the trigger.
2.3.2 Trigger Modes

Three triggering modes are available: Edge, Window, and Slope. The Edge and Slope have selectable direction. The direction of the trigger is changed in the “Adjust Trigger Level” menu, by moving up or moving down the trigger level.

- **Edge Trigger**: The trigger occurs when the signal crosses the trigger level in a certain direction. The trigger level is represented on the display as a rising (↑), falling (↓) or dual arrow (↔).
  - **Rising edge**: The trigger occurs when the signal crosses the level from below to above.
  - **Falling Edge**: The trigger occurs when the signal crosses the level from above to below.
  - **Dual Edge**: The trigger occurs when the signal crosses the trigger level in any direction.

To select the Dual Edge mode, deselect Window, Edge, and Slope in the “Trigger Mode Menu”, the trigger mark will change to a dual arrow: ↔

- **Window Trigger**: The trigger occurs when the signal leaves a voltage range. This mode is useful for detecting overvoltages or undervoltages. Two arrow trigger marks represent the window levels.

- **Slope Trigger**: The trigger occurs when the difference between two consecutive samples is greater or lower than a predefined value. This is useful for detecting spikes or for detecting high frequency signals. The trigger mark is represented on the screen as two small lines, with a size proportional to the trigger value.
2.3.3 Trigger Hold

The trigger hold specifies a time to wait before detecting the next trigger. It is useful when the signal can have multiple trigger events occurring close to each other, but you only want to trigger on the first one.

2.3.4 Post Trigger

The oscilloscope is continuously acquiring samples in a circular buffer. Once the trigger event occurs, the oscilloscope will acquire more samples, specified by the Post Trigger value. The ability to show samples before or after the trigger is one of the most powerful features of a digital sampling oscilloscope. The post trigger is only available on the fast sampling rates.

Depending on the post trigger settings, different parts of a signal can be displayed. Consider the signal on figure 22:

![Figure 22: Sample signal](image)

Even though the buffer sample is relatively small, any section of the shown figure can be analyzed by varying the post trigger value. Examples:

- Post trigger = 0 (don’t acquire more signals after the trigger).
  Only the signals that occurred before the trigger event are shown.

![Figure 23: Post trigger value equal zero](image)

- Post trigger = 50% of the sample buffer (default setting).
  Half of the buffer contains samples before the trigger, and half contains the samples after the trigger.

![Figure 24: Post trigger = 50% of sample buffer](image)

- Post trigger = 100% of the sample buffer
  Only signals immediately after the trigger event are shown.

![Figure 25: Post trigger = 100% of buffer](image)

The actual post trigger value can vary between 0 and 32768 samples, so you can explore the signal after a very long time after the trigger event has occurred, but with a high post trigger value, the refresh rate of the scope will be reduced.

2.3.5 Trigger Source

Any analog or digital channel can be the trigger source. If selecting a digital channel as trigger source, the slope and window modes are not applicable; the device will use edge triggering. The external trigger input is an additional digital trigger source which tolerates voltages up to 5.5V.
2.4 Device Modes

There are multiple device modes that can be selected; the menus shown on figure 26 allow selecting the Scope Mode, the Meter Mode or the Spectrum Analyzer Mode (FFT). Another device mode is the Protocol Sniffer, which is discussed in section 3.8.

![Device Mode Menus](image)

Figure 26: Device mode menus

2.4.1 Oscilloscope Mode

This is the default mode of the XScope. The 2 analog and 8 digital channels are sampled simultaneously. Any of these 10 channels can be shown on the display. Figure 27 shows the oscilloscope mode and the various sections of the display are detailed.

![Oscilloscope Mode](image)

Figure 27: Oscilloscope Mode

2.4.1.1 Roll Mode

The data on the display is scrolled to the left as new data comes in. This is only available on the Slow Sampling rates. The Roll mode and Elastic mode cannot be selected simultaneously. The Roll mode disables the triggering.

2.4.1.2 Elastic Traces

This is also called “Display average” on other digital oscilloscopes. It works by averaging the trace data with the new data. The result is a more stable waveform displayed on the screen. However, using this setting only makes sense when the scope is properly triggered. The Elastic trace computes this equation for every point in the trace:

\[
NewTrace = \frac{OldTrace + NewData}{2}
\]
2.4.1.3 XY Mode

The XY mode changes the display from volts vs. time display to volts vs. volts. You can use XY mode to compare frequency and phase relationships between two signals. XY mode can also be used with transducers to display strain versus displacement, flow versus pressure, volts versus current, or voltage versus frequency. Lissajous figures can also be plotted using the XY Mode. Component curves can also be plotted, see section 8.5.

**TIP**
When using the XY modes with a Slow Sampling rate, activating the ROLL mode will display a continuous “beam”.

![XY Mode](image)

2.4.2 Meter Mode

The XScope can function as a dual digital voltmeter. The font used is bigger in meter mode to facilitate reading. The available measurements in meter mode are: Average Voltage (DC), Peak to Peak Voltage, and Frequency. A small trace of the analog signals is displayed below the measurements.

**TIP**
If there is more than 10mV of voltage in the VDC measurement with no signal, recalibrate the device’s offset (Section 1.6).

![Meter Mode](image)

2.4.2.1 Frequency Measurements

The device can measure frequencies on the analog channels and on the external trigger pin.

Frequency measurements on the analog channels are done using the FFT of the acquired data, so measured frequencies have discrete steps. The frequency range is determined by the highest frequency of the analog channels. If there is a high frequency on one channel and a low frequency on the other, the channel with the lowest frequency will have low resolution. Frequency measurements with the FFT are best suited for analog signals.

Frequency measurements on the external trigger are done counting the pulses on the pin over one second. The resolution of the measurement is 1Hz. Frequency measurements with the Freq. counter are best suited for digital signals.

<table>
<thead>
<tr>
<th></th>
<th>FFT (Analog channels)</th>
<th>Frequency Counter (Ext. Trigger)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum voltage range</td>
<td>-14V to 20V</td>
<td>-2.2V to 5.5V</td>
</tr>
<tr>
<td>Maximum Frequency</td>
<td>500kHz</td>
<td>Over 12MHz</td>
</tr>
<tr>
<td>Resolution</td>
<td>Variable, depending on frequency range. From 6.25Hz to 7.812kHz</td>
<td>1Hz</td>
</tr>
<tr>
<td>Signal is noisy, or is mixed with other signals</td>
<td>Finds the fundamental frequency</td>
<td>Not suitable</td>
</tr>
<tr>
<td>Signal has a high offset</td>
<td>Still works</td>
<td>Stops working when the offset is above the logic threshold.</td>
</tr>
</tbody>
</table>

Table 6: FFT vs. Frequency Counter
### 2.4.3 Spectrum Analyzer

The spectrum analyzer is done by calculating the Fast Fourier Transform (FFT) of the selected analog channels (or the channel math functions if enabled). When the FFT is enabled, the spectrum is plotted as frequency vs. magnitude. The horizontal axis represents the frequency (Hertz), and the vertical axis represents the magnitude. Figure 30 shows the XScope in Spectrum Analyzer Mode. The Nyquist frequency is shown on the top right corner of the display.

**Tip:** If only interested in one channel, turn off the other channel to maximize the vertical display.

#### 2.4.3.1 IQ FFT Mode

When the IQ FFT is disabled, the XScope calculates two independent 256 point FFTs of the analog channels, the Real and Imaginary components of the FFT have the same data. The output of the FFT is symmetrical, but only half of the result is shown on the display. When the IQ FFT is enabled, only one FFT is calculated, the Real component is filled with the CH1 data, and the Imaginary component is filled with the CH2 data. The result is a 256 point FFT, you can use the horizontal controls described in section 2.1.3 to explore all the data (since only 128 points can be shown on the display). The IQ FFT is useful to monitor RF Spectrums with the proper hardware mixer.

#### 2.4.3.2 Logarithm display

The log is useful when analyzing low level components on the signal. When analyzing audio, it is also very useful as it maps more directly to how humans perceive sound. The actual function performed is: \( y = 16 \times \log_2(x) \).

Example:

#### 2.4.3.3 FFT Windows

To reduce the spectral leakage, an FFT window function can be applied. Four FFT window types are available:

- **Rectangular**: No window applied
- **Hamming**: \( 0.53836 - 0.46164 \times \cos\left(\frac{2\pi n}{F_{FTN-1}}\right) \)
- **Hann**: \( 0.5 \times \left(1 - \cos\left(\frac{2\pi n}{F_{FTN-1}}\right)\right) \)
- **Blackman**: \( 0.42 - 0.5 \times \cos\left(\frac{2\pi n}{F_{FTN-1}}\right) + 0.08 \times \cos\left(\frac{4\pi n}{F_{FTN-1}}\right) \)

Figure 34: Window and sine frequency response, from left to right: Rectangular, Hamming, Hann and Blackman

---

Figure 30: Spectrum Analyzer Mode

Figure 31: Triangle Wave

Figure 32: FFT without Log

Figure 33: FFT with Log

---

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2.5 Cursors

You can measure waveform data using cursors. Cursors are horizontal and vertical markers that indicate X-axis values (usually time) and Y-axis values (usually voltage) on a selected waveform source. The position of the cursors can be moved on the respective menu. Figure 35 shows the cursor menus.

2.5.1 Vertical Cursors

Time interval measurements are made with a pair of time markers. The oscilloscope automatically calculates the time difference between the two markers and displays the difference as a delta time. Additionally, the oscilloscope calculates the inverse of the delta time, which is the frequency of the selected period.

2.5.2 Horizontal Cursors

Voltage measurements are made with a pair of voltage markers to determine 1 or 2 specific voltage points on a waveform. The oscilloscope automatically calculates the voltage difference between the two markers and displays the difference as a delta voltage value.

2.5.3 Automatic Cursors

The device will try to automatically make measurements on the waveform.

- **Vertical Cursors**: The device will try find a full or half cycle of the selected waveform. If both CH1 and CH2 are enabled, the channel with the most amplitude will be used.
- **Horizontal Cursor**: The selected horizontal cursor will be set with the maximum and minimum points of the waveform.

2.5.4 Track Horizontal Cursors

The location of the horizontal cursor will track the signal located on the vertical cursor.

2.5.5 Reference Waveform

A snapshot is taken of the analog waveforms to be used as reference waveforms. The reference waveforms are stored in non-volatile memory.
2.6 Display Settings
These menus control various characteristics of the display. Figure 38 show the display menus.

![Display Menu](image)

2.6.1 Persistent Display
When the persistent display is enabled, the waveform traces are not erased. The persistent display is useful as a simple data logger or to catch glitches in the waveform. The persistent mode can also be used to make frequency plots in combination with the AWG frequency sweep.

2.6.2 Line / Pixel Display
This menu item selects the drawing method.

- **Line**: A line is drawn from one sample to the next.
- **Pixel**: A single pixel represents a sample. The pixel display is useful at slow sampling rates or when used in combination with the persistent mode. Figure 39 shows the pixel display.

2.6.3 Show scope settings
Toggles the display of the scope settings (Channel gain and time base).

2.6.4 Grid Type
There are 4 different grid types:

- **No grid**.
- **Dots for each division**: Vertical dots represent the scale divisions. Horizontal dots represent the time base setting and the ground level of each channel.
- **Vertical grid line follow trigger**: Vertical dots represent the position of the trigger, the location of the vertical dots follow the trigger position. Horizontal dots represent the time base setting and the ground level of each channel.
- **Dot graticule**: The screen is filled with dots that represent the vertical and horizontal divisions.

2.6.5 Flip Display
The display orientation is flipped. This is useful when mounting the XScope on a panel, and the display’s orientations is backwards.

2.6.6 Invert Display
When enabled, the display’s pixels are inverted (the display will have a white background).
3. Logic Analyzer and Protocol Sniffer

The XScope has an 8 bit logic analyzer and can do sniffing on standard protocols: I2C, UART and SPI. The logic inputs are 3.3V level (the logic inputs are not 5V tolerant!). If you need to connect 5V signals to the logic analyzer, you could add a 3K resistor in series with the signal, or use a 5V to 3.3V level converter chip. Figure 40 shows the logic menus.

3.1 Input Selection
A subset of the 8 digital signals can be selected. Any digital signal can be enabled or disabled.

3.2 Channel Position
The selected digital channels can be moved up or down. Only applicable if less than 8 digital signals are selected.

3.3 Invert Channel
All digital channels are inverted. This setting also affects the protocol sniffer!

3.4 Thick Logic ‘0’
A thick line is drawn when the signal is at logic ‘0’. This is useful to quickly differentiate a ‘0’ from a ‘1’.

![Figure 40: Logic Analyzer Menus]
3.5 Parallel Decoding

Shows the hexadecimal value of the 8 bit digital input lines. The hexadecimal number is shown below the last digital trace. If all the 8 digital traces are enabled, then there is no space to show the parallel decoding. Figure 41 shows an example of the parallel decoding with 4 logic lines enabled.

3.6 Serial Decoding

Shows the hexadecimal value of the stream of bits on each channel. The decoding starts at the first vertical cursor and ends at the second vertical cursor, 8 bits are decoded. If the cursors are disabled, then the decoding is done from the start of the screen, to the end. The data can be decoded MSB first or LSB first, depending on the position of the first vertical cursor.

3.7 Protocol Sniffer

When the XScope is in Sniffer mode, a small text appears on the screen before any data is received, to indicate where to hook up the signals. As soon as the data is received, the data is displayed in "pages". There are 16 pages of data. To browse thru the pages, use the buttons K2 and K3. To stop and start the sniffer, press the K1 button. Figure 43 shows the device in sniffer mode.

In the UART and SPI sniffers, the data can be displayed in HEX or ASCII, press K2 and K3 simultaneously to toggle between them. If using ASCII, only codes 0x20 thru 0x7A will show valid characters. Figure 44 shows the 3x6 font.

3.8 Sniffers Modes

- **Normal** mode: Continuous operation, when the buffer is filled, all pages are erased, the index goes back to page 1
- **Single** mode: The sniffer will stop when the buffer is filled.
- **Circular** mode: New data will be placed at the end of the last page, older data will be shifted towards the first page. At the beginning, the device will show 0x00 an all pages, and the last page will be set.
3.9 I2C Sniffer
Connect SDA to Bit 0, SCL to Bit 1

The XScope implements the I2C sniffing in a bit-bang fashion. The maximum tested clock frequency is 400kHz (Standard I2C Fast Speed). As the data is decoded, the data in HEX will appear on the screen, accompanied by a symbol:

When the Master initiates a read, < is an ACK and ( is a NACK
When the Master initiates a write, > is an ACK and ) is a NACK
Subsequent data in the frame will be accompanied by + for ACK or a − for NACK.

There are 16 pages of data, each page shows 64 bytes => the total memory for the I2C sniffer is 1024 bytes.

Example communicating to a Si570 Programmable oscillator:

```
55> 07+  (Master initiates Write to slave 55, byte address 7)
55< 05+ 42+ B6+ 04+ 79+ 9A− (Master initiates Read to slave 55, then reads 6 bytes)
```

3.10 UART Sniffer
Connect RX to Bit 2, TX to Bit 3

The XScope can decode both the TX and RX lines of the UART at the standard baud rates:

1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200

The screen is split in two, the left side is used for the RX line, and the right side is used for the TX line. Each side can show 40 bytes per page. With 16 pages, a total of 640 bytes can be stored for each decoded line.

3.11 SPI Sniffer
Connect the Select to Bit 4, MOSI to Bit 5, MISO to Bit 6, SCK to Bit 7

The XScope can decode both the MOSI and MISO lines of an SPI bus. The SPI's MOSI pin decoding is done in hardware, so it can decode data at high speed, But the SPI's MISO pin decoding is implemented in software using bit-banging, so the maximum clock allowed will be limited.

The screen is split in two, the left side is use for the MOSI line, and the right side is used for the MISO line. Each side can show 40 bytes per page. With 16 pages, a total of 640 bytes can be stored for each decoded line.
4. Arbitrary Waveform Generator

The XScope has an embedded arbitrary waveform generator. The waveform generator output is independent from the data acquisition and is always running in the background. You can adjust all the parameters of the waveform: frequency, amplitude, offset and duty cycle. You can sweep the frequency, amplitude and duty cycle. Figure 46 shows the AWG Menus.

**Figure 46: AWG Menus**

- **TIP**: When adjusting the parameters, the K1 button serves as a shortcut key, which sets predefined values.

- **TIP**: When enabling the Sweep, the waveform will be updated only on a screen refresh. For a smooth sweep, set the scope with a high speed sampling, or stop the oscilloscope.
4.1 Predefined Waveforms

<table>
<thead>
<tr>
<th>Sine Wave</th>
<th>Square Wave</th>
<th>Triangle Wave</th>
<th>Exponential</th>
<th>Periodic Noise</th>
<th>Custom Wave *</th>
</tr>
</thead>
</table>

Table 7

The XScope can output the following waveforms: Sine, Square, Triangle and Exponential. There is a “Periodic Noise” option that fills the AWG buffer with random data, it is periodic because the same data is output over and over, but each time the Noise wave is selected, new random data will be generated. There is also a custom waveform which is initially set with an ECG wave, but can be changed with the PC XScope Interface.

4.2 Parameter Sweep

The XScope has a SWEEP feature, which increases one or more parameter values automatically on each screen refresh of the oscilloscope. When the sweep is enabled, three dots will appear at the bottom of the screen, representing the start, end, and current sweep value. When doing a Frequency sweep, the frequency range is determined by the current time base. Since the frequency sweep is synchronized with the oscilloscope, displaying perfect frequency plots is easy. To make a frequency plot, set the mode to FFT, and set the display to persistent. See section 8.6 for an example.

4.2.1 Sweep Modes

In the Sweep Mode menu, the sweep direction can be changed. Automatic change of the direction is done by enabling the Ping Pong mode. The sweep acceleration increases or decreases the sweep speed, the sweep speed is reset when reaching the start or end of the sweep.

4.3 Technical Details

The waveform is stored in a 256 byte long buffer, this buffer is fed to the XMEGA's DAC thru the DMA. Once the waveform is set, the waveform will be generated without any CPU intervention. The maximum conversion rate of the DAC is 1Msp, this limits the maximum output frequency of the AWG as a system. For example, if the AWG is generating a sinewave with 256 points, the maximum frequency is 3906.25Hz. If generating a sinewave with only 32 points, the maximum frequency is 31.25KHz. The AWG amplifier has a low pass filter of 44.1KHz. The predefined AWG Frequency range is: 1Hz thru 125k Hz.

The resolution of the waveform generator varies depending on the frequency range: the lower the frequency, the higher the resolution. Note that the possible frequencies are discrete:

\[
Frequency = \text{Cycles} \times \frac{125000}{\text{Period}}
\]

**Cycles**: Integer number, with these possible values: 1, 2, 4, 8, 16, 32

**Period**: Integer number, with values between 32 and 65535
5. PC Interface

The XScope can communicate to a PC with USB. It can also communicate using the UART on the external port (by using a UART adapter or the Bluetooth module). Figure 47 shows a snapshot of the PC interface.

![Xprotolab PC interface](image)

**Figure 47: Xprotolab PC interface**

6. Interface Protocol

The XScope can communicate to external devices thru the USB or the external port. Each interface can access the Xscope’s main settings. Follow the protocols to make your own applications, or to make devices that attach to the XScope.

6.1 Interface settings

The settings for communicating with the serial port are shown in Table 8. If using the USB interface, you can use WinUSB or LibUSB libraries. The USB device’s endpoints have a size of 64 bytes. The device uses BULK IN transfers on endpoint 1 for transferring data (CH1, CH2 and CHD, 256 bytes each), BULK OUT transfers on endpoint 1 to write to the AWG RAM buffer, and CONTROL READ transfers on endpoint 0 for changing and reading settings.

<table>
<thead>
<tr>
<th>Data Bits: 8</th>
<th>Baud rate: 115200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity: None</td>
<td>Stop Bits: One</td>
</tr>
<tr>
<td>Handshaking: None</td>
<td></td>
</tr>
</tbody>
</table>

**Table 8: Serial settings**

6.2 Control data

All the XScope’s settings are stored in 43 bytes, table 9 shows these variables, section 6.2.1 describes the bitfield variables.
<table>
<thead>
<tr>
<th>Index</th>
<th>Name</th>
<th>Data Type</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Srate</td>
<td>Unsigned 8bit</td>
<td>Sampling Rate</td>
<td>Range: [0, 21] 8 us/div to 50 s/div</td>
</tr>
<tr>
<td>1</td>
<td>CH1ctrl</td>
<td>Bit Field 8bit</td>
<td>Channel 1 controls</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CH2ctrl</td>
<td>Bit Field 8bit</td>
<td>Channel 2 controls</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CHDctrl</td>
<td>Bit Field 8bit</td>
<td>Logic Analyzer Options 1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>CHDmask</td>
<td>Bit Field 8bit</td>
<td>Logic enabled bits</td>
<td>Selects which logic channels are displayed</td>
</tr>
<tr>
<td>5</td>
<td>Trigger</td>
<td>Bit Field 8bit</td>
<td>Trigger control</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>MCursors</td>
<td>Bit Field 8bit</td>
<td>Cursor Options</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Display</td>
<td>Bit Field 8bit</td>
<td>Display Options</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>MFFT</td>
<td>Bit Field 8bit</td>
<td>FFT Options</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sweep</td>
<td>Bit Field 8bit</td>
<td>AWG Sweep Options</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Sniffer</td>
<td>Bit Field 8bit</td>
<td>AWG Controls</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>MStatus</td>
<td>Bit Field 8bit</td>
<td>Scope Status</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>CH1gain</td>
<td>Unsigned 8bit</td>
<td>Channel 1 gain</td>
<td>Range: [0, 6] 5.12V/div to 80mV/div</td>
</tr>
<tr>
<td>13</td>
<td>CH2gain</td>
<td>Unsigned 8bit</td>
<td>Channel 2 gain</td>
<td>Range: [0, 6] 5.12V/div to 80mV/div</td>
</tr>
<tr>
<td>14</td>
<td>HPos</td>
<td>Unsigned 8bit</td>
<td>Horizontal Position</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>15</td>
<td>VcursorA</td>
<td>Unsigned 8bit</td>
<td>Vertical Cursor A</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>16</td>
<td>VcursorB</td>
<td>Unsigned 8bit</td>
<td>Vertical Cursor B</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>17</td>
<td>Hcursor1A</td>
<td>Unsigned 8bit</td>
<td>CH1 Horizontal Cursor A</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>18</td>
<td>Hcursor1B</td>
<td>Unsigned 8bit</td>
<td>CH1 Horizontal Cursor B</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>19</td>
<td>Hcursor2A</td>
<td>Unsigned 8bit</td>
<td>CH2 Horizontal Cursor A</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>20</td>
<td>Hcursor2B</td>
<td>Unsigned 8bit</td>
<td>CH2 Horizontal Cursor B</td>
<td>Range: [0, 127] pixels</td>
</tr>
<tr>
<td>21</td>
<td>Thold</td>
<td>Unsigned 8bit</td>
<td>Trigger Hold</td>
<td>Range: [0, 255] 0 to 255 milliseconds</td>
</tr>
<tr>
<td>22</td>
<td>Tpost L</td>
<td>Unsigned 16bit</td>
<td>Post Trigger</td>
<td>Range: [0, 32767] Indicates how many samples to acquire after the trigger. Default is 128.</td>
</tr>
<tr>
<td>23</td>
<td>Tpost H</td>
<td>Unsigned 8bit</td>
<td>Post Trigger</td>
<td>Range: [0, 255]</td>
</tr>
<tr>
<td>24</td>
<td>Tsource</td>
<td>Unsigned 8bit</td>
<td>Trigger Source</td>
<td>0: CH1; 1: CH2; 2-9: CHD; 10: EXT</td>
</tr>
<tr>
<td>25</td>
<td>Tlevel</td>
<td>Unsigned 8bit</td>
<td>Trigger Level</td>
<td>Range: [3, 252]</td>
</tr>
<tr>
<td>26</td>
<td>Window1</td>
<td>Unsigned 8bit</td>
<td>Windows Trigger Level 1</td>
<td>Range: [0, 255]</td>
</tr>
<tr>
<td>27</td>
<td>Window2</td>
<td>Unsigned 8bit</td>
<td>Windows Trigger Level 2</td>
<td>Range: [0, 255]</td>
</tr>
<tr>
<td>28</td>
<td>CH1pos</td>
<td>Signed 8bit</td>
<td>Channel 1 Position</td>
<td>Range: [-128, 0] pixels</td>
</tr>
<tr>
<td>29</td>
<td>CH2pos</td>
<td>Signed 8bit</td>
<td>Channel 2 Position</td>
<td>Range: [-128, 0] pixels</td>
</tr>
<tr>
<td>30</td>
<td>CHDpos</td>
<td>Unsigned 8bit</td>
<td>Logic Analyzer position</td>
<td>Range: [0, 7]</td>
</tr>
<tr>
<td>31</td>
<td>CHDdecode</td>
<td>Unsigned 8bit</td>
<td>Selected Protocol</td>
<td>0: SPI; 1: I2C; 2: RS232</td>
</tr>
<tr>
<td>32</td>
<td>Sweep1</td>
<td>Unsigned 8bit</td>
<td>Sweep Start</td>
<td>Range: [0, 255]</td>
</tr>
<tr>
<td>33</td>
<td>Sweep2</td>
<td>Unsigned 8bit</td>
<td>Sweep End</td>
<td>Range: [0, 255]</td>
</tr>
<tr>
<td>34</td>
<td>SWSpeed</td>
<td>Unsigned 8bit</td>
<td>Sweep Speed</td>
<td>Range: [0, 127]</td>
</tr>
<tr>
<td>35</td>
<td>AWGamp</td>
<td>Signed 8bit</td>
<td>AWG Amplitude</td>
<td>Range: [-128, 0] 4V to 0V</td>
</tr>
<tr>
<td>36</td>
<td>AWGtype</td>
<td>Unsigned 8bit</td>
<td>AWG Wave Type</td>
<td>0: Noise; 1: Sine; 2: Square; 3: Triangle; 4: Custom</td>
</tr>
<tr>
<td>37</td>
<td>AWGDuty</td>
<td>Unsigned 8bit</td>
<td>AWG Duty Cycle</td>
<td>Range: [1, 255] 0.391% to 99.61%</td>
</tr>
<tr>
<td>38</td>
<td>AWGoffset</td>
<td>Signed 8bit</td>
<td>AWG Offset</td>
<td>Range: [-128, 127] +2V to -1.985V</td>
</tr>
<tr>
<td>39</td>
<td>desiredF LLB</td>
<td>Unsigned 32bit</td>
<td>AWG Desired Frequency multiplied by 100</td>
<td>Range: [100, 12500000] 1Hz to 125kHz</td>
</tr>
<tr>
<td>40</td>
<td>desiredF LHB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>desiredF HLB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>desiredF HLB</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Xscope’s settings
## 6.2.1 Bitfield variables

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH1ctrl</td>
<td>Bit 0: Channel on</td>
<td></td>
</tr>
<tr>
<td>and</td>
<td>Bit 1: x10 probe</td>
<td>For future hardware</td>
</tr>
<tr>
<td>CH2ctrl</td>
<td>Bit 2: Bandwidth limit</td>
<td>For future hardware</td>
</tr>
<tr>
<td></td>
<td>Bit 3: AC/DC select</td>
<td>For future hardware</td>
</tr>
<tr>
<td></td>
<td>Bit 4: Invert channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Average samples</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 6: Math Active</td>
<td>Enables math (addition or multiplication)</td>
</tr>
<tr>
<td></td>
<td>Bit 7: Math operation</td>
<td>Subtract (1) or Multiply (0)</td>
</tr>
<tr>
<td>CHDctrl</td>
<td>Bit 0: Channel on</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 1: Pull</td>
<td>Pull resistor enabled</td>
</tr>
<tr>
<td></td>
<td>Bit 2: Pull Up</td>
<td>Pull up (1) or pull down (0)</td>
</tr>
<tr>
<td></td>
<td>Bit 3: Low</td>
<td>Thick line when logic '0'</td>
</tr>
<tr>
<td></td>
<td>Bit 4: Invert channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Serial Decode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 6: Parallel Decode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 7: ASCII Sniffer display</td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>Bit 0: Normal Trigger</td>
<td>The Normal Trigger bit must also be enabled for Single Trigger</td>
</tr>
<tr>
<td></td>
<td>Bit 1: Single Trigger</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 2: Auto Trigger</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 3: Trigger Direction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 4: Round Sniffer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Slope Trigger</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 6: Window Trigger</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 7: Edge Trigger</td>
<td>Dual Edge Trigger is enabled by clearing bits 5,6,7.</td>
</tr>
<tr>
<td>Mcursors</td>
<td>Bit 0: Roll Scope</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 1: Automatic Cursors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 2: Track Cursors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 3: CH1 Horizontal Cursors on</td>
<td>CH1 and CH2 Horizontal cursors are mutually exclusive</td>
</tr>
<tr>
<td></td>
<td>Bit 4: CH2 Horizontal Cursors on</td>
<td>CH1 and CH2 Horizontal cursors are mutually exclusive</td>
</tr>
<tr>
<td></td>
<td>Bit 5: Vertical Cursor on</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 6: Reference waveform on</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 7: Single Sniffer Capture</td>
<td></td>
</tr>
<tr>
<td>Display</td>
<td>Bit 0: Grid 0</td>
<td>00: No Grid, 01: Dots per division</td>
</tr>
<tr>
<td></td>
<td>Bit 1: Grid 1</td>
<td>10: Follow trigger, 11: Graticule</td>
</tr>
<tr>
<td></td>
<td>Bit 2: Elastic Display</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 3: Invert Display</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 4: Flip Display</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Persistent Display</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 6: Line / Pixel Display</td>
<td>Line (1), Pixels (0)</td>
</tr>
<tr>
<td></td>
<td>Bit 7: Show Settings</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Bits</td>
<td>Notes</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>MFFT</td>
<td>Bit 0: Hamming Window</td>
<td>Only one window must be selected, or none for No Window.</td>
</tr>
<tr>
<td></td>
<td>Bit 1: Hann Window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 2: Blackman Window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 3: Vertical Log</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 4: IQ FFT</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Scope Mode</td>
<td>Multiple modes can be selected simultaneously. If no bits are set, the Meter mode is displayed.</td>
</tr>
<tr>
<td></td>
<td>Bit 6: XY Mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 7: FFT Mode</td>
<td></td>
</tr>
<tr>
<td>Sweep</td>
<td>Bit 0: Acceleration Direction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 1: Accelerate Sweep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 2: Sweep Direction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 3: Ping Pong Mode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 4: Sweep Frequency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Sweep Amplitude</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 6: Sweep Offset</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 7: Sweep Duty Cycle</td>
<td></td>
</tr>
<tr>
<td>Sniffer</td>
<td>Bit 0: Baud 0</td>
<td>UART Sniffer Baud Rates:</td>
</tr>
<tr>
<td></td>
<td>Bit 2: Baud 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 3: CPOL Clock Polarity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 4: CPOH Clock Phase</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bit 5: Parity Mode</td>
<td>Enables parity check</td>
</tr>
<tr>
<td></td>
<td>Bit 6: Parity</td>
<td>Parity Odd (1), Parity Even (0)</td>
</tr>
<tr>
<td></td>
<td>Bit 7: Stop Bit</td>
<td>1 Stop bit (0), 2 Stop bits (1)</td>
</tr>
<tr>
<td>MStatus</td>
<td>Bit 0: Update</td>
<td>Exits triggering if the bit is set</td>
</tr>
<tr>
<td></td>
<td>Bit 1: Update AWG</td>
<td>The AWG parameters must be updated if the bit is set</td>
</tr>
<tr>
<td></td>
<td>Bit 2: Update MSO</td>
<td>The MSO parameters must be updated if the bit is set</td>
</tr>
<tr>
<td></td>
<td>Bit 3: Go Sniffer</td>
<td>Enters the Sniffer mode if the bit is set</td>
</tr>
<tr>
<td></td>
<td>Bit 4: Stop</td>
<td>Oscilloscope Stopped</td>
</tr>
<tr>
<td></td>
<td>Bit 5: Triggered</td>
<td>Oscilloscope Triggered</td>
</tr>
<tr>
<td></td>
<td>Bit 6: Meter VDC</td>
<td>If the bits are cleared, the Meter mode measures frequency</td>
</tr>
<tr>
<td></td>
<td>Bit 7: Meter VPP</td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Bitfield variable description

### 6.3 Command Set

When using the serial port, the commands are sent to the XScope in ASCII format, further data sent or received is in binary. When using the USB interface, the commands are sent as CONTROL READ requests, where the request byte is the command, and the Index and Value are additional parameters sent to the XScope. If the PC is requesting data, it will be returned in the endpoint 0 IN buffer. Table 11 shows the XScope Interface Protocol Command Set.
6.4 Vendor ID and Product ID

If you are using LibUSB to interface with the device, you will need the VID and PID of the device:
VID=16D0      PID=06F9

If you are using WinUSB, you will need the GUID defined on the driver’s .inf file:
GUID= 36FC9E60-C465-11CF-8056-444553540000
7. BMP Screen Capture

7.1 To send a BMP screen capture to a PC:

You can send a screen capture of the XScope to your PC using HyperTerminal. All the screen captures bitmaps in this manual where generated using this method. The screen capture is done thru the XScope’s serial port.

- Open HyperTerminal.
- Enter a name for a new connection (example: scope).
- Enter the COM port where the device is connected.
- Select 115200 bits per second, 8 data bits, Parity None, 1 Stop bit, Flow control None. (See figure 48)

![Figure 48: HyperTerminal Settings]

- In the Transfer menu, select Receive File.
- Enter a folder where to save the file and use the XMODEM protocol. (See figure 49)
Enter a file name with a BMP extension and press OK

7.2 To send a BMP screen capture to Linux:
Create the following script and save as capture.sh:

capture.sh

```bash
echo "Please enter filename. e.g capture.bmp"
read name
stty -F $1 115200
rx -c $name < $1 > $1
```

To use, make the script executable with “chmod +x capture.sh”. Then enter “./capture.sh” into a terminal followed by the serial device for example “./capture.sh /dev/ttyUSB0”.

Then enter a name for the bmp image including the .bmp file extension.

Figure 50: Screen capture in Linux
8. XScope’s Examples

8.1 Resistor Voltage Divider

1) Build the circuit shown on figure 51.
2) Set the device to Meter mode
3) You should see similar voltages as shown on figure 52.

Theory of operation: The circuit is a voltage divider, where \( V_{in} \) is 5V, and \( V_{out} \) is the voltage at CH2: 

\[
V_{out} = \frac{V_{in} + R_1}{R_1 + R_2}
\]

8.2 Measurement of an RC time constant

1) Build the circuit shown on figure 54.
2) Set the time base to 500\( \mu \)s/div.
3) Set the AWG to Square wave, 500Hz, 4V.
4) Set the gain on both channels to 2.56V/div.
5) The display should look similar to figure 53.
6) Now set the time base to 16\( \mu \)s/div.
7) Turn off CH1, set the CH2 gain to 1.28V/div.
8) Adjust the horizontal and CH2 positions so that the rising wave takes most of the screen.
9) Turn on the vertical and CH2 horizontal cursors.
10) Enable the cursors TRACK option.
11) Set the first vertical cursor at the corner of the wave, and the second cursor where the voltage equals 0V.
12) The display should look like figure 55. The measured time, \( T_{1/2} = 69 \mu s \), is the “half-life” time, so \( RC = 9.95 \mu s \)

Theory of operation: Circuit theory shows that if the RC circuit is fed with a step input, the output will approach a DC value exponentially; figure 55 shows the equation from which we can obtain RC when the half-life value is known.

8.3 Half Wave Rectifier with Smoothing Capacitor

1) Build the circuit shown on figure 58.
2) Set the time base to 2mS/div.
3) Set the AWG to Sine wave, 125Hz, 4V.
4) Set the gain on both channels to 1.28V/div.
5) The display should look like figure 57.
6) If the capacitor is removed, the display should look like figure 59.

Theory of operation: The diode will allow current to flow only during the positive half of the sine wave. The output voltage is a little bit lower because of the voltage drop of the diode. When the AWG voltage is negative, the diode acts like an open circuit and the capacitor discharges thru the resistor at an exponential rate.
8.4 BJT Amplifier
1) Build the circuit shown on figure 61.
2) Set the time base to 2ms/div
3) Move the position on both channels all the way down (GND reference grid is at the bottom of the screen).
4) Set CH1 to 0.32V/div, Set CH2 to 1.28V/div.
5) Set the AWG to Sine wave, 125Hz, 0.250V amplitude.
6) Increase the AWG offset until the CH2 wave is centered on the display. The display should look like figure 60.

Theory of operation: The transistor needs to be biased in its forward active region; this is what the offset in the AWG is for. The output voltage will vary according to the BJT transfer curve: changes in the input make large changes in the output.

8.5 Component V/I Curves
1) Build the circuit shown in figure 64.
2) Set the time base to 500µs/div.
3) Set the AWG to Sine wave, 125Hz, 4V.
4) Set the gain on both channels to 0.64V/div.
5) Enter the CH2 options and select SUBTRACT.
6) Set the device oscilloscope in XY mode.

Theory of operation: The goal is to plot the component’s voltage, versus the component’s current. Using the integrated waveform generator and an external resistor, we can inject current into the component. The voltage is measured directly using CH1. The current thru the component is the same as the current thru the resistor, the voltage on the resistor is proportional to the current. The voltage on the resistor is equal to CH2-CH1. 1V on the scope will represent 1mA on the component. Figure 62 and figure 63 show examples of V/I curves on components.

8.6 Frequency Plots
The AWG sweep function can be used to plot the frequency response of a circuit. This method is not directly a BODE plot since the horizontal axis is not logarithmic, it is linear.

1) Connect the AWG to the input and CH1 to the output.
2) Set the device to FFT mode.
3) Change to the desired time base. The maximum frequency is shown on the top right of the display.
4) Set the AWG to Sine Wave.
5) Enable the Frequency Sweep.
6) Set the AWG Sweep range to 1:255
7) Set the display to persistent.

Figure 65 shows an RLC circuit, and figure 66 shows the frequency response. This example shows the vertical scale with the LOG disabled.
9. Firmware Updating

This guide will show how to upgrade the firmware on your AVR XMEGA based device. There are two upgrade methods; you can use either one depending on your needs.

9.1 Firmware upgrade using an external programmer

9.1.1 Tools required

- AVRISP mkII, or similar PDI capable programmer
- AVR Studio 4 or Atmel Studio 6 IDE (Integrated Development Environment)
- HEX and EEP files for the device, found on the product’s page (Look for the HEX icon).

A regular AVR programmer might not work, the programmer needs to be PDI capable. PDI is the new interface to program XMEGA microcontrollers.

9.1.2 Instructions to install the tools

- Install AVR Studio and USB driver
- Connect the programmer to the computer and auto install the hardware

A more detailed guide on how to install the tools is found here: http://www.atmel.com/dyn/resources/prod_documents/AVRISPmkII_UG.pdf

9.1.3 Instructions to update the firmware

1. Start AVR Studio
2. Connect the cable from the AVRISP to the PDI connector on the board
3. Power the board
4. Press the "Display the 'Connect' dialog" button. Alternatively, you can go to this menu: Tools-> Program AVR - > Connect -
5. Select your programmer and port. (AVRISP mkII and AUTO or USB)
6. In the MAIN tab, select the device: ATXMEGA32A4
7. In the programming mode, select PDI
8. To check that everything is ok, press the "Read Signature" button. You will see a message saying that the device matches the signature.
9. Go to the PROGRAM tab
10. In the Flash section, look for the .HEX file and click Program
11. In the EEPROM section, look for the .EEP file and click Program
12. Go to the FUSES tab
13. Set BODPD to BOD enabled in sampled mode
14. Set BODACT to BOD enabled in sampled mode
15. Set BODLVL to 2.9V
16. Click Program
17. After updating the firmware, make sure to recalibrate the device (See section 1.6).
9.2 Firmware upgrade using the bootloader

9.2.1 Tools required
- Standard USB type A to micro USB cable
- Atmel’s FLIP software: http://www.atmel.com/tools/FLIP.aspx
- HEX and EEPROM files for the device, found on the product’s page (Look for the HEX icon).

9.2.2 Activating the bootloader
The K1 button needs to be pressed while connecting the device to the computer with the USB cable. Once the XScope enters the bootloader, the red LED will be lit, and will blink with USB activity. The XScope will appear as a new device on the host computer, the drivers required are found in the FLIP application folder.

9.2.1 FLIP application instructions
1) Start Flip.
2) Select ATXMEGA32A4U in the device selection list.
3) Select USB as communication medium
4) Open the USB port to connect to the target
5) Make sure the FLASH buffer is selected and check ERASE, BLANK CHECK, PROGRAM, VERIFY.

6) Load the HEX file .hex
7) Press RUN
8) Press SELECT EEPROM
9) Load the HEX file .eep
10) Uncheck ERASE and BLANK CHECK, only leave checked PROGRAM and VERIFY
11) Press RUN
12) Press START APPLICATION
13) After updating the firmware, make sure to recalibrate the device (See section 1.6).
10. Frequently Asked Questions

1) What tools do I need to develop my own programs on the XScope?
   If you don’t need debugging capabilities, only a regular cable is needed to program the device. If you want to be able to debug your code, you need an external debugger, such as the AVR JTAGICE mkII or the AVR ONE!

   **Software Tools:**
   - Integrated Development Environment: AVR Studio 4 or Atmel Studio 6
   - If using AVR Studio 4, the C compiler is a separate package, found in the WinAVR package.

2) Can the waveform generator and the oscilloscope run simultaneously?
   Yes, the waveform generator runs on the background. (The AWG uses the DMA, so it doesn't need any CPU intervention).

3) How do I power the XScope?
   The XScope can be powered thru the micro USB port. Alternatively, the XScope can be powered by connecting a 5V power supply on the 5V pin. Do not connect a 5V power supply and the USB at the same time.

4) Can I connect the XScope to the computer to control the oscilloscope and get the data?
   Yes, you can use the XScope PC Interface. A UART to USB cable will be required for hardware revisions 1.4 and 1.5.

5) Can I connect the XScope to the computer using the USB for firmware updates?
   Yes. Only the old hardware revisions (1.4 and 1.5) need a PDI programmer for firmware updates.

6) How much power can the XScope supply?
   The XScope can also power external devices. This is the maximum current on each voltage:
   - **+5V**: Will be the same as the power source minus 60mA.
   - **-5V**: Approximately 50mA, but this subtracts from the available current on the +5V line.
   - **+3.3V**: Approximately 200mA, but this subtracts from the available current on the +5V line.

7) What is the maximum frequency that I can measure with the XScope?
   The analog bandwidth is set at 200kHz. However, you can still measure frequencies up to almost Nyquist/2, i.e. 1MHz. The FFT analysis will be particularly useful when measuring high frequencies.

8) Can I measure voltages above 20V?
   Yes, by adding a 9Mohm resistor on the input. Since the input impedance of the device is 1Mohm, the voltage will be divided by 10 (This is the equivalent of using a 10:1 probe).

9) Are the logic inputs 5V tolerant?
   No, the logic inputs are not 5V tolerant. An easy solution would be to place a 3K resistor in series with the 5V signal, this will work for signals with a frequency lower than 200kHz. Another solution would be to use a voltage translator chip.
10) The source code says "evaluation version", can I get the full version?
The full source code is currently not open. The evaluation source code does not contain the MSO application. The HEX file does contain the full version of the oscilloscope.

11) What is the current consumption of the XScope?
Between 40mA and 60mA, depending on how many pixels are lit on the OLED.

12) There is a new firmware for the XScope, how do I update?
Follow the instructions on section 9.

13) How does the XScope compare to other digital oscilloscopes?
You can check this comparison table: [http://www.gabotronics.com/resources/hobbyists-oscilloscopes.htm](http://www.gabotronics.com/resources/hobbyists-oscilloscopes.htm)

11. Troubleshooting

Is the XScope not working? Check out these tips:

1) The unit does not power up
If using the USB connector to power, try applying 5V directly instead with another power supply.

2) The unit powers up but the MSO is not working
Try restoring the default settings: Press K4 during power up, then select "Restore"

3) The screen turns off after a certain amount of time
This is the screen saver in action. The screen saver time can be changed in factory options (See Section 1.6).

4) I built my own Xprotolab, a particular button doesn't work
There might be shorted pins on the microcontroller. Check for debris or solder bridges. Using a solder wick on the pins will help.

5) When powering up, the splash screen stays for a very long time (more than 4 seconds)
The crystal is defective or the traces on the crystal are shorted.

6) It still isn't working!
If you have a multimeter and want to try to fix yourself, check the following voltages. If any of the voltages are wrong, there might be a defective part.

- Voltage at +5V should be between +4.75 and +5.25V
- Voltage at -5V should be between -4.75 and -5.25V
- Voltage at +3.3V should be between +3.2 and +3.4V
- Voltage at pin 8 of U3 should be between +2.00 and +2.09V

If all fails and if the device is under warranty, you can send it back for repairs.

TIP: If the unit is powered with more than 5.5V, the negative voltage generator would be the first component to get damaged.
12. XScope Design

12.1 System Architecture

The XScope uses many resources and peripherals of the XMEGA microcontroller. Figure 67 shows the XScope’s Architecture block diagram.

![XScopes Architecture Block Diagram](image)

*Figure 67: XScopes Architecture Block Diagram*
12.2 Schematics

Figure 68: Xprotolab Schematic
Figure 69: Xminilab Schematic