KE·SYSTEM

WAVER AD

Users Guide

Version 1.4.0

Safety Instructions

This device fulfills the EU regulations 2004/108/EG (CE-Identification).
The following safety instructions for the operation of the device have to be strictly followed in order to guarantee operational safety of the device and to avoid injuries by voltage or current.
Any liability is excluded for damages caused by the user not following any of these instructions.

- Do not operate the device on moist or wet undergrounds or after the device has come in contact with moistness or wet conditions.
- Do not operate the device in close vicinity to strong magnetic fields (motors, transformers, etc.).
- Do not operate the device by any other voltage source than the USB Interface (5V).
- Do not connect signal outputs to points under voltage.
- Operate signal inputs (trigger inputs) strictly within the specified voltage limits.
- Do not operate the device if damages are visible or the device isn't completely closed.
- WaverAD is designed for operation at room temperature and normal humidity conditions. Exceeding these operational conditions can lead to malfunction or in extreme cases even to damages to the device.
- The device does not contain any components that can be serviced by the customer or any non-authorized repair service. Neither of the two safety seals on the bottom side of the device must be damaged.
- Any warranty expires, if the customer or an unauthorized service provider conducts any kind of intrusion and/or repair without prior, explicit and written approval from KE-System. Also we do not grant warranty for defects or damages caused by inappropriate or incorrect use, neglect of usage instructions or wrong or negligent handling.

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WaverAD Hardware

Front View

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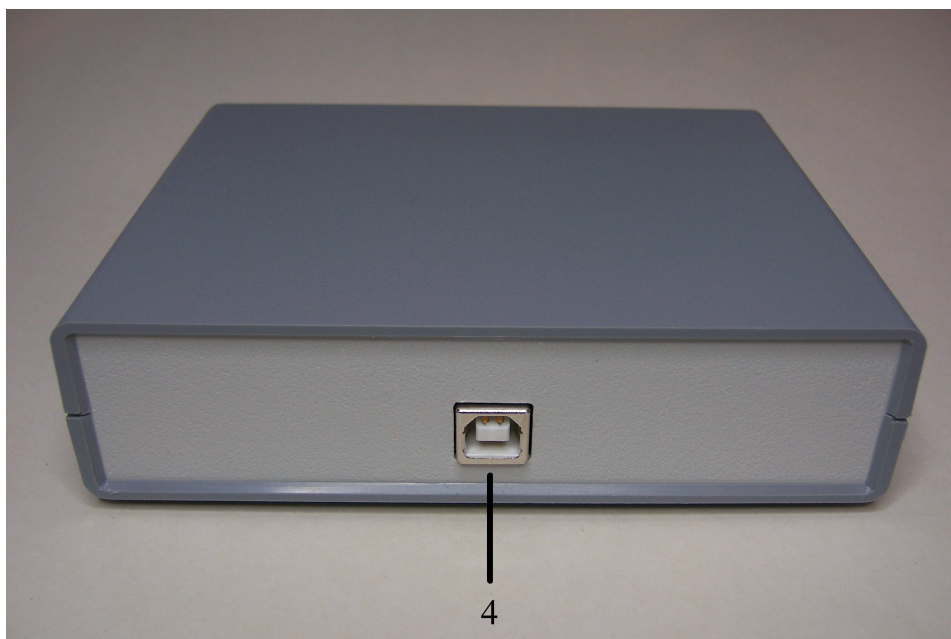
4: USB Connection

Installation

PC Software Installation

The WaverAD PC-Software is installed by simply unzipping the download package into a directory of own choice. Simply use your normal unzip application (e.g. Winzip or WinRAR) or the functionality integrated into the Windows operating system. The destination folder does not necessarily have to be on drive C:.

The installation routine will copy files only into the chosen directory and sub-directories thereof. The directory structure is as follows:
- Destination directory.
  - \App: Executables and necessary assisting files
  - \Driver: Drivers for the WaverAD Hardware
  - \Projects: Signal projects
  - \Waveforms: Single signals

After unzipping, use Windows Explorer or a comparable file manager to change into the executable directory and run the application (WaverAD.exe) by double-clicking on it. The software will lead you through some configuration steps at the first start:

1. Choose a language from the list of available languages.
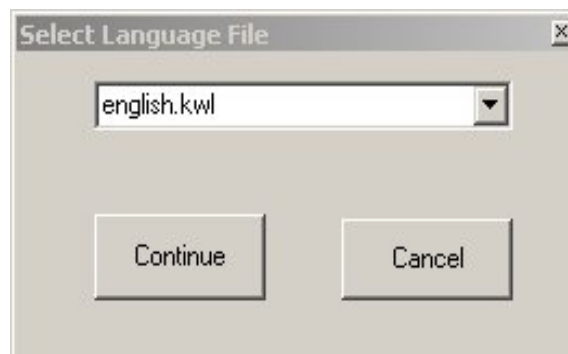
2. Select which of the offered shortcut options (Start menu, desktop and/or quick start) you would like to have created automatically. Please read the license terms carefully and accept those to continue.
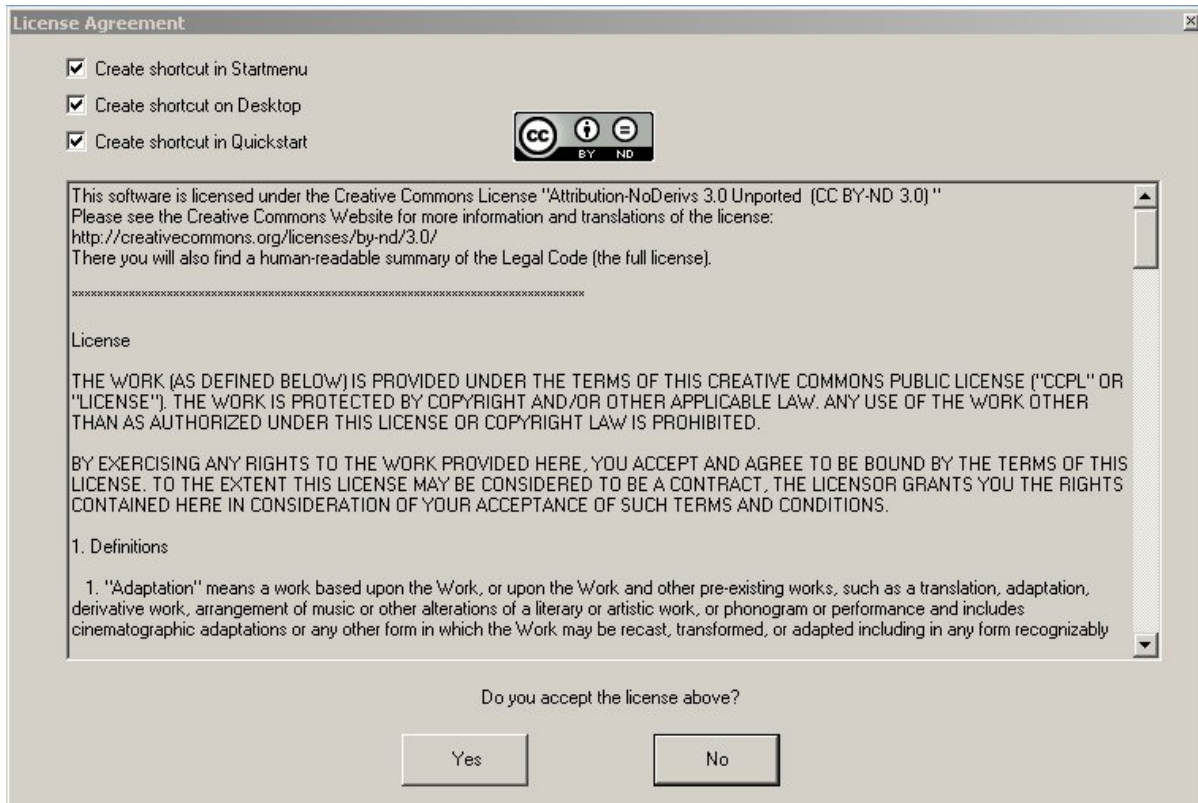
This will complete the installation of the WaverAD software on your PC.

Hardware Driver Installation

Please consult the respective documentation ("Driver Installation Guide.pdf") from the KE-System website for the installation of the WaverAD drivers.

Operation

It is not relevant, whether the software is started before a hardware is connected or the other way around. The PC-Software will automatically detect a connected hardware and will initialize the hardware for operation within some seconds.
You can verify the status of the initialization from the feedback messages in the hardware status field of the PC-Software.

PC-Software
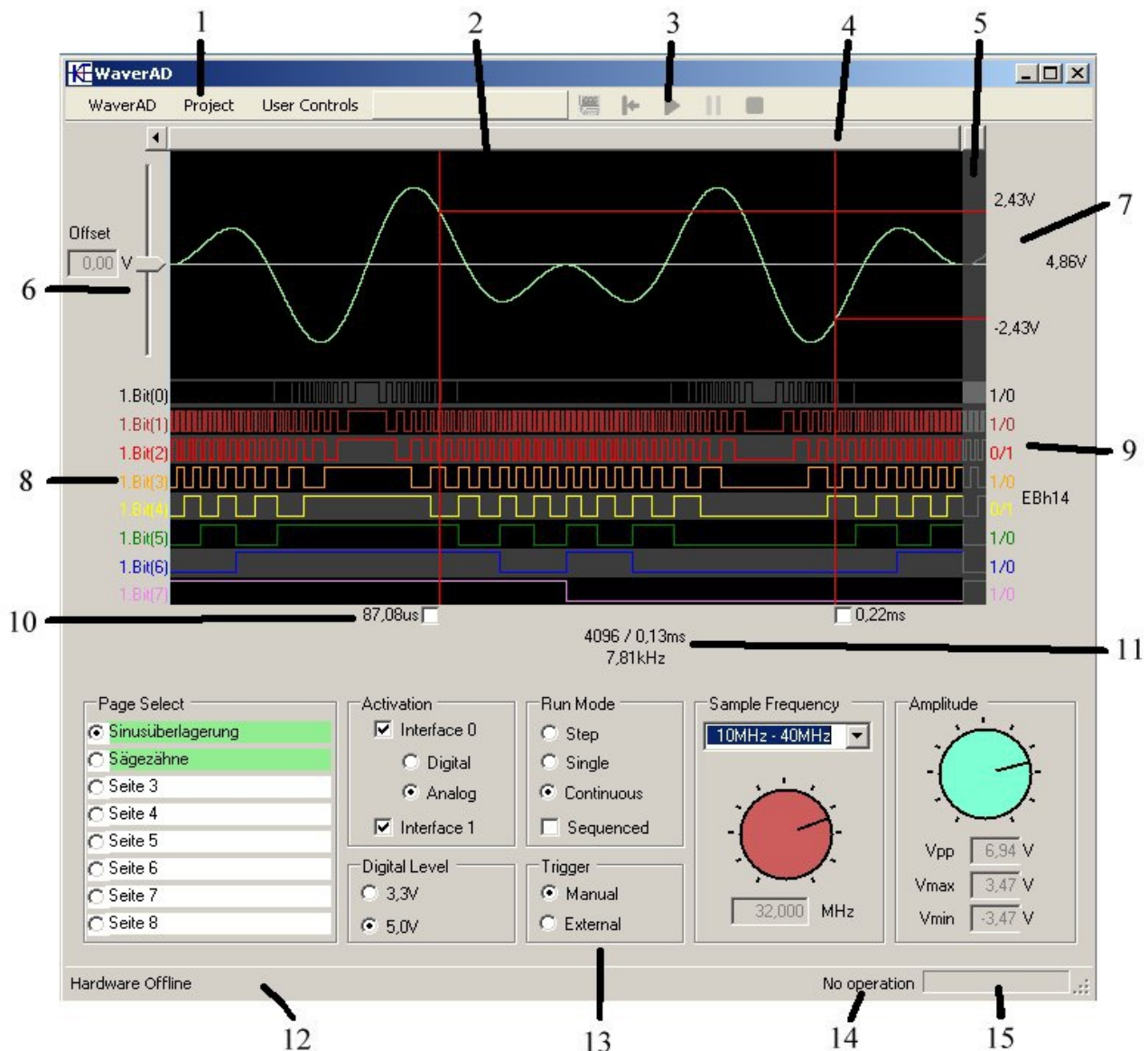
Control functions on the main screen

1: Program Menu	6: Offset Adjustment	11: Time Display
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3: Action Console	8: Signal Names	13: User Console
4: Horizontal Scroll	9: Bit-Value Display	14: Activity Field
5: Continuing Signal	10: Measurement Cursors	15: Progress Display

The signals shown in the above picture have the following mathematical functions:

Upper signal (analog)

$$5\text{V}\cdot\sin\left(2\cdot\pi\cdot\left(\frac{t}{T}\right)\right)\cdot\sin\left(2\cdot\pi\cdot\left(\frac{4\cdot t}{T}\right)\right)$$

(adjusted to +/- 3,47V amplitude)

Lower signal (8-bit digital)

$$h80 + h80\cdot\sin\left(2\cdot\pi\cdot\left(\frac{t}{T}\right)\right)$$

1 - Program Menu

The program menu controls the basic functions of the PC-Software. The following options exist in this menu:

WaverAD	Options	Here the user can adjust the user language and the standard directory for user waveforms and projects. Also it can be specified which hardware device will be connected to this software instance (refer to the section "Operating Multiple Systems")
	Info	Contains information about the connected hardware device and the version of the PC Software.
	Exit	Closes the WaverAD Software.
Project	New	Starts a new project.
	Load...	Opens an existing project (kwp-file).
	Save...	Saves the current project (as kwp-file).
User Controls	Functions to operate and configure extension modules. Refer to section "Extension Modules" for more.	

2 - Signal Display

The currently active signals will be displayed here. The upper half of the screen displays the signal in channel 0, which can be either analog (8 bit resolution) or 8-bit digital (selectable in the user console). The lower half of the screen displays the signal in channel 1, which is always 8-bit digital. A signal contains 8192 single 8-bit values. Refer to the respective section of this document for more information about signals.

Signals that are activated for electric output (user console) are displayed in color or gray if deactivated for electric output. The color coding of the digital signals is according to the color code of electric resistors (DIN IEC 62).

Apart from the signals the signal display shows a variety of cursors.
- 2 measurement cursors (red) - see section "Measurement Cursors"
- 1 position cursor (blue) - this shows the actual value in the signal, when the output is paused (see for example section "Action Console"-"Pause").
- 2 modification cursors (green) - see section "Signal Modification"

Measurement cursors can be placed with the left mouse button within the signal display. The right mouse button opens the context menu within the signal display.

Please notice, that the signal display can only show idealized views of the signals. Depending on the electric load on the signal outputs of the hardware device the real electric signal output can differ from the displayed waveform. The signal display is not a measurement of the real electric signal!

Context Menu

A right mouse click within the signal display opens the context menu that contains various functions for handling of the display and signals.

Load Waveform	Opens an existing signal (kww-file or csv-file). If the signal is single-channel, the loaded signal will be filled into the respective half of the display, where the menu-opening mouse click was detected. If the signal is dual-channel both upper and lower display half will be filled.
Modify Waveform	Opens the signal editor. Refer to section "Signal Modification" for more.
Clear Waveform	The chosen signal will be reset (analog value 0V, digital value h80)
Save Waveform	Saves the signals (selectable whether single-channel or dual-channel) into a kww-file or csv-file.
Waveform Analysis	Opens the waveform analysis window, where different analysis methods can be applied to the signal area as shown in the signal display.
Zoom In	Zooms into the signal by 2x, centered around the x-scale where the menu-opening mouse click was detected.
Zoom Out	Zooms out of the signal by 0.5x.
Zoom Full	Displays the full signal area.
Clear Page	Both signals will be reset (analog value 0V, digital value h80).
Swap Waveforms	Swaps signals in channels 0 and 1.

3 - Action Console

The Action Console controls the signal output. The shown symbols have the following functions.

	Upload the project to the hardware device. All signals on all 8 pages will be loaded to the hardware. The upload is the basic requirement to be able to output the signals. Depending on the number of used signals this data transfer can take a few seconds. The progress display informs about the progress of this upload.
	Reset position. The output value of the actual signal is reset to the first value of the signal. This is comparable to the function of a music player that starts a title from the beginning.
	Run. This option exists in the operation modes "Continuous" and "Single Run" only. With manual trigger: Start signal output With external trigger: Activates trigger detection
	Single Step. This option exists in the operation mode "Single Step" only. With manual trigger: Steps through the signal with every click. With external trigger: Activates trigger detection for single step with every trigger event
	Pause signal output. The actual signal output will be paused. The last value will be continuously output. The position cursor indicates this value.
	Stop signal output. The actual signal output will be paused and the output value will be reset to the first signal value. An activated trigger detection will be deactivated.

4 - Horizontal Scroll

The bar in the horizontal scroll control indicates the sector of the signal that is currently displayed in the signal display (especially in zoom-in modes). The respective displayed sector can be scrolled using the bar in the scroll control.

5 - Continuing Signal

The continuing signal shows the waveform that will follow the currently displayed signal sector. This is especially interesting to see how the waveform will continue at the end of a signal sweep. Depending on the operating mode the following will be displayed:

- Continuous, non-Sequenced: After the end of a signal sweep, the signal output will continue at the beginning of this same signal. Hence the continuing signal will show the first few values of the same signal
- Continuous, Sequenced: After the end of a signal sweep, the signal output will continue at the beginning of the signal on the next page. Hence the continuing signal will show the first few values of the signal on the next page.
- Single Run, non-Sequenced: After the end of a signal sweep, the signal output will pause automatically. Hence the continuing signal will show the last signal value of this signal.
- Single Run, Sequenced: After the end of a signal sweep, the signal output will continue at the beginning of the signal on the next page until the end of the signal on the last page (page 8) has been reached. Then the signal output will pause automatically. Hence the continuing signal will show the first few values of the signal on the next page as long as signals on pages 1-7 are displayed. If page 8 is displayed the continuing signal will show the last signal value of this signal.
- Single Step, non-Sequenced: Like for Continuous, non-Sequenced.
- Single Step, Sequenced: Like for Continuous, Sequenced.

6 - Offset Adjustment

With the Offset control the user can adjust the offset of the analog output signal with a positive or negative bias. The offset adjustment happens in steps of 150mV and can equally happen during signal design as well as signal output. Thus the offset setting is not static for a signal but can be adjusted during run-time.

7 - Voltage Display

The voltage display shows the signal voltage at the signal positions indicated by the two measurement cursors. In addition to that the voltage difference between those to voltages is calculated.

Please notice, that the signal display can only show idealized views of the signals. Depending on the electric load on the signal outputs of the hardware device the real electric signal output can differ from the displayed waveform and with that also the real voltages from those displayed in the software.

8 - Signal Names

The single bit lines of a digital signal can be named individually. Click on the names of the respective bit line and change the name in the opening form. Bit line names on channel 0 will be

automatically extended by the identifier "0.", bit line names on channel 1 are extended with "1."

9 - Bit Value Display

Similar to the voltage display in the analog signals, bit values of the single bit lines are displayed in the form "x/y", where x is the bit value at the position of the left measurement cursor and y is the bit value at the position of the right measurement cursor.
Additionally the Byte-Value of the total 8-bit signal is displayed in the form "XhY" respectively "XdY", where again X is the byte value of the signal at the position of the left measurement cursor and Y the byte value of the signal at the position of the right measurement cursor. By clicking on this display the user can toggle between a hexadecimal (XhY) and a decimal (XdY) representation of these values.

10 - Measurement Cursors

The two measurement cursors (red) can be positioned within the signal display by clicking left within the display area.
Through the cursors both signal timings will be displayed in the time display as well as voltage measurements or bit- and byte values in the Bit Value Display.
The time display at the foot of the measurement cursors can be toggled by a mouse click between time value and value position.

Each measurement cursor can be operated in two modes:
- Floating - the check box at the foot of the cursor is unchecked. With that, the respective cursor is fixed in its position at the frame of the signal display. Scrolling the signal horizontally will virtually move the signal "underneath the cursor".
- Sticky - the check box at the foot of the cursor is checked. With that, the respective cursor is sticky to its respective position within the signal. Scrolling the signal horizontally the cursor will move its position together with the signal. Sticky cursors will not re-position by left-clicking in the signal display.

By combining floating and sticky cursors, various measurement and positioning tasks can be accomplished very comfortably.
- Both cursors are floating
  With each left-click in the signal display the two measurement cursors will be alternately re-positioned. With that consecutive signal points can be comfortably measured.
  With one click a cursor gets positioned on the first signal point of interest, with the second click the second cursor on the second position. The measurement for these two points can be analyzed. With a third click the first cursor gets re-positioned to the third signal point of interest, which immediately allows the analysis of the measurement between point 2 and point 3.
  Another measurement task in this cursor combination could be to arrange the cursors for a fixed time period, allowing the signal to be horizontally scrolled "underneath the cursors" and measured against this fixed time period.
- One cursor floating, one cursor sticky
  This cursor combination can be used, when several different signal points need to measured against one fixed point.
  In this case the static position in the signal is marked with a sticky cursor. Each left-click in the signal display will now re-position the floating cursor to a new position that shall be

measured against the fixed position.
- Both cursors sticky
This cursor combination helps to specify a certain signal area, for example for signal modification (own section is this document).
Under large zoom, the signal area can be chosen very precisely and marked with sticky measurement cursors. These cursors will retain their position relatively to the signal even if the signal is scrolled horizontally or further zoomed in or out.

11 - Time Display

The time display shows the timely difference between the two measurement cursors in three different ways.
1. As an number of signal points
2. As time difference
3. As frequency, that a single period of an oscillation would have between the two measurement cursors

12 - Hardware Status Field

The hardware status indicates, whether a WaverAD device is connected or not. During the device initialization the status field informs about the progress of the initialization.

13 - User Console

Next to the Offset adjustment control, the user console is the main area, where the user can adjust the signal output in various ways and modes.
All functions contained in the user console can adjust signal parameters while the signal is in actually output (like the offset adjustment can). Thus these functions do not have to be statically fixed for a signal during signal design, but can be adjusted while the signal is "running".
The different functions are explained in the following.

Page Select

The user can manually as well as automatically switch between 8 different signal pages. Each page contains two signals (channel 0 and channel 1) with each having 8192 data values at 8 bit of width. The pages can contain different waveforms on each page (e.g. sine wave, square wave, triangle, ...), but also the pages can be designed to contain signals that are consecutive to each other. In sequenced mode this allows for 2 channels (analog/digital) of each 8*8192 = 65536 data values (each 8 bit width). This can be for example a very low frequency oscillation (down to ~0,1 Hz) on the analog output or a 64kByte transmission on the digital channel.

Left clicking on a page name selects the respective page as active.
Right clicking on a page name allows renaming of this page.
Pages that contain a signal (e.g. by loading a signal or creating one on this page) are shown with green background. On pages that are shown with white background, both signals are empty (Analog: 0V, Digital: value h80).

Activation

The activation field is used to switch output channels on or off. Activated channels are displayed in color in the signal display and a respective voltage signal is output on the hardware interface. Non-

activated channels are displayed gray in the signal display and the output is deactivated (digital outputs are high-impedance, analog output is set to 0V). The operating mode of channel 0 (analog or digital) can also be selected in the activation field. The signal display is adjusted accordingly.

Digital Level

In this field the user can select the voltage level of any digital output. The WaverAD device offers the two logic level 5,0V and 3,3V.

Run Mode

This field selects the run mode of the signals. Three different modes are available, each of which can be used in sequenced or non-sequenced mode.
- Continuous, non-Sequenced
  The activated signals of the chosen page will be output continuously. After reaching the end of one signal, the signal output will automatically continue at the beginning of the same signal.
- Continuous, Sequenced
  The activated signals of the chosen page will be output continuously. After reaching the end of one signal, the signal output will automatically continue at the beginning of the signal on the next page. After reaching the end of signal on page 8 the output will automatically continue at the beginning of the signal on page 1.
- Single Run, non-Sequenced
  The activated signals of the chosen page will be output exactly one time. After reaching the end of the signal, the output will automatically pause and the signal outputs will remain on the last signal value.
- Single Run, Sequenced
  The activated signals of the chosen page will be output exactly one time. After reaching the end of the signal, the output will automatically continue at the beginning of the signal on the next page. After reaching the end of signal on page 8, the output will automatically pause and the signal outputs will remain on the last signal value.
- Single Step, non-Sequenced
  On each trigger event (either a manual mouse click or a voltage pulse on either one of the two trigger inputs) the next signal value of the activated signal on the selected page will be output. After reaching the end of one signal, the signal output will automatically continue at the beginning of the same signal.
- Single Step, Sequenced
  On each trigger event (either a manual mouse click or a voltage pulse on either one of the two trigger inputs) the next signal value of the activated signal on the selected page will be output. After reaching the end of one signal, the signal output will automatically continue at the beginning of the signal on the next page. After reaching the end of signal on page 8 the output will automatically continue at the beginning of the signal on page 1.

Trigger

In this field the user can select whether a manual trigger event (mouse click on action button "Run" or "Single Step") or an external trigger event (positive voltage pulse on either of the two trigger inputs) shall cause a signal run.
After choosing "external", the user first has to initiate the trigger detection by clicking on the action button "Run" or "Single Step" before external trigger events will be detected.

The section "Hardware Specifications" gives details on the recommended conditions of the voltage pulse on the external trigger inputs.

Sample Frequency

This field enables the user to analyze and adjust the sample frequency of the output signal. The single data values of activated signals (8192 per signal) will always be output with this sample frequency.
The adjustable frequency can be selected out of 12 ranges. Within each of these ranges the user can adjust the final sample frequency with a turn knob in 150 frequency steps.
The minimum possible sample frequency is 6,25kHz.
The maximum possible sample frequency is 100MHz.

Please notice, that a change of the sample frequency does not change the signal display. The display always shows the full signal, independently of the time period in which the signal is output by the hardware. What changes though by modifying the sample frequency is the scale of the display, visible through the time measurement or the time values of the measurement cursors.

Amplitude

This turn knob changes the amplitude of the output analog signal. Changes in amplitude will be simultaneously displayed in the signal display.
At the same time this field shows a variety of basic measurements of the analog signal in three different text fields.
- Vmax: The maximum voltage in the analog signal of the selected page
- Vmin: The minimum voltage in the analog signal of the selected page
- Vpp: The difference between maximum and minimum voltage in the analog signal of the selected page

Please notice, that the signal display can only show idealized views of the signals. Depending on the electric load on the signal outputs of the hardware device the real electric signal output can differ from the displayed waveform and with that also the real voltages from those displayed in the amplitude field.

14 - Activity Field

This field shows the execution status of the hardware device with the following possibilities:
- Uploading: new signals are uploaded from the PC to the device
- No operation: Signal output is paused
- Waiting on trigger: External trigger detection has been initialized, but no trigger event has been detected yet
- Executing: The device is actively outputting a signal

15 - Progress Display

The progress bar informs about the status of a signal upload from the PC to the hardware device. Depending on the number of existing signals, the transfer can take a few seconds.

Example for a Use Case

Please take the chance to walk through the following example for a signal generation project with WaverAD step by step. Having completed this, you will be experienced in the basic functionality of the software and the hardware device.
All you need is a PC, having the WaverAD software installed and a WaverAD device together with the accompanying USB cable.
Ideally you also have access to an oscilloscope connected to the analog interface of the WaverAD. With this you can even better comprehend the results of every step - however it is not necessary.

This example focuses on the output of an analog signal, because the visualization of the output is much easier with an oscilloscope than with a logic analyzer. However a digital or mixed-signal signal generation follows exactly the same principles and should be equally understandable after walking through this example.

Action	Visible Result
Start the PC software	After a short splash screen the user console screen of the PC software will be displayed
Load the project "User Guide Example.kwp", through Project-Load...	The signal display fills up with an analog and a digital signal
Change to page 4	The signal display gets empty
Right-click into the upper half (analog signal) of the signal display	The context menu shows up
Choose "Load Waveform" and load the signal "_Sine 8 Periods.kww"	The upper half of the signal display fills up with 8 sine periods. At the same time the page name updates and is marked green as "filled".
Connect the WaverAD device with your PC using the USB cable	The hardware status field indicates the hardware initialization steps and finalizes with the output "Hardware ready". At the same time the Upload action button is enabled.
Left-click on the action button "Upload".	The activity field changes from "No operation" to "Uploading" and the progress bar indicates the status of the upload. After finalization, the action button "Run" is enabled.
Activate channel 0	The signal color changes from gray to green
Left-click on the action button "Run"	The device starts output of a sine wave with 5,2V peak-peak and a frequency of 9,8kHz. The activity field changes to "Executing".
Place the two measurement cursors so that exactly one single sine period is measured in the signal display.	The time measurement shows a frequency of 9,8kHz (as well as 1024 data values and 0,10ms period)
Use the sample frequency turn	The frequency of the output signal changes on the

| knob to modify the sample frequency	oscilloscope. At the same time the sine frequency is displayed in the time measurement field of the WaverAD software (the measurements continue to measure one sine period).
Use the amplitude turn knob to modify the signal amplitude	The output signal changes simultaneously to the change in the software console.
Use the offset slider to modify the signal offset	The output signal changes simultaneously to the change in the software console.
Change to signal page 2	The signal output changes from sine wave to saw tooth wave with half the frequency. The signal display changes accordingly.
Left-click the action button "Pause"	The signal output on the oscilloscope stops. The blue cursor is shown in the signal display, indicating the signal value that is currently output. The activity field changes to "No operation".
Toggle the run mode "Single Step"	The action button "Run" changes to "Single Step"
Left-click the action button "Single Step" multiple times.	Each mouse click moves the output signal position one step further, visible by the moving blue cursor. At the same time the output signal on the oscilloscope changes its voltage.
Left-click the action button "Reset"	The voltage output on the oscilloscope changes to the voltage of the first signal value. Equally the position cursor is moved to this position in the signal display.
Change to signal page 1, modify the offset to 0V and the amplitude to maximum.	The output voltage on the oscilloscope changes from a negative voltage (first value of the previous saw tooth signal) to 0V (first value of the current signal). The signal display shows a complex sine wave.
Toggle the run mode "Single Run".	The action button "Single Step" changes to "Run"
Adjust your oscilloscope to "single trigger", triggering at positive slope just above 0V	
Left-click action button "Run"	The position cursor in the signal display jumps from the first signal position to the end of the signal. If your oscilloscope has been adjusted correctly, it shows exactly one single signal wave of the current signal.
You can repeat the last step as often as you want. However please note, that it is necessary to "reset" the current signal position before running the waveform again.	

Signals

A signal in WaverAD contains 8192 data values (enumerated from 0 to 8191), each being 8-bit wide. Each signal can be interpreted in an analog or digital (8 bit lines) way. WaverAD supports 8 signal pages, each of which can contain 2 signals (channel 0 and channel 1), enabling access to 16 different signals during operation. Each of those 16 signals is freely programmable.

Signal Modification

This chapter exclusively discusses the options of the PC software to define own signals or modify existing ones.
The respective signal editor can be accessed through the context menu in the signal display (menu item "Modify Waveform").
Many of the entry field of the signal editor can handle complex mathematical terms. WaverAD offers a variety of mathematical operators and functions that can be used. These are explained in detail in the appendix of this document.
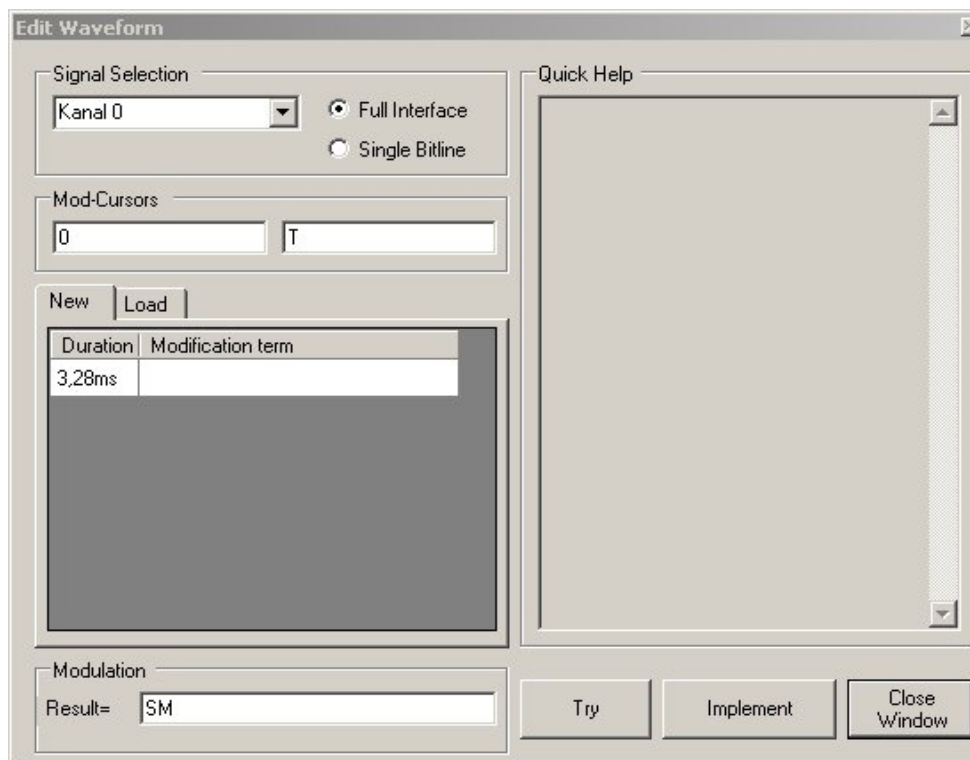
Signal Selection

In this field the user chooses, which signal of the active page shall be modified (channel 0 or channel 1). Equally single bit lines within the signals can be modified.

Mod-Cursors

It is not necessary to always modify the full signal. Much rather, the user has the option to specify a section within one signal, that shall be modified. This section is bordered by two modification cursors.

Each of the two entry fields in the Mod Cursors frame handles the position of one of the two mod cursors, whereat it is not significant, which field is used for which cursor.

The position of the cursors can be specified as a data value position, as time value or a mix of both of those. Equally the position of the mod cursors can be related to the position of the measurement cursors.

Both of the mod cursor fields can handle complex mathematical terms. In case of a syntactical error in a term, the field will be displayed in red font.

The modification cursors are displayed in the signal display (green dashed lines) while entering the respective term into the fields.

The field "Quick Help" shows a list of allowed constants and units while typing.

Examples:

Field Entry	Position of the Modification Cursor
0	at the left border of the signal display
T	at the right border of the signal display
8192	at the right border of the signal display
T/2	exactly in the middle of the signal display
2356	on data value position 2356
1ms	1ms to the right of the left border of the signal display
1ms+100	1ms plus 100 data values to the right of the left of the signal display
CL	on the left measurement cursor
CR	on the right measurement cursor
CL+C/2	in the middle between the two measurement cursors

While measurement cursors can be placed anywhere within a signal, the modification cursors are always placed to the starting time of the respective time-discrete signal value. Under large zoom factors in the signal display it may happen that a modification cursor is placed in a certain distance to the measurement cursor, even though the mod cursor position was defined by the measurement cursor constants (CL or CR). This is intentionally, to be able to clearly define the selected modification area by the two mod cursors.

The modification will happen over the signal area, including the data value defined by the left mod cursor but excluding the data value defined by the right mod cursor.

Modification Term

This area is used to define the new signal values that shall be injected into the signal area selected by the modification cursors. This can happen by defining a new signal waveform (Tab "New") or by injecting an existing signal (Tab "Load").

Load
An existing signal can be loaded and a part of it can be injected into the signal to be modified. In case the loaded signal is dual-channels, the field "Waveform Selection" determines which of the two channels within the waveform file shall be used for modification. The signal area that has been selected by the mod cursors will be inserted.

New

The table in this section can be used to divide the modification section of the signal defined by the mod cursors into several sub-sections. Unlike the definition of the modification sections, these sub-sections are not defined by start- and end-times (like with the modification cursors), but much rather they are defined by time ranges. These time ranges are specified in the column "Duration" of the table, while the column "Modification Term" specifies the waveform term to be used within this time range.

The time duration can be entered as a number of data values, a time or a mixture of both. The duration fields can also contain complex mathematical functions to calculate the time duration. In case of a syntax error in one of these terms, the respective cell is displayed in red font. The field "Quick Help" shows a list of allowed constants and units while typing. Refer to the examples on the following pages for explanations on the entry of time durations.

Every time duration for a sub-section entered is accompanied by one mathematical term that defines the waveform of the signal within this sub-section. This waveform function is defined in the column "Modification Term" of the table. This function can reach from a simple constant (e.g. constant voltage) up to a complex mathematical term.

When entering analog signals it needs to be taken care, that the result of the function will always have the unit 1 Volt referencing the amplitude turn knob being at its maximum and the offset voltage at 0V. The signal displayed in the signal display and the output voltage differs from the calculated function according to the amplitude knob not being at maximum and the offset slider not being at 0V.

To ease the entry of the function terms and to make the terms easier to read, a number of constants, variables and operators can be used. these are shown in the field "Quick Help" while entering the term.

Refer to the examples on the following pages for explanations on the entry of waveform terms.

Right clicking on single cells of the modification table opens a specific context menu with some row handling options like for example delete or move.
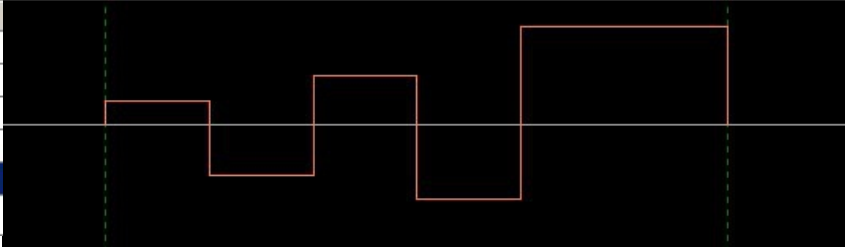
<u>Examples</u>
The following examples are based on a sample frequency of 1MHz (1us). The modification cursors have been set to 1ms (=position 1000) and 7ms (=position 7000).
Only examples of analog signals are shown here, as these are easier to visualize than signals with 8 different bit lines. The creation/modification of a digital signal follows the same principles.

Entry options for the time duration

Time	Mod Term
1ms	1V
1000	-2V
0,3ms+700	2V
X/6	-3V
-	4V
0	

The first 4 rows in the duration column each specify a duration of 1ms in different ways
  • time duration ("1ms")
  • number of data values ("1000" values at a time base of 1MHz/1us)
  • as a mixture of time value and number of data values ("0,3ms+700")
  • as a fraction of the modification area ("X/6", equally to 1/6 of X, which is a constant for the section from 1ms to 7ms)
The fifth row simply contains a "-", which specifies the remaining time duration within the modification section.

Modification term, working with constants

| Time	Mod Term
3ms	Y*sin(2*#*r/T)
2ms	Y*sin(2*#*r/X)
1ms	Y*sin(2*#*r/R)
0	

The constant "Y" is a voltage constant, specifying the maximum voltage value, that can be displayed and output by the hardware (~ 5V). Similarly, concrete voltage values like "1V" or "3,4V" could be entered.
Next to the voltage constant, different time constants are available (see quick help), that can be used to define signal terms as easy as possible. The three sub-sections of the example show how to use them.
  • „T" (=8192, equal to the whole signal area (reaching from 0 to 8191)): With that, the sine wave of the first row has a period spanning over the full signal range, out of which only the specified 3ms are used in the sub-section.
  • „X" (=XR-XL, equal to the range in between the modification cursors): With that, the sine wave of the second row has a period spanning over the modification range, out of which only the specified 2ms are used in the sub-section.
  • „R" (=RR-RL, equal to the duration of the sub-section defined in the third row): With that, the sine wave of the third row has a period spanning over this whole sub-section.
The following graph is a summary of the usable time constants
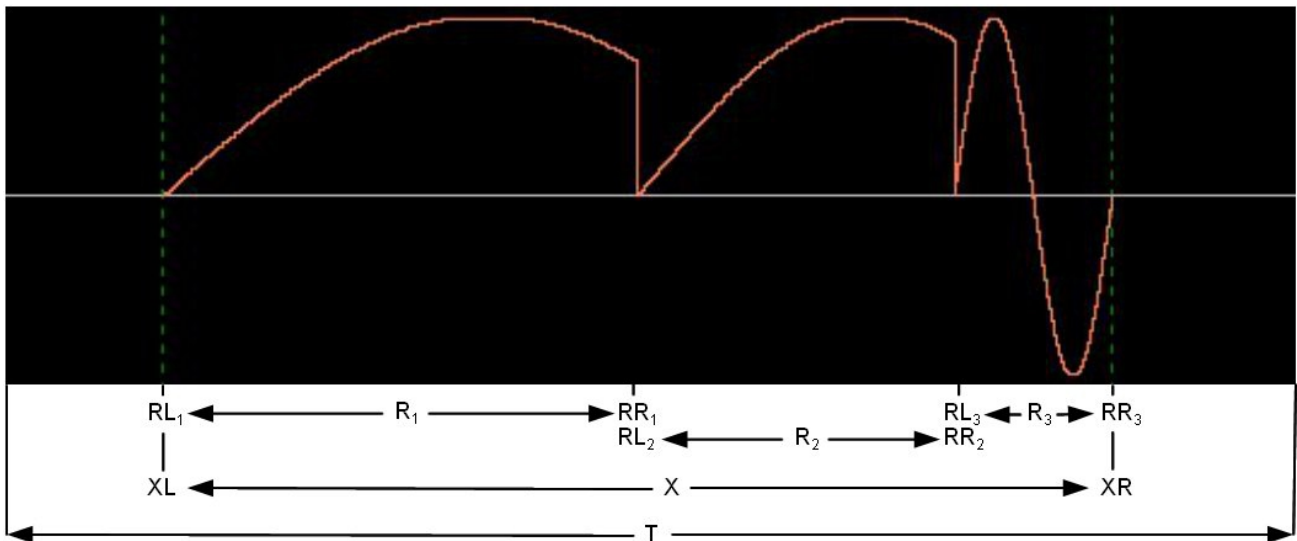
RLx, RRx and Rx are the usable constants RL, RR and R in the respective sub-sections x (rows of the modification table).

Instead of the time constants, specific absolute time values (e.g. "1ms"), number of data values (e.g. "1000") or mixtures out of those two (e.g. "0,3ms+700") could be used respectively.

Hence, instead of the term "Y*sin(2*#*r/R)", the term "Y*sin(2*#*r/(1ms))" could be used to calculate the same waveform. However in this case it is necessary to take care of correct bracketing to make sure that the time unit ("ms") is correctly assigned to the time value and not to the full sine term.

Modification term, working with variables

Time	Mod Term
2ms	Y*sin(2*#*t/X)
2ms	Y*sin(2*#*x/X)
2ms	Y*sin(2*#*r/X)
0	
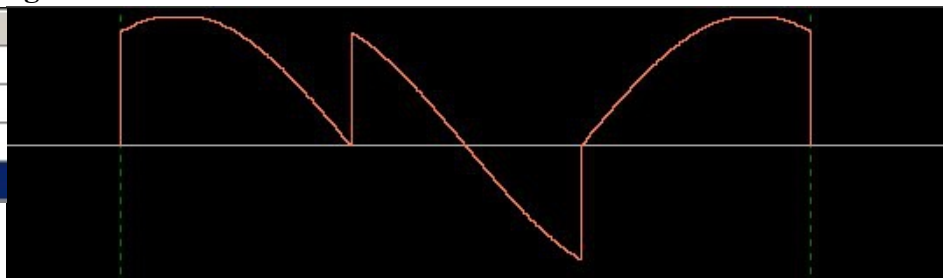
3 different time variables can be used to calculate waveforms. These three time variables differ in their time offset, meaning in the position within the signal, where time is assumed to be 0.

This way, the function terms for signal calculations simplify significantly, as phase shifts of the signal can be very comfortably realized.

The above graph shows three sub-sections with sign waves, each spanning over a period of X (one period over the full modification range). By using the different time variables, the different signals are based on different phase shifts in a way that is much easier to read than without such variables.

- „t": This time variable has value 0 at the left border of the signal, or equally at the beginning of the time range "T", or equally at data value position 0. With that, the sine wave of the first row has its starting point at the left border of the display, whereas only the part in the specified sub-section is used.
- „x": This time variable has value 0 at the left border of the modification range, or equally at the beginning of the time range "X", or equally at data value position XL. With that, the sine wave of the second row has its starting point at the left border of the modification range, whereas only the part in the specified sub-section is used.

Without using the variable "x" the function term would look like this:
Y*sin*2*#*(t-XL)/X)

- „r": This time variable has value 0 at the left border of the respective sub-section, or equally at the beginning of the time range "R", or equally at data value position RL. With that, the sine wave of the third row has its starting point at the left border of the sub-section, whereas only the part in the specified sub-section is used.
  Without using the variable "r" the function term would look like this:
  Y*sin*2*#*(t-RL)/X)

Modification term, working with the @-operator

| Time	Mod Term
0,1ms	3V
0,4ms	-2V
2ms	@
-	Y*sin(2*#*r/R)
0	
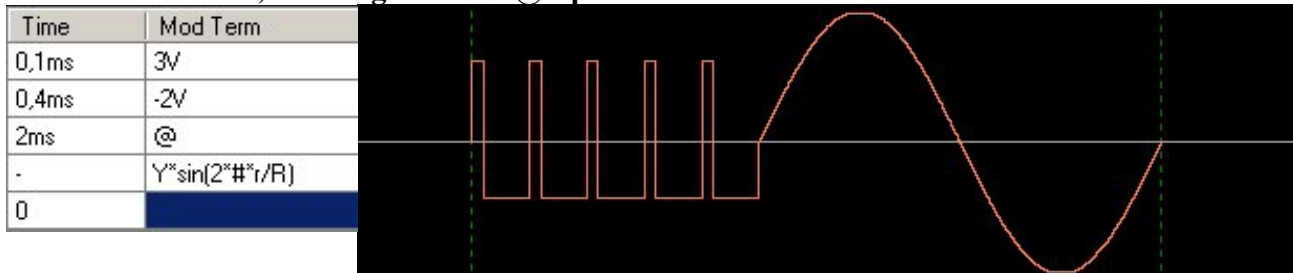
The @-operator allows the easy generation of repeating signal waveforms.

The above example uses the first two rows of the table to define a single voltage pulse (0,1ms at 3V and 0,4ms at -2V).

The third row contains the @-operator, which advises the signal calculation to repeat the preceding modification rows, beginning from row 1, over the specified time range (in this case 2ms). As one pulse has a duration of 0,5ms (0,1ms+0,4ms), the @-operator generates exactly another 4 further pulses. After completion, the remaining time within the modification range ("-") is calculated according to row 4, a single sine period in the subsection.

@-operators can be nested, as shown in the following example

Time	Mod Term
0,05ms	3V
0,15ms	-2V
0,8ms	@
1ms	Y*sin(2*#*r/R)
3ms	@
0,5ms	Y/R*r
-	Y-Y/R*r
0	
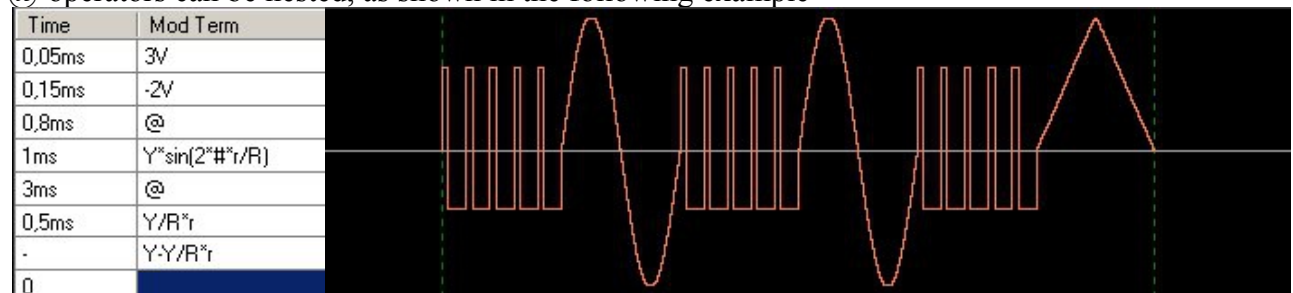
Like in the previous example, the first four rows of the modification table define a signal containing 5 voltage pulses followed by a single sine period.

Row 5 repeats this signal by using the second @-operator for the following 3ms. As this 3ms range does not offer enough time to contain a full third repetition, the final repetition is capped at the end of the specified sub-section. The modification range closes with the waveforms defined in rows 6 and 7, a rising and a falling voltage slope.

Specifics of calculating digital signals

As described in the beginning of this chapter, the calculation of digital signals equals the calculation of analog signals in principle. Nevertheless there are some specifics that need to be observed, when dealing with digital signals. These are shown here:

For full 8-bit digital signals:

- The unit "V" (Volts) is not available
- The discrete nature of 8-bit values allows results of calculations being in the integer range from 0 to 255 only. Should a calculation result into a real number, this result will be rounded down for decimal values <0,5 and rounded up for decimal values >=0,5.
- Should a calculation result into a negative value, the 2's complement value of this number will be used
- Should a calculation result into a value greater than 255, only the 8 least significant bits of this result will be used

For single bit lines:

- The unit "V" (Volts) is not available
- The constant "Y" is not available
- A bit value can only be 0 or 1. Should a calculation result into a real number between 0 an 1, this result will be rounded down for decimal values <0,5 and rounded up for decimal values >=0,5.
- Should a calculation result into a negative value, the value 0 will be used
- Should a calculation result into a value greater than 1, the value 1 will be used

Modulation

The created signal waveform (as explained above trough new creation or loaded from a file) cannot only be used to replace the existing signal in the specified modification range. It is also possible to combine (modulate) the two signals in a mathematical way.

To enable this, the input filed in the modulation section can work with complex mathematical terms to modulate the calculated signal together with the signal existing in the signal display.

Next to the already known constants and variables, this field allows two more special constants:

- „SX": This is the identifier for the already existing signal as shown in the signal display
- „SM": This is the identifier of the signal that was defined in the above modification area

In case the newly created signal shall overwrite the existing signal (without modulating them), the modulation field must contain the input "SM". This way it is specified, that the resulting signal shall be the signal defined in the modification area. This is the standard option in this field.

An example for a standard use case of the modulation field is the superposition of noise over a clear signal, following these steps.

- Load base signal (e.g. "Sine_10V_0,76Hz-12,2kHz.kww") into the signal display
- Open context menu - "Modify Signal"
- Set modification range over the full signal range (modifications cursors to "0" and "T")
- In the modification area choose Tab "Load"- Signal "Noise 1V.kww"
- A good modulation term would be for example "0,95*SX+0,5*SM"

With this, the base signal (reaching over the full voltage range) is reduced by ~0,5Vpp (so that the superposition of the noise signal does not bring the signal into saturation) and the noise signal is added with an amplitude of about 0,5Vpp.

The result is the following signal.
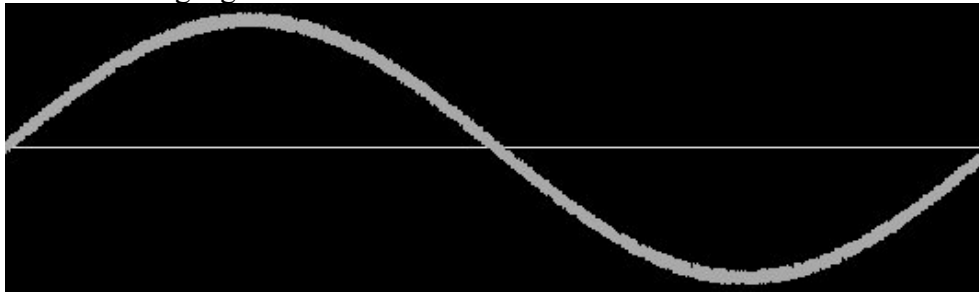
Try

Clicking the button "Try", the currently defined modification signal is calculated and shown in orange in the signal display. The existing signal is not changed, allowing a comparison of the current signal with the potential new signal.

Implement

Clicking the button "Implement", replaces the signal in the signal display with the one that was calculated by clicking on "Try". The new signal can now be uploaded used on the WaverAD hardware.

Saving Signals

WaverAD can save signals in three different ways:
- Embedded in projects (.kwp) together with other user settings
- In waveform files (.kww), single- or dual-channel including signal description
- In readable files (.csv), single- or dual-channel

The first two file formats can only be generated and read by WaverAD. In those files the signals are coded to allow compact storage.
The csv-format allows signal generation in other applications (e.b. OpenOffice Calc or Microsoft Excel) and to import those into WaverAD.
The syntax of a csv-file is easy and can be displayed with any standard text editor (e.g. Microsoft notepad).
For single-channel signals, a csv file lists all 8192 data values in separate rows (one value per row).
For dual-channel signals, the values of two channels are listed in one line, separated by a comma.
In any case, the signal values range from 0 to 255.
For digital signals, these values are direct representatives of the respective byte values.
For analog signals, the values have the following representation:
- 255: Maximum positive voltage
- 128: 0V
- 0: Maximum negative voltage

Waveform Analysis

The signal displayed in the signal display on channel 0 can be analyzed by a powerful frequency spectrum analyzer.
The Waveform Analyzer can be invoked by a right click into the signal display.
It should be noted that not necessarily the whole signal on channel 0 is to be analyzed, but in deed only displayed section of the signal. Zooming and horizontal scrolling will be in effect, allowing the user to not only analyze the full signal (without any zoom) but also single signal sections.
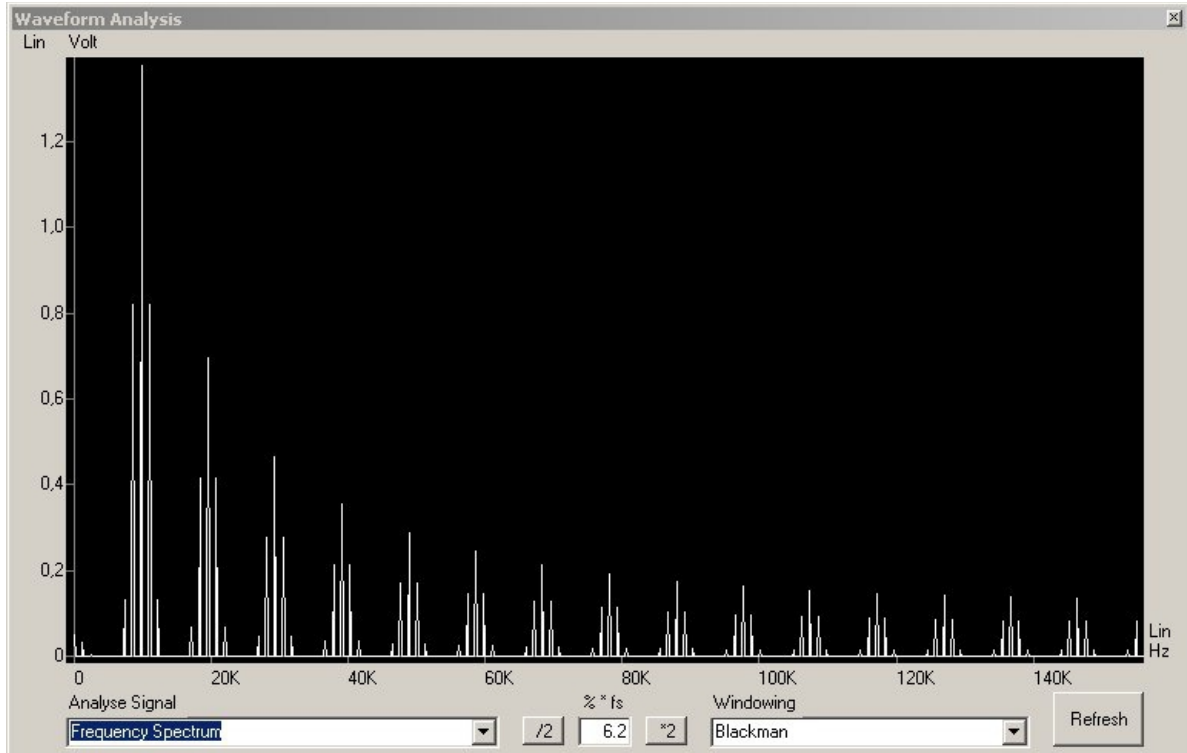
Analyse Signal

The Analyse Signal selector allows the user to choose the function, which is to be displayed in the analysis display. The following functions can be selected:

- **Time Signal**: This is the signal section from the signal display

- **Window**: This is an optional window function (see windowing)

- **Windowed Time Signal**: This is the time signal with the respectively selected window function applied

- **Frequency Spectrum**: This is the frequency spectrum (Fourier analysis) of the time signal in the frequency domain

*Spectrum Width (% * fs)*

Showing the frequency spectrum, the width of the frequency range can be selected by the two push

buttons „/2" and „*2". This selects the maximum displayed frequency as a percentage of the sample frequency (fs). Allowed values range from 0,2% up to 800% of the sample rate.

Windowing

One out of the most commonly used window functions can be chosen by the windowing selector. This window function will be applied to the time signal before the frequency spectrum analysis is done.

Refresh

This push button refreshes the analysis display, after changes have been made to the original signal in the WaverAD console (e.g. loading a new waveform, horizontal scroll, zooming, change of the sample frequency, etc.)

Scales

The scales of the analysis display automatically adjust to a useful unit for the currently displayed function.

Showing a frequency spectrum, both the x- and the y-scales can be shown in a linear or a logarithmic graduation. A left-click on the label „Lin" respectively „Log" switches the graduation mode. The y-scale will automatically switch to a dB scale, when in logarithmic graduation.

Display Cursor

Moving the mouse pointer over the display window of the waveform analysis automatically displays the current position values in the valid scale units on top of the display window in red font. Having the left mouse button continuously pressed, locks the display cursor to the y-value of the shown function.

Extension Modules

Apart from the basic functionality to output the 8 bit of a digital signal, the two digital output interfaces of the WaverAD device offer extended functionality.
A detailed pin-out of the interfaces can be found in the hardware specification chapter of this document.
Three of the pins in the pin-out of the each interface build a communication interface by which external extension modules can be controlled by the WaverAD PC Software. The communication protocol is explained in detail in the hardware specification.
Extension modules can be addressed allowing multiple modules being operated serially or in parallel. To enable this, every extension module can be programmed with a specific address, just as each user-defined control element in the PC software. Single software elements control only those extension modules that are programmed to the same address as the software element.
Using a software control element during operation, an address byte followed by a data byte is sent to every connected hardware extension module. The extension modules will analyze the address byte and execute the data byte accordingly. Experienced users can build their own extension modules and hence adjust WaverAD very closely to their own needs.
The KE-System website offers a separate guide covering this topic in more detail.

User Controls Menu

Hardware extension modules are controlled by dedicated software control elements that can be designed and configured through the menu "User Controls". This menu has the following items:
- **View User Control Console**: The user control console contains all defined user control elements. This menu item shows or hides the user control console, indicated by a check mark in this menu item.
- **Add User Control**: This menu item allows the definition and configuration of user control elements and adds those to the user control console. 4 different types of user control elements are available. Refer to the section "User Control Types" of this document for more information. User control configurations can be loaded and saved into files (.kwc).
- **Program Extension Address**: Single software user controls can be individually addressed to allow the simultaneous operation of multiple user controls and extension modules. In the mask opened by this menu item, a specific address (between 0 and 254) can be programmed into all connected and programmable hardware extension modules.

User Control Types

4 different types of software user controls are available to suit the best option for the respective hardware extension module.
Each user element controls a single or multiple extension modules that are programmed to the same address as the user element.
The respective element type is selected in the upper left area of the configuration form. All the right part of the form shows a preview of the user control element as it would be displayed in the user console.
The following are the available user control elements together with configuration and user options.

Turn Knob

The turn knob is typically used for extension modules that represent linear functions, for example output voltages, amplification factors, etc.

The configuration options are:

Control Text: This is the text that appears in the upper left area of the user control box and gives an indication about what the user control is used for.

Address Byte: All hardware extension modules that are programmed on this address will be controlled by this user element.

Min. Data Code: This is the minimum data code that can be sent by this control element to the addressed extension modules. Values between this and the maximum code are adjusted linearly by turning the knob.

Max. Data Code: This is the maximum data code that can be sent by this control element to the addressed extension modules. Values between this and the minimum code are adjusted linearly by turning the knob.

Init. Data Code: This is the code that will be sent to the addressed extension modules at start-up of WaverAD.

Units: Depending on the function of the respective hardware extension module, the user can have the sent data code being translated into a user comprehensible display. This field specifies the freely definable unit of this display.

Max. Display Value: This is the value that will be displayed in the user control, when the turn knob has been set to maximum (sending the maximum data code). The display value translates the current turn knob setting into a readable visualization for the user.

Min. Display Value: This is the value that will be displayed in the user control, when the turn knob has been set to minimum (sending the minimum data code). The display value translates the current turn knob setting into a readable visualization for the user.

Track Bar

The track bar control element offers the same functionality as a turn knob in a different graphical representation. The single configuration elements have the same function as for the turn knob.

Combo Box

The combo box typically controls extension modules that map a number of discrete settings. The configuration options are:

Control Text: This is the text that appears in the upper left area of the user control box and gives an indication about what the user control is used for.
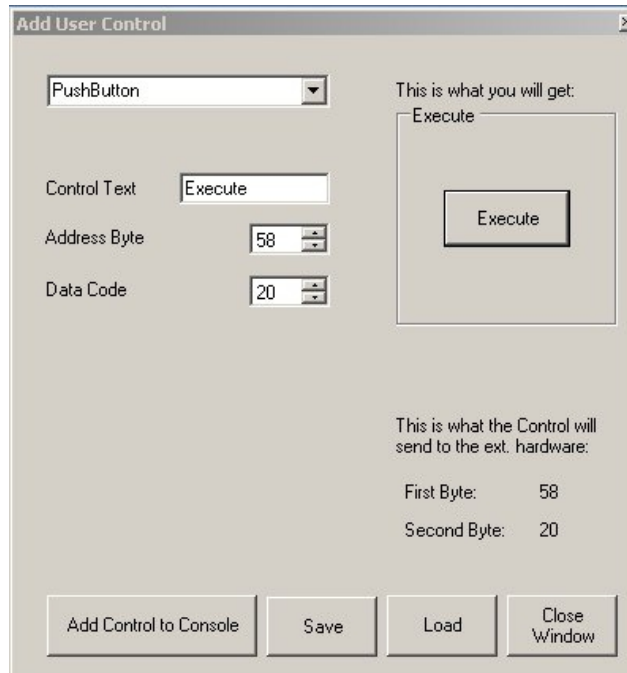
Address Byte: All hardware extension modules that are programmed on this address will be

controlled by this user element.

Selection table: This table pairs the different selection items with the respective data codes that shall be available in the combo box during operation of the user element. Right clicking on single cells of the selection table opens a specific context menu with some row handling options like for example delete or move.

Push Button

Push button elements are typically used to trigger single and special functions in a hardware extension module. Multiple push buttons can control the same hardware extension if they are configured for the same address.

The configuration options are:

Control Text: This is the text that appears in the upper left area of the user control box and gives an indication about what the user control is used for.

Address Byte: All hardware extension modules that are programmed on this address will be controlled by this user element.

Data Code: This code will be sent to all addressed extension modules, when the push button is clicked.

User Control Console
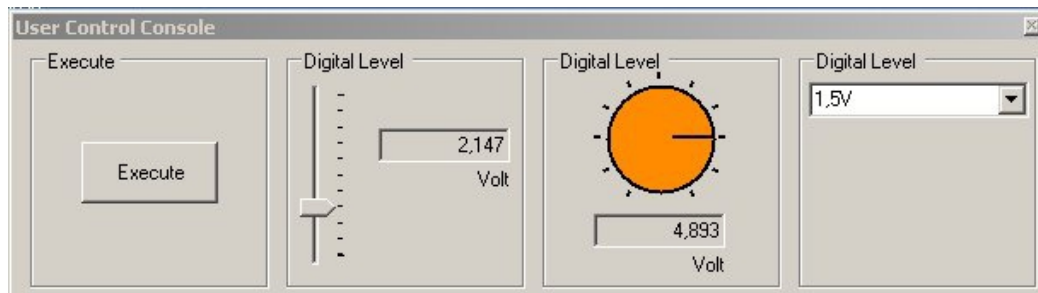
The user console collects all defined user control elements in specific tiles. Right-clicking to a free area within one of those tiles shows a context menu that allows moving or deleting the respective tile.

The user console can be shown or hidden by using the menu item "View User Control Console" in the User Controls menu.

Operating Multiple Systems

WaverAD is designed to be able to be operated in multiple instances on the same PC. To enable this, each instance of the PC Software is directly linked to one specific WaverAD hardware device. This link is independent from other links, so that multiple signals can be generated independently and at the same time.
Limitations to the number of devices being operated in parallel are the number of free USB ports on the PC, the performance of the PC and the available power of the PC power supply (with regards to power supply requirements of the WaverAD hardware, please see the hardware specifications in this document).

The following steps are necessary to operate multiple devices in parallel.
- Each hardware device needs its own instance of the PC software. Copy the whole sub-directory "App" of the software installation into new sub-directories named for example "App2", "App3", etc.
- Create shortcuts to the respective application files "WaverAD.exe" in the new sub-directories on the desktop or in the start menu (depending on your preferences).
- Each software instance needs to be linked with one specific hardware device. Start the respective software instance by clicking on the created shortcut. To link a devices in the software, the serial number of the respective hardware device needs to be entered into the field in the options form (Program Menu - WaverAD - Options).
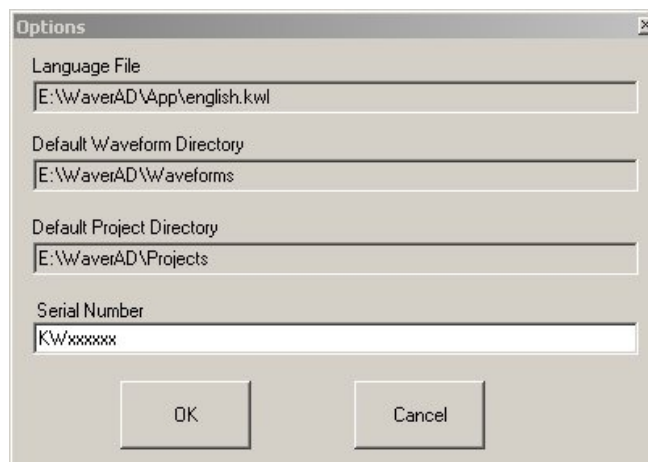
You can find the serial number on the bottom side of the hardware device. Please take good care, entering the serial number into the mask. In particular it is important to consider upper and lower case letters.
Alternatively the serial number can be copied from the Info screen (Program Menu - WaverAD - Info), when the hardware is connected (e.g. using the serial number entry "ALL").
If a specific serial number is entered into the options form, this PC software instance can only connect to the hardware device having exactly this serial number.
In case the software instance shall be able to connect to any WaverAD hardware device, the identifier "ALL" needs to be entered into the serial number field instead of a specific serial number.

Hardware Specifications

Device:

| Parameter	Typical Value
Height	3,8 cm
Width	14,0 cm
Length	12,7 cm
Weight	194 g
Operating Voltage	5V (USB 2.0, Typ B)
Current consumption (idle, without output currents)	120-210 mA
Current consumption (max, without output currents)	270-370 mA

Analog Interface:

Standard BNC connector, Center pin = Signal, Shield = Analog GND

Parameter	Typical Value
Output Impedance	50 Ohm
Output Voltage (max.)	-4,7V bis +4,8V (*)
Output Current (max.)	79 mA

(*) Output voltages depend on the tolerance of the USB operating voltage

Digital Interface (Channel 0 and Channel 1):

Standard male socket, 16 pin, pin pitch 2,54mm
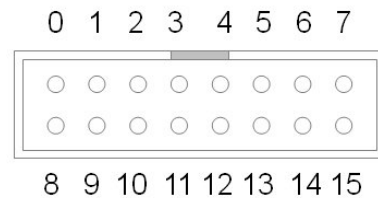
Pin Number	Pin Name	Pin Type	Description
0 ... 7	D0 ... D7	Out	Digital Interface Output (bit lines 0 ... 7)
8	Trig	In	External Trigger Input
9	ExtRC	Out	Extension Module RC
10	ExtClk	Out	Extension Module Clk
11	ExtDat	Out	Extension Module Dat
12	5VOut	Out	5V Output
13	DLOut	Out	Digital Level Output
14	GND	-	Digital GND
15	DClk	Out	Sample Frequency Output (as set in software)

Hardware Specifications

Parameter	Typical Value
D0 ... D7 Output Voltage	3,3V oder 5V (*)(**)
D0 ... D7 Output Impedance	220 Ohm
D0 ... D7 Output Current per pin (max.)	14mA (3,3V), 21mA (5V)
D0 ... D7 Output Current all pins (max.)	72 - 98 mA
DClk Output Voltage	3,3V oder 5V (*)(**)
DClk Output Impedance	220 Ohm
DClk Output Current per pin (max.)	14mA (3,3V), 21mA (5V)
5VOut Output Voltage	5V (**)
5VOut Output Current (max.) (***)	72-98 mA
DLOut Output Voltage	3,3V oder 5V (*)(**)
DLOut Output Current (max.) (***)	72 -98 mA
ExtRC, ExtClk, ExtDat Digital Level	3,3 V
ExtRC, ExtClk, ExtDat Output Impedance	330 Ohm
Trig Input Voltage (max.)	-20V bis +20V
Trig Threshold Voltage	0,6 V
Trig Input Impedance	10 kOhm
Trig Input Capacitance	15 pF

(*): Depending on the setting of the digital level in the WaverAD software
(**): 5V output voltage depends on the tolerance of the USB operating voltage
(***): Total current on all correspondent output pins on both digital interfaces

Timing for the extension modules
The control interface towards the external extension modules was designed to allow even slowly clocked processors or normal 8-bit serial-in/parallel-out shift registers to be used for analysis of the data stream.
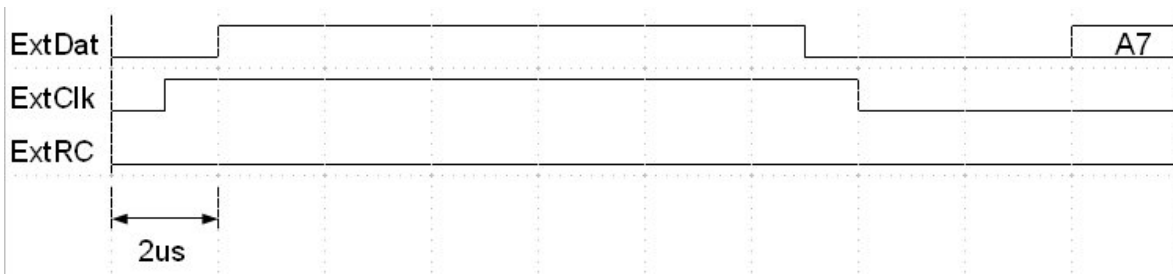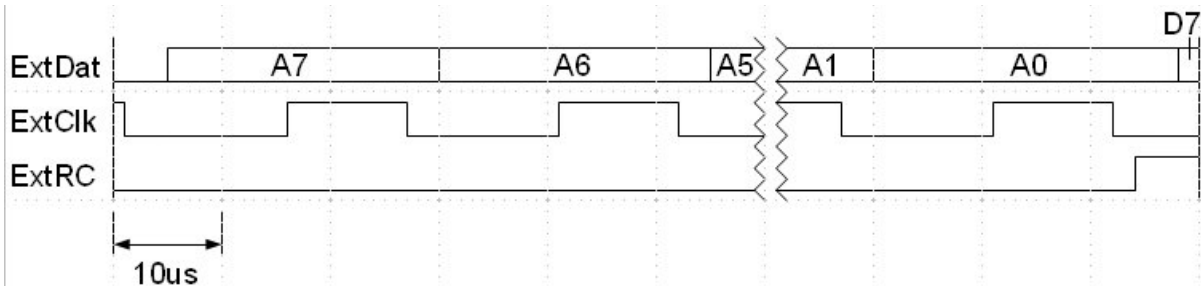A command sequence has 4 phases:
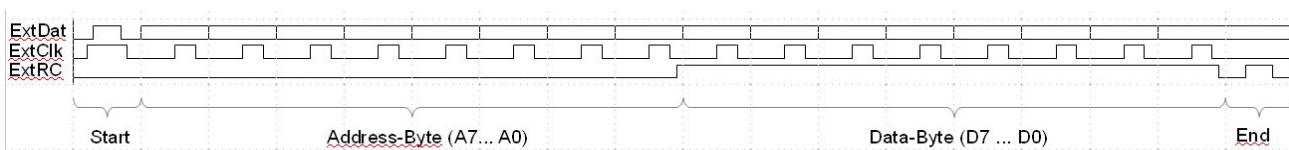
Start-Phase:
The start phase synchronizes the receiving extension module to the upcoming command transmission. This is established by a level change of the signal ExtDat while ExtClk is set high.
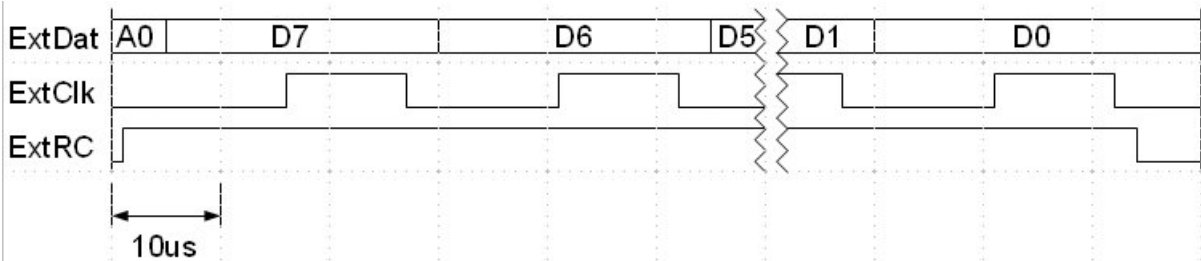
Address-Phase:
During the address phase the address byte is sent to the extension modules. The transmission is MSB first.
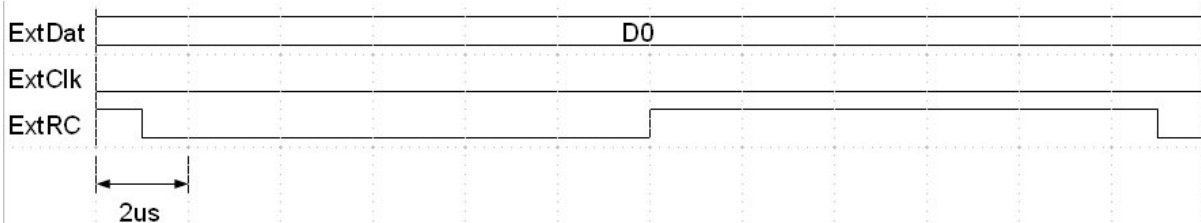

Data-Phase:
During the data phase the address byte is sent to the extension modules. The transmission is MSB first.


End-Phase:
The end phase closes the command sequence. The closing pulse on ExtRC can be used to latch the serially received data byte into a parallel register (e.g. using a SN74xx595).

It needs to be noticed that the signals ExtDat and ExtRC can randomly toggle outside of a command sequence. ExtClk is guaranteed to toggle only during a command sequence in the specified way.

Hardware Specifications

Timing for Trigger Input
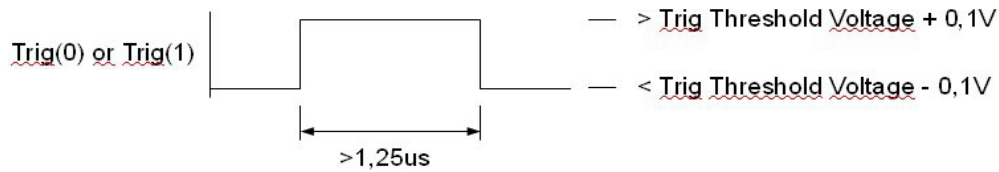
A trigger pulse is detected after a maximum time of 1,25us after the threshold voltage has been surpassed. An earlier detection is possible but not guaranteed. To allow a guaranteed detection of a trigger pulse, a minimum pulse duration of 1,25us is required.
The maximum allowed input voltages on the trigger inputs need to be considered.

Timing Signal Outputs
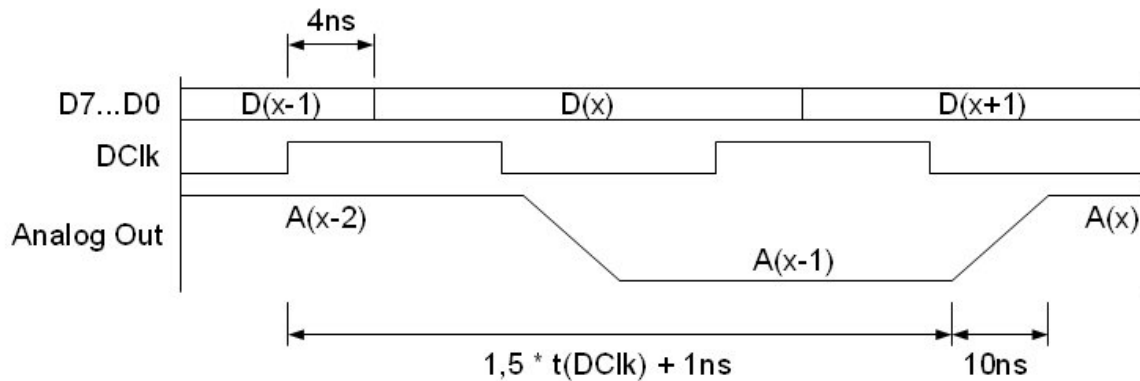
All timings are typical values. Depending on the external circuitry on the output interfaces and environmental parameters, the realized values can differ.

Appendix

Mathematical functions and operators for the signal modification

The following section summarizes the mathematical functions and operators that can be used in the input fields of the signal editor.
The following input field accept these functions and operators:
- Both fields "Mod-Cursors"
- Column "Duration" in the modification table
- Column "Modification Term" in the modification table
- Field "Modulation"

Depending on the kind of calculation, the result values are adjusted to different result ranges:

Calculation of time values or time durations
- Final results of calculations are an integer data value position (0-8191), respectively an integer number of data values (1-8192). Real result values will be rounded to the closest integer value.
- Exceeding the maximum value results in a reduction to the maximum value.
  Values below the minimum value will be replaced by the minimum value.

Calculation of analog signals (voltage values)
- Final results of calculations are real numbers between the minimum and the maximum voltage that can be generated by WaverAD.
- Exceeding the maximum voltage results in a reduction to the maximum voltage.
  Values below the minimum voltage will be replaced by the minimum voltage.

Calculation of 8-bit digital signals
- Final results of calculations are byte values (integer numbers between 0 and 255). Real result values will be rounded to the closest byte value.
- Values beyond 255 will be reduced to their 8 least significant bits (256 becomes 0).
  Result values below 0 the minimum voltage will be replaced by the 2's complement of this value (-1 becomes 255).

Calculation of single bit lines
- Final results of calculations are bit values (either 0 or 1). Real result values will be rounded to the closest bit value.
- Values beyond 1 will be replaced by the bit value 1. Values below 0 will be replaced by the bit value 0.

Appendix

„*a*" and „*b*" are general operands

Operator / Function	Description	Result
a + b	Addition	Real Number
a - b	Subtraction	Real Number
a * b	Multiplication	Real Number
a / b	Division	Real Number
a \ b	Division to Integer	Integer Number
a **MOD** *b*	Modulo	Integer Number
a ^ b	Exponentiation	Real Number
EXP(*a***)**	Exponent, EXP(a)=e ^ a	Real Number
LOG(*a***)**	Natural Logarithm	Real Number
SQR(*a***)**	Square Root	Real Number
SIN(*a***)**	Sine, radial	Real Number
COS(*a***)**	Cosine, radial	Real Number
TAN(*a***)**	Tangent radial	Real Number
ATN(*a***)**	Arc Tangent, radial	Real Number
ABS(*a***)**	Absolute Value	Real Number
ROUND(*a***)**	Rounding	Integer Number
FIX(*a***)**	Truncate	Integer Number
SGN(*a***)**	Sign	-1 if negative 0 if null +1 if positive
RND	Random Number	Real number between 0 and 1
NOT(*a***)**	Bit-wise Negation If *a* is a real number, it is rounded first	Integer Number
a **AND** *b*	Bit-wise AND If *a* is a real number, it is rounded first	Integer Number
a **OR** *b*	Bit-wise OR If *a* is a real number, it is rounded first	Integer Number
a **XOR** *b*	Bit-wise Exclusive OR If *a* is a real number, it is rounded first	Integer Number
a **EQV** *b*	Bit-wise Equivalence (*a = b*) If *a* is a real number, it is rounded first	Integer Number
a **IMP** *b*	Bit-wise Implication (*b >= a*) If *a* is a real number, it is rounded first	Integer Number