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High Performance
Photon Counting

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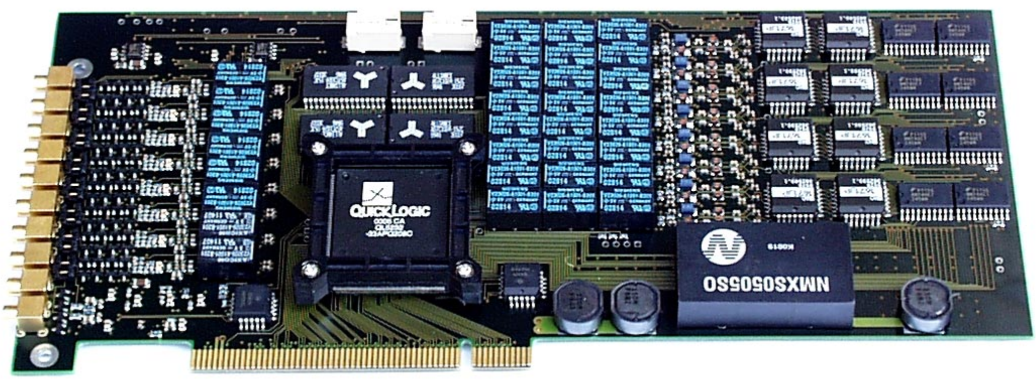
SHM-180
Eight Channel Sample & Hold Module

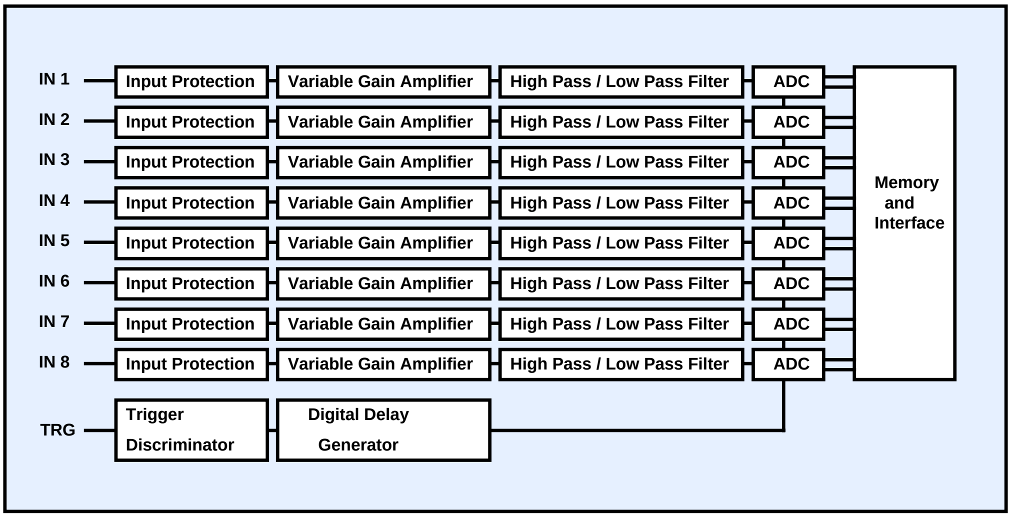
- ♦ **8 parallel sampling channels in one SHM-180 module**
- ♦ **Parallel operation of up to four SHM-180 modules supported**
- ♦ **On-board sample delay generator**
- ♦ **Low noise due to selectable input filtering**
- ♦ **Wide, adjustable input voltage range**
- ♦ **High baseline and gain stability**
- ♦ **12 bit single-shot conversion accuracy**
- ♦ **Accumulation of up to 65.535 samples**
- ♦ **Accumulation rate up to 1 MS / s**
- ♦ **Operation software for Windows 95, 98, NT4, 2000 and XP**



The SHM-180 module is used to detect the intensity of optical pulses or other ultra-fast signals in several parallel signal channels. The results are recorded as a function of an externally controlled parameter, such as pulse delay, sample position, polarisation, wavelength, or simply as a function of time. Typical applications are parallel recording of fluorescence spectra with multichannel PMTs or photodiode arrays, nonlinear absorption measurements with ps and fs lasers and femtosecond pump-probe experiments.

System Architecture

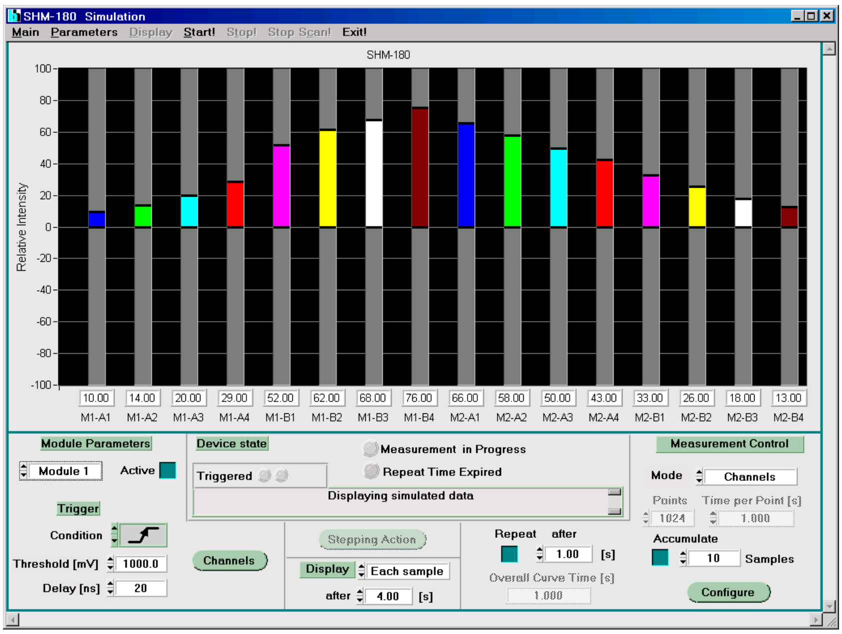
The system architecture of the SHM-180 is shown in the figure below. The module contains eight fully parallel sample & hold channels. Each channel consists of an input protection circuit, a variable gain amplifier, a high pass and a low pass filter, and a 12 bit sampling analog-to-digital converter. The ADCs of all channels are triggered by one common programmable digital delay generator. The sampled signal values are written into an on-board memory. A large number of ADC samples can be accumulated to improve the signal-to-noise ratio. The accumulation is hardware-controlled and can be as fast as 10^6 ADC samples per second. Depending on the mode of operation, the result of each accumulation cycle can be read out individually or written into subsequent locations of the memory.



SHM-180 system architecture

User Interface

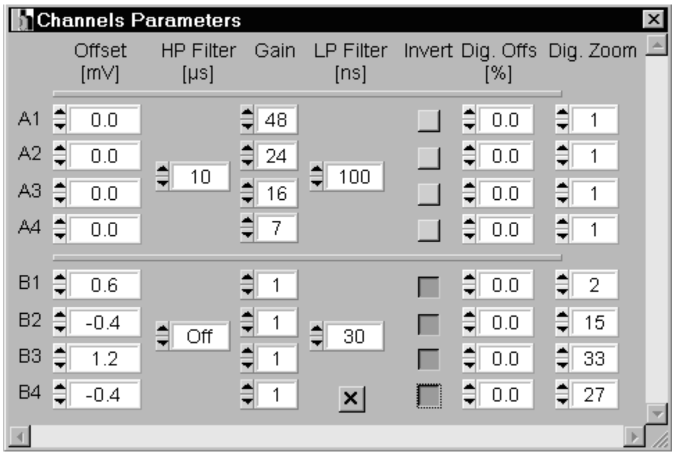
All system parameters are controlled by the device software and written into the internal registers of the SHM-180 via a PCI interface. The software is able to control up to four SHM-180 modules set up in one computer. The main panel of the user interface is shown in the figure below.



SHM-180 user interface, two modules operated parallel

Module Parameters

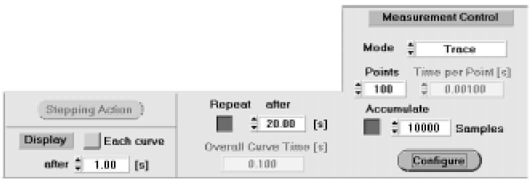
Under 'Module Parameters' the trigger and delay channel and the signal channels of the SHM module - or of several SHM modules - are configured. You can set the active slope of the trigger input the trigger threshold, and the delay from the trigger to the sample point. The signal channel parameters are accessible via the 'Channels' button which opens the panel shown below.



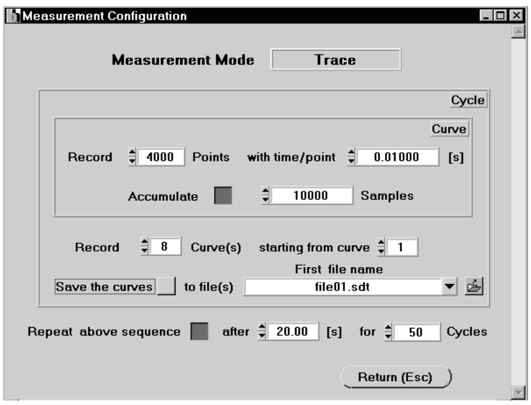
Channel parameters panel

The channels of each module are arranged in two groups. Within each group, the high pass and low pass filter settings are common. The input offset and the gain can be set individually for each channel. Each channel can be configured either to invert or not invert the signal. A digital offset can be added to the ADC output data, and a digital zoom can be applied to the data.

Measurement Control



The measurement control part of the main panel allows to set the operation mode, the number of accumulations per data point, and the number of data points per curve. Furthermore, the measurement can be repeated after a specified time. Intermediate results can be displayed after a specified time or when the recording of the next curve has been completed. More control parameters are available via the 'Configure' button, which opens the panel shown right.



'Configure' panel

The configure panel allows to define a sequence of measurements. A defined number of curves is measured with the defined number of points and accumulations per point. The curves are recorded immediately one after another and written into the internal SHM memory. When the sequence has been completed the recorded data set is read by the software and written into a file.

The whole sequence can automatically be repeated after a defined time for a defined number of cycles.

Device State

The ‘Device State’ part of the main panel informs about the state of the measurement. The trigger lamp turns on when the trigger pulses are detected. ‘Measurement in Progress’ is on as long as a measurement - either a single measurement or a predefined measurement sequence - is running. ‘Repeat Time Expired’ is a warning that the last measurement cycle of a defined sequence could not be completed before the next one had to be started. In this case the next cycle is started immediately, and the measurement is finished with the defined number of cycles. Therefore, the time between the cycles is longer than the defined repeat time.

Device state window

The message window displays messages like ‘Nothing to display’, ‘Waiting for Trigger’, ‘Waiting for repeat’, etc.

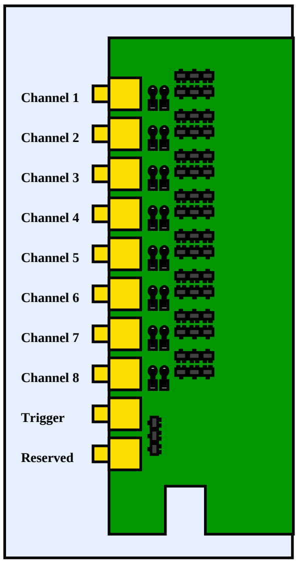
Using the SHM-180

Connecting the Input Signals

The input connectors are shown in the figure right. The connectors (from top to bottom) are Channel 1 through Channel 8. The next to last connector is the trigger input. The last (bottom) connector is an additional trigger input reserved for special applications.

The connectors are MXC. The MCX connector is used because of its small size and good high frequency behaviour. MCX connectors are available from almost all high frequency component suppliers, such as Radiall or Macom. Please contact bh for cables and adapters. Cables should be RG174, with 50 Ω impedance.

If the inputs are configured for an input impedance of 50 Ω (see below) the cable length has almost no influence on the signal quality. 1 meter of cable adds a delay of approximately 5 ns to the signal but leaves the signal shape unchanged. However, you should avoid excessive cable length because it makes the setup more susceptible to noise pickup, and module damage due to connecting charged cables is more likely.



Input Connectors

If the inputs are configured for 1 kΩ the behaviour depends on the source impedance of the signal. For 50 Ω source impedance the cable is matched at the input, and no signal distortion occurs. However, if the signal comes from a current source, i.e. from a PMT or a photodiode, each meter of cable adds about 100 pF of capacitance to the input circuitry. The rise time of the signal at the input is about

$$Tr = 2 \cdot C_{cable} \cdot 1\ k\Omega$$

For cables not longer than 1 or 2 meters this may be still acceptable, and the 1 kΩ input configuration can be used to get a higher signal amplitude than for 50 Ω. However, the unmatched cable causes ringing in the signal shape, so that some care is recommended.

Safety Recommendations

Caution! Do not connect a photomultiplier to the SHM module when the high voltage is switched on! Do not connect a photomultiplier to the SHM module if the high voltage was switched on before with the PMT output left open! Do not use switchable attenuators between the PMT and the SHM! Do not use cables and connectors with bad contacts! The same rules should be applied to photodiodes which are operated at supply voltages above 20V.

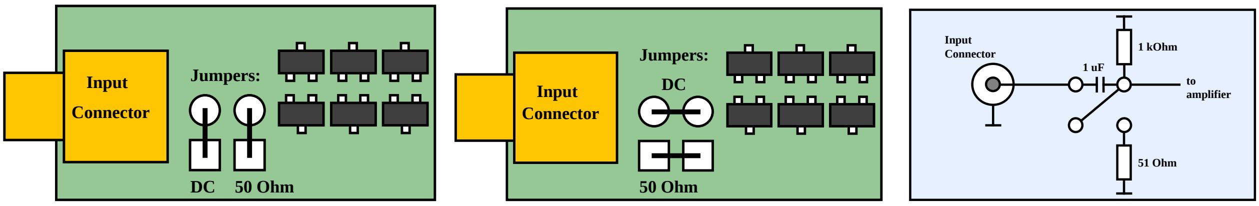
The reason is as follows: If the detector output is left open while the high voltage is switched on, the output cable is charged by the dark current. For a PMT the voltage can reach several 100 V. When connected to the SHM the cable is discharged into the SHM input. The energy stored in the cable is sufficient to destroy the input amplifier. Normally the input protection circuit prevent a destruction, but the action can stress the protection diodes enormously so that an absolute safety is not given. Therefore, be careful and don't tempt fate!

To provide maximum safety against damage we recommend to connect a resistor of about 10 kOhm from the PMT anode to ground inside the PMT case and as close to the PMT anode as possible. This will prevent cable charging and provide protection against damage due to bad contacts in connectors and cables.

Furthermore, please pay attention to safety rules when handling the high voltage of a PMT. Make sure that there is a reliable ground connection between the HV power supply and the PMT. Broken cables, lose connectors and other bad contacts must be repaired immediately.

Configuring the Channel Inputs

The Channel inputs can be configured by jumpers for DC or AC coupling, and for 50 Ω or 1 kΩ input impedance. When the module is delivered the inputs are configured for ‘DC’ and ‘50 Ω’. The jumpers can be inserted in different ways as shown in the figure below.



Input configuration

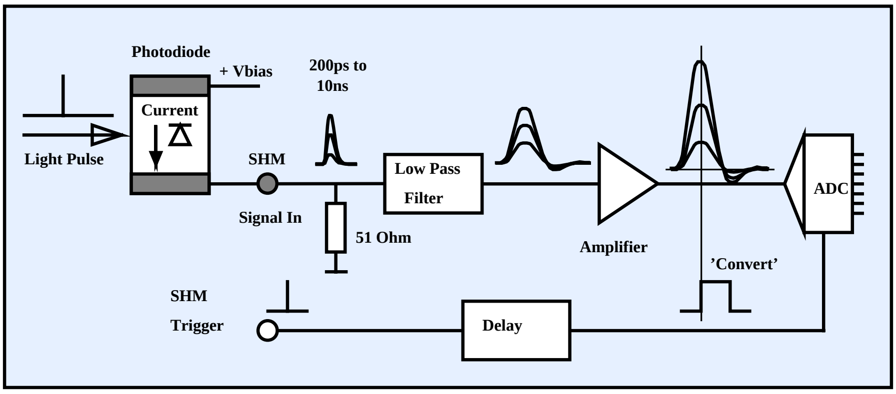
When the jumpers are inserted the configuration is ‘DC’ and ‘50 Ω’. To change the configuration to ‘AC’ or ‘1k Ω’, pull off the corresponding jumper.

Caution: The ‘AC’ configuration will not work if a current source is connected to the input. Most optical detectors, such as pin and avalanche photodiodes or PMTs are current sources. The output current of a source like that would charge the input capacitor of the SHM module until the detector is not longer correctly biased or the input capacitor breaks down. The input voltage may increase to a value that can cause danger of electrical shock. If you want to operate a detector with AC coupling for whatever reason, connect an external resistor from the detector output to ground. Make sure that there is a reliable connection to ground. The maximum voltage at the input capacitor is 20 V.

Signal Processing Considerations

Photodiode Signals

The figure below shows the detection of a fast optical signal with the SHM-180 and a pin or avalanche photodiode.

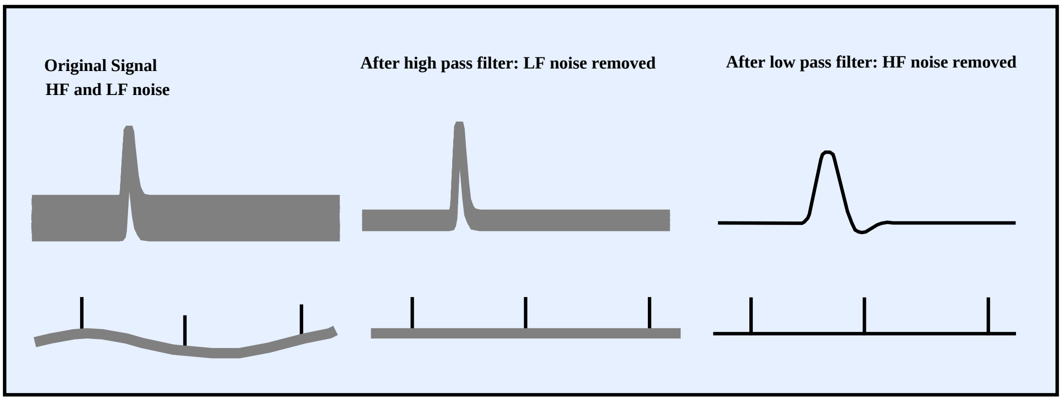


Detection of ultra-short light pulses

The light pulse is very fast - the typical application is the detection of picosecond or femtosecond pulses. Therefore, the photodiode delivers a pulse that resembles its ‘pulse response function’. That means the pulse shape is constant, but the amplitude changes depending on the energy of the detected light pulse. It may be surprising that the photodiode signal is proportional to the optical energy for such short pulses. The reason is that the diode is reverse-biased (this is absolutely required) so that its p-n junction acts as a storage capacitor for the generated charge. The charge is then dissipated through the load resistor, typically the input resistor of the SHM module. The width of the resulting voltage pulse depends on the diode capacitance. Depending on the active area, pin and avalanche photodiodes have a junction capacitance between a few pF and 100pF. With 50 Ω input impedance of the SHM, the pulse width is between a few 100ps and about 10 ns.

The photodiode signal is too short to be accurately converted by an AD converter. However, after passing the low pass filter of the SHM signal channel, the pulse duration becomes longer. Of course, the pulse amplitude decreases, but this decrease is compensated by the gain of the amplifier. The amplified pulse is fed to the ADC, which is started in the moment when the pulse goes through its maximum.

Photodiodes operated in the fast pulse detection mode shown above are almost free of noise. (Please forget about the 'NEP' of photodiodes. This definition is completely useless for fast pulse detection.) In practice, there is noise from the input matching resistor, from preamplifiers and - which is usually the largest contribution - from radio and television transmitters, from laboratory power supplies, and from the 50 or 60 Hz line frequency. With proper filtering of the signal, a large amount of the noise can be suppressed, see figure below.



Effect of filtering on signal-to-noise ratio

PMT signals

For photomultiplier (PMT) signals the signal processing works in the same way as for photodiode signals. However, there is one fact to take into regard. If a PMT is operated near its maximum gain each detected photon delivers an output pulse of a few mA amplitude and a few ns duration. This is clearly above the noise level of any kind of electronics in a reasonably 'clean' environment. Due to the random gain process in the PMT the amplitude of the single photon pulses can vary by a factor of 5 and more. Therefore, the noise of PMT signals is almost essentially determined by the poissonian distribution of the number of recorded photons and the random gain. Any attempt to improve the signal-to-noise ratio of the signal by additional amplifiers is useless. Once the recording system is able to detect a single photon any additional gain only reduces the useful dynamic range of the measurement. Also filtering does not help unless there is a noise contribution from the environment. All you can do to improve the signal-to-noise ratio is to

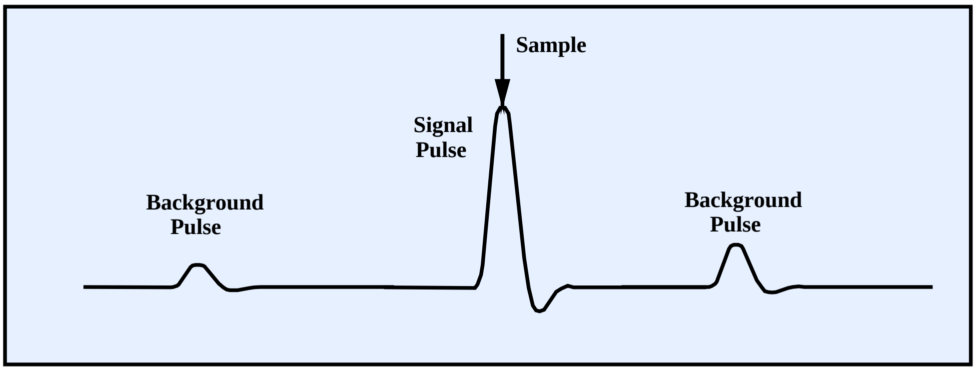
- improve the efficiency of the optical system to get more photons on the PMT cathode

- use a PMT with a spectral characteristic that fits to the recorded wavelength range

- operate the PMT and the recording electronics at a gain as *low* as possible

- keep the daylight out of the detector

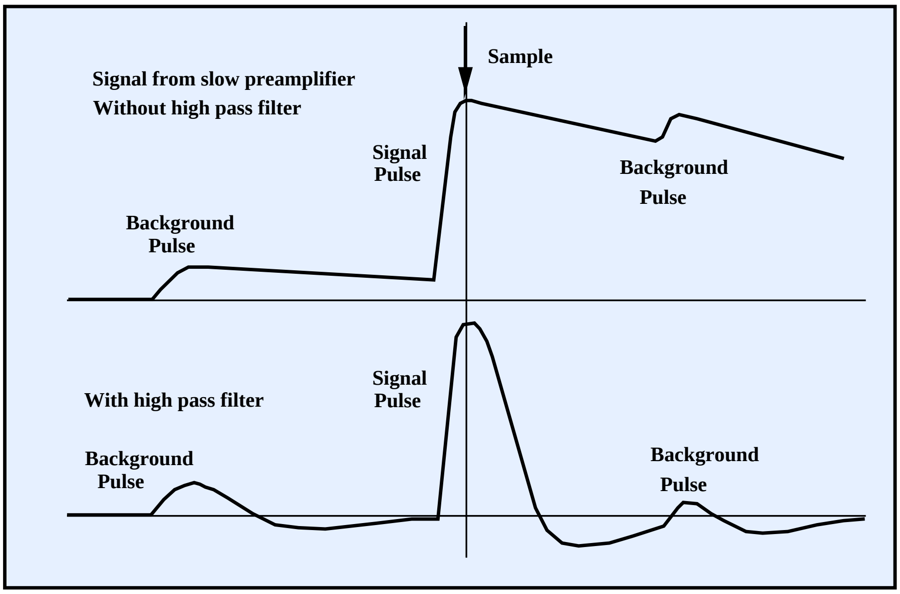
To reduce the noise, it is often recommended to cool the PMT. Cooling certainly reduces the thermal emission of the cathode and therefore the background signal. However, in fast pulsed applications the background signal has no appreciable influence on the measurement unless you are using NIR photocathodes with extremely high dark count rates. As shown below, the probability to detect a background 'photon' just within the time of the low pass filter response is negligible as long as the low pass filter response is much shorter than the reciprocal dark count rate.



Effect of PMT background: Background pulses are not likely to be recorded

However, what you should *not* do is to use a slow, high gain preamplifier between the PMT and the SHM input. This would mix the background pulses into the signal pulses, see figure below.

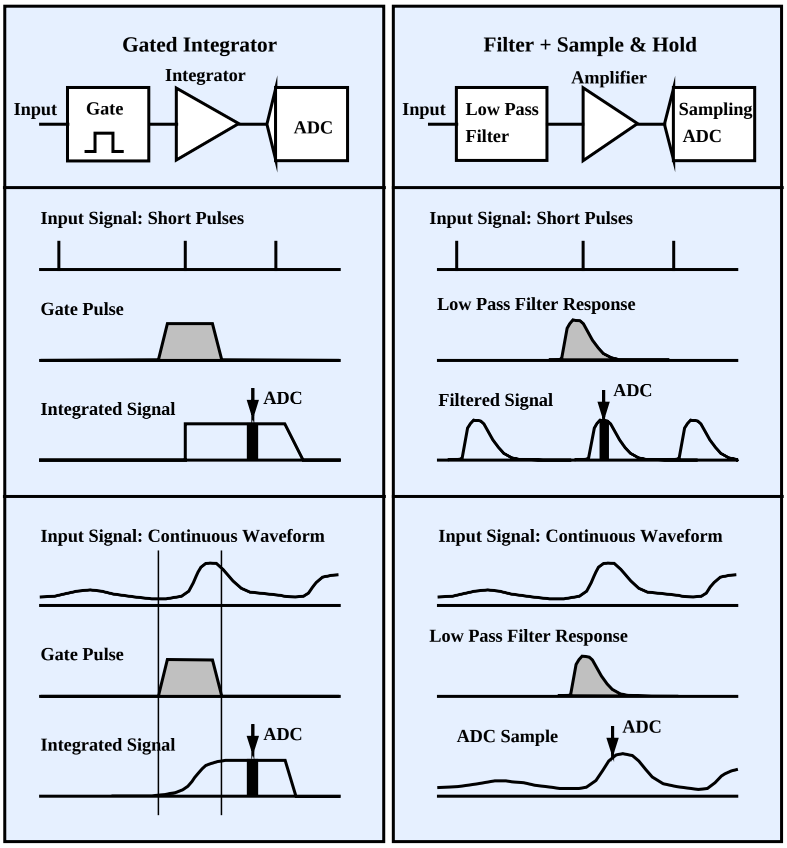
If you must use a PMT with a slow amplifier for whatever reason - e.g. because the amplifier is integrated in the PMT module - use the high pass filter of the SHM to separate the pulses.



PMT signal from slow preamplifier. The high pass filter helps to unmix background and signal pulses

Sample & Hold or Gated Integrator?

As can be seen from the considerations above, the principle of the SHM is different from the 'Gated Integrator' often used for similar applications. The differences between both approaches are shown in the figure below.



Comparison of the Gated Integrator and the Filter + Sample & Hold architecture of the SHM

The principle of the 'Gated Integrator' is shown left. The signal is sent through a gating circuit. The gate transmits only the part of the signal that is inside the gating pulse, or, more exactly, multiplies the input signal with the gate pulse shape. The output of the gate is integrated, and the result of the integration is sent to the ADC. After the ADC has converted the signal, the integrator is cleared.

The Filter plus Sample & Hold approach of the SHM is shown right. The signal is sent through a low pass filter, amplified and sampled by the ADC at a defined delay.

At first glance the two techniques may look very different, but from the point of view of signal theory they are not. A multiplication of the signal with the gate pulse and subsequent integration is equivalent to a convolution of the signal with the gate pulse shape. On the other hand, filtering means a convolution of the input signal with the filter response function. The conclusion is that an SHM-180 channel behaves *like a gated integrator with a gate pulse shape similar to the filter response function*.

If the amplitude of short pulses is measured, i.e. to record the energy of ultra-short light pulses, both techniques deliver the same result. If a signal longer than the filter response or the gate width is sampled the SHM delivers the energy in the time before the ADC start pulse weighted with the filter response function. The gated integrator delivers the energy within the gating time weighted with the gate pulse shape. For ns gating times the gate pulse cannot be considered rectangular, so that different portions of the signal are not longer integrated with different weight.

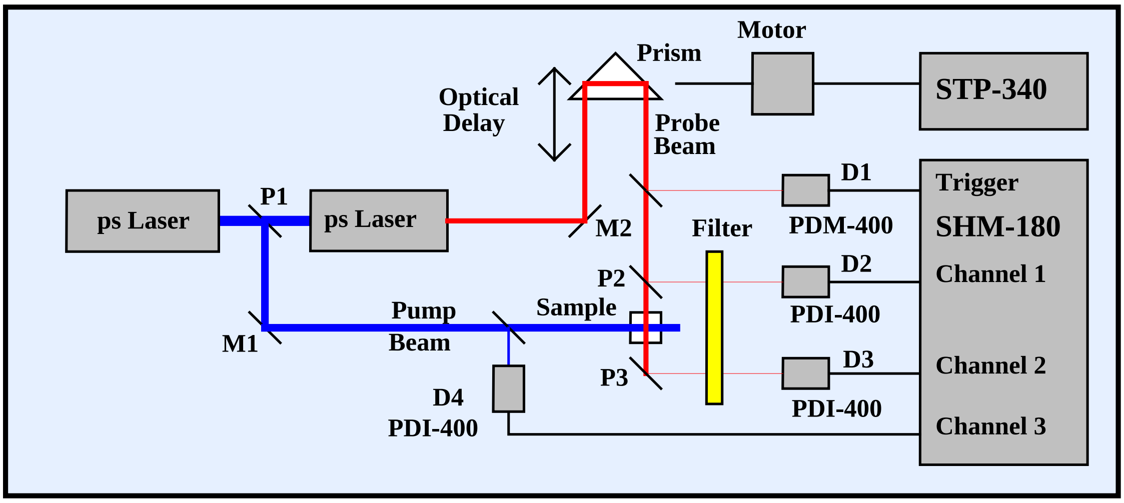
For practical application differences resulting from the different electronic circuitry are more significant. In a gated integrator the gate duration has considerable influence on the size of the recorded signal. However, it is almost impossible to keep the width of a nanosecond gate pulse constant within better than a few percent. Moreover, in a nanosecond gate the gate pulse interacts with the signal so that the baseline offset depends on the gate width, and baseline stability is a problem. Therefore, gain and baseline stability of the SHM is much better compared to any gated integrator. Moreover, a gated integrator needs a more complicated signal processing sequence -

starting the gate pulse, starting the ADC some time after the end of the gate pulse, and clearing the integrator. The SHM does not need most of these steps and therefore achieves a sample rate higher than a gated integrator.

Applications

Transient Absorption (Pump-Probe) Measurements

The figure below shows a simple arrangement for transient absorption experiments.



Pump-probe experiment

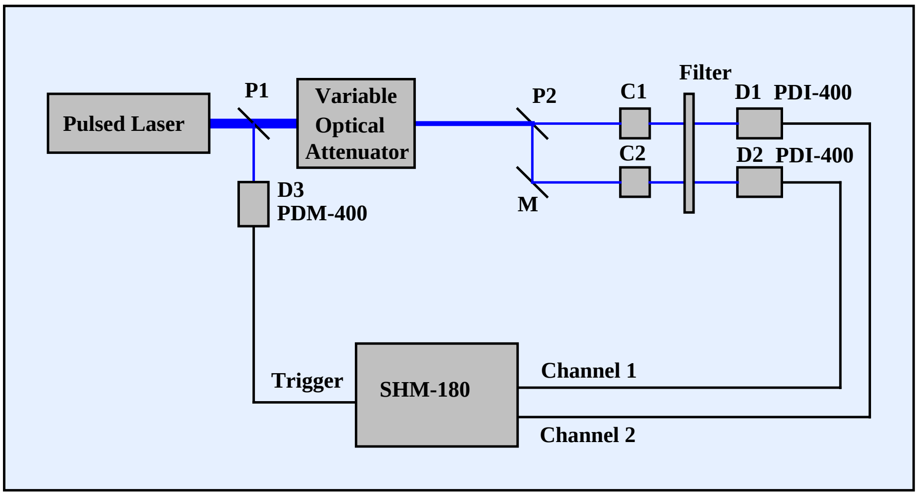
The output of a high power picosecond or femtosecond laser is divided into two parts. One part is used to pump the sample, the other part pumps a second laser which generates a light pulse of the appropriate wavelength to probe the absorption of the excited molecules in the sample. The detector D1 is a fast PDM-400 photodiode module which generates a trigger pulse for the SHM-180 Module. The absorption in the sample is measured by the detectors D2 and D3. D4 is used to monitor the power of the pump beam. D1, D2 and D3 are PDI-400 integrating photodiode modules and deliver energy proportional output pulses of some 100ns duration. The amplitudes of these pulses are recorded by two signal channels of the SHM-180 module. The SHM-180 is run in the ‘Trace’ mode. Thus, it records a curve consisting of subsequent averages over a selectable number of intensity values of the probe beam at the input and the output of the sample. If the optical delay is continuously changed during the measurement and the quotient A/B is displayed the result shows the decay of the absorption of the excited state species in the sample. The delay change can be run simply time-controlled and started simultaneously with the recording in the SHM. However, a better solution is to use a step motor controlled by a bh STP-340 step motor controller.

Nonlinear Optical Absorption Measurements

The setup shown below can be used to measure of the intensity-dependence of the light absorption in organic dyes.

A high power pulsed laser generates short pulses with an energy of the order of 1mJ. The intensity is controlled by a suitable optical attenuator. The beam is split into two parts by the glass plate P2. The main part of the light is focused into the sample cell C1. The other part is fed through the reference cell C2. Both light signals are fed through a filter to the Detectors D1 and D2. D1 and D2 are PDI-400 integrating photodiode modules and deliver energy proportional output pulses of some 100ns duration. These pulses are recorded by two signal channels of the SHM-180. The trigger pulse for the SHM-180 is generated by the photodiode PD3. The gate width and the delay of the SHM-180 are set to sample a signal portion near the peak of the detector pulses.

The main problem in non-linear optical absorption measurements is that an absorption accuracy of better than one percent over several orders of magnitude of the intensity is required. To reach the required absorption accuracy, the shown setup uses a second signal path trough a reference cell that contains only the solvent. By using the same replaceable filter for both channels the signal intensity can be held inside the useful input voltage range of the SHM-180 without degrading the accuracy of the measured absorption values.

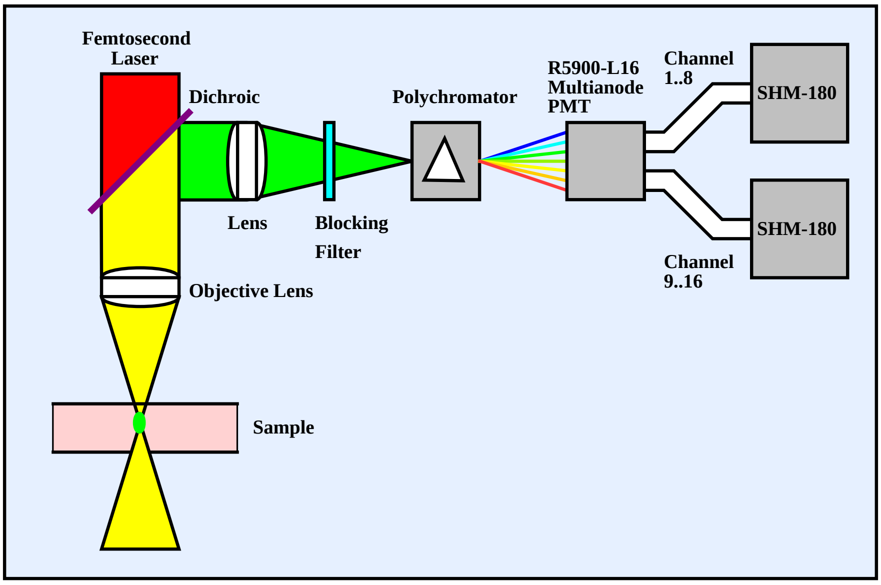


Nonlinear transient absorption experiment

The measurement delivers pairs of signal values from which the intensity and the sample transmission can be derived. The quotient of channel 1 and channel 2 is proportional to the transmission of the sample cell. To record the transmission versus intensity the attenuation of the laser beam is varied, and the quotients of the signal values of channel 1 and 2 are displayed versus the values of channel 1. The setup shown above is able to measure transient absorption curves with a relative accuracy of better than 1%.

Multi-Wavelength Two-Photon Fluorescence

Two-photon excitation can be used to obtain tree-dimensional fluorescence images of biological tissue. The principle of a two-photon fluorescence imaging setup is shown in the figure below. A femtosecond laser with a wavelength in the range of 750 to 900 nm is used to excite the fluorescence. The fluorescence is focused into the tissue by a high numerical aperture objective lens. The fluorescence light is collected via the same lens, and diverted into the detector by a dichroic mirror. The NIR laser relatively easily penetrates into the tissue. Fluorescence excitation occurs only in the focus of the laser beam. By scanning the sample in x-y direction and changing the depth of the focus in z direction a three-dimensional image can be obtained up to a depth of about 0.5 mm. The image is free of scattering both at the excitation and the emission wavelength. This is an essential benefit of the scanning technique compared to direct imaging techniques, such as CCD cameras or gated image intensifiers.



Two-photon fluorescence

The basic setup is known from two-photon laser scanning microscopy. The microscopes use femtosecond titanium-sapphire lasers for excitation, PMTs for detection and photon counters or frame grabbers for signal recording. The repetition rate of the excitation pulses is of the order of 80 MHz. Due to the high numerical aperture of the microscope objective the excited sample volume is if the order of femtoliters.

When macroscopic objects are scanned with a large objective lens the excited sample volume is larger than in a microscope. This can require higher pulse peak power, which, in turn, requires lower repetition rate to avoid heating the sample. The number of photons detected per laser pulse is then correspondingly higher, so that analog detection with the SHM module becomes favourable. The setup shown above uses a polychromator and an R5900-L16 sixteen channel PMT for wavelength-resolved detection. The output signals of the PMT channels are fed to the input channels of two SHM-180 modules. By scanning the laser spot over the sample and repeating the scan for different focus depth three-dimensional images for 16 wavelength intervals are obtained.

Specification

Signal Channels	
Input Impedance	1 kΩ or 50 Ω, jumper selectable
Input Coupling	DC or AC, jumper selectable
Input Connectors	MCX
Low Pass Filter	30 ns - 100 ns - 300 ns - 1 µs
High Pass Filter	1 µs - 10 µs - 100 µs - 'off'
Channel Gain	1 to 56
Full scale input voltage	± 45 mV to ± 2.5V
Max. Sample Rate	1 MS/s
ADC Resolution	12 bit
Trigger Input	
Input Impedance	50 Ω
Input Coupling	DC
Input Connector	MCX
Trigger Threshold	-1 V to +1 V
Min. Trigger Pulse Width	1 ns
Max. Trigger Input Frequency	100 MHz
Max. Trigger Rate	1 MHz
Sample Delay Generator	
Delay Range	0 to 655 µs
Delay Step Width	10 ns
Delay Jitter	2.5 ns
Delay Stability	< 50 ppm
Multi Module Systems	
Number of modules operable parallel	4
Operation Environment	
Computer System	PC Pentium
Bus Connector	PCI
Power Consumption	approx. 10 W at +5V
Dimensions	PCI card, 235 x 110 mm