Becker & Hickl GmbH
Intelligent Measurement
and Control Systems

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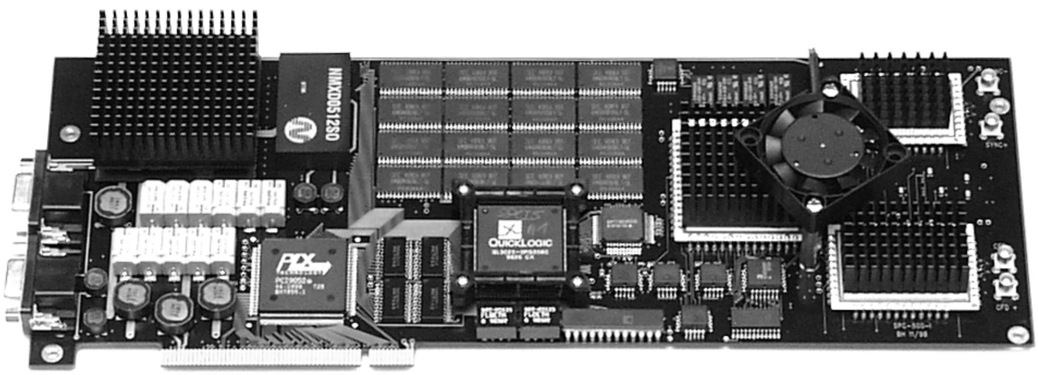
Time-Correlated Single Photon Counting Modules

SPC-134
SPC-300 SPC-330
SPC-400 SPC-430
SPC-401 SPC-431 SPC-402 SPC-432
SPC-500 SPC-530
SPC-505 SPC-535 SPC-506 SPC-536
SPC-600 SPC-630
SPC-700 SPC-730

- Complete TCSPC Systems on PC Boards
- Reversed Start/Stop: Repetition Rates up to 200 MHz
- Electrical Time Resolution down to 7 ps FWHM or 4 ps RMS
- Channel Resolution down to 813 fs
- Up to 4096 Time Channels / Curve
- Imaging Capability: Up to 256 x 256 decay curves (SPC-5xx, SPC-7xx)
- Multi Detector Capability: Up to 16 384 Detector Channels
- Count Rate up to 8 MHz (SPC-4x0, SPC-6x0, SPC-134)
- Measurement Times down to 1 ms
- Software Versions for Windows 3.1 and Windows 95/98/NT
- Optional Step Motor Control for Wavelength or Sample Scanning
- Direct Interfacing to most Detector Types
- Single Decay Curve Mode
- Multiple Decay Curve Mode (Parameter Wavelength, Time or User Defined)
- Oscilloscope Mode
- Spectrum Scan Mode with 8 Independent Time Windows
- Multichannel X-Y-t-Mode
- Continuous Flow Mode (SPC-4x0, SPC-6x0)
- BIFL Mode (SPC-4x1, SPC-4x2, SPC-6x0)
- TCSPC Imaging Modes (SPC-5x5/5x6, SPC-7x0)



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set 5 levels, user defined

Introduction

General Features

The SPC-300/330, SPC-400/430, SPC-500/530, SPC-600/630 and SPC-700/730 modules contain complete electronic systems for recording fast light signals by time-correlated single photon counting (TCSPC) on single PC boards. The Constant Fraction Discriminators (CFDs), the Time-to-Amplitude Converter (TAC), a fast Analog-to-Digital Converter (ADC) and the Multichannel Analyser (MCA) with the data memory and the associated control circuits are integrated on the board.

The SPC-134 'TCSPC Power Package' is a stack of four TCSPC modules. Each module is a complete TCSPC system and contains its own CFDs, TAC, ADC and MCA.

All functions of the SPC modules are controlled by a common 'SPC Standard Software'. The software provides functions such as set-up of measurement parameters, 2-dimensional and 3-dimensional display of measurement results, mathematical operations, selection of subsets from 4 dimensional data sets, loading and saving of results and system parameters, control of the measurement in the selected operation mode, etc. With an optional step motor controller the software is able to control a monochromator or to scan a sample. The SPC Standard Software runs under Windows 3.1, Windows 95/98 and Windows NT.

The SPC-3.. through SPC-7.. modules are available in two versions. These 00 and 30 versions differ in the input voltage range and the time resolution. The 00 modules work with input signals from ±10 mV to ±80 mV and can therefore be used without preamplifiers in most cases. The electrical time resolution of the SPC-x00 is 10 ps FWHM or 5 ps RMS typically. The SPC-x30 modules have an input voltage range from -50 mV to -1 V and an electrical time resolution of 8 ps FWHM or 4 ps RMS.

All SPC systems are designed to work in the reversed start-stop mode. This enables operation at the full repetition rate of mode-locked cw lasers. Effective count rates of more than $4*10^6$ photons/s can be achieved (SPC-4x0, SPC-6x0). Therefore results are obtained with data acquisition times down to 1 ms. The systems can be used to investigate transient phenomena or other variable effects in the sample. Furthermore, the SPC modules can be used as high resolution optical oscilloscopes with a sensitivity down to the single photon level.

The SPC-300 through SPC-730 modules have built in multichannel and multidetector capabilities. In the device memory space is provided for several waveforms, and the destination of each individual photon is controlled by an external signal. In conjunction with a fast scanning device, time resolved images are obtained with up to 256 x 256 pixels containing a complete waveform each. Furthermore, several detectors can be used with one TCSPC module. This technique makes use of the fact that a simultaneous detection of several photons in different detectors is very unlikely. Therefore, the output pulses of all detectors are processed in one TCSPC channel and an external 'Routing' device determines in which detector a particular photon was detected. The routing information is used to store the photons from different detectors in different memory blocks.

A digital lock-in technique is provided to suppress scattered light and detector background pulses. In conjunction with fast optical scanning devices or flip-mirror arrangements multiplexing into 128 waveform channels is achieved.

Measurement Modes

The SPC systems provide the following basic measurement modes:

In the 'Single' mode the intensity versus time (usually a fluorescence decay curve) is measured. In the 'Oscilloscope' mode a repetitive measurement is performed and the results are displayed in short intervals. Multichannel operation is possible in both modes with up to eight detector channels displayed simultaneously.

In the 'f(t,T)' mode the measurement is repeated in specified time intervals. The results represent the change of the measured waveform (decay curve) with the time. In the 'f(t,EXT)' mode an external parameter is controlled via the optional step motor controller. The results represent the change of the waveform as a function of the external parameter (usually wavelength or sample displacement).

In the 'fi(ext)' and fi(T)' modes time resolved spectra are recorded. Up to 8 time independent time windows can be selected on the measured waveforms, and the intensities within these windows are displayed as a function of time or an externally variable parameter.

The 'f(t,x,y)' mode is used for multichannel measurements with detector arrays. Up to 128 decay curves (16384 for the SPC-5 and -7) can be recorded simultaneously and displayed as f(t,x), f(t,y) or f(x,y).

The 'Continuous Flow' mode is available in the SPC-400/430, the SPC-600/630 and in the SPC-134 only. The 'Continuous Flow' mode is targeted at single molecule detection in a continuous flow setup and other applications which require a large number of curves to be recorded in defined (or short) time intervals without time gaps between subsequent recordings. Unlike f(t,T), the ‘Continuous Flow’ mode is strictly hardware controlled and thus provides an extremely accurate recording sequence.

The 'FIFO' mode is available in the SPC-4x1/4x2, the SPC-600/630 and the SPC-134. This mode is used for single molecule investigations by the ‘BIFL’ method. For each photon the time within the laser pulse sequence and the time from the start of the experiment is stored. The memory is configured as a FIFO (First In First Out) buffer. During the measurement, the FIFO is continuously read by the device software and the results are stored to the hard disk of the computer.

The ‘Scan’ and ‘TV’ modes are used for image recording with the SPC-505/535/506/536 and in the SPC-700/730 modules. In conjunction with a laser scanning microscope or another scanning device, these modes acquire images with up to 65535 pixels containing a complete waveform each.

Module Types

SPC-300/330

The SPC-300/330 is the TCSPC module for basic applications. It comes in two versions. The SPC-300/330-10 have up to 128 detector channels and a resolution of 1024 points per curve, the SPC-300/330-12 have up to 32 detector channels and a resolution of 4096 points per curve. Although the SPC-300/330 was the first of all BH TCSPC modules it is far from being obsolete. It has continuously been upgraded with the development of newer modules and contains the same CFD, SYNC, TAC and ADC modules as the latest SPC-6 and SPC-7 PCI bus modules.

SPC-400/430

The SPC-400/430 modules differ from the SPC300/330 in that they use a dual memory structure for simultaneous measurement and data readout. Furthermore, the exceptionally low dead time of the SPC-4 modules allows high count rates. This makes the SPC-400/430 an excellent choice for all applications which require maximum data throughput. A ‘Continuous

Flow' mode is implemented for single molecule detection in a continuos flow arrangement. It continuously records decay curves with short collection times and without time gaps between subsequent recordings and stores the results to the hard disk.

Of course the SPC-400/430 can also be used for the traditional applications. Recording of fluorescence decay curves, time-resolved fluorescence spectra, multi-detector measurements etc. can be done in the same way as with the SPC-300/330.

SPC-401/431, SPC-402/432

The SPC-401/431 and SPC-402/432 are designed for single molecule detection by the BIFL method. They employ a fast FIFO memory to store the time within the excitation pulse sequence, the time from the start of the experiment and the detector channel for each detected photon. During the measurement, the FIFO is continuously read by the device software and the results are stored to the hard disk of the computer. Due to an extremely fast signal processing circuitry and a large FIFO size burst count rates of more than $4*10^6$ photons/s can be recorded for more than 10 ms.

The SPC-401/431 and SPC-402/432 modules differ in the data format in which the photon information is stored. The SPC-401/431 data contain 4096 time channels and 128 detector channels thus providing a minimum time channel width of 813 fs and a FIFO size of 64k photons. The SPC-402/432 uses a reduced data format containing 256 time channels and 8 detector channels only. This gives a minimum time channel width of 13 ps while increasing the FIFO size to 128k photons.

SPC-500/530

The SPC-500/530 modules have extremely large memories and are targeted at fast scanning and imaging applications. Up to 16384 decay curves can be measured simultaneously. A 14 bit routing signal is used to select the curve into which a detected photon is stored. In scanning applications this signal must be provided by the scanning device.

The SPC-500/530 work also for the traditional applications. Recording of fluorescence decay curves, time-resolved fluorescence spectra etc. can be done in the same way as with the SPC-300/330 and in the SPC-400/430. However, the maximum count rate is lower due to the higher dead time.

SPC-505/535

These modules are special versions of the SPC-500/530. They are designed for use with a scanning device that is controlled by the SPC module. The modules acquire images with up to 16384 pixels containing a complete waveform each. The SPC-505/535 internally steps through the pixels of the recorded image while delivering signals to control an external scanning device.

The SPC-505/535 work also for the traditional applications. Recording of fluorescence decay curves, time-resolved fluorescence spectra etc. can be done in the same way as with the SPC-300/330 and in the SPC-400/430. However, multi-detector measurements are not possible with the SPC-505/535 and the maximum count rate is lower due to the higher dead time.

SPC-506/536

The SPC-506/536 accepts synchronisation signals from ultra-fast video-compatible scanners from which the stepping through the pixels of the image is derived. As the other SPC-5 modules, the SPC-506/536 acquire images with up to 16384 pixels containing a complete waveform each.

The SPC-505/535 work also for the traditional applications. Recording of fluorescence decay curves, time-resolved fluorescence spectra etc. can be done in the same way as with the SPC-300/330 and in the SPC-400/430. However, multi-detector measurements are not possible with the SPC-505/535 and the maximum count rate is lower due to the higher dead time.

SPC-600/630 - the TCSPC General Solution

The SPC-600/630 PCI bus modules combine the features of the SPC-400/430, SPC-401/431 and the SPC-402/432 modules. They use a dual memory structure for simultaneous measurement and data readout. The exceptionally low dead time of the SPC-6 modules allows high count rates. This makes the SPC-600/630 an excellent choice for all applications which require maximum data throughput. A ‘Continuous Flow’ mode is implemented for single molecule detection in a continuos flow arrangement. It continuously records decay curves with short collection times and without time gaps between subsequent recordings and stores the results to the hard disk.

Furthermore, the SPC-6 modules can be configured for single molecule detection by the BIFL method. In this mode the device memory is configured as a fast FIFO memory to store the time within the excitation pulse sequence, the time from the start of the experiment and the detector channel for each individual photon. During the measurement, the FIFO is continuously read by the device software and the results are stored to the hard disk of the computer. Due to an extremely fast signal processing circuitry and a large FIFO size burst count rates of more than $4*10^6$ photons/s can be recorded for more than 10 ms.

Thus, the SPC-600/630 modules are an excellent choice for the complete range from the traditional fluorescence lifetime experiments to single molecule fluorescence lifetime investigations.

SPC-700/730 - the TCSPC Imaging Solution

The SPC-700/730 PCI bus modules combine the features of the SPC-500/530, SPC-505/535 and the SPC-506/536 modules. Therefore, the SPC-700/730 is the solution for all TCSPC scanning and imaging applications.

Due to their flexible scanning interface, the SPC-7 modules can be coupled to almost any scanning device. The modules can be synchronised by the frame/line synchronisation pulses or by X/Y signals from free running scanners such as confocal laser scanning microscopes or ultra-fast video-compatible scanners. Furthermore, the SPC-7 modules can actively control a scanning device by sending appropriate synchronisation pulses or X/Y signals. The maximum scanning area is 128 x 128 pixels for the X/Y control modes and 256 x 256 pixels for the modes using synchronisation pulses.

The SPC-700/730 work also for the traditional applications. Fluorescence decay curves, time-resolved fluorescence spectra etc. can be recorded in the same way as with the SPC-300/330 and in the SPC-400/430.

SPC-134 - The TCSPC Power Package

The SPC-134 is a stack of four completely independent TCSPC modules. Due to space, power supply and price constraints the SPC-134 channels have reduced routing capabilities and are available only in the 3x version, i.e. for negative input signals. However, no compromises have been made for the essential parameters as count rate, time resolution, or differential nonlinearity. The SPC-134 requires the ‘Multi SPC Software’ and works in the Single, Oscilloscope, f(t,T), f(t, ext), fi(T), fi(ext) and in the Continuous Flow and FIFO mode.

With its four channels and 32 MHz overall count rate the SPC-134 is an extremely powerful solution for all applications which require maximum data throughput. Although the SPC-134 can be used for traditional fluorescence experiments the typical applications are for optical tomography, stopped flow experiments and single molecule detection.

A comparison of the different SPC versions is given in the table on the next page.

	SPC-300 -10 -12	SPC-330 -10 -12	SPC-400	SPC-430	SPC-401 SPC-402	SPC-431 SPC-432	SPC-500	SPC-530	SPC-505 SPC-506	SPC-535 SPC-536	SPC-600	SPC-630	SPC-700	SPC-730	SPC-134
TCSPC Channels	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**4**
Points /Curve	1024 4096	1024 4096	64, 256, 1024, 4096				64, 256, 1024, 4096		64, 256, 1024, 4096		64, 256, 1024, 4096		64, 256, 1024, 4096		64, 256, 1024, 4096
Curves in Memory	128 32	128 32	32..128				**up to 16384**		**up to 16384**		32..128		**up to 65536**		32..128
Input Voltage	10..80 mV	50mV..2V	10..80 mV	50mV..2V	10..80 mV	50mV..2V	10..80 mV	50mV..2V	10..80 mV	50mV..2V	10..80 mV	50mV..2V	10..80 mV	50mV..2V	50mV..2V
Time Resol. (el., FWHM)	11 ps	**6 ps**	11 ps	7 ps	11 ps	7 ps	11 ps	7 ps	11 ps	7 ps	11 ps	7 ps	11 ps	7 ps	7 ps
Time Resol. (MCP, FWHM)	30 ps	25 ps	30 ps	25 ps	30 ps	25 ps	30 ps	25 ps	30 ps	25 ps	30 ps	25 ps	30 ps	25 ps	25 ps
Dead Time	200 ns	200 ns	**125 ns**	**125 ns**	**125 ns**	**125 ns**	330ns	330ns	330ns	330ns	**125 ns**	**125 ns**	330ns	330ns	**125ns**
Count Rate Limit	5 MHz	5 MHz	**8 MHz**	**8 MHz**	**8 MHz**	**8 MHz**	3 MHz	3 MHz	3 MHz	3 MHz	**8 MHz**	**8 MHz**	5.5 MHz	5.5 MHz	**8 MHz per Channel**
Memory (MCA)	single	single	**dual**	**dual**	**FIFO**	**FIFO**	single	single	single	single	**dual/FIFO**	**dual/FIFO**	single	single	**dual**
Multi-Detector Operation	yes	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes	yes	yes	no
Readout during Measurement	no	no	**yes**	**yes**	**yes**	**yes**	no	no	no	no	**yes**	**yes**	no	no	yes
Count Rate Display	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Sync Rate Display	no	no	no	yes	no	yes	no	yes	no	yes	no	yes	no	yes	yes
Dead Time Compensation	yes	yes	on/off	on/off	on/off	on/off	on/off	on/off	on/off	on/off	on/off	on/off	on/off	on/off	on/off
'Start Measurement' Trigger	no	no	no	no	no	no	no	no	no	no	**yes**	**yes**	**yes**	**yes**	**yes**
PC Bus Interface	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA	ISA	**PCI**	**PCI**	**PCI**	**PCI**	**PCI**
Application for															
Optical Oscilloscope	X	X	X	X			X	X	X	X	X	X	X	X	x
Fluorescence Decay	X	X	X	X			X	X	X	X	X	X	X	X	x
Fluorescence Spectra	X	X	X	X			X	X	X	X	X	X	X	X	x
Photon Correlation		X		X				x		x		X		x	X
Single Molecule (CFD)			**X**	**X**							X	X			X
Single Molecule (BIFL)					**X**	**X**					**X**	**X**			**X**
Opt. Tomography	x	x	x	x			X	X	X	X	x	x	X	X	X
Lifetime Imaging							X	X	X	X			**X**	**X**	
Fast Image Scanning							x	x	**X**	**X**			**X**	**X**	

X = recommended

x = applicable, but other versions give better performance or lower cost

Accessories

Preamplifiers

If the SPC-x30 modules are used with PMTs and MCPs preamplifiers are recommended. The SPC-x00 can be used without preamplifiers. However, to achieve optimum resolution with MCPs and to extend the lifetime of these detectors preamplifiers should be used also for the SPC-x00 modules. For safe operation of MCPs and PMTs the HFAC-26 amplifier (26 dB, 1.6 GHz) with current sensing is available. This amplifier indicates overload conditions in the detector by a LED and by a TTL signal. For multidetector measurements the HFAM-26 with eight amplifier channels is available. Other amplifiers are the ACA-2 and ACA-4 devices with gains from 10 dB to 40 dB and a bandwidth up to 2 GHz.

Detectors

A wide variety of PMT and MCP detectors can be delivered with the SPC modules. This includes also cooling devices and high voltage power supplies. As a simple and rugged solution the PMH-100 detector head is available. This device contains a fast, small PMT, the high voltage generator and a preamplifier altogether in a 32x38x92mm housing. The PMH-100 is powered directly from the SPC module - no high voltage power supply is required. For 16-channel measurements the PML-16 detector head is available.

Diode Lasers

The BHL-150 pulsed diode laser modules offer low cost, short pulse width and high repetition rate. They can be used for fluorescence excitation from 635 nm to 780 nm and for testing purposes.

Reference Photodiodes

To generate the synchronisation signal for the SPC from a laser pulse sequence fast photodiode modules are available. The PHD-400 and PDM-400 use fast PIN photodiodes. If high sensitivity is required the APM-400 avalanche photodiode modules are recommended. All photodiode modules are powered directly from the SPC card.

Step Motor Controller

For driving a monochromator or scanning a sample the Step Motor Controller STP-240 is available. The STP-240 drives up to two unipolar 4 phase motors with up to 1 A phase current. The electrical and mechanical drive parameters are set via a configuration file. The control software for the STP-240 is included in the SPC software.

Routing devices

The HRT-41 and HRT-81 routers are used to connect up to four (eight) individual PMTs or MCPs to one bh SPC module. To connect up to eight APD modules the HRT-82 is available. With the HRT devices, all detector channels work simultaneously and the detected photons are ‘routed’ into individual memory blocks (see 'Multichannel Measurements' and individual descriptions and data sheets).

Adapters

To connect signals from different sources to the SPC modules a wide variety of adapters are available. This includes attenuators and inverting transformers for TTL signals (e.g. from SPCM-AQR avalanche photodiode modules).

Time-correlated single photon counting: General measurement principle

Time-Correlated Single Photon Counting is based on the detection of single photons of a periodical light signal, the measurement of the detection times of the individual photons and the reconstruction of the waveform from the individual time measurements.

The method makes use of the fact that for low level, high repetition rate signals the light intensity is usually so low that the probability to detect one photon in one signal period is much less than one. Therefore, the detection of several photons can be neglected and the principle shown in the figure below can be used.

The detector signal consists of a train of randomly distributed pulses due to the detection of the individual photons. There are many signal periods without photons, other signal periods contain one photon pulse. Periods with more than one photons are very rare.

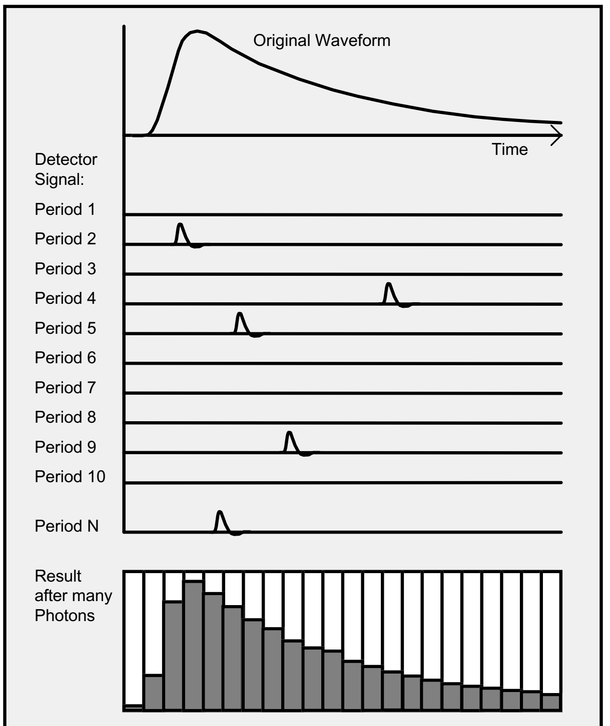


Fig. 1: TCSPC Measurement Principle

When a photon is detected, the time of the corresponding detector pulse is measured. The events are collected in a memory by adding a ‘1’ in a memory location with an address proportional to the detection time. After many photons, in the memory the histogram of the detection times, i.e. the waveform of the optical pulse builds up.

Although this principle looks complicated at first glance, it is very efficient and accurate for the following reasons:

The accuracy of the time measurement is not limited by the width of the detector pulse. Thus, the time resolution is much better then with the same detector used in front of an oscilloscope or another analog signal acquisition device. Furthermore, all detected photons contribute to the result of the measurement. There is no loss due to ‘gating’ as in ‘Boxcar’ devices or gated image intensified CCDs.

Depending on the desired accuracy, the light intensity must be not higher than to detect 0.1 to 0.01 photons per signal period. Modern laser light sources deliver pulses with repetition rates of 50..100MHz. For these light sources, the count rate constraint is satisfied even at count rates of several 10^6 photons per second. Such count rates already cause overload in many detectors. Consequently the intensity limitation of the SPC method does not cause problems in conjunction with high repetition rate laser light sources.

Sensitivity

The sensitivity of the SPC method is limited mainly by the dark count rate of the detector. Defining the sensitivity as the intensity at which the signal is equal to the noise of the dark signal the following equation applies:

$$S = \frac{(Rd * N/T)^{1/2}}{Q}$$

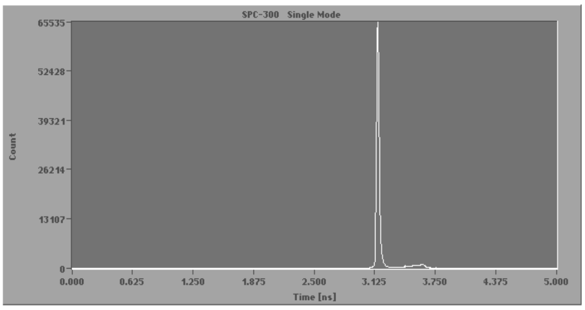
(Rd = dark count rate, N = number of time channels, Q = quantum efficiency of the detector, T = overall measurement time)

Typical values (PMT with multialkali cathode without cooling) are $Rd=300s^{-1}$, N=256, Q=0.1 and T=100s. This yields a sensitivity of S=280 photons/second. This value is by a factor of 10^{15} smaller than the intensity of a typical laser (10^{18} photons/second). Thus, when a sample is excited by the laser and the emitted light is measured, the emission is still detectable for a conversion efficiency of 10^{-15}.

Time resolution

The SPC method differs from methods with analog signal processing in that the time resolution is not limited by the width of the detector impulse response. For the SPC method the timing accuracy in the detection channel is essential only. This accuracy is determined by the transit time spread of the single photon pulses in the detector and the trigger accuracy in the electronic system. The timing accuracy can be up to 10 times better than the half width of the detector impulse response. Some typical values for different detector types are given below.

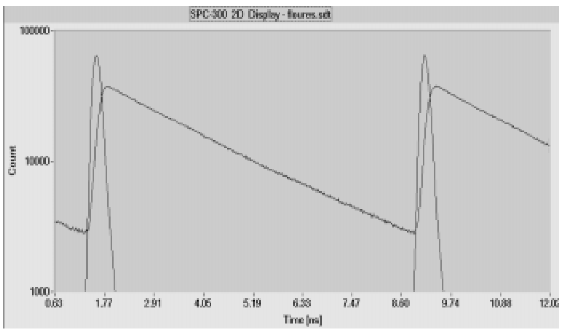
conventional photomultipliers	
standard types	0.6 ... 1 ns
high speed (XP2020)	0.35 ns
Hamamatsu TO8 photomultipliers	
R5600, R5783	140 ... 220 ps
micro channel plate photomultipliers	
Hamamatsu R3809	25 ... 30 ps
avalanche photodiodes	60 ... 500 ps



A laser pulse recorded with 30 ps fwhm

Accuracy

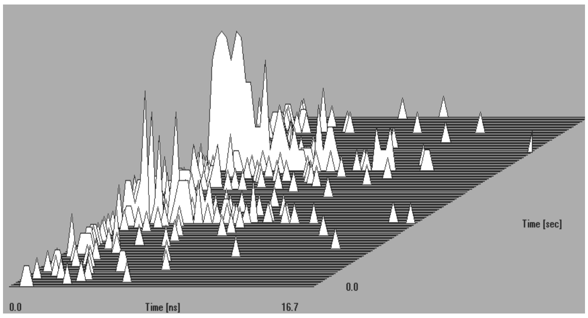
The accuracy of the measurement is given by the standard deviation of the number of collected photons in a particular time channel. For a given number of photons N the signal-to-noise ratio is $SNR = N^{1/2}$. If the light intensity is not too high, nearly all detected photons contribute to the result. Therefore, the SPC yields the maximal signal-to-noise ratio for a given intensity and measurement time. Furthermore, for the SPC method noise due leakage currents, gain instabilities, and the stochastic gain mechanism of the detector does not appear in the result. This yields an additional SNR improvement compared to analog signal processing methods.



Fluorescence decay curves, excitation with Ar+ laser

Recording Speed

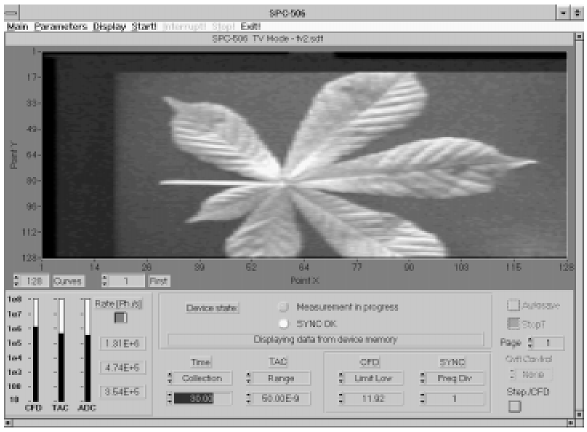
The TCSPC method is often thought to suffer from slow recording speed and long measurement times. This ill reputation comes from traditional TCSPC devices built up from nuclear instrumentation modules which had a maximum count rate of some 10^4 photons per second. State-of-the-art TCSPC devices from Becker & Hickl achieve count rates of some 10^6 photons per seconds. Thus, 1000 photons can be collected in less than 1 ms, and the devices can be used for high speed applications such as the detection of single molecules flowing through a capillary, fast image scanning, for the investigation of unstable samples or simply as optical oscilloscopes.



Fluorescence decay signals from single molecules running through a capillary. Collection time 1 ms per curve.

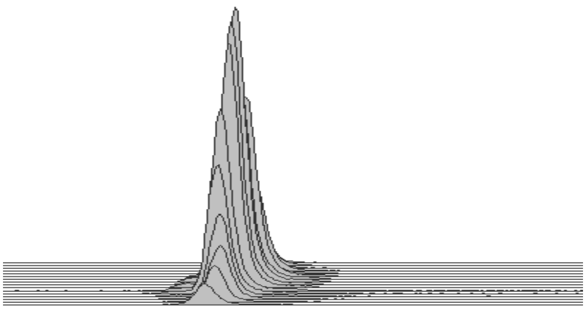
Multichannel and Multidetector Capability

Becker & Hickl from the beginning have introduced multichannel and multidetector capabilities into their TCSPC modules. In the device memory space is provided for several waveforms, and the destination of each individual photon is controlled by an external signal. In conjunction with a fast scanning device, time resolved images are obtained with up to 256 x 256 pixels containing a complete waveform each.



A 128 x 128 pixel scan containing 16384 waveforms

Furthermore, several detectors can be used with one TCSPC modules. This technique makes use of the fact that a simultaneous detection of several photons in different detectors is very unlikely. Therefore, the output pulses of the detectors are processed by only one TCSPC channel and an external 'Routing' device determines in which detector a particular photon was detected. This information is used to route the photons into different memory blocks containing the waveforms for the individual detectors.

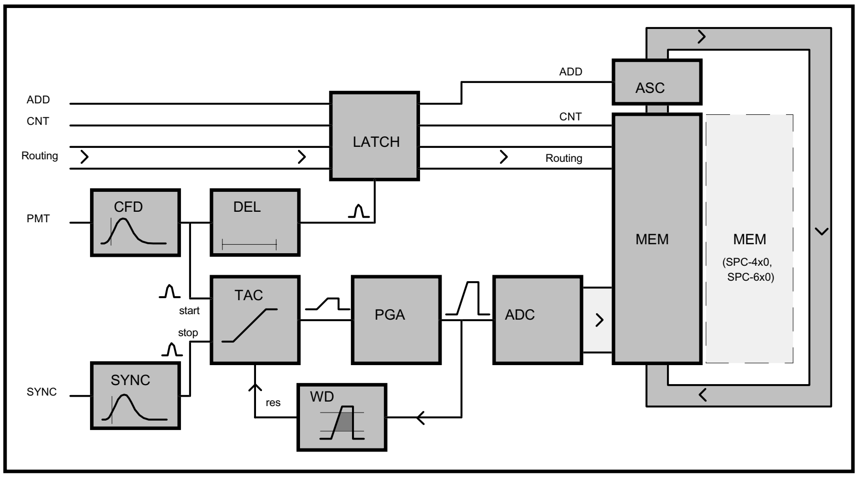


16 signals measured simultaneously with a 16 channel PMT

Measurement System

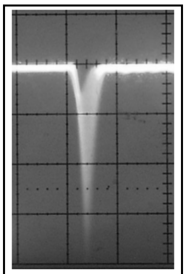
General Principle

The general principle of the bh TCSPC modules is shown in the figure below.



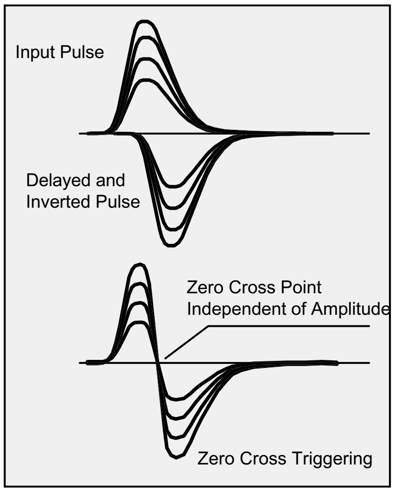
CFD and SYNC circuits

The single-photon pulses from the photon detector are fed to the input 'PMT'. Due to the stochastic gain mechanism in the detector these pulses have a considerable amplitude jitter (figure right). The constant fraction discriminator, CFD has to deliver an output pulse that is correlated as exactly as possible with the temporal location of the detector pulse. This is achieved by triggering on the zero cross point of the sum of the input pulse and the delayed and inverted input pulse (figure below, right).



Single Photon Pulses of a PMT

Since the temporal position of the crossover point is independent of the pulse amplitude, this timing method minimises the time jitter due to the amplitude jitter of the detector pulses. Furthermore, the CFD contains a window discriminator that rejects input pulses smaller than the discriminator threshold (SPC-x3x) or outside the selected amplitude window (SPC-x0x). The threshold or the amplitude window are adjusted to reject noise from the environment, noise from preamplifiers or small background pulses of the detector.



The input signal SYNC is derived from the pulses of the light source and is used to synchronise the time measurement with the light pulses. The SYNC signal is received by the SYNC circuit which, as the CFD, has a fraction trigger characteristics to reduce the influence of amplitude fluctuations. Controlled by the software, the internal SYNC frequency can be divided by a factor of 2...16. In this case several signal periods are displayed in the result. At very high pulse repetition rates the frequency divider may be used to reduce the internal synchronisation frequency.

TAC

The time-to-amplitude converter, TAC, is used to determine the temporal position of a detected photon within the SYNC pulse train. When the TAC is started by a pulse at the start input, it generates a linear ramp voltage until a stop pulse appears at the stop input. Thus the TAC generates an output voltage depending linearly on the temporal position of the photon. The time measurement is done from the photon to the next SYNC pulse. This 'reversed start-stop' method is the key to process high photon count rates at high pulse repetition rates. It reduces the speed requirements to the TAC because its working cycle (start-stop-reset) has to be performed with the photon detection rate instead of the considerably higher pulse repetition rate.

The TAC output voltage is fed to the programmable gain amplifier, PGA. The PGA is used to stretch a selectable part of the TAC characteristic over the complete measurement time window. To increase the effective count rate at high PGA gains, the output voltage of the PGA is checked by the window discriminator WD which rejects the processing of events outside the time window of interest.

ADC

The analog-digital converter, ADC, converts the amplified TAC signal into the address of the memory, MEM. The ADC must work with an extremely high accuracy. It has to resolve the TAC signal into 4096 time channels, and the width of the particular channels must be equal within 1..2%. This requires a 'no missing code' accuracy of more than 18 bits. This accuracy cannot be achieved with fast ADCs which are, however, required to achieve a high count rate. In the bh SPC modules the problem is solved with a fast flash ADC of 12 bit 'no missing code' accuracy in conjunction with a proprietary error correction method. The error correction is described in the section 'ADC with Error Correction'.

Memory

The address delivered by the ADC is proportional to the temporal position of the photon within the SYNC pulse train. Together with some external ‘Routing’ bits it controls the address of the device memory MEM. When a photon is detected, the contents of the addressed memory location is increased by a fixed increment. This is done by the add/subtract circuit, ASC. The ASC is able to add or subtract a selectable number from 1 to 255. Values >1 are used to get full scale recordings in short collection times (e.g. in the oscilloscope mode). Furthermore, the circuit delivers an overflow signal when the memory contents of the addressed memory location has reached its maximum value. In this moment the measurement can be stopped automatically.

In the SPC-400/430, the SPC-600/630 and the SPC-134 modules a ‘dual memory’ structure is implemented. For sequential curve recording, the dual memory structure allows to continue the measurement in the second memory bank when the data from first bank is read and vice versa. Thus, an unlimited sequential recording without gaps between subsequent curves is achieved.

Memory Control

Multidetector operation is achieved by controlling the higher memory address bits by the external ‘Routing’ signal. The routing bits (6 in the SPC-3/12, 7 in the SPC-3/10 and the SPC-4 and -6, 14 in the SPC-5, and -7) control the higher address bits of the memory. Thus, by the routing signal the recorded photons are ‘routed’ into different part of the memory. Each selected memory part represents an individual curve (waveform). Corresponding to the number of routing bits, the maximum number of curves is 32 for the SPC-3x0-12, 128 for the SPC-3x0-10 and the SPC-4x0 and -6x0 and 16384 for the SPC-5 and -7.

Furthermore, the higher memory address can be controlled internally. In this case the number of curves can be much higher, i.e. 4096 for the SPC-6 and 65536 for the SPC-7.

By the implemented memory control new powerful measurement modes become possible which are beyond the reach of conventional TCSPC devices:

Several light signals can be measured quasi-simultaneously with one detector by multiplexing the light signals and controlling the destination curve by the routing signals (see also ‘Multiplexed SPC’). With optical scanners (e.g. a laser scanning microscope) images can be recorded with up to 256 x 256 pixels (SPC-7) containing a complete decay curve each.

Simultaneous multichannel operation with several detectors is accomplished by combining the photon pulses from all detectors into one common timing pulse and providing a routing signal which directs the photons from the individual detectors into different memory blocks (see also 'Multichannel Measurements'). Routing devices for individual detectors are available for 4 and 8 detector channels (HRT-4 and HRT-8). Complete detector heads are available with 16 channels in a linear arrangement.

If external parameters are changed during the measurement (temperature, oxygen pressure, location on the sample) and an appropriate routing signal is provided, a sequence of decay curves for different parameter values can be recorded. The routing capability can even be used to record signals from intrinsically variable objects. If a routing signal describing the state of the object is can be provided, the photons from the object are routed to different curves depending on the state of the object. The result of the measurement are several decay functions recorded in different states of the object.

In all SPC modules the destination curve of the recorded photons can also be controlled by software. Controlled by the on-board timers, a sequence of subsequent decay curves can be recorded. In the SPC-134, SPC-6 and SPC-7 the start of a sequence can be triggered, and several sequences can be accumulated. This allows to record transient phenomena in the decay curves down the ms time scale and below.

CNT and ADD Control

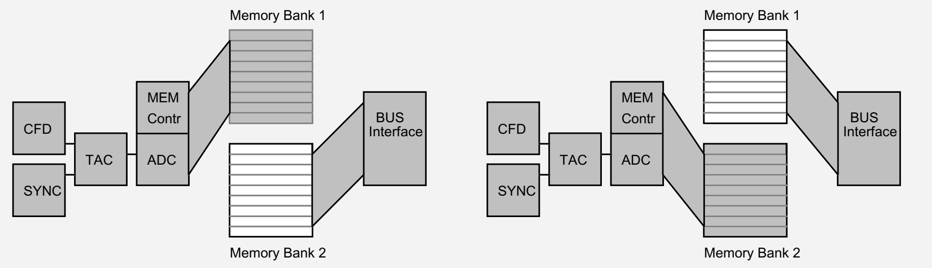
Additional control over the measurement is given by the signals CNT and ADD. CNT is a ‘Count Enable’ signal, i.e. a photon is stored only if CNT is ‘1’ in the moment of its detection. The CNT signal is used to suppress photons for which no valid routing information is provided or to confine the recording to externally controlled time intervals.

The ADD signal controls whether a photon is added or subtracted. This enables the SPC to be combined with a digital lock-in technique. By using an optical system with light choppers or rotating sector mirrors background or the scattered light signals can be suppressed (see also ‘Lock-in SPC).

All external control signals are read by the latch register LATCH. The signals are latched at an adjustable delay time after the start pulse. By adjusting this delay it can be assured that every photon be processed with the corresponding state of the control signals.

Memory Control in the Continuous Flow Mode

In the SPC-400/430, the SPC-600/630 and the SPC-134 modules a ‘Continuous Flow’ mode is implemented which is used to record a virtually unlimited number of decay curves. The Continuous Flow Mode makes use of the two independent memory banks which are implemented in the SPC-4, SPC-6 and SPC-134 modules. As usual, the decay curves are measured in intervals of ‘Collection Time’. However, the measurement is repeated while the measurement system automatically switches through all memory blocks of both memory banks. While the measurement is running in one memory bank, the results of the other bank are read and stored to the hard disk. Thus, a virtually unlimited number of decay curves can be recorded without time gaps between subsequent curves.

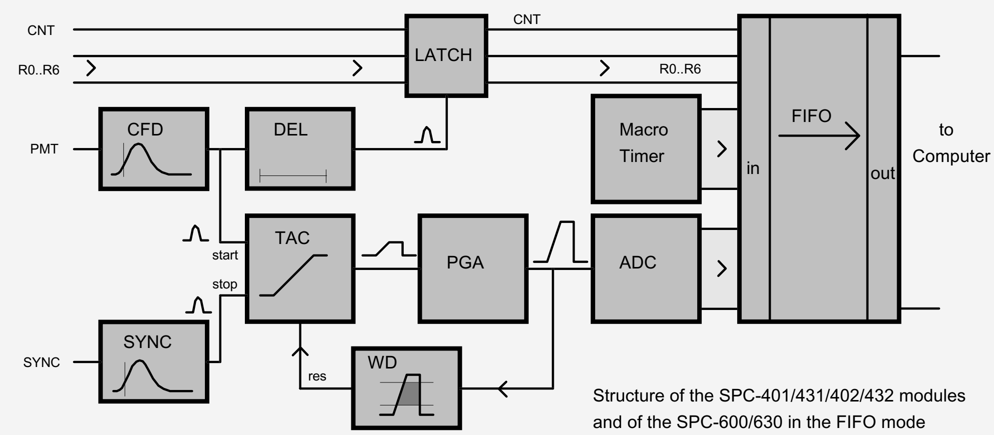


SPC-400/430 Continuous Flow Mode: Alternating Measurement and Readout of both Memory Banks

Usually, the 'Continuous Flow' mode is used for single molecule detection in a continuous flow setup. It can, however, be used for all applications which require a large number of curves to be recorded time intervals down to the 100us scale. The ‘Continuous Flow’ mode is strictly hardware controlled and thus provides an extremely accurate recording sequence.

Memory Control in the FIFO Mode

The SPC-4x1/4x2 modules and the ‘FIFO’ Mode of the SPC-6x0 and the SPC-134 employ a ‘First-In-First-Out’ structure of the memory. In the FIFO mode, the measurement does not deliver a histogram but a continuous stream of information about the individual photons. The principle shown in the next figure.



Structure of the SPC-401/431/402/432 modules and of the SPC-600/630 in the FIFO mode

The signal processing is the same as in the other modules up to the output of the ADC. Thus, the ADC delivers the time of the current photon within the excitation pulse sequence.

In addition, the ‘Macro Timer’ delivers the time from the start of the measurement. Both times, i.e. the time of the current photon within the excitation pulse sequence and the time since the start of the measurement, are fed to the input of the FIFO memory.

At the output, the FIFO memory is continuously read out by the software. A FIFO (first-in-first out) memory can be seen as a data shift register which accepts data at its input while providing them in the same order at the output. The capacity of the FIFO is depends on the module type and the operation mode:

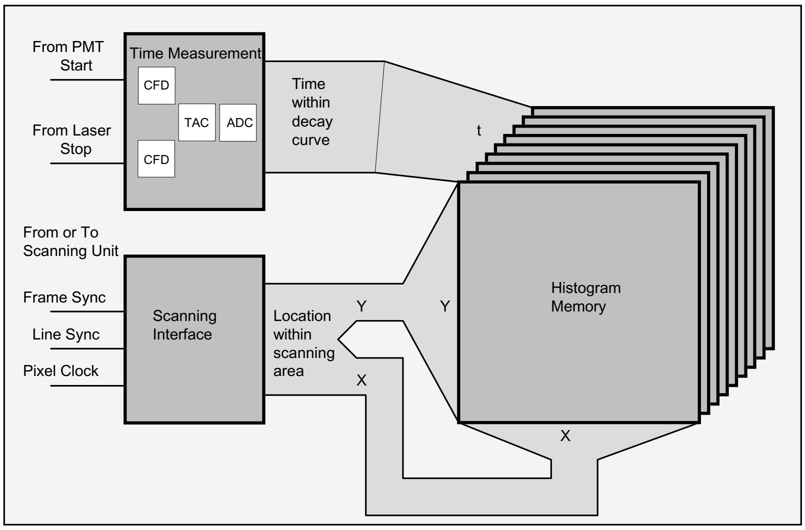
SPC-401/431	64k photons
SPC-402/432	128k photons
SPC-600/630, ADC Resolution 12bit	128k photons
SPC-600/630, ADC Resolution 8 bit	256k photons
SPC-134 (each TCSPC channel)	256 k photons

Thus, bursts of up to 256k photons can be detected with very high count rate independently of the readout rate of the computer.

Multichannel recording is achieved by the Routing bits R0...R6. These bits are stored for each photon together with the ADC data and the Macro Time. CNT is a count enable signal, i.e. CNT=0 suppresses the recording of the current photon. All external control signals are read via the latch register LATCH. The signals are latched with an adjustable delay after the CFD pulse. By adjusting this delay, it is assured that every photon is processed with the correct state of the control signals.

Memory Control in the Scan SYNC Modes

The SPC-5 and SPC-7 modules are designed for imaging with optical scanning devices (e.g. Laser Scanning Microscopes). The memory control in these modes is shown below.



The modules contain a scanning interface which controls the higher addresses of the memory. In the ‘Scan Sync In’ mode the scanning interface accepts the synchronisation pulses from the scanner and determines the current spatial location in the image. In the ‘Scan Sync Out’ mode the scanning interface by itself steps through all pixels of the image and controls the scanner by sending synchronisation pulses.

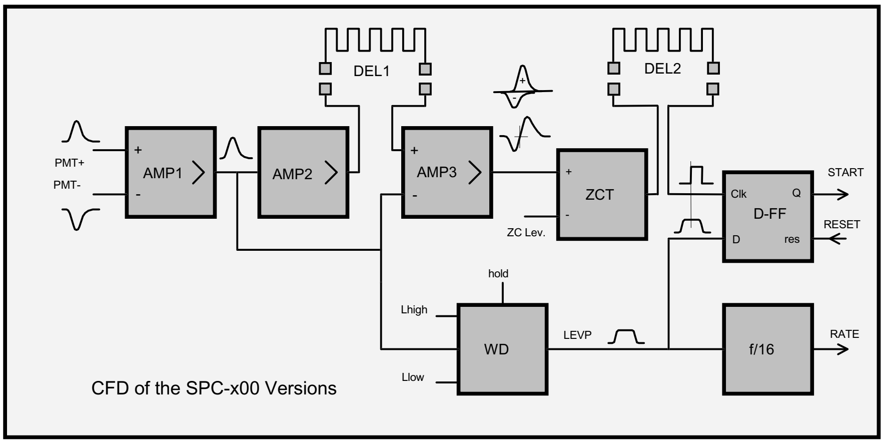
This spatial information is used to control the higher memory addresses. The lower addresses are controlled in the normal way by the TAC and ADC circuitry. Therefore, for each photon the TCSPC module determines the time of the photon within the laser pulse sequence and the location within the scanning area. These values are used to address the histogram memory in which the events are accumulated. Thus, in the memory the distribution of the photon density over X, Y, and the time within the fluorescence decay function builds up. The result can be interpreted as a two-dimensional (X, Y) array of fluorescence decay curves or as a sequence of fluorescence images for different times (t) after the excitation pulse.

Detailed Description of Building Blocks

Constant Fraction Discriminator

SPC-x00 Versions

The principle of the CFD of the SPC-x00 versions is shown in the figure below.



CFD of the SPC-x00 Versions

Depending on the polarity of the detector signal, the input pulses are fed to the ‘plus’ or ‘minus’ input of the amplifier AMP1. The output pulse of AMP1 is fed through AMP2 and the delay line DEL1 into the '-' input of AMP3. AMP 3 generates the difference of the signal from AMP1 and the delayed signal from AMP2. The result is a bipolar pulse which is positive at the beginning, than crosses the baseline and becomes negative. The position of the zero cross point does (as long as the amplifiers are in the linear range) not depend on the amplitude of the input pulses.

The zero cross trigger ZCT converts the baseline transition into a pulse edge of a logical signal (ECL levels). The zero cross level is adjusted by the reference voltage 'ZC level' to compensate small DC offsets in the circuit.

The window discriminator WD checks the pulse amplitude at the output of AMP1. WD switches its output voltage to 'High' when the lower threshold (CFD limit low) is exceeded. If the amplitude exceeds the upper threshold (CFD limit High) WD switches back immediately. Thus WD delivers a 'Level Pulse' LEVP if the amplitude of the input pulse is in the desired range. The output is switched back to 'Low' after the programmable time 'CFD Hold'.

The LEVP pulse is used to control the D input of an ultra-fast ECL flip-flop. The clock of the flip-flop is the delayed zero cross pulse from the zero cross trigger ZCT. The flip-flop is set if the rising edge of this pulse is inside the LEVP pulse. Thus the flip-flop is triggered by the zero cross of pulses that are inside the desired amplitude range. The flip-flop is reset by the TAC when the processing of the current photon pulse is finished.

To measure the count rate in the CFD the frequency divider f/16 is used. The frequency division is necessary because the subsequent counter/timer circuits are not able to count short pulses as they appear inside the CFD. The frequency divider counts the pulses on the LEVP line. Therefore, the CFD count rate represents the all pulses with amplitudes greater than ‘CFD Limit Low’.

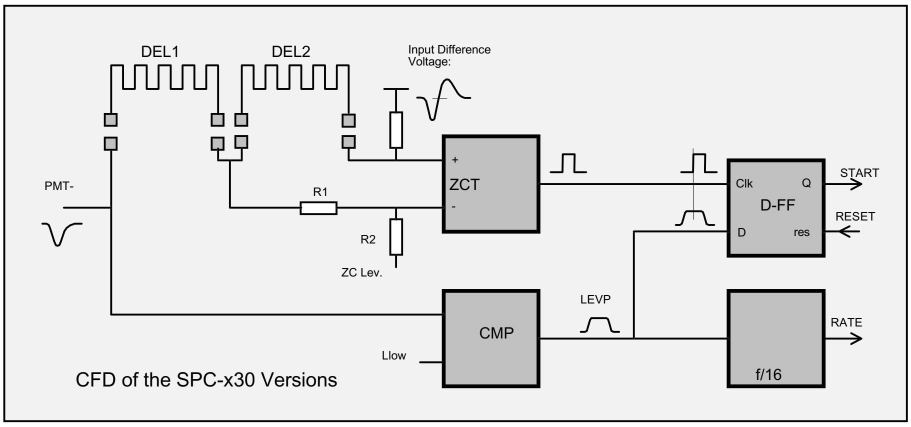
The delay lines DEL1 and DEL2 are exchangeable to adapt the CFD to various detectors. DEL 1 serves for zero cross shaping. The sum of the delay through DEL1 and the internal delay in

AMP2 should be about the rise time of the detector pulses. The internal delay is 0.6...0.8ns, so a zero-delay of DEL1 is adequate for fast detectors with rise times below 0.8ns (please see also ‘Configuring the CFD and SYNC Inputs’).

The delay line DEL2 shifts the rising edge of the zero cross pulse into the level pulse LEVP. Normally the internal delay is sufficient for this purpose, so that DEL2 can be zero. An additional delay is needed only if a detector with a long rise time is used with a short DEL1. In this (unusual) case the zero cross pulse must be shifted to a time after the pulse maximum at the output of AMP1 to detect the exceeding of 'Limit High' correctly.

SPC-x30 Versions

Compared to the SPC-x00 CFD which is designed for maximum input sensitivity and flexibility regarding the detector signals, the CFD of the SPC-x30 versions is designed for ultimate time resolution. The amplifiers of the SPC-x00 CFD have been omitted to achieve maximum signal speed at the zero cross trigger and to reduce the influence of noise and amplifier nonlinearities. However, the circuit can be used for negative input pulses only and external amplifiers are required for most detectors. A block diagram of the SPC-x30 CFD is shown in the figure below.



CFD of the SPC-x30 Versions

The input signal is fed via the delay lines DEL1 and DEL2 to the '+' input of the zero cross trigger ZCT. The '-' input gets the same signal, but with less delay and a smaller amplitude. Therefore the comparator sees an input difference voltage which has a zero cross point at a time determined by the delay line DEL2 (please see also ‘Configuring the CFD and SYNC Inputs’). The zero cross comparator picks off the zero cross point and converts it into a positive edge of an ECL signal.

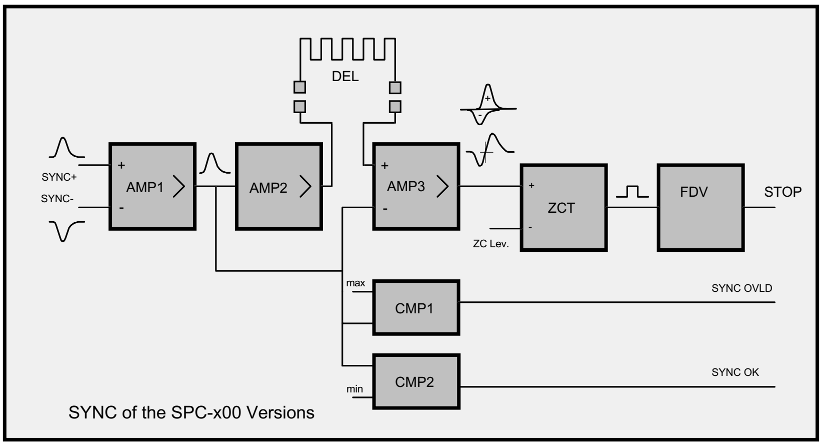
The amplitude of the input pulses is checked by the comparator CMP. If the amplitude exceeds the threshold 'Llow', CMP responds and its output voltage goes to the 'high' state. The resulting pulse is used as the D input of the ultra-fast ECL D flip-flop. When a positive edge from ZCT appears inside a pulse from CMP, the D flip-flop is set and a 'start' signal for the TAC is generated.

To measure the count rate in the CFD the frequency divider f/16 is used. The frequency division is necessary because the subsequent counter/timer circuits are not able to count short pulses as they appear inside the CFD. The frequency divider counts each pulse that occurs at the LEVP line. That means that all events with amplitudes greater than 'TAC Limit Low' are counted.

Synchronisation Circuit

SPC-x00 Versions

The principle of the synchronisation circuit of the SPC-x00 versions is shown in the next figure.



Depending on the polarity the pulses of the synchronisation detector are fed to the plus or minus input of the amplifier AMP1. The output pulse of AMP1 is fed through AMP2 and the delay line DEL1 into the minus input of AMP3. AMP 3 generates the difference of the signal from AMP1 and the delayed signal from AMP2. The result is a bipolar pulse which is negative at the beginning, than crosses the baseline and becomes positive. The temporal position of the zero transition does (as long as the amplifiers are in the linear range) not depend on the amplitude of the input pulse. (Please see also ‘Configuring the CFD and SYNC Inputs’)

The zero cross trigger ZCT converts the zero transition into an ECL pulse. The zero cross level can be adjusted by the reference voltage 'ZC level' to compensate small DC offsets in the circuit. The duration of the pulse is adjustable by the 'SYNC Holdoff' control voltage. 'SYNC Holdoff' is set to a value that allows triggering at the normal SYNC frequency, but suppresses multiple triggering due to ringing or reflections.

The pulse from the ZCT is fed to the frequency divider, FDV. The divider ratio can be selected from 1 to 16. The divider ratio determines the number of signal periods displayed in the result.

The output signal of AMP3 is checked by the comparators CMP1 and CMP2. If the amplitude is in the optimum range, CMP1 switches on and the signal 'SYNC OK' becomes active. If the amplitude is too high, CMP2 switches on and 'SYNC OVLD' becomes active.

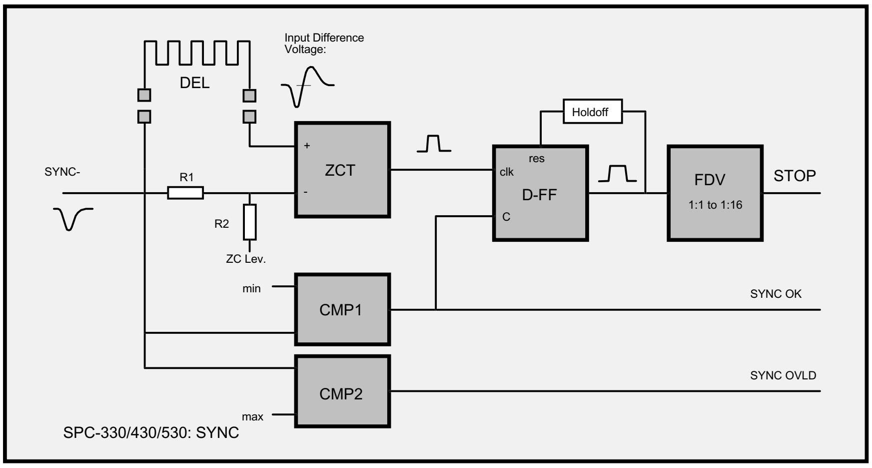
The delay line DEL1 is exchangeable to adapt the CFD to the pulse shape of the synchronisation pulses. The sum of the delay through DEL1 and the internal delay in AMP2 should be about the rise time of the input pulses. The internal delay is 0.6...0.8ns, so a zero-delay of DEL1 is adequate for pulse rise times below 0.8ns (please see also ‘Configuring the CFD and SYNC Inputs’).

The zero cross trigger in the SYNC channel is intended for applications where an amplitude jitter of the SYNC signal cannot be avoided. If the amplitude of the SYNC signal is stable, the zero cross triggering is not needed. In this case the value of DEL1 is not critical and the 'SYNC OVLD' level may be exceeded without degradation of the trigger accuracy.

SPC-x30 Versions

Compared to the SPC-x00 SYNC which is designed for maximum input sensitivity and flexibility regarding the detector signals the SYNC of the SPC-x30 versions is designed for ultimate time resolution. The amplifiers of the SPC-300 SYNC have been omitted to achieve maximum signal speed at the zero cross trigger and to reduce the influence of noise and amplifier nonlinearities. Furthermore, a threshold discriminator has been introduced which improves the performance of the circuit when used with PMTs (e.g. in autocorrelation measurements). However, the circuit can be used for negative input pulses only and external amplifiers are required in some cases. A block diagram of the SPC-x30 SYNC is shown in the next figure.

The input signal is fed via the delay line DEL to the '+' input of the zero cross trigger ZCT. The '-' input gets the same signal, but without delay and with a smaller amplitude. Therefore the comparator sees an input difference voltage which has a zero cross point at a time determined by the delay DEL (please see also ‘Configuring the CFD and SYNC Inputs’). The zero cross comparator picks off the baseline transition and converts it into a positive edge of an ECL signal.

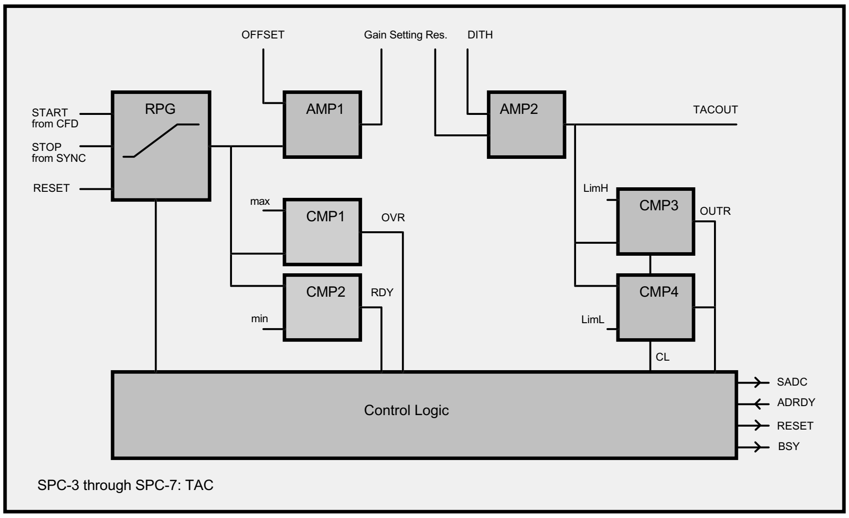


The amplitude of the input pulses is checked by the comparators CMP1 and CMP2. If the amplitude is in the optimum range, CMP1 switches on and the signal 'SYNC OK' becomes active. If the amplitude is too high, CMP2 switches on and 'SYNC OVLD' becomes active. Furthermore, the signal from CMP1 is used as an enable signal for the zero cross pick-off. If the amplitude exceeds the threshold 'min', CMP1 responds and its output voltage goes to the 'high' state. The resulting pulse is used as the D input of the ultra-fast ECL D flip-flop. When a positive edge from ZCT appears inside a pulse from CMP1, the D flip-flop is set and a 'stop' signal for the SPC is generated. The flip-flop is reset automatically after the 'holdoff' delay.

The pulse from the D flip-flop is fed to the frequency divider, FDV. The divider ratio can be selected from 1 to 16. The divider ratio determines the number of signal periods that are displayed in the result.

Time-to-Amplitude Converter

The principle of the TAC is shown in the figure below.



The TAC includes a linear ramp generator, a biased variable gain amplifier, several comparators to check the conversion result an the associated control circuitry.

The ramp generator RPG is started when a pulse from the CFD arrives at the start input. Once started, the ramp voltage increases until a stop pulse from the SYNC arrives at the stop input. After the stop pulse the voltage remains constant until the TAC is reset.

The amplifier AMP1 adds an adjustable offset voltage to the ramp voltage. AMP2 is a variable gain amplifier with a gain of 1...15. The signal DITH is used for the ADC error correction. It is used to shift the TAC output voltage up and down at the ADC characteristic (see 'ADC with error correction').

CMP3 and CMP4 are latched comparators. They check whether the ramp voltage is inside the selected window ‘TAC Limit L’ to ‘TAC Limit H’. The comparator latch pulse, cl, is generated by the TAC control logic. It is derived from the delayed stop pulse. If the ramp voltage is outside the selected window when the cl pulse occurs, the OUTR (outrange) signal is generated.

If the ramp voltage is inside the selected window (i.e. OUTR not active) the control logic generates the SADC (start ADC) pulse. This pulse starts the ADC and the signal processing in the digital part of the board. When the output voltage is not longer needed (ADRDY active), the control logic generates a reset signal for the ramp generator. The reset signal remains active until the comparator CMP2 detects the reset of the ramp voltage. The reset signal is also used to reset the CFD. Thus the CFD is released at the end oft the reset pulse.

If the TACOUT amplitude is not inside the selected window the control logic does not generate a SADC pulse but immediately starts a reset sequence. If a considerable part of the photons is outside the TAC window this increases the speed of the measurement.

The comparators CMP3 and CMP4 are not present in the TAC of the SPC-134. In this module, the TAC window is set by comparing the ADC result during the digital steps of the signal processing.

If the stop pulse from the SYNC does not arrive within the time of the selected TAC range the comparator CMP1 detects an OVR (overrange) condition. In this case the OVR signal initiates a reset sequence to avoid blocking of the TAC. The additional comparator CMP1 is needed because in such cases the cl pulse does not occur so that CMP3 is not able to detect the OUTR condition and to reset the TAC.

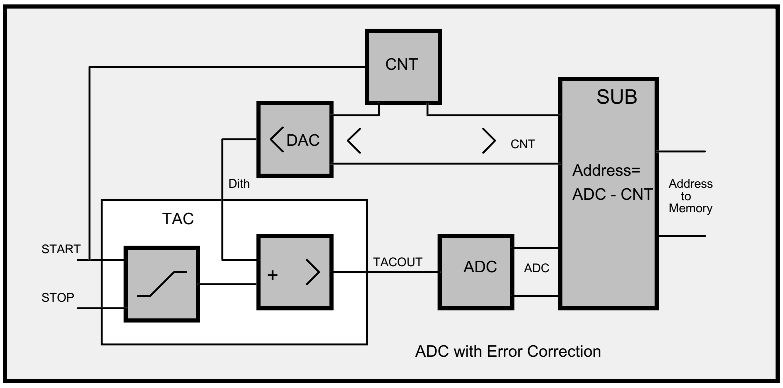
To determine the dead time of the system the control logic delivers a BSY ('BUSY') signal. This signal can be used to stop the 'Collection Time' timer during the signal processing phases. The collection time is then increased by the sum of the dead time over the whole measurement. This 'Dead Time Compensation' yields a correct intensity scale in the sequential recording and spectrum modes.

ADC with Error Correction

The high maximum count rate of the SPC modules is achieved by a fast flash ADC in conjunction with a special error correction. The error correction improves the accuracy of the ADC by several bits without any loss in speed.

The error correction is based on a modified 'Dithering' process and is essential to the operation of the module. The following description helps to understand the principle of the method and the effects caused by its application.

The basic idea of the method is to give the TAC characteristics a variable offset referred to the ADC characteristics. Thus each photon is converted at a slightly different position on the ADC characteristic. This results in an averaging of the errors of the ADC characteristic and a considerable reduction of the difference of the particular ADC steps. The arrangement is shown in the figure below.

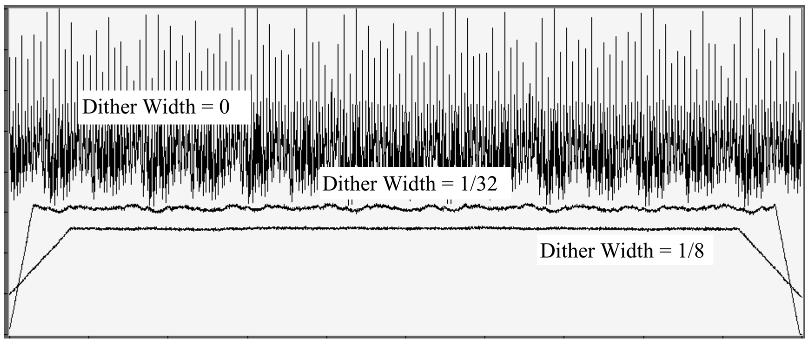


The DA converter, DAC, is used to shift the TAC output voltage up and down on the ADC characteristics. The DAC is controlled by a counter that counts the start pulses of the TAC. Consequently the DAC generates a sawtooth voltage that increases by one DAC step at the recording of each photon. The DAC voltage is added to the TAC output voltage. The resulting signal is converted by the ADC. The ADC data word corresponds to the sum of the DAC and the TAC voltage. To restore the correct address byte for the memory the counter bits are subtracted from the ADC value in a digital subtraction circuit SUB.

Of course each address byte still contains the unavoidable deviation of the particular ADC step from the correct value. But there is a significant difference to a direct ADC conversion in that the error is now different for different photons - even if these photons appeared at equal times and caused equal TAC voltages. When the photons are collected the errors are averaged resulting in a smoothing of the effective ADC characteristic.

For an ideal DAC, the smoothing of the ADC characteristics does not cause any loss of signal detail. In practice, gain and linearity errors of the DAC cause a slight broadening of the recorded signal. This is, however, smaller than 1 or 2 ADC steps or 0.8 to 1.6 ps in the fastest TAC Range.

The improvement of the conversion accuracy depends on the number of ADC steps Ndac over which the signal is shifted by the DAC voltage (‘Dither Width’) and on the distribution of the errors of the ADC characteristic. If the error of an ADC step has no correlation to the errors of the adjacent ones the improvement is $Ndac^{1/2}$. However, in practice the errors of flash ADCs are more or less periodical, i.e. near a big ADC step a smaller one occurs and vice versa. In this case the accuracy improvement is considerably greater than $Ndac^{1/2}$. In the figure below the differential nonlinearity of an SPC-600 is shown for ‘Dither Width’ = 0 (original ADC characteristics) and ‘Dither Width’ = 1/32 and 1/8 of the conversion range.



Effect of ‘Dither Width’ on the ADC nonlinearity

The drawback of the used method is, that the outer parts of the ADC characteristic are lost because the sum of the TAC and the DAC signals is clipped at the ends of the ADC range. These parts of the ADC range are visible as ramps in the SPC results. With the parameter 'dither width' the shift width can be selected to find an optimum between ADC accuracy and useful ADC range.

Installation

General Requirements

The computer must be a IBM compatible 486 or Pentium machine. For convenient working we recommend a computer with a minimum speed of 300 MHz and 32 Mb RAM. The SPC-3, -4 and -5 modules require a free space of two ISA slots. For the SPC-6 and -7 modules a space of two PCI slots is required. The SPC-134 occupies four adjacent PCI slots.

Software Installation - Single Modules

The SPC-3, -4, -5 ,-6 and -7 modules come with the ‘SPC Standard Software’, a comfortable software package that allows for measurement parameter setting, measurement control, step motor control, loading and saving of measurement and setup data, and data display and evaluation in 2 dimensional and 3 dimensional modes. For data processing with other software packages conversion programs to ASCII and Edinburgh Instruments format is included.

There are two versions of the SPC Standard Software: One works under Windows 3.1, the other is for Windows 95/98 and Windows NT. To facilitate the development of user-specific software a DLL and a LabView library for Windows 95 and Windows NT are available on demand.

The SPC Standard Software is based on 'LabWindows/CVI' of National Instruments. Therefore the so-called 'CVI Run-Time Engine' is required to run the SPC software. The 'Run-Time Engine' contains the library functions of LabWindows CVI and is loaded together with the SPC software. The installation routine suggests a special directory to install the Run-Time Engine. If the required version of the Run-Time Engine is already installed for another application, it is detected by the installation program and shared with the existing LabWindows CVI applications.

The installation of the SPC Standard Software is simple. Put the installation disk into the appropriate drive, start setup.exe from the disk drive and follow the instructions of the setup program. Should there be a message about an ‘unknown device’ or a ‘missing driver’ - ignore it. Windows sometimes produces these messages because it cannot find the SPC in its list of standard devices. The SPC installation routine will install all the required components.

When you have installed the SPC software, please send us an email with your name, address and telephone number. This will help us to provide you with information about new software releases and about new features of your module which may become available in future.

Software Installation - Multi SPC Systems

For the SPC-134 ‘TCSPC Power Package’ or for parallel operation of other SPC modules the ‘Multi SPC Software’ is required. The Multi SPC Software includes all functions of the SPC Standard Software, but the module parameters, display functions and the data management are structured for up to four modules. The Multi SPC Software works with all PCI modules (SPC-6, SPC-7, SPC-134), but not with the ISA modules. The Multi SPC software is available only for Windows 95/98 and Windows NT.

The installation for the Multi SPC Software is the same as for the SPC Standard Software. Put the installation disk into the appropriate drive, start setup.exe from the disk drive and follow the instructions of the setup program. Should there be a message about an ‘unknown device’ or a ‘missing driver’ - ignore it. Windows sometimes produces these messages because it cannot find the SPC in its list of standard devices. The SPC installation routine will install all the required components.

To operate two ISA modules (SPC-3, -4, -5) in one computer the SPC Standard Software must be used. It is installed separately for each module and the modules must have different modules addresses. Run the installation procedure for each module and specify different directories. Then edit spc400.ini of at least one of the installations and change the DIP switch settings on the SPC board correspondingly (please see ‘Changing the Module Address’). To operate both modules, start both applications.

The different configurations are listed in the table below.

Module	Single SPC-3, 4, 5	Two SPC-3, 4, 5	Single SPC-6, -7	Two SPC-6, -7	SPC-134
SPC Standard Software	X		X		
SPC Standard Software, 2 Installations		X			
Multi SPC Software			X	X	X

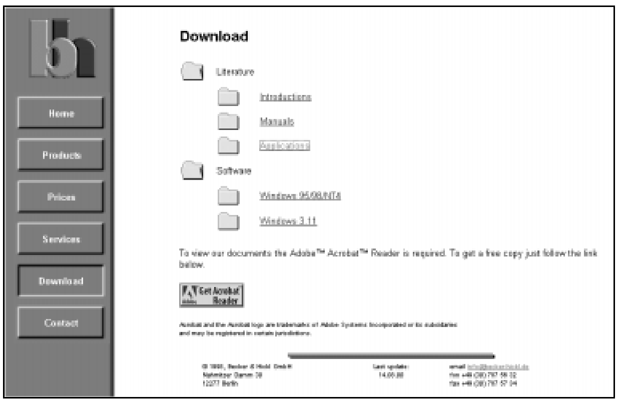
When you have installed the SPC software, please send us an email with your name, address and telephone number. This will help us to provide you with information about new software releases and about new features of your module which may become available in future.

Software Update

If you install a new SPC software version over an older one only the files are copied which have a newer date. This, to a certain extend, avoids overwriting setup files like auto.set (the last system settings) or spc400.ini (hardware configuration). Consequently, you cannot install an older software version in the place of a newer one. If you want to do this (normally there is no reason why you should), run the ‘Uninstall’ program before installing.

Update from the Web

The latest software versions are available from the Becker & Hickl web site. Open www.becker-hickl.de, click on ‘Download’.



Click on ‘Software’, ‘Windows 95/98/NT’ or ‘Windows 3.1’. Choose the SPC software and you will get a ZIP file containing the complete installation. Unpack this file into a directory of your choice and start setup.exe. The installation will run as usual.

For a new software version we recommend also to download the corresponding manual. Click on ‘Manuals’ and download the PDF file. Please see also under ‘Applications’ to find notes about typical applications of the bh TCSPC modules.

Hardware Installation - Single SPC Modules

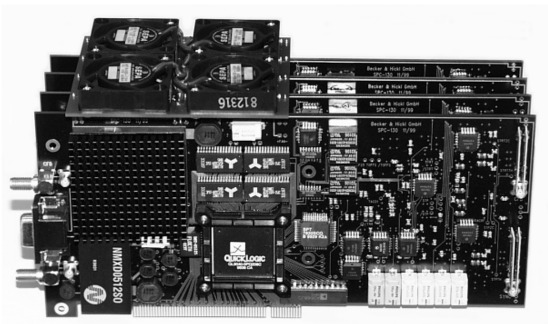
Upgrading a PC with measurement modules sometimes causes problems as system crashes, malfunction of hardware or software components or other unexplainable effects. These effects are usually caused by sharing of interrupt lines or DMA functions between different modules. Therefore, the SPC modules have been designed without interrupts or DMA accesses. So the installation normally does not cause any problems.

Insert your SPC Module into your computer, switch on and start the SPC software. If the software starts without displaying hardware errors you can expect that everything works correctly. If you are in doubt about the correct function of your SPC, run the SPC_TEST program delivered with the module. If does not find errors, all internal registers of the module are correctly accessed by the software.

Should there be any malfunction, the reason may be an insufficient power supply in the computer, insufficient memory or - more likely - a second module that uses the same I/O Addresses as the SPC (ISA) module. If the default address of the SPC module (380h) is not free, change the address (see 'Changing the module Address'). Furthermore, there are some older PCs which violate the ISA bus specification (/IOW before address or data valid). It is very unlikely that you have such a motherboard in your PC. Nevertheless, it is worth to try another computer if there are problems with the module access.

Hardware Installation - Several SPC Modules

Generally, several SPC modules can be operated in one computer (please see also ‘Software Installation, Several Modules). If you plan to build up a multi SPC configuration you should check that you have a computer with a sufficient number of free ISA or PCI slots. The power supply must be strong enough to deliver 3.5 to 4 A at +5V for each module. Although most computers have no problems to power two SPCs, operating the SPC-134 can be a problem if the computer itself is a fast, power eating high end machine.



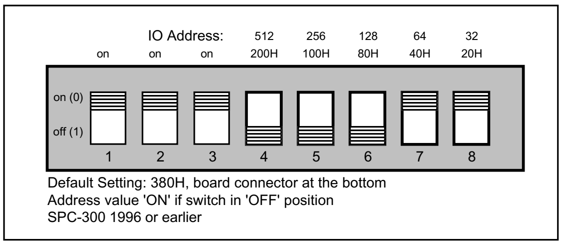
The SPC-134 package comes with a fan assembly which is plugged onto the four adjacent cards. Please make sure that the assembly is attached correctly and all fans are working. The correct setup is shown in the figure right. Working without fan for an extended period can cause serious damage to the module and to the computer. Please check the temperature of the computer when the system has been run for the first 30 minutes or so. If necessary, improve the air flow in the computer, e.g. by installing a second fan into the computer case.

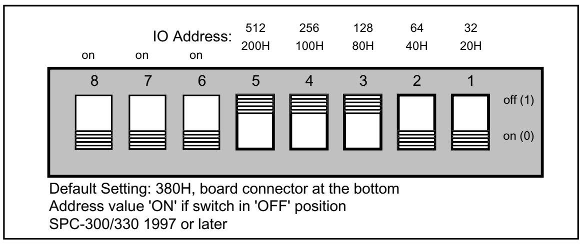
Changing the Module Address (ISA Modules, SPC-3, -4, -5)

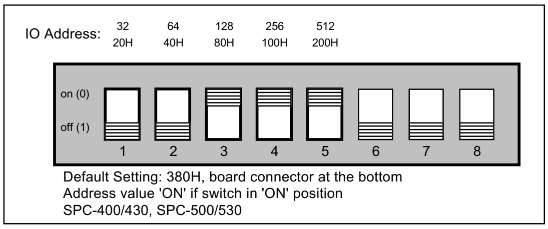
In the ISA modules (SPC-3, -4, -5) the module address is set by a DIP switch on the board. (On the PCI modules SPC-6, -7 there is no such switch, the address is set automatically by the operating system during the boot sequence.)

To change the module address the setting of the DIP switches on the SPC module has to be changed, and the new address must be declared in the SPC configuration file SPC400.INI.

The meaning of the DIP switches is shown in the figure below. Each switch represents a particular address value. The actual address is the sum of all values that are switched on. Please note that the switch setting is different for different board versions.







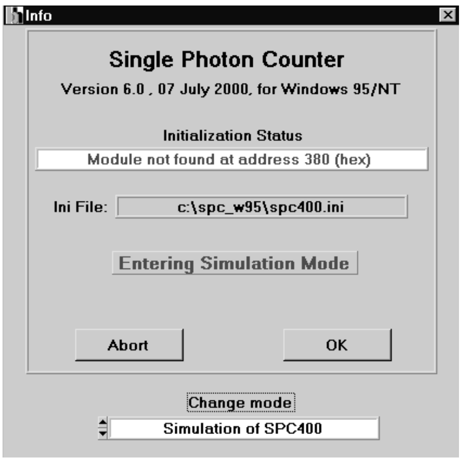
To inform the software about the changed address this must be typed into the 'SPC Configuration File'. The name of this file is SPC400.INI disregarding the type of the module. The place of the address in this file is as follows:

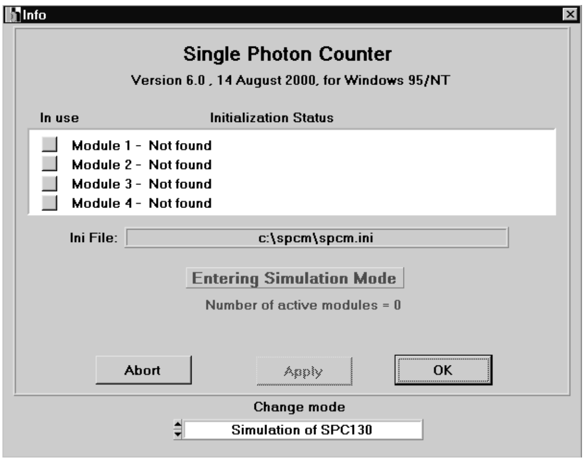
```
;    SPC400 initialization file
;    SPC parameters have to be included in .ini file only when parameter
;    value is different from default.
;    only baseadr in spc_base section  is required
;    other parameters can have default values


[spc_base]
baseadr=  0x380       ;base I/O address   (0 ... 0x3E0,default 0x380)
simulation = 0        ; 0 - hardware mode(default) ,
                      ; >0 - simulation mode (see spc_def.h for possible values)
```

The address is written as a decimal number or hex number (0x...) after the designator 'baseadr='. We recommend to make a copy of SPC400.INI before making any changes.

Using the SPC software without an SPC Module

You can use the SPC Standard Software and the Multi SPC Software also without an SPC module. In its start window the software will display a warning that the module is not present (see figure below).





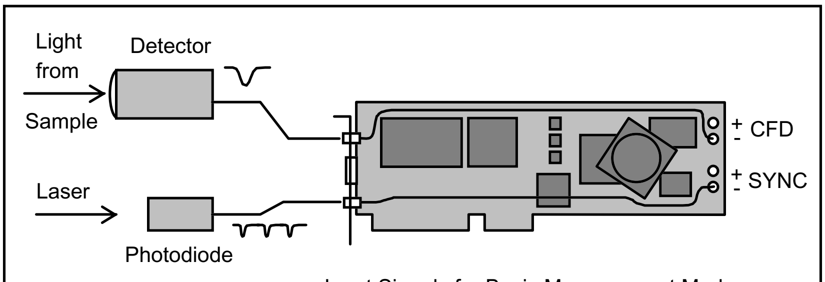
To configure the software for the desired module type, use ‘Change Mode’ and select the module type from the list which is opened. The software will start in a special mode and emulate the measurement memory in the extended memory area. So you can load, display and store data and do everything with the exception of a true measurement.

Operating the SPC Module

Input Signal Requirements

For the basic measurement modes, all SPC modules require only two input signals:

- at the SYNC input the synchronisation signal derived from the pulse sequence of the light source
- at the CFD input the single photon pulses from the detector



Input Signals for Basic Measurement Modes

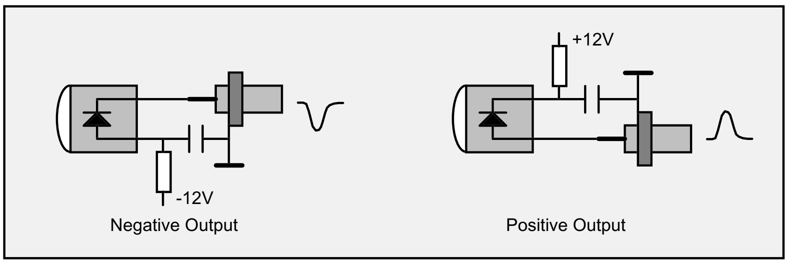
The SPC-x0x modules accept either positive or negative input signals. To select the polarity, plug the cables from the front panel into the appropriate connector on the board. Terminate the unused inputs with the 50 Ohm terminators delivered with the board. After manufacturing both inputs are set to 'negative'. The pulses on both inputs should be in the amplitude range of 10...80 mV. Due to the finite bandwidth of the input circuitry the amplitudes may be greater if the pulse duration is below 1ns.

The SPC-x3x modules (including the SPC-134) require negative input pulses at both inputs. The pulses on both inputs should be in the amplitude range of 50 mV to 1 V.

The inputs of both the SPC-x0x and the SPC-x3x are protected with limiter diodes which clip input amplitudes above 1.5 V. The diodes withstand input currents up to 2A (100V from a 50 Ohm source) for times <1us. DC input currents must be limited to values below 100mA (5V from a 50 Ohm source). Therefore pulse amplitudes up to some volts will not damage the SPC modules. They should, however, be avoided during the normal operation to reduce crosstalk effects and to achieve a good accuracy of the measurement. Especially, do not connect PMTs or photodiode to the inputs when the operating voltage of the detectors is switched on (please see ‘Safety Recommendations’).

Generating the Synchronisation Signal

To derive the synchronisation signal from a laser pulse sequence a fast PIN photodiode with >300 MHz bandwidth should be used. In the figure below two simple circuits for positive and negative output pulses are shown.

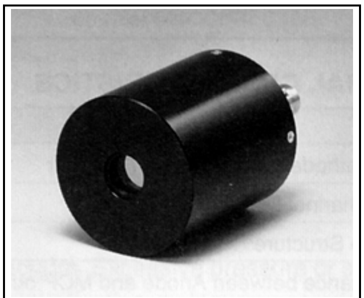


Complete photodiode modules are available from Becker & Hickl. These modules get their power from the SPC module so that no special power supply is required. For low repetition rates we recommend the PDM-400, for high repetition rates the PHD-400 which incorporates a current indicator for convenient adjusting. Please contact Becker & Hickl or your supplier.

Fast Photodiode Modules from BH

Choosing and Connecting the Detector

Although a wide variety of detectors is available, there are only a few detectors which really give top results. Depending on the desired time resolution, wavelength range, detector area and budget the following recommendations can be given.



Hamamatsu R3809UMCP

MCP PMTs

Best time resolution is achieved with MCPs. The Hamamatsu R3809U achieves a FWHM below 30 ps. However, MCPs are expensive and are easily damaged. Their life time is limited due to degradation of the microchannels under the influence of the signal electrons. Although the R3809U can be connected directly to the SPC-x00, we recommend to use a preamplifier both for the SPC-x00 and the SPC-x30. To provide maximum safety, we recommend our HFA-C-01 preamplifier which has an overload LED that turns on when the maximum MCP current is exceeded.

The Hamamatsu H5783 with a PMA-100 low cost amplifier

Hamamatsu R5600 and Derivatives

The R5600 tube made by Hamamatsu is a small (15 x 15 mm) PMT with a correspondingly fast response. Based on this PMT are the H5783P and R5773P Photosensor modules and the PMH-100 detector head of bh. The H5783P incorporates a small size PMT and the HV power supply. It requires a +12 V supply and some gain setting resistors only. The +12 V is available from the SPC module. The time resolution is 150 to 240 ps FWHM and the background count rate is very low. For optimum results, use the '-P' type, which is specified for photon counting. The H5783-P can be connected directly to the SPC-x00 modules. For the SPC-x30 we recommend to use the HFAC-26-10 preamplifier of bh. This amplifier incorporates an detector overload indicator which responds when the maximum detector current is exceeded.

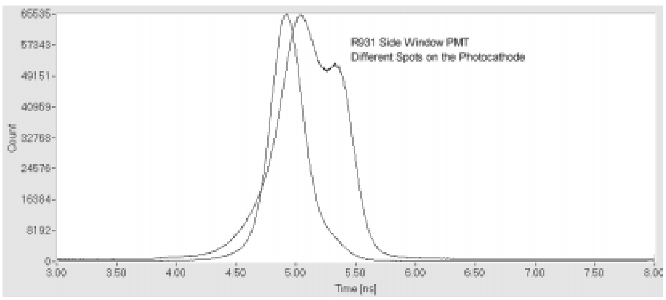
The PMH-100 Detector

A more comfortable solution is the PMH-100 module from Becker & Hickl. This module contains an H5773-P, a fast preamplifier and an overload indicator LED. The PMH-100 has a ‘C Mount’ adapter for simple attaching to the optical setup. Its simple +12 V power supply and the internal preamplifier allow direct interfacing to all bh photon counting devices. The resolution of the PMH-100 is, as for the H5773, 150 to 240 ps FWHM.

Conventional PMTs

Compared to the H5783 and the PMH-100, conventional PMT tubes are not recommended for the SPC modules. The least objectionable are short time PMTs with high gain and single photon specification as the XP2020. Due to the high gain and output current, these tubes work best without amplifier, even with the SPC-x30. The time resolution is about 350 ps (FWHM), but this value depends strongly on the wavelength and the illuminated area of the photocathode. Sometimes older PMTs (as the 56 UVP) were built up with voltage dividers with an extremely high cross current (some 10 mA). We strongly discourage to use such devices. They require high power HV supplies which are extremely dangerous. Furthermore, the detector current can be very high and the PMT is easily damaged at higher light levels. For SPC applications a voltage divider current of some 100 uA is sufficient.

Sometimes simple side window PMTs (R928, R931 etc.) are reported to yield time resolutions below 300 ps FWHM in the TCSPC mode. This is correct - with some serious restrictions. A short response is obtained only if the light is focused to a spot of less than 1 mm on the PMT cathode and the best location on the cathode is selected (figure right). There is a considerable ‘Colour Delay’, i.e. a change of the delay and the shape of the response as a function of the wavelength. Furthermore, there is usually a long tail in the response with a ugly bump some ns after the main peak. Therefore, we do not recommend to use such tubes. Nevertheless, side window PMTs work with the SPC modules. This can be a benefit if an SPC module has to be connected to an apparatus with a built-in PMT.



Avalanche Photodiodes

Avalanche photodiodes (APDs) have a high quantum efficiency in the near infrared. Although this looks very promising, some care is recommended. The time resolution achieved with these devices depends on the operation conditions and on the wavelength. The dark count rate per detector area is much higher than with a good PMT, even if the APD is cooled. Good results can be expected if the light can be focused to an extremely small detector area and a correspondingly small APD is used. Furthermore, APDs emit a small amount of light if a photon is detected. This can be a problem if several detectors are used at one SPC module. Complete Si APD detector heads (SPCM-AQR series) are available from EG&G (Perkin Elmer) and work well with the SPC-x00 if connected to the positive CFD input via an attenuator of 25 to 30dB. For the SPC-x30 modules an inverting transformer and an attenuator is required unless a HRT-82 router is used. Please contact bh. The FWHM with the SPCM-AQR is 300 to 600 ps.

Simple passively quenched circuits (similar to the circuit given for the SYNC photodiodes) usually require a preamplifier. A circuit of this type containing a liquid nitrogen cooled Ge-

APD (!) has been successfully used with the SPC-300 and a 32 dB preamplifier from Becker & Hickl.

Preamplifiers

Most MCPs and PMTs deliver pulses of 20 to 50 mV when operated at maximum gain. Although these pulses can easily be detected by the input discriminators of the SPC modules a preamplifier can improve the time resolution, the noise immunity, the threshold accuracy and the safety against damaging the SPC input. Furthermore, it can extend the detector lifetime because the detector can be operated at a lower gain and a lower average output current.

For TCSPC applications we recommend our HFAC-26 preamplifier. The HFAC-26 has 20 dB gain and 1.6 GHz bandwidth. The maximum linear output voltage is 1 V. Therefore, it amplifies the single photon pulses of a typical PMT or MCP without appreciable distortions. Furthermore, the HFAC-26 incorporates a detector overload detection circuit. This circuit measures the average output current of the PMT and turns on a LED and activates a TTL signal when the maximum safe detector current is exceeded.

HFAC-26 Amplifier

Thus, even if the gain of the amplifier is not absolutely required the overload warning function helps you to make your measurement setup 'physicist proof'. If you use an MCP with your SPC module you should always connect it via an HFAC-26 preamplifier.

The HFAC-26 is available with different overload warning thresholds from 100 nA (for MCPs) to 100 uA (for large PMTs).

Safety Recommendations

Caution! Never connect a photomultiplier to the SPC module when the high voltage is switched on! Never connect a photomultiplier to the SPC module if the high voltage was switched on before with the PMT output left open! Never use switchable attenuators between the PMT and the SPC! Never 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 PMT output is left open while the HV is switched on, the output cable is charged by the dark current to a voltage of some 100V. When connected to the SPC the cable is discharged into the SPC input. The energy stored in the cable is sufficient to destroy the input amplifier. Normally the limiter diodes at the input will prevent a destruction, but the action will stress the 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 the PMT. Make sure that there is a reliable ground connection between the HV supply unit and the PMT. Broken cables, lose connectors and other bad contacts should be repaired immediately.

Optimising a TSPC System

General Recommendations

The optimisation of a system containing the SPC-3, -4, -5, -6 or -7 is done very efficiently in the 'Oscilloscope Mode'. In the Oscilloscope Mode the measurement is repeated automatically at the maximum available speed. The result is displayed on the screen at the end of each measurement cycle. Furthermore, the overall number of counts and the half-width of the measured signal can be displayed. To have a fast response to the adjustments made we recommend a ‘Collection Time’ of 0.1s to 0.5s and a ‘Count Increment’ of 40 to 100.

For all optimising work you should apply the general rule that reproducibility is more important than pure time resolution. Indeed, the shortest impulse response is of little value if its temporal location or shape varies with the time, the count rate or with the setting of the optical system. For system optimisation the following advises should be taken into consideration.

Before spending much time to optimise the SPC module and the photomultiplier you should check the laser for pulse stability. This may be done by inspecting the pulses from the SYNC photodiode with an oscilloscope. Amplitude modulation, drift or jitter should be as small as possible. The influence of these effects on the timing will be small due to the constant fraction characteristic of the SYNC channel, but it cannot be absolutely avoided. Especially synchronously pumped dye lasers and mode locked argon lasers are prone to instability. In this case we suggest to monitor the laser action by a fast oscilloscope connected to the SYNC diode or a second photodiode. This is recommended especially if the laser system tends to produce prepulses or afterpulses. If you use active mode locking in your laser, make sure that the mode locking frequency does not interfere with the SYNC signal. This frequency is one half the repetition rate an can seriously affect the synchronisation.

The HV power supply for the PMT should have a good stability. Instabilities or AC components change the transit time in the photomultiplier and therefore degrade resolution and reproducibility.

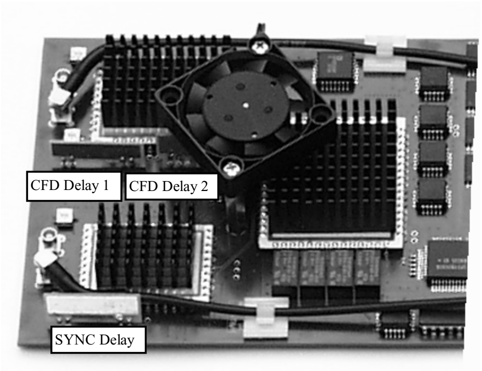
Make sure that your system does not pick up noise from power lines and network cables. Use a distribution board to connect the power cables of all system components to only one socket. This avoids ground loops which can induce high noise currents in signal ground connections. If the computer is connected to a network, disconnect the network cable for sensitive measurements.

Often the optical system has a great influence on the time resolution and the stability of the instrument response. Critical parts are monochromators, narrow slits or pinholes. A common source of errors are scattering solutions. If the density of the scattering particles is too high a broadening of some 100ps can result. Therefore, for optimising the time resolution we recommend to put a package of ND filters in front of the PMT and to illuminate it directly by the laser (see also ‘Trouble Shooting’, ‘Time Resolution’).

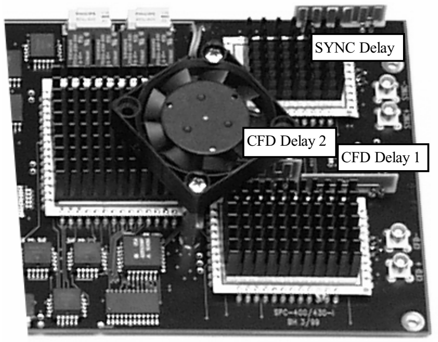
Configuring the CFD and SYNC Inputs

The CFD and SYNC inputs can be configured for different detector rise times by replacing the delay lines in the zero cross shaping network. Furthermore, the inputs of the -00 modules can be configured for positive and negative input signals.

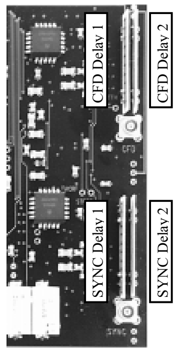
The delay lines for the CFD and SYNC inputs are shown in the figure below.



SPC-3, 4, 5 (ISA Modules)



SPC-6, 7 (PCI Modules)



SPC-134 Modules

The table below gives some recommendations for the CFD configuration.

		-30 Modules		-00 Modules		SPC-134	
Detector for CFD Channel	**typ. Rise Time**	**Delay 1**	**Delay 2**	**Delay 1**	**Delay 2**	**Delay 1**	**Delay 2**
MCPs (Hamamatsu R3809)	< 0.5 ns	0 or 0.6ns	0	0	don't change	0.6ns	0.6ns
Ultra-Fast PMTs (PMH-100)	0.7 ns	0 or 0.6ns	0.6ns	0 or 0.6ns	don't change	0.6ns or 1ns	1ns
Standard PMTs (R928)	1 .. 3 ns	0 or 0.6ns	1ns	1ns	don't change	1ns	1ns
EG&G APD-Modules	1ns	0 or 0.6ns	0.6ns or 1ns	0.6ns or 1ns	don't change	0.6ns or 1ns	0.6ns or 1ns

If you do not know the shape of the SER you can measure it with a fast oscilloscope when the PMT is illuminated with a weak continuous light (please see 'Checking the SER of PMTs').

For the SYNC channel, the configuration usually has negligible influence on the timing performance unless the synchronisation amplitude is unstable or a PMT in the photon counting mode is used (e.g. for correlation experiments). The recommended configuration is shown in the table below.

Detector for SYNC Channel	**typ. Rise Time**	**-30 Modules Delay**	**-00 Modules Delay**	**SPC-134 Delay 1**	**SPC-134 Delay 2**
MCPs (Hamamatsu R3809)	< 0.5 ns	0 ns	0ns	0.6ns or 1ns	0.6ns
Fast Photodiode (PHD-400)	< 0.5 ns	0 ns	0ns	0.6ns or 1ns	0.6ns
Ultra-Fast PMTs (PMH-100)	0.7 ns	0 or 0.6 ns	0 or 0.6 ns	1ns	1ns
Standard PMTs	1 .. 3 ns	1ns	1ns	1ns	1ns
EG&G APD-Modules	1ns	0.6 ns or 1 ns	0.6 ns or 1 ns	0.6ns or 1ns	0.6ns or 1ns

For the -00 modules, the SYNC and CFD inputs can be configured for positive and negative input pulses. To change the configuration, connect the signal cable on the module to the appropriate connector (CFD+, CFD-, SYNC+ or SYNC-) and plug the matching resistor into the unused input. Please note that this is possible only for the -00 modules. The -30 modules and the SPC-134 work with negative pulses only. Connecting the cable of a -30 SPC to SYNC+ or CFD+ will do no harm to the module, it just doesn't work.

Optimising the CFD and SYNC Parameters

CFD Parameters

The CFD parameters strongly influence the time resolution. For optimisation the zero cross level and the amplitude interval should be adjusted. To adjust the zero cross level change the parameter 'CFD ZC Level' until you get the best impulse response.

Furthermore, the resolution can be improved by reducing the with of the amplitude window. This is done by the parameters 'CFD limit L' and 'CFD limit H' (SPC-x00 only). The improvement is caused by two different effects. First, a narrower amplitude window decreases the influence of the stochastic photon pulse amplitude on the trigger point. Second, there is a correlation between the amplitude of a single photon pulse and its transit time in the PMT. Afterpulses or distortions of the system response often are reduced this way. Normally the 'CFD limit L' has a much greater influence than 'CFD limit H'. The reason is, that the amplitude distribution decays steeply towards higher amplitudes.

Make some experiments at different HV values to find the best combination of HV and amplitude window. Normally the resolution improves with increasing HV, because the transit time spread in the PMT is reduced. Furthermore, noise from external sources has less influence if the amplitude of the pulses is greater.

Do not reject more than 90% of the pulses by 'CFD Limit L'. This might cause an overload of the PMT at higher count rates. Furthermore, multiple events become more probable and could degrade linearity. Under normal conditions not more than 50% of the pulses should be rejected.

The parameter 'CFD Hold' is intended to adapt slow detectors to the CFD of the SPC-x00 modules (see section 'Constant Fraction Discriminator'). For detectors with SER rise times below 1.5ns CFD Hold = 5ns is adequate. Only for detectors with longer rise times (which also require longer delay lines) higher values can be required.

For different detectors, the CFD can be configured by replacing the delay lines in the zero cross shaping network (please see ‘Configuring the CFD and SYNC Inputs’).

SYNC Parameters

The SYNC parameters have little influence on the time resolution unless the SYNC signal is noisy or has an unstable amplitude. The zero cross timing is optimised by the parameter 'SYNC ZC Level'. If reflections or ringing cause multiple triggering increasing the 'SYNC Holdoff' may help. If the rise time of the SYNC pulses is greater than 1.5ns we recommend to use a delay line with a longer delay (please see ‘Configuring the CFD and SYNC Inputs’).

Avalanche photodiodes operated at high gain are not recommended for SYNC generation because they introduce a considerable noise to the signal.

TAC Linearity

The differential nonlinearity of time measurement is the most important source of errors in SPC measurements. Often the TAC is considered as the source of differential nonlinearity. It is, however, not the only source of the linearity errors. Parasitic coupling of start and stop pulses - outside the module, between CFD and SYNC, inside the TAC, coupling of other start and stop related signals and linearity errors in the ADC also cause a nonuniformity of the time scale. This causes a nonuniformity of the channel width and consequently a nonuniform count result in the particular channels. The errors appear as additional noise, ringing or curve distortion.

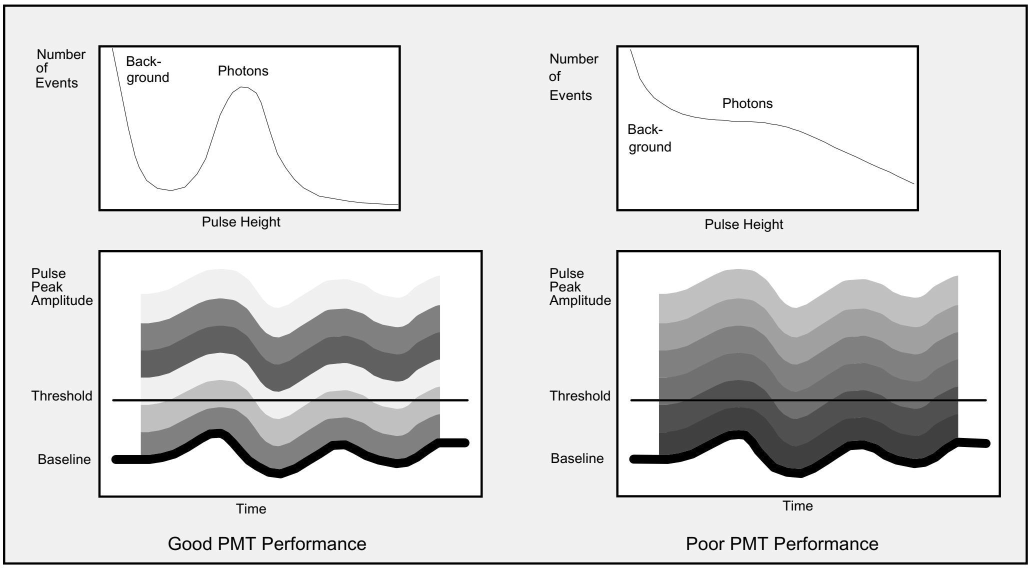
Compared to conventional NIM systems the bh SPC modules achieve a very good accuracy even at high pulse repetition rates. Some unavoidable linearity errors are, however, detectable in the results of the measurements. The following advises may help to hold linearity errors small:

Strictly avoid any coupling of the SYNC signal or other excitation-related signals to the detector. Avoid very small SYNC amplitudes at high CFD amplitudes and vice versa.

Separate detector and synchronisation cables spatially. Avoid noise radiation by active mode lockers, cavity dumpers, laser diodes or flash lamps.

Often diode lasers are the source of TAC linearity problems. To achieve short laser pulses, the diodes are driven by extremely steep and powerful current pulses. If the lasers are not shielded very carefully noise from the driver couples into the PMT signal or directly into the SPC module. If the trigger for the SPC is taken directly from a connector at the laser diode controller noise coupling via the trigger cable will almost surely cause problems. We recommend to snap some ferrite cores (which are available for EMC purposes) over the cable.

The PMT should be operated at a gain as high as possible. Use a good photomultiplier which is specified for single photon counting. These devices have a narrow SER (Single Electron Response) pulse amplitude distribution well separated from the background noise spectrum. The figure below shows the interaction of spurious signals with the PMT pulse height spectrum.



If spurious signals are present, the complete pulse height spectrum is shifted up and down with the warped pulse baseline. Consequently, the probability to exceed the threshold changes with time. The result is a modulation of the measured waveform by the spurious signal. If the detector has a narrow pulse height distribution and the threshold is adjusted correctly, the effect on the result is small. However, if the pulse height spectrum is broad, even a small ripple on the baseline causes serious distortions of the measured waveform.

Spurious signals in the PMT channel also have a direct effect on the timing because the zero cross pickoff in the CFD is influenced. Although in this case the t axis is warped rather than the intensity axis the apparent result is the same as described above.

Noise signals which are not related to the excitation (e.g. radio transmitters) have no direct influence on the differential nonlinearity. They affect, however, the time resolution and cause an apparent widening of the pulse height spectrum.

For spurious signals in the SYNC channel the direct effect on the timing dominates. Some peculiar effects can appear if noise from active modelockers or cavity dumpers (with 1/2, 1/4 etc. of the SYNC frequency) is coupled into the SYNC channel. To decouple the SYNC photodiode from such sources we recommend to isolate it from the optical setup so that the only ground connection is via the signal and power supply cables from the SPC module.

The SYNC signal should have a short rise time and a clean pulse shape. The SYNC zero cross level should be adjusted for optimum trigger performance.

For best performance, avoid to use the very first part of the TAC characteristic. This may be done using a TAC Gain > 1 and a TAC Offset > 0. In the first part the time difference between start and stop is small, resulting in a higher degree of mutual influence. Furthermore, use 'SYNC Frequency Divider' > 1 at high repetition rates. This will perhaps waste some measurement time, but it decreases the internal stop rate and reduces the internal noise from the SYNC channel.

For measurements that require maximum accuracy we recommend to record a reference curve with a continuous light source and to divide the measurement results by this reference curve. Because the reference curve has the same linearity errors as the measurement results, the division will reduce the errors considerably.

Optimising the Photomultiplier

In older books and papers about TCSPC a lot of hints were given how to improve the time resolution of a photomultiplier. Optimised voltage divider chains, changed voltages at the focusing electrodes, or even magnetic fields at the photocathode were reported to improve the resolution by nearly one order of magnitude. This may be true for the PMTs of that time, especially if they had poorly designed voltage dividers.

Now, the fastest detectors are the Hamamatsu R3809U MCPs. There is nothing you could adjust at these detectors. Another fast detector, the Hamamatsu H5783 module with its 150 to 240ps FWHM is completely sealed. Thus, there is little you can do to improve the response of these detectors. However, sometimes PMTs of conventional design must be used because of the spectral range, the dark count rate or the lower price. For such applications some hints are given below.

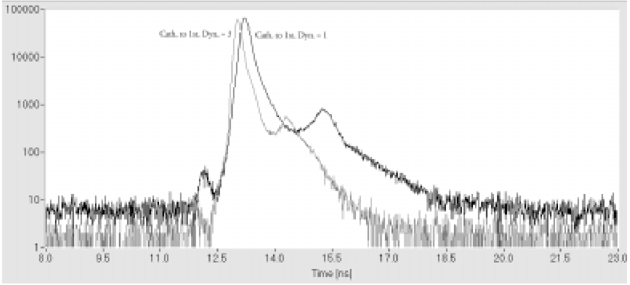
Time Resolution

Voltage Divider

Conventional fast photomultipliers often have one or more focusing electrodes between the cathode and the first dynode. The voltage at these electrodes influence the resolution, the ‘colour shift’ (dependence of the response on the wavelength) and the dark count rate. The adjustment is difficult because the trim pots are at high voltage potentials. Thus, the photomultiplier housing should include a light protection between the voltage divider and the tube. So the adjustment need not be done in the dark and is less dangerous.

For almost all photomultipliers the time resolution is improved by increasing the voltage between the photocathode and the first dynode. This also decreases the ‘colour shift’ - the dependence of the system response on the wavelength. It may also be useful to increase the voltage between the first two dynodes.

The FWHM decreases reciprocally with the square root of the voltage. The effect of the voltage between the cathode and the first dynode for an R5600 is shown in the figure right. The response functions were measured with the nominal bleeder circuit and with a circuit applying a 3-fold increased voltage between the cathode and the first dynode. Unfortunately for most PMTs no maximum values for this voltage is given. Consequently there is a certain risk to damage the photomultiplier if the voltage is increased too much.



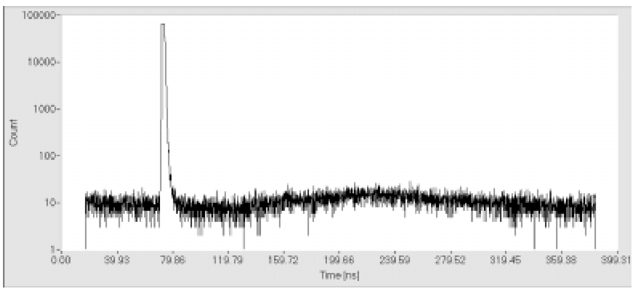
Illuminated Area

To achieve a good time resolution with a conventional photomultiplier the light has to be focused onto a very small area of the photocathode. Even for a focus diameter below 1mm an effect can be detectable. Therefore, a possibility to adjust the focus should be provided. Also the position of the light spot on the photocathode has an influence on the time resolution.

However, for MCPs we recommend to illuminate the whole cathode area even if the time resolution should be slightly impaired. The lifetime of an MCP is limited by degradation of the coating in the microchannels. This degradation is caused by sputtering under the influence of the secondary electrons. In first approximation, the degradation of a channel is proportional to the overall charge it has delivered. Spreading the light over the full cathode area extends the life time of the MCP by reducing the load of a particular channel.

Signal-Dependent Background

Some photomultiplier tubes have a dark count rate that depends on the signal count rate. The signal-dependent background can seriously impair the dynamic range of a measurement. The problem is usually caused by ion feedback, dynode luminescence or other slow effects in the PMT. The effects show up clearly when you record a system response on a time scale of some 100ns to 1us with a pulse repetition rate around 1 MHz. Switch off 'Stop on Overflow' and run the measurement until you see the background counts between the pulses. Ion feedback shows up by a slow bump between the pulses. The relative area of the bump usually increases with increasing PMT gain. Ion feedback at a level of 10^{-5} to 10^{-4} of the system response maximum is detectable in almost all PMTs (figure right, R5600-P).



If ion feedback is in the range of some % of the system response, no adjustment will remove the problem entirely. For tubes severely plagued by ion feedback we recommend the same treatment which Russell W. Porter (the father of amateur telescope making) suggested for warped telescope mirrors: *'Seek out a good hard, solid hydrant. Hurl the mirror (the photomultiplier) as fiercely as possible at said hydrant. Walk home.'*

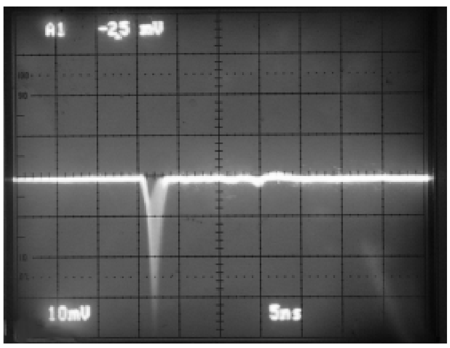
Dark Count Rate

For high sensitivity applications a low dark count rate of the PMT is important. Attempts to decrease the dark count rate by increasing the CFD threshold are not very promising. Except for very small pulses, the pulse height distribution is the same for dark pulses and photon pulses. Thus, with increasing threshold the photon count rate decreases by almost the same ratio as the dark count rate. To achieve a low dark count rate, the following recommendations can be given:

- The simplest (but not the cheapest) solution is to cool the detector. For PMTs which are sensitive in the infrared range (Ag-O-Cs, InGaAs) cooling is absolutely required.
- Avoid heating the detector by the voltage divider or by step motors, shutters, preamplifiers etc. Already a few degrees increase of temperature can double the dark count rate.
- Use a PMT with the smallest possible cathode area and with a cathode type not more red sensitive than required for your application.
- Keep the PMT in the dark even if the operating voltage is switched off. After exposing to daylight it can take days until the PMT reaches the original dark count rate.
- Do not overload the PMT. This can increase the dark count rate permanently. Extreme overload conditions are sometimes not noticed, because the count rate saturates or even decreases at high light levels.
- Keep the cathode area clear from lenses, windows and housing parts. The cathode area is at high voltage and contact with grounded parts can cause tiny discharges or scintillation in the glass of the PMT.
- Keep the cathode area absolutely clean.
- Avoid the contact of the PMT with helium. Helium permeates through the glass and impairs the vacuum in the tube.

Checking the SER of PMTs

If you do not know the amplitude or shape of the Single Electron Response of your PMT you can measure it with a fast oscilloscope. The oscilloscope must have sufficient bandwidth (>400 MHz) to show the rise time of the pulses. Connect the PMT output to the oscilloscope. Do not forget to switch the oscilloscope input to 50 Ω. Set the trigger to ‘internal’, ‘normal’, ‘falling edge’. Start with no light at the PMT. Switch on the high voltage and change the trigger level of the oscilloscope until it is triggered by the dark pulses. This should happen at a trigger level of -5 mV to -50 mV. When the oscilloscope triggers, give some light to the PMT until you get enough pulses to see a clear trace.



The single photon pulses have an amplitude jitter of 1:5 or more. This causes a very noisy curve at the oscilloscope display. Nevertheless, the pulse shape can be roughly estimated from the displayed curves. A typical result is shown in the figure right.

Please don't attempt to check the single electron response of an MCP with an oscilloscope. Because there is no control over the output current, the MCP easily can be damaged. Furthermore, the measurement is of little value because the pulses are too short to be displayed correctly by a conventional oscilloscope. If you really cannot withstand the temptation to measure the SER, use an HFAC-26-01 preamplifier.

Optical System

At a time resolution below 100ps (FWHM) the optical system has a considerable influence on the system response. Scattering and reflections at diaphragms, lens holders, lens or mirror surfaces, windows, cuvette walls, monochromator slits and spherical and chromatical aberration are often underestimated.

For numerical deconvolution of the data it is a precondition that the system response does not depend on the wavelength or on the monochromator setting. Obviously this condition is not met. All you can do is to reduce the errors as far as possible.

The sources of errors in the monochromator are obvious. Turning the grating changes the optical path length. Astigmatism and coma of off-axis mirrors introduce errors that depend on the used focal ratio and on the light distribution over the aperture. The way out is a double monochromator designed to compensate for the path length variations. If you do not have such a device all you can do is to reduce the focal ratio by a suitable diaphragm. Furthermore you should make sure, that the grating is illuminated symmetrically around its centre.

Often the diffraction at the monochromator entrance slit is problem. If the scattered light reaches the exit slit you may get prepulses and afterpulses that depend on the slit width and the wavelength setting. Often the insertion of some simple stops helps. Do not use too narrow slits.

Use a good optical system. Strong spherical and chromatic aberration, coma and astigmatism may introduce path length variations that vary with the wavelength and the sample geometry. Make sure that reflections at windows or lens surfaces do not get into the detector and that there are no multiple reflections. Use diaphragms at the appropriate positions.

Insert filters far away from image planes. Filters often show an appreciable fluorescence. The fluorescence light must not be focused into the signal light path. Furthermore, thick filters cause a noticeable signal delay. Therefore use thin filters and, when replacing filters, use filters of the same thickness.

For deconvolution of the measured data, the sample cell and the reference cell must have a similar absorption and scattering behaviour. Because this cannot be achieved practically, the active thickness should be as small as possible. Tilt the cell with respect to the excitation beam to keep multiple reflections out of the measured area. For fluorescence measurements, take into account polarisation effects. Usually the excitation light is polarised. Thus, molecules with a different orientations in the sample are excited with a different efficiency. Depending on the polarisation characteristics of the detection path the relaxation of the fluorescence anisotropy shows up in the detected decay curves. The effect can be avoided by placing a polariser under the ‘magic angle’ of 54.7 degrees in the detection path.

Another problem can arise from re-absorption. If the absorption and fluorescence spectra of the sample overlap an appreciable part of the molecules can be excited by absorbing fluorescence photons from other molecules. Re-absorption can severely affect the measured lifetimes of highly concentrated samples. Furthermore, if the optical system is not well aligned or plagued by serious aberrations, it can happen that the detector sees light from molecules which are excited rather by re-absorption than by the laser itself. Due to the high sensitivity of the TCSPC method such situations are sometimes not notices.

Routing and Control Signals

All SPC modules have one or two 15 pin Sub-D connectors to connect routing and control signals and to provide power supply to external amplifiers, routers, PMT heads and photodiodes. The signals at these connectors are described below.

Please be careful not to connect a device to the routing connectors which is not intended for this purpose. This could damage the connected device or the SPC board.

SPC-300/330 and SPC-400/430

1	+5V (Load max. 100mA, Rout = 1Ω)
2	Routing Signal, /R 0
3	Routing Signal, /R 1
4	Routing Signal, /R 2
5	Ground
6	-5V (Load max. 100mA, Rout = 1Ω)
7	Routing Signal, /R 3
8	Routing Signal, /R 4
9	Routing Signal, /R 5
10	+12V (Load max. 60mA)
11	-12V (Load max. 60mA)
12	Routing Signal, /R 6
13	ADD
14	CNTE
15	Ground

/R0 .. /R13: Routing Inputs. Polarity is ‘active low’, i.e. /R0 ... /R13 = ‘high’ will address curve 0. The open input represents a ‘high’ value.

ADD: The ADD signal is used for the lock-in SPC method. At ADD = 1 the events are added, at ADD = 0 the events are subtracted in the memory. Open inputs represent a logical ‘1’ value.

CNTE: CNTE=L suppresses the storing of the current photon in the SPC memory. In conjunction with a router, the signal is used to reject misrouted events. The open input represents a logical ‘1’ value.

All signals are read with a selectable ‘Latch Delay’ after a valid photon pulse at the CFD input has been detected (see 'System Parameters', 'Latch Delay').

SPC-500/530

Connector 1 (lower connector)

1	+5V (max. 100mA)
2	Routing Signal, /R 0
3	Routing Signal, /R 1
4	Routing Signal, /R 2
5	Ground
6	-5V (max. 100mA)
7	Routing Signal, /R 3
8	Routing Signal, /R 4
9	Routing Signal, /R 5
10	+12V (max. 60mA)
11	-12V (max. 60mA)
12	Routing Signal, /R 6
13	ADD1 (ADD=ADD1&ADD2)
14	CNTE1 (CNTE=CNTE1&CNTE2)
15	Ground

Connector 2 (upper connector)

1	+5V (max. 100mA)
2	Routing Signal, /R 7
3	Routing Signal, /R 8
4	Routing Signal, /R 9
5	Ground
6	-5V (max. 100mA)
7	Routing Signal, /R 10
8	Routing Signal, /R 11
9	Routing Signal, /R 12
10	+12V (max. 60mA)
11	-12V (max. 60mA)
12	Routing Signal, /R 13
13	ADD2 (ADD=ADD1&ADD2)
14	CNTE2 (CNTE=CNTE1&CNTE2)
15	Ground

All routing bits are low active, i.e. /R0 ... /R13 = 1 will address curve 0. The count enable signals CNTE1 and CNTE2 must be both ‘1’ to enable the storing of the currently detected photon. In conjunction with a router, the signal is used to reject misrouted events. The ADD1 and ADD2 signal is used for the lock-in SPC method. At ADD1=1 and ADD2=1 the events are added, at ADD1 or ADD2 = 0 the events are subtracted in the memory. Open inputs represent a logical ‘1’ value. All signals are read with a selectable ‘Latch Delay’ after a valid photon pulse at the CFD input has been detected (see 'System Parameters', 'Latch Delay').

SPC-503/535

Connector 1 (lower connector)

1	+5V (max. 100mA)
2	PIXEL
3	FBX
4	FBY
5	Ground
6	-5V (max. 100mA)
7	-- (do not connect)
8	-- (do not connect)
9	-- (do not connect)
10	+12V (max. 60mA)
11	-12V (max. 60mA)
12	-- (do not connect)
13	ADD1 (ADD=ADD1&ADD2)
14	CNTE1 (CNTE=CNTE1&CNTE2)
15	Ground

Connector 2 (upper connector)

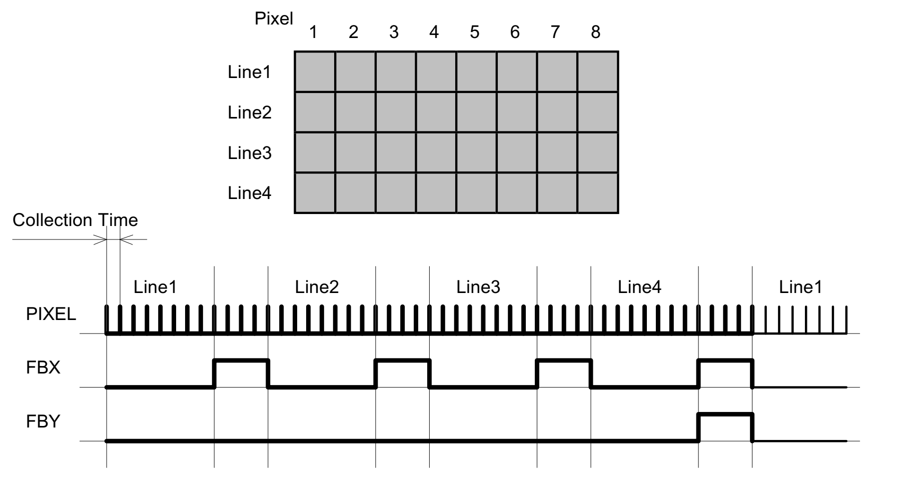
1	+5V (max. 100mA)
2	Routing Signal /R0
3	Routing Signal /R1
4	-- (do not connect)
5	Ground
6	-5V (max. 100mA)
7	-- (do not connect)
8	-- (do not connect)
9	/REN0
10	+12V (max. 60mA)
11	-12V (max. 60mA)
12	/REN1
13	ADD2 (ADD=ADD1&ADD2)
14	CNTE2 (CNTE=CNTE1&CNTE2)
15	Ground

PIXEL: ‘Pixel Clock’, indicates the start of the measurement of the next pixel. PIXEL is a 100 ns TTT H pulse. The duration of the measurement of each pixel is set by ‘Collection Time’, the number of points in X and Y direction by ‘Scan Pixels X’ and ‘Scan Pixels Y’ (see SPC system parameters).

FBX: ‘Flyback X’, TTL H during the X flyback phase of the scanner.

FBY: ‘Flyback Y’, TTL H during the Y flyback phase of the scanner.
The flyback duration for X and Y is set in the SPC system parameters. The time is given in units of ‘Collection Time’.

The function of the PIXEL, FBX and FBY signals for a simple 8x4 matrix is shown in the figure below.



Scanning of a 8x4 matrix: PointsX=8, PointsY=4, Flyback=4

/R0, /R1: The routing bits /R0 and /R1 address a block of curves in the memory in which the current photon is stored. /R0 and /R1 can be used in conjunction with a routing device HRT-41 to simultaneously record up to four images with four detectors. The photons are routed into four different memory pages representing the different images. 'Scan Pixels X' and 'Scan Pixels Y' must be set to values which provide memory space for at least four different memory pages. The routing bits are low active, i.e. /bit0.../bit6 = 1 addresses page 0. Since the page start addresses controlled by /R0 and /R1 are fixed memory addresses the block numbers at which the results appear depends on the ADC resolution and 'Scan Pixels X' x 'Scan Pixels Y'. Some examples are given below.

Scan Pixels X x Scan Pixels Y	ADC Resolution	Linear Start Curve No. / Page /R01=11	/R01=10	R01=01	/R01=00
256	4096	0 / 1	256 / 2	512 / 3	768 / 4
1024	1024	0 / 1	1024 / 2	2048 / 3	3072 / 4
256	1024	0 / 1	1024 / 8	2048 / 12	3072 / 16
4096	256	0 / 1	4096 / 2	8192 / 3	12288 / 4
1024	256	0 / 1	4096 / 8	8192 / 12	12288 / 16
256	256	0 / 1	4096 / 32	8192 / 48	12288 / 64

/REN0, /REN1: Routing Enable. /REN0 enable routing bit /R0, /REN1 enables routing bit /R1. Connect /REN0, /REN1 to GND to enable the routing.

CNTE1, CNTE2: CNTE=L suppresses the storing of the current photon in the SPC memory. Both CNTE signals are AND connected, i.e. a photon is suppressed when one or both CNTEs are L. The count enable signal is used to reject photons for which no valid routing signal could be generated (see also descriptions of the routers HRT-41 and HRT-81 or detector heads PML-16).

ADD1, ADD2: The ADD signals are used for lock-in SPC measurements. At ADD=1 the events are added, at ADD=0 the events are subtracted in the memory. Open inputs represent a logical 1 (add) value.

The /R0, /R1, CNTE and ADD are read with a selectable 'Latch Delay' after a photon pulse at the CFD input has been detected (see 'System Parameters', 'Latch Delay').

SPC-506/536

Connector 1 (lower connector)

1 +5V (max. 100mA)
2 YSync
3 XSync
4 -- (do not connect)
5 Ground
6 -5V (max. 100mA)
7 -- (do not connect)
8 -- (do not connect)
9 -- (do not connect)
10 +12V (max. 60mA)
11 -12V (max. 60mA)
12 -- (do not connect)
13 ADD1 (ADD=ADD1&ADD2)
14 CNTE1 (CNTE=CNTE1&CNTE2)
15 Ground

Connector 2 (upper connector)

1 +5V (max. 100mA)
2 -- (do not connect)
3 -- (do not connect)
4 -- (do not connect)
5 Ground
6 -5V (max. 100mA)
7 -- (do not connect)
8 -- (do not connect)
9 -- (do not connect)
10 +12V (max. 60mA)
11 -12V (max. 60mA)
12 -- (do not connect)
13 ADD2 (ADD=ADD1&ADD2)
14 CNTE2 (CNTE=CNTE1&CNTE2)
15 Ground

XSync: X synchronisation pulse. XSync indicates the start of the next line.
YSync: Y synchronisation Pulse. YSync indicates the start of the next frame.

CNTE1, CNTE2: CNTE=L suppresses the storing of the current photon in the SPC memory. Both CNTE signals are AND connected, i.e. a photon is suppressed when one or both CNTEs are L.

ADD1, ADD2: The ADD signals are used for lock-in SPC measurements. At ADD=1 the events are added, at ADD=0 the events are subtracted in the memory. Open inputs represent a logical 1 (add) value.

SPC-600/630

1	+5V (Load max. 100mA, Rout = 1Ω)
2	Routing Signal, /R 0
3	Routing Signal, /R 1
4	Routing Signal, /R 2
5	Ground
6	-5V (Load max. 100mA, Rout = 1Ω)
7	Routing Signal, /R 3
8	Routing Signal, /R 4
9	Routing Signal, /R 5
10	+12V (Load max. 60mA)
11	-12V (Load max. 60mA)
12	Routing Signal, /R 6
13	ADD or TRIGGER[1] or /R7[2]
14	CNTE
15	Ground

1. If 'Trigger Condition' other than 'none'
2. In the FIFO Mode only

/R0 .. /R13: Routing Inputs. Polarity is 'active low', i.e. /R0 ... /R13 = 'high' will address curve 0. The open input represents a 'high' value.

ADD: The ADD signal is used for the lock-in SPC method. At ADD = 1 the events are added, at ADD = 0 the events are subtracted in the memory. Open inputs represent a logical '1' value. The ADD input is shared with the TRIGGER input. The ADD function is activated if the trigger condition is set to 'none' (please see 'System Parameters', 'More Parameters'). Thus, the trigger cannot be used when the ADD/SUB function is used.

TRIGGER: If a trigger condition is set (see 'System Parameters', 'More Parameters') the measurement starts when a L/H or H/L transition at the TRIGGER Input is detected. The TRIGGER input is shared with the ADD input. The TRIGGER function is activated if a trigger condition is set to 'rising edge' or 'falling edge' (please see 'System Parameters', 'More Parameters'). Therefore, the ADD/SUB function cannot be used when the trigger is used.

CNTE: CNTE=L suppresses the storing of the current photon in the SPC memory. In conjunction with a router, the signal is used to reject misrouted events. The open input represents a logical '1' value.

All signals (except the trigger) are read with a selectable 'Latch Delay' after a valid photon pulse at the CFD input has been detected (see 'System Parameters', 'Latch Delay').

SPC-700/730

Connector 1 (lower connector)		Connector 2 (upper connector)	
1	+5V (max. 100mA)	1	+5V (max. 100mA)
2	Routing Signal, /R 0	2	Routing Signal, /R 7 or ARMED[2]
3	Routing Signal, /R 1	3	Routing Signal, /R 8 or TRGD[2]
4	Routing Signal, /R 2	4	Routing Signal, /R 9 or MEASURE[2]
5	Ground	5	Ground
6	-5V (max. 100mA)	6	-5V (max. 100mA)
7	Routing Signal, /R 3	7	Routing Signal, /R 10 or 'Do not Connect'[2]
8	Routing Signal, /R 4	8	Routing Signal, /R 11 or YSYNC[1] or FBY[2]
9	Routing Signal, /R 5	9	Routing Signal, /R 12 or XSYNC[1] or FBX[2]
10	+12V (max. 60mA)	10	+12V (max. 60mA)
11	-12V (max. 60mA)	11	-12V (max. 60mA)
12	Routing Signal, /R 6	12	Routing Signal, /R 13 or PxlClk[1,2]
13	ADD	13	TRIGGER[3]
14	CNTE1 (CNTE=CNTE1&CNTE2)	14	CNTE2 (CNTE=CNTE1&CNTE2)
15	Ground	15	Ground

1. 'Scan Sync In' Mode
2. 'Scan Sync Out' Mode
3. Used if 'Trigger Condition' other than 'none' only

The function of the control bits depend on the operation mode:

Single, Oscilloscope, F(t,x,y), F(t,T), F(t,ext), Fi(T), Fi(ext)

/R0 .. /R13: Routing Inputs. Polarity is 'active low', i.e. /R0 ... /R13 = 1 (or open) will address curve 0.

ADD: The ADD signal is used for the lock-in SPC method. At ADD = 1 the events are added, at ADD = 0 the events are subtracted in the memory. Open inputs represent a logical '1' value.

TRIGGER: If a trigger condition is set (see 'System Parameters', 'More Parameters') the measurement starts when a L/H or H/L transition at the TRIGGER Input is detected.

CNTE1, 2: CNTE=L suppresses the storing of the current photon in the SPC memory. Both CNTE signals are AND connected, i.e. a photon is suppressed when one or both CNTEs are L. In conjunction with a router, the signal is used to reject misrouted events.

All signals (except the trigger) are read with a selectable 'Latch Delay' after a valid photon pulse at the CFD input has been detected (see 'System Parameters', 'Latch Delay').

Scan Sync In

The 'Scan Sync In' mode is used for image recording. The recording procedure is controlled by the scanning device via the 'XSync', 'YSync' and 'Pixel Clock' pulses. The control signals for the 'Scan Sync In' mode are listed below.

/R0 .. /R10: Routing Inputs. Polarity is 'active low', i.e. /R0 ... /R6 = 1 (or open) will address curve 0. The count enable signals CNTE1 and CNTE2 must be both '1' to enable the storing of the currently detected photon. In conjunction with a router, the signal is used to reject misrouted events.

XSync (Input): X synchronisation pulse. XSync forces the start of the next line.

YSync (Input): Y synchronisation Pulse. YSync forces the start of the next frame.

PxlClk (Input): External Pixel Clock. If the source of the pixel clock is set to 'external' the signal starts the measurement of the next Pixel.

CNTE1, CNTE2: CNTE=L suppresses the storing of the current photon in the SPC memory. Both CNTE signals are AND connected, i.e. a photon is suppressed when one or both CNTEs are L.

ADD: The ADD signal is used for lock-in SPC measurements. At ADD=1 the events are added, at ADD=0 the events are subtracted in the memory. Open inputs represent a logical 1 (add) value.

TRIGGER: If a trigger condition is set (see 'System Parameters', 'More Parameters') the measurement starts when a L/H or H/L transition at the TRIGGER input is detected. Once triggered, the measurement runs until it is stopped by the collection timer, by an overflow or by the user. After a stop command the measurement stops after the next Ysync pulse. If the 'Repeat' of 'Accumulate' functions are used, a trigger pulse is required to start each repetition or accumulation cycle.

Scan Sync Out

The 'Scan Sync Out' mode is used for image recording. The recording procedure is controlled by the SPC module via the 'Flyback X', 'Flyback X' and 'Pixel Clock' pulses. The control signals for the 'Scan Sync Out' mode are listed below.

/R0 .. /R6: Routing Inputs. Polarity is 'active low', i.e. /R0 ... /R6 = 1 (or open) will address curve 0. The count enable signals CNTE1 and CNTE2 must be both '1' to enable the storing of the currently detected photon. In conjunction with a router, the signal is used to reject misrouted events.

PxlClk (Output): 'Pixel Clock', indicates the start of the measurement of the next pixel. PIXEL is a 50 ns TTT H pulse. The duration of the measurement of each pixel is set by 'Collection Time', the number of points in X and Y direction by 'Scan Pixels X' and 'Scan Pixels Y' (see SPC system parameters).

FBX (Output): 'Flyback X', controls the X flyback phase of the scanner. For polarity and duration please see 'System Parameters'

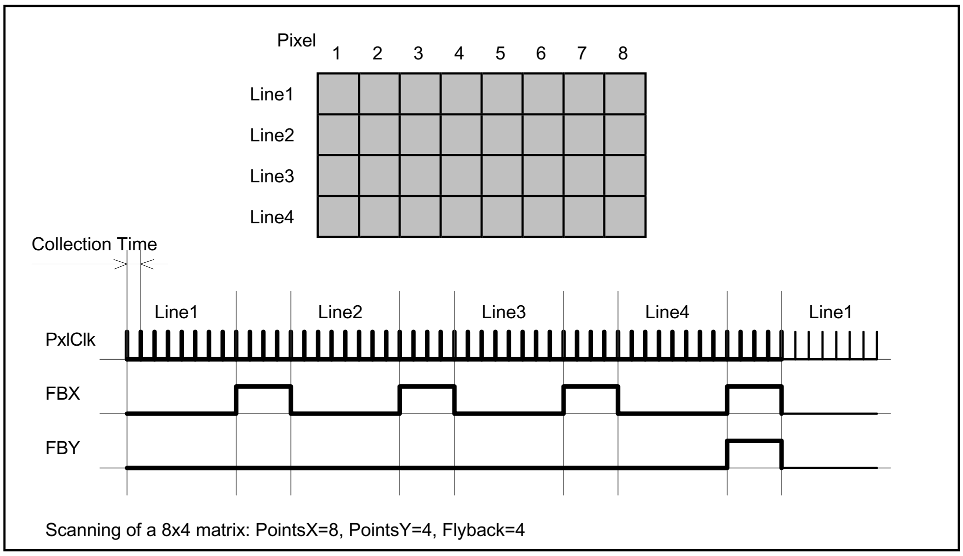
FBY (Output): 'Flyback Y', controls the Y flyback phase of the scanner. For polarity and duration please see 'System Parameters'

CNTE1, 2: CNTE=L suppresses the storing of the current photon in the SPC memory. Both CNTE signals are AND connected, i.e. a photon is suppressed when one or both CNTEs are L.

ADD: The ADD signal is used for lock-in SPC measurements. At ADD=1 the events are added, at ADD=0 the events are subtracted in the memory. Open inputs represent a logical 1 (add) value.

TRIGGER: If a trigger condition is set (see 'System Parameters', 'More Parameters') the measurement starts when a L/H or H/L transition at the TRIGGER input is detected. Once triggered, the measurement runs until it is stopped by the collection timer, by an overflow or by the user. After a stop was set the measurement stops after the next Ysync pulse. If the 'Repeat' of 'Accumulate' functions are used, a trigger pulse is required to start each repetition or accumulation cycle.

The function of the PxlClk, FBX and FBY signals for a simple 8x4 matrix is shown in the figure below.



Scan XY Out

The ‘Scan XY Out’ mode is used for image recording. The recording procedure is controlled by the SPC module via the position signals /R0 through /R13. /R0 through /R13 are outputs and indicate the actual scan position.

/R0 .. /R13: Scan Position Outputs. Polarity is ‘active low’, i.e. /R0 ... /R13 = 1 sets the scanner position to X=Y=0 and addresses curve 0 in the SPC memory.

ADD: The ADD signal is used for the lock-in SPC method. At ADD = 1 the events are added, at ADD = 0 the events are subtracted in the memory. Open inputs represent a logical ‘1’ value. All signals are read with a selectable ‘Latch Delay’ after a valid photon pulse at the CFD input has been detected (see 'System Parameters', 'Latch Delay').

TRIGGER: If a trigger condition is set (see ‘System Parameters’, ‘More Parameters’) the measurement starts when a L/H or H/L transition at the TRIGGER Input is detected. It stops when the scan of the frame is complete. If the ‘Repeat’ or ‘Accumulate’ functions are used, a trigger pulse is required to start each repetition or accumulation cycle.

CNTE1, 2: CNTE=L suppresses the storing of the current photon in the SPC memory. Both CNTE signals are AND connected, i.e. a photon is suppressed when one or both CNTEs are L. In conjunction with a router, the signal is used to reject misrouted events.

SPC-134

1	+5V (Load max. 100mA, Rout = 1Ω)
2	Routing Signal, /R 0
3	Routing Signal, /R 1
4	Routing Signal, /R 2
5	Ground
6	-5V (Load max. 100mA, Rout = 1Ω)
7	Not used, do not connect
8	Not used, do not connect
9	Not used, do not connect
10	+12V (Load max. 60mA)
11	-12V (Load max. 60mA)
12	Not used, do not connect
13	ADD or TRIGGER
14	CNTE
15	Ground

/R0 .. /R2: Routing Inputs. Polarity is 'active low', i.e. /R0 ... /R13 = 'high' will address curve 0. The open input represents a 'high' value.

ADD: The ADD signal is used for the lock-in SPC method. At ADD = 1 the events are added, at ADD = 0 the events are subtracted in the memory. Open inputs represent a logical '1' value. The ADD input is shared with the TRIGGER input. The ADD function is activated if the trigger condition is set to 'none' (please see 'System Parameters', 'More Parameters'). Thus, the trigger cannot be used when the ADD/SUB function is used and vice versa.

TRIGGER: If a trigger condition is set (see 'System Parameters', 'More Parameters') the measurement starts when a L/H or H/L transition at the TRIGGER Input is detected. The TRIGGER input is shared with the ADD input. The TRIGGER function is activated if a trigger condition is set to 'rising edge' or 'falling edge' (please see 'System Parameters', 'More Parameters'). Therefore, the ADD/SUB function cannot be used when the trigger is used.

CNTE: CNTE=L suppresses the storing of the current photon in the SPC memory. In conjunction with a router, the signal is used to reject misrouted events. The open input represents a logical '1' value.

All signals are read approximately 10ns after a valid photon pulse at the CFD input has been detected. There is no 'Latch Delay' as in the other SPC modules. The SPC-134 is therefore not recommended for multidetector operation.

Getting Started

Quick Startup

If you have a minimum of experience with optical detectors it should be no problem for you to put the SPC setup into operation. In this case proceed as described below. However, if you are not sure whether all components of your arrangement work correctly, which HV and light intensity your PMT needs or whether your photodiode signal is correct, please see 'Startup for Beginners'.

- Insert filters for maximum light attenuation
- Switch on all components, set HV to minimum value
- Start the SPC software
- Select 'Main', 'Load' and load standard setup/data STARTUP.SDT
- Start the measurement
- Adjust photodiode until 'SYNC OK' is displayed
- Increase HV until the count rate display shows the first events
- Take out filters until the count rate has the desired value
- Select TAC Range, TAC Gain and TAC Offset until the curve is displayed in correct scale and position
- Optimise the PMT high voltage, 'CFD Zero Cross', 'CFD Level Low' and 'CFD Level High' until you have found a good compromise between sensitivity, background signal and time resolution.
- Optimise the amplitude of the SYNC signal for maximum time resolution

To achieve a good time resolution and a low differential nonlinearity, noise pickup in the signal connections must be carefully avoided. The most important sources of noise are ground loops, i.e. grounding of different system components at different ground potentials. Please make sure, that all components (measurement arrangement, PMT, HV supply unit, synchronisation diode, PC with SPC module, PC peripheral devices) have one (and only one) common ground. The simplest solution is to supply all components from the same power plug.

Caution: Don’t connect a photomultiplier tube to the SPC when the high voltage is switched on (see 'Input Signals').

Startup for Beginners

Putting into operation an SPC module does not cause any problems if all components (photomultiplier, photodiode, optical system) work correctly or if you have experience with photon counting techniques. In this case you need not read this section. Simply proceed as described under 'Quick Startup'. However, if you are not experienced with photon counting or have any doubt about the function of your detector, photodiode, light source and optics we suggest at least to read the following section.

To check a PMT (not an MCP) connect a simple meter to the output and switch it to a range less or equal 10uA. Use a rugged, inexpensive meter. This will withstand possible accidents as connecting charged cables or sparks in the voltage divider chain. Close the PMT housing so that the PMT cathode will be in the absolute dark. Caution: A Photomultiplier is extremely sensitive to light. The maximum output current is exceeded even at a light intensity not visible by the eye!

Now switch on the HV supply and slowly increase the voltage starting from the lowest available value. Check which voltage can be applied without exceeding the maximum output current (usually 10 to 100uA for PMTs) or causing irregular effects. Don't exceed the maximum operating voltage of the PMT.

If the test without light is successful, repeat the same procedure at a low light level. Use room light that is attenuated by filters, a variable ND filter and/or a pinhole. Slowly increase the voltage until an output current appears. Decrease the light intensity to hold the output current at 1..2uA (<0.1 uA for MCPs). Increase the HV to the maximum value and mark the setting of your filter and pinhole setup.

If you use an MCP photomultiplier you should be extremely careful. These devices have maximum output currents of less than 0.1 uA. A higher current will normally not destroy the device immediately, but may degrade the device performance and reduce the residual life time if it flows for an extended period. Thus the described test is not recommended for MCPs unless you can measure such small currents reliably. In general, we recommend our HFAC-26-0.1 preamplifier for MCPs. This amplifier has an overload indicator LED which turns on when the maximum output current of 100nA is exceeded.

Please withstand the temptation to check the single electron response of an MCP with an oscilloscope. There is no control over the output current, which easily can become too high. Furthermore, the measurement is of little value because the pulses are too short to be displayed correctly on the oscilloscope.

If the photomultiplier works correctly the work at the SPC module begins. Connect the SYNC signal from the photodiode and the CFD signal from the photomultiplier to the SPC module. Caution: Never connect the PMT cable to the SPC when the HV is switched on (see 'Input Signals')!

Load STARTUP.SDT ('Main', then 'Load'). If you do not find this file we recommend to set the parameters as shown below:

System Parameters:
Operation Mode: Single or Oscilloscope
Overflow: Stop
Trigger: None
Coll Time: 100s for ‘Single’, 1s for ‘Oscilloscope’
Display Time: 1s
CFD Limit L: 5mV (SPC-x00), -20mV (SPC-x30)
CFD Limit H: 80mV (SPC-x00)
CFD ZC Level: 0
SYNC: ZC Level -10mV
SYNC Threshold: -20mV (SPC-x30)
SYNC Freq Divider: 4

TAC Range: 50ns
TAC Gain: 1
TAC Offset: 10%
TAC limit Low: 10%
TAC Limit High: 90%
ADC Resolution: 1024 or 4096
Memory Offset: 0
Dith Rng: 1/16, 128 (SPC-3/10), 256 (SPC-3/12)
Routing Channels X,Y: 1
Scan Pixels X,Y: 1
Page: 1
Memory Bank: 0

Display Parameters:
Scale Y: Linear
Max Count: 65535
Baseline: 0
Point Freq: 1
Style: Line
2D Display Mode: Curve

Trace Parameters:
Trace 1: Active, Curve 1, Page 1

Now switch on the pulsed light source. The following instructions refer to a laser source with 50...100 MHz repetition rate. If you use a nanosecond flash lamp or another low repetition rate source you should use a signal generator at the beginning to provide the SYNC signal. This will simplify the next steps.

Start the measurement ('START' in the menu bar above the curve window). As long as no SYNC signal is present nothing should happen. The status of the synchronisation should be 'No SYNC'.

Now switch on the operating voltage of the photodiode and direct a part of the laser light to it. The SYNC status will change to 'SYNC OK' if the signal is in the correct amplitude range. If the amplitude is too high 'SYNC Overload' will be displayed. If you are sure that the SYNC amplitude is below 1V you can ignore this message. If not, you should reduce the light intensity.

Now, switch on the high voltage of the PMT. Do not give light to the PMT at the beginning. Increase the HV and look at the count rate bars in the lower left part of the screen. At a certain voltage the first dark count pulses should be detected. The count rate bars show count rates >0 and in the curve window the first photon events appear. If you are not successful in this step, repeat it with a small light intensity at the PMT. Do not exceed the light intensity found in the PMT test at the beginning.

If the system does not behave as expected, check whether the signal cables at the SPC board are connected according to the polarities of the SYNC and the CFD signal. Check your PMT with an oscilloscope as described under 'Optimising the Photomultiplier'. You should find single photon pulses with amplitudes >10mV. Check the SYNC signal with an oscilloscope. It should go exactly to zero between the pulses or cross the baseline temporarily. Check the parameter 'SYNC ZC level'. It should be -10mV to ensure triggering with most input signal shapes.

When the first events are detected, the optimum operation voltage of the PMT must be found. Give some light to the PMT, but do not exceed the intensity determined in the PMT test at the beginning. Adjust the light intensity to a CFD count rate of about 5000 /s. Vary the operating voltage of the PMT, but do not exceed the maximum value given by the manufacturer.

The count rate rises with the operating voltage. Hold the count rate below 10^5 /s by decreasing the light intensity. If you have a good photomultiplier the increase of the rate should flatten or nearly stop. When you have reached this target you have found the operating voltage for maximum sensitivity.

When you have finished this step successfully you should have a break and drink a cup of tea. You can also use coffee if you prefer.

After that you may start the test with the laser signal. Apply the PMT operating voltage determined in the previous step. Start the measurement. As long as there is no light at the PMT the normal dark count rate is displayed. Now give some laser light to the PMT until the count rate increases significantly. If the repetition rate of the laser pulses is >50 MHz at least one laser pulse should appear on the screen.

Next become familiar with the basic operation modes and the measurement parameters. Switch to 'Oscilloscope Mode' (Menu 'System Parameters'), 'Collection Time' = 1s, 'Stop T' = on. After starting the measurement the curve will be measured and displayed in intervals of 1s. If the curve is too small increase the parameter 'Count Increment' (System parameters) or increase the light intensity. Select an appropriate time scale and screen position of the pulse(s) by changing 'TAC Gain' and 'TAC Offset'.

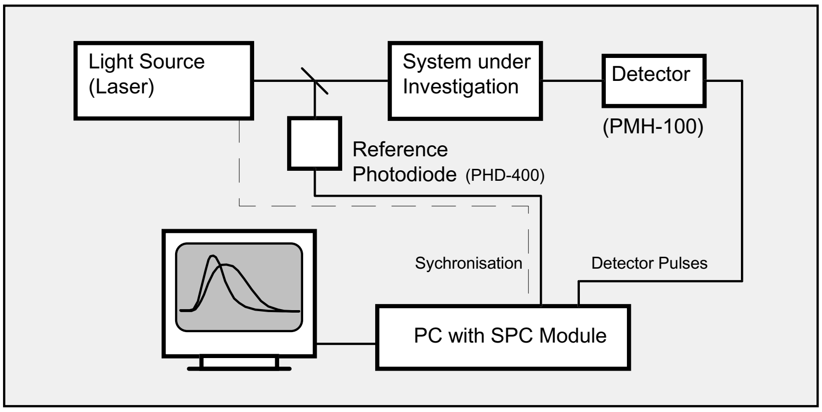
The pulse shape is influenced by the SYNC and CFD parameters which control the processing of the input signals. If the SYNC signal contains reflections, ringing, noise or other distortions this may cause false triggering or multiple triggering within one laser period. If you see such effects, change 'SYNC ZC level' and 'SYNC Holdoff'.

The amplitude window of the CFD is set by the parameters 'CFD limit L' and CFD limit H'. The CFD will recognise pulses in this amplitude window only. The zero cross level at which the CFD triggers is set by 'CFD ZC level'. It should be possible to achieve a satisfactory pulse shape by adjusting these parameters. For optimisation of the time resolution see section 'Optimising a TCSPC System'.

Applications

Optical Oscilloscope

Due to the high count rates and the short measurement times the SPC modules are an excellent choice for oscilloscope applications at high repetition rate light signals. The setup is shown in the figure below.

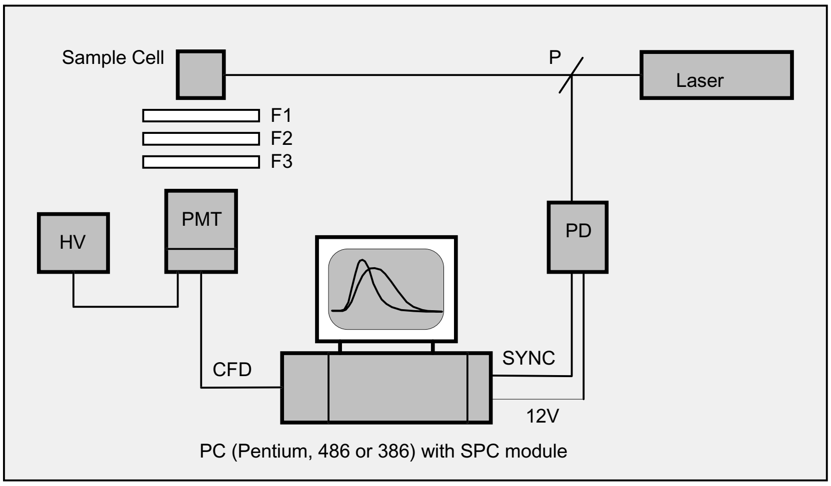


The system requires an SPC module, a PC, the detector and (if there is no suitable trigger signal from the light source) a reference photodiode to generate the synchronisation signal for the SPC. For most applications, the detector can be a fast, but rugged and inexpensive PMH-100 or a Hamamatsu Photosensor Module (H5783). These detector yield an FWHM between 150 and 240 ps with all SPC versions. They are powered with 12 V directly from the SPC module so that no special HV power supply is needed. For higher resolution (down to 25 ps) an MCP (Multichannel Plate) can be used. The SPC module is used in the 'Oscilloscope' mode. If the repetition rate of the light pulses is sufficiently high so that the counting speed of the SPC module can be utilised a screen update rate of less than 100 ms can be achieved.

Measurement of Luminescence Decay Curves

A simple arrangement for the measurement of luminescence decay curves is shown in the next figure.

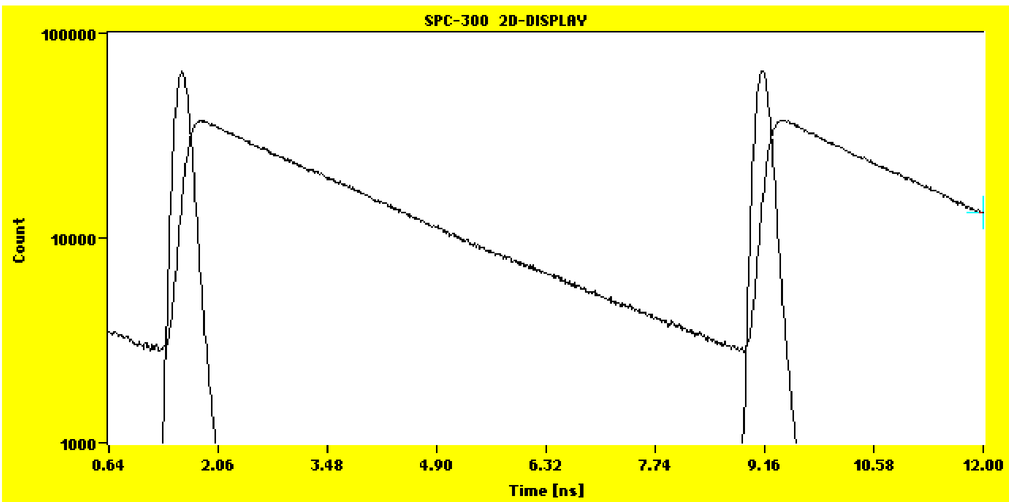
The laser (titanium sapphire laser, frequency doubled YAG Laser etc.) generates short light pulses with a repetition rate of 50...100 MHz. The light is directed into the sample cell via the mirrors M1 and M2. A part of the excitation light is reflected by the glass plate P and fed to the photodiode PD. The photodiode generates the synchronisation signal SYNC for the SPC module. The operating voltage for the photodiode is taken from the Sub-D connector of the SPC module.



The luminescence light passes the filters F1, F2 and F3 to the photomultiplier tube PMT. The high voltage supply unit HV provides the operating voltage to the PMT. The single photon pulses from the PMT are fed to the CFD input of the SPC.

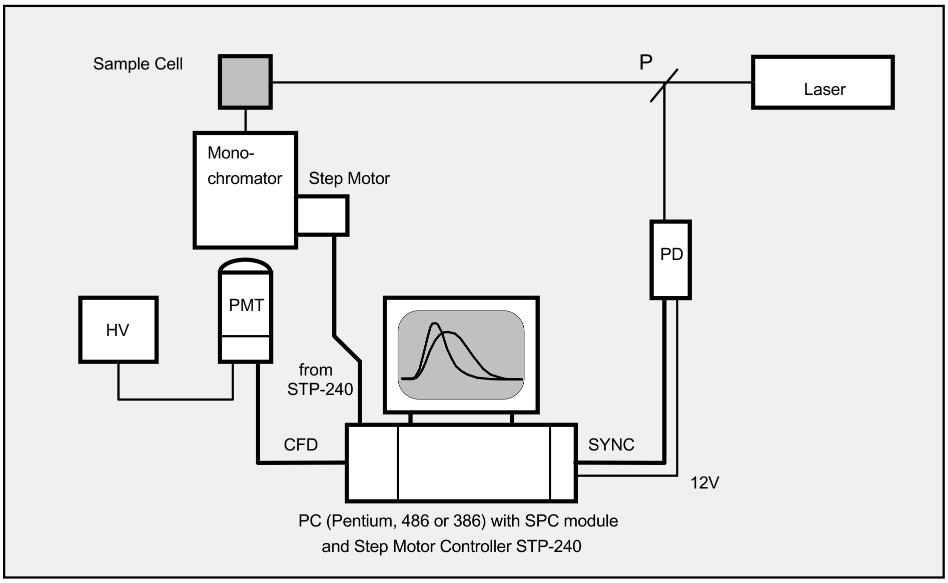
To achieve a good time resolution, noise pickup in the signal connections must be carefully avoided. The most important sources of noise are ground loops, i.e. grounding of different system components at different ground potentials. Please make sure, that all components (measurement arrangement, PMT, HV supply unit, synchronisation diode, PC with SPC module, PC peripheral devices) have one (and only one) common ground. The simplest solution is to supply all components from the same power plug. **Caution:** Don’t connect a photomultiplier tube to the SPC when the high voltage is switched on (see 'Input Signal Requirements').

The arrangement described above allows for recording of fluorescence decay curves at different wavelengths selected by the filters. A typical result is shown in the figure below.

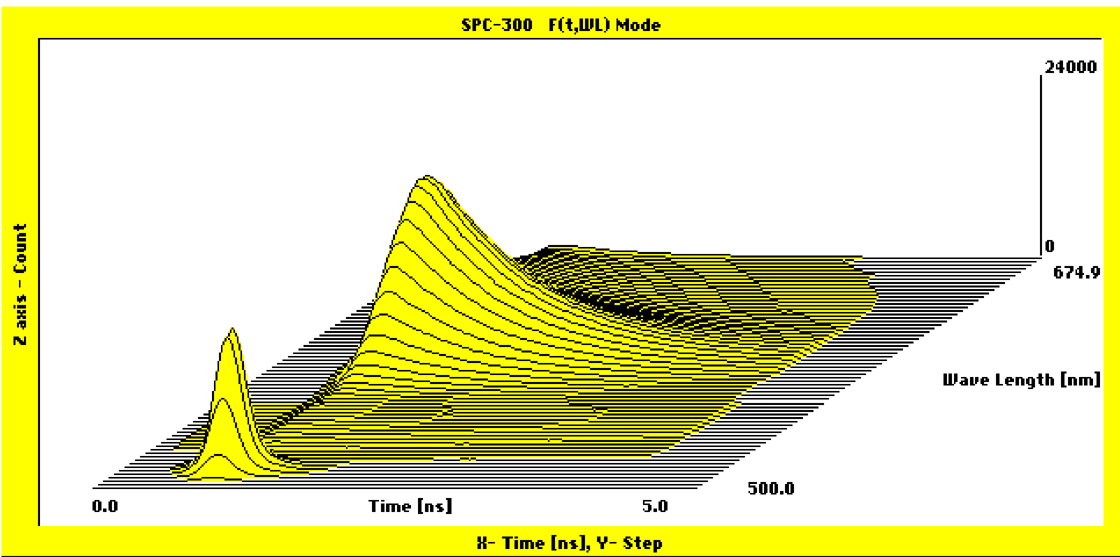


Due to the high efficiency of the optical path (filters instead of a monochromator) the sensitivity of the shown setup is excellent. It is usually limited by Raman scattering or fluorescence of solvent impurities.

For more detailed fluorescence investigations the measurement wavelength should be selected by a monochromator as shown in the figure below.



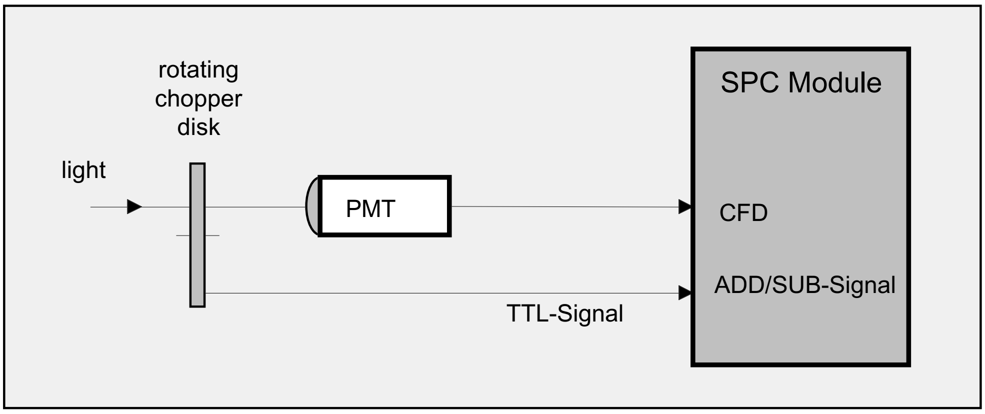
The monochromator is driven by a step motor and the step motor controller card STP-240. The SPC software allows for drive calibration, wavelength setting and wavelength scanning by the 'fi(ext)' and f(t,ext)' modes. In the 'fi(ext)' mode time resolved spectra are recorded. Up to 8 independent time windows can be selected on the measured waveforms, and the intensities within these windows are displayed as a function of time or an externally variable parameter. The f(t,EXT) mode provides a simple way to record sequences of decay curves at different wavelengths. Up to 128 decay curves can be recorded in one measurement. A typical result is shown in the figure below.



Lock-in SPC

Each detector generates a background signal which is caused by thermal emission of electrons. This background signal limits the sensitivity and degrades the accuracy of the numerical data analysis. It is possible to reduce the background by cooling, but this often causes unpleasant problems like frost on optical windows or water in the PMT voltage divider chain.

The SPC modules provide a digital lock-in technique that eliminates the background from the results. The principle is shown in the figure below.



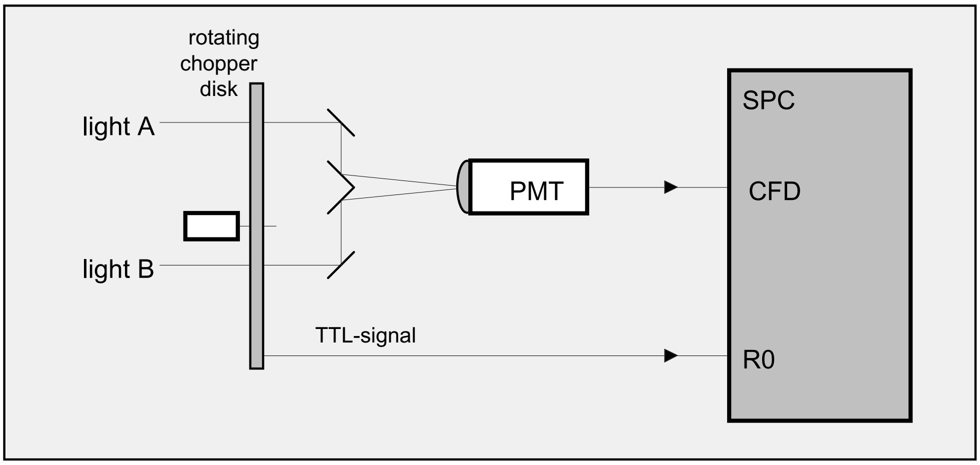
The light chopper interrupts the light with an bright/dark ratio of 1:1. At the same time the chopper disk controls the /SUB signal which is connected to the /SUB input of the SPC module. This signal acts in a way that the events in the bright phase are added and in the dark phase are subtracted in the memory. Because both phases have the same duration the background (but not the background noise) is compensated in the result.

For luminescence measurements the chopper disk may be placed more easily in the excitation light path in front of the sample cell. Similar arrangements are possible to measure two different objects (for instance the sample cell and a reference cell with the pure solvent) at the same time. The excitation and luminescence light beams are handled by rotating sector mirrors or by light choppers and 50% mirrors. This arrangement suppresses fluorescence or Raman lines of the solvent, which normally set a limit to the sensitivity in analytical applications.

Multiplexed TCSPC

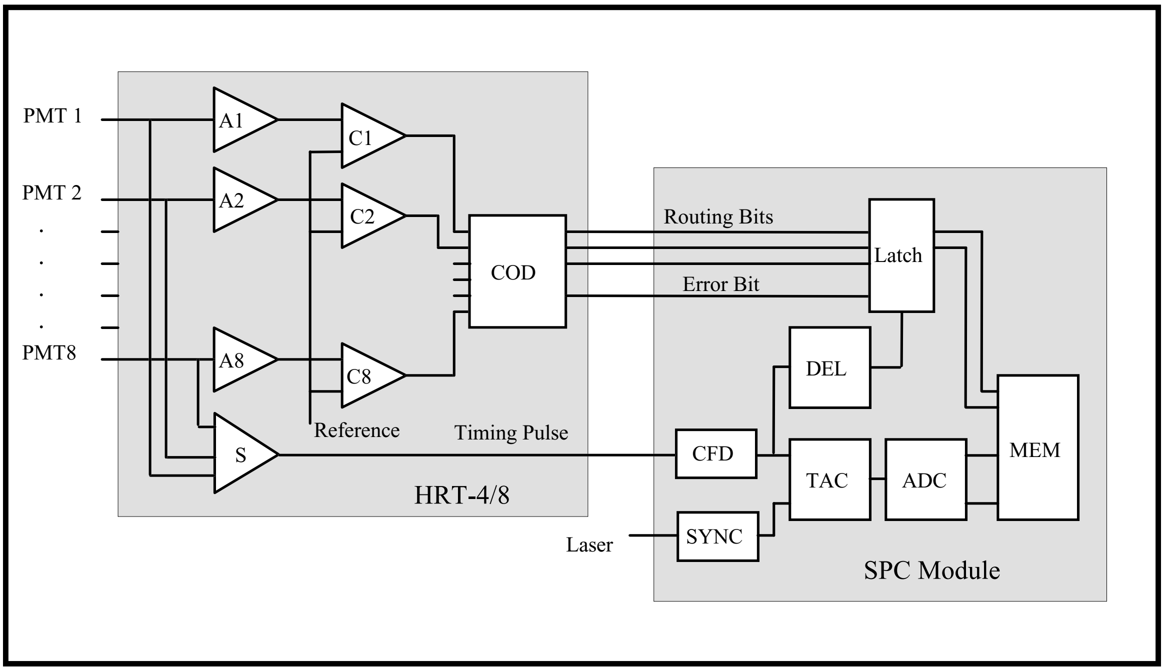
The arrangement shown in the following figure is used to measure two different light signal quasi-simultaneously. The chopper disk alternatingly opens the light path for the two signals A an B. Both signals are fed to the same detector. The signal R0 is derived from the rotation of the chopper disk and routes the events from the two signals into different memory blocks of the SPC module. Thus two different curves are obtained according to the two different signals. The method is very useful for fluorescence applications where the fluorescence decay and the impulse response are measured at the same time. It is, however, difficult to achieve the same system response for both optical channels.

The ultimate application of multiplexed TCSPC is for Fluorescence Lifetime Imaging (FLIM) with scanning microscopes or other fast scanning devices. These applications are described under ‘TCSPC Imaging’.



Multichannel Operation

The SPC modules are designed to measure the signals of several independent detector channels simultaneously. Multichannel operation is accomplished by combining the photon pulses from all detectors into one common timing pulse and providing a 7 bit routing signal which directs the photons from the individual detectors into different memory blocks. Routing devices for individual detectors are available for 4 and 8 detector channels (HRT-41 and HRT-81, HRT-82, please see individual manuals). Complete detector heads are available with 16 channels in a linear arrangement (PML-16, individual manual). The block diagram of the HRT / SPC combination is shown in the figure below.



The photon pulses from the individual detectors PMT1 through PMT8 are fed to the amplifiers A1 trough A8. The amplifier outputs are connected to the comparators C1 through C8. When a photon is detected in one of the PMTs so that the amplifier output voltage exceeds the reference voltage at the comparators, the corresponding comparator responds. The comparator output pulses have a duration of some 10 ns.

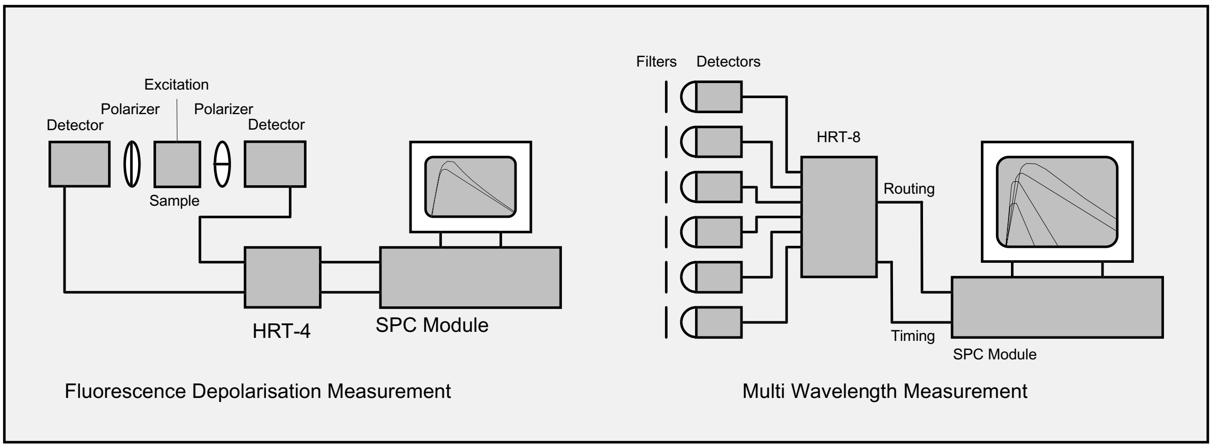
The comparator output signals are encoded in the encoder COD to yield 3 (2 for HRT-4) routing bits and one error bit. The routing bits contain the information about the detector channel which detected the corresponding photon. The error signal is active when either none or more than one of the comparators respond.

To provide the timing information to the SPC module the input pulses from all detectors are combined in the summing amplifier S. The output pulses from S are used as photon pulses at the 'CFD' input of the SPC module. When a pulse at the CFD is detected, the SPC starts the normal processing sequence. It determines the time of the pulse referred to the laser pulse sequence, performs an ADC conversion and addresses a memory location which corresponds to the measured time of the photon.

During the photon is processed in the TAC and the ADC, the SPC reads the routing bits and the error signal from the encoder COD into a data latch. The SPC memory is divided into individual parts corresponding to the individual detectors. The routing information controls the part of the memory into which the event is stored, thus routing the photons into individual curves for the individual detectors. To compensate the delay in the HRT and cable delays, the routing information is latched with an adjustable delay after each CFD pulse.

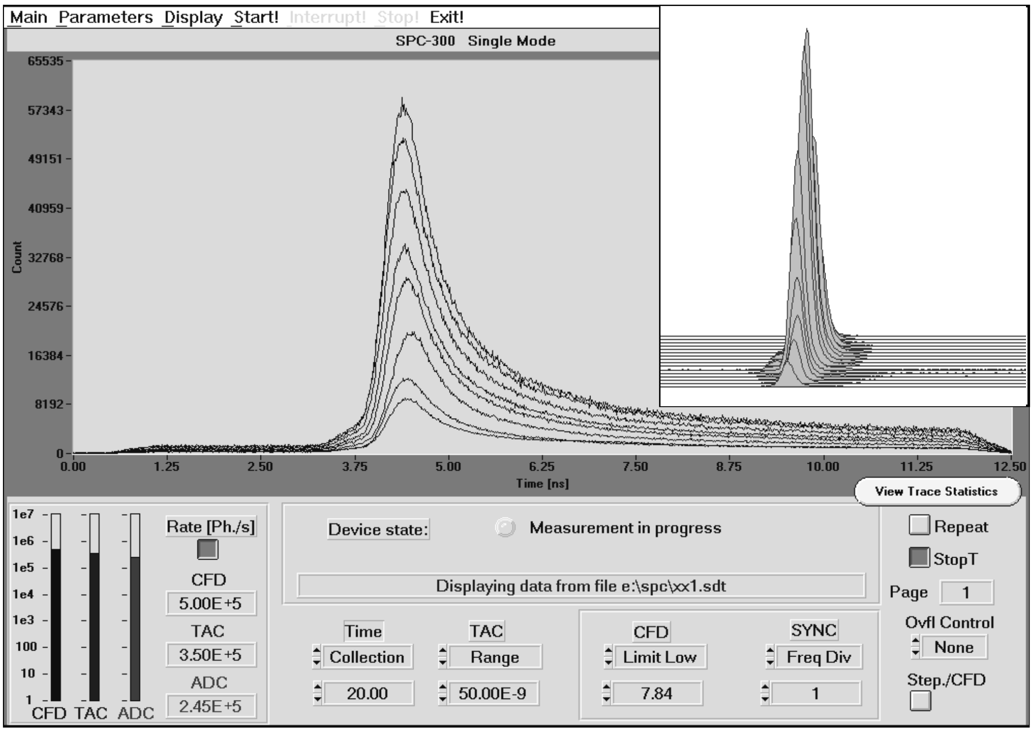
Due to the high count rates in the SPC modules there is a certain probability to detect more than one photon within the response time of the amplifier/comparator circuitry in the HRT. Furthermore, it can happen that the CFD of the SPC detects a photon pulse which was too small to be seen by a comparator in the HRT. In such cases the encoder sets the 'Error' bit which suppresses the recording of the misrouted event in the SPC module.

In the figures below two applications of the SPC's multichannel capability are shown. The first example shows an arrangement for fluorescence depolarisation measurements with two polariser / detector channels. In the second example the fluorescence of the sample is measured in different wavelength channels simultaneously.



Multichannel measurements are possible with the SPC-3, -4, -5, -6 and -7 modules. The SPC-134 is not recommended for routing application.

The results can be displayed as individual curves (up to 8 curves simultaneously), as 3-dimensional intensity-time-distance/wavelength or colour-intensity pattern. Some examples are shown in the figure below. For 2-dimensional detector arrays different sections through the internal (t,x,y) data set can be selected.



TCSPC Imaging

Due to their large memory size the SPC-5x0 and the SPC-7x0 modules are an ideal choice for ps resolution imaging applications. In the figure below a sample is scanned with 128 x 128 pixels. For each pixel a decay curve with 256 points is recorded. By using a fast MCP detector a time resolution better than 30 ps is achieved.

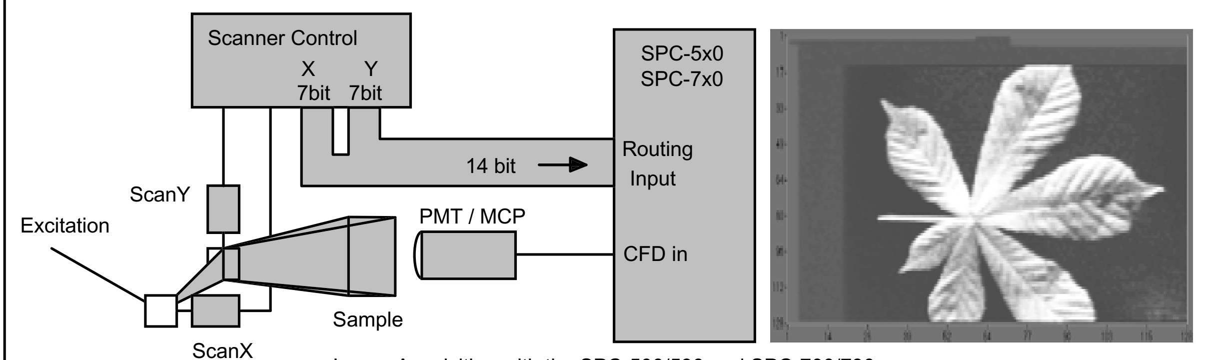


Image Acquisition with the SPC-500/530 and SPC-700/730

Scanning is accomplished by two fast piezo or galvo scanning elements. The excitation spot sweeps over the sample in 128 rows and 128 columns. The x-y position of the spot is used as a routing signal for the SPC-5 or SPC-7 module. The routing bits are either taken directly from the scan controller or - if a digital x-y signal is not available - generated by digitising the analog x and y signals with two ADCs.

Other scanning interfaces can be built with the SPC-700/730 modules and the 505/535 and 506/536 versions of the SPC-500/530. The SPC-505/535 and the SPC-700/730 in the ‘Scan

Sync Out' mode send synchronisation pulses to the scanner. These pulses control the start of a new frame, a new line and a new pixel.

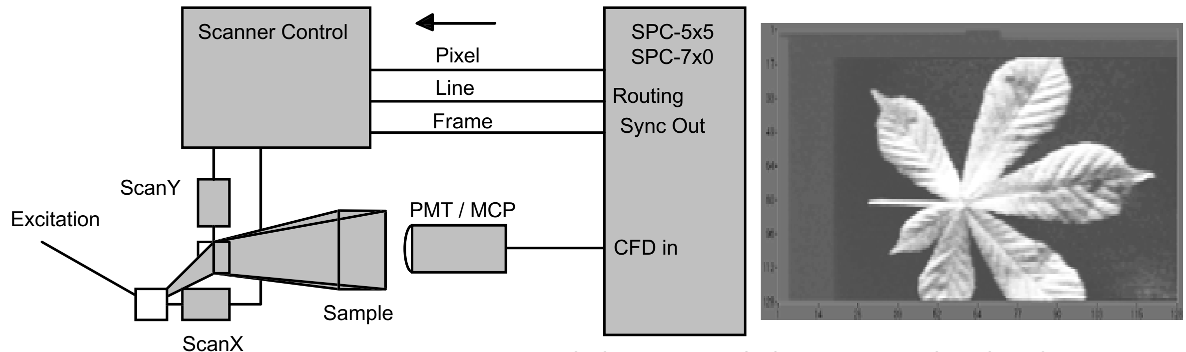


Image Acquisition with the SPC-505/535 and SPC-700/730 in the 'Scan Sync Out' mode

The SPC-506/536 and the SPC-700/730 in the 'Scan Sync In' mode receive synchronisation pulses from the scanner. These pulses control the start of a new frame, a new line and a new pixel in the memory of the SPC module. This mode is designed for ultra-fast (video-compatible) scanners.

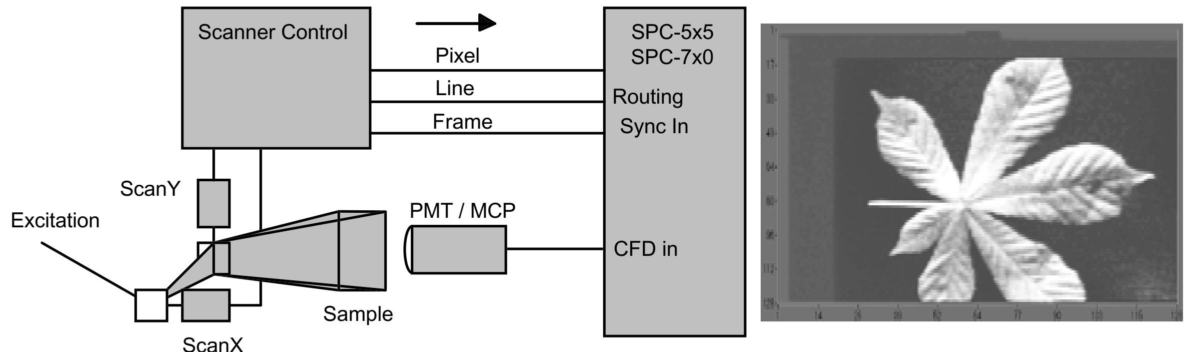


Image Acquisition with the SPC-506/536 and SPC-700/730 in the 'Scan Sync In' mode

The figure below shows the SPC-700/730 in the 'Scan XY Out' mode. Controlled by the parameters 'Scan X' and 'Scan Y' the SPC modules internally scans through all pixels of the image and sends the actual X/Y information to the scanner.

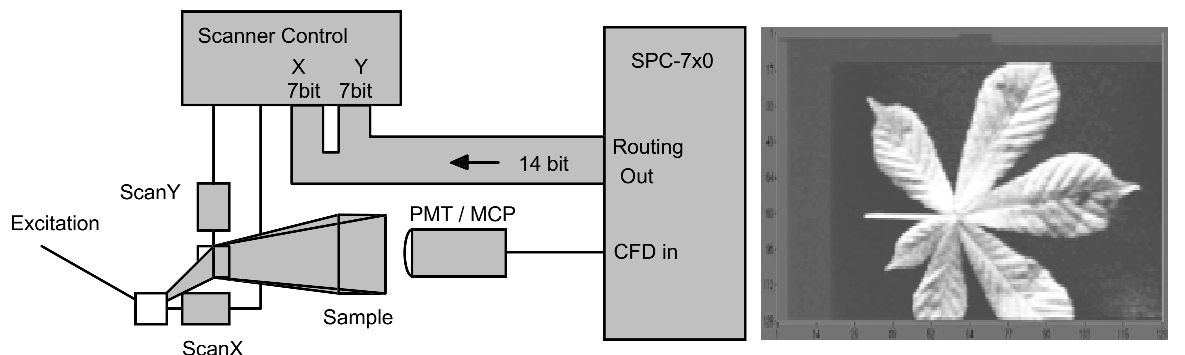
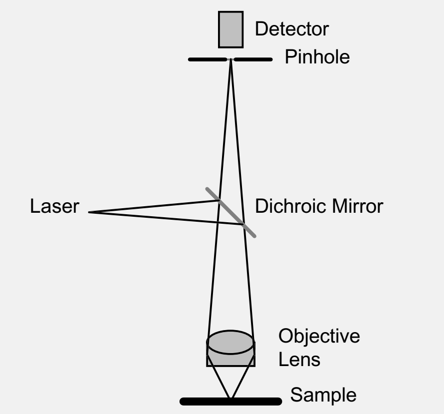


Image Acquisition with the SPC-700/730 in the 'Scan XY Out' mode

The TCSPC Laser Scanning Microscope

Confocal laser scanning microscopes have initiated a breakthrough in biomedical imaging. High contrast due to effective suppression of light scattered from outside the focal plane, the 3D imaging capability, and simple fluorescence imaging combined with effective two-photon excitation opened applications beyond the reach of conventional microscopes.

The optical principle of a confocal microscope is shown in the figure right. The laser is fed into the optical path via a dichroic mirror and focused into the sample by the microscope objective lens. The light from the sample goes back through the objective lens, through the dichroic mirror and through a pinhole in the image plane of the objective lens. Light from outside the focal plane is not focused into the pinhole plane and therefore substantially suppressed. Due to the high numerical aperture of the objective lens the suppression is so effective that a tree-dimensional imaging of the sample is possible.

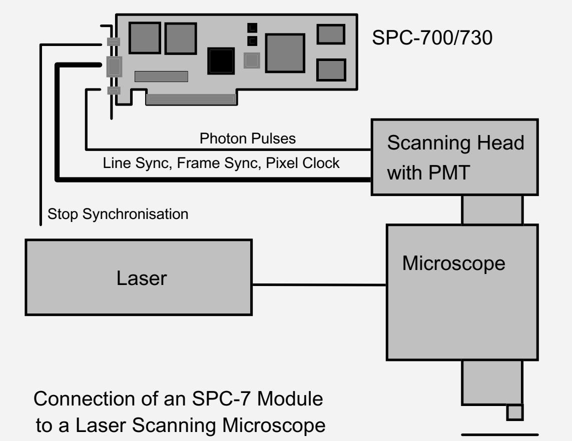


Basic optical setup of confocal laser microscope (Scanning setup not shown)

If a femtosecond laser is used for excitation the sample can be excited by two-photon absorption. Due to the small diameter of the Airy disk the photon density in the focus is very high, so that the two photon excitation works with high efficiency. Furthermore, the two-photon absorption decreases rapidly outside the focal plane. Therefore, two-photon 3 D imaging works without a pinhole in front of the detector.

By combining a confocal laser scanning microscope with an SPC-700 or SPC-730 a powerful fluorescence lifetime imaging instrument can be built up. The principle is shown in the figure below.

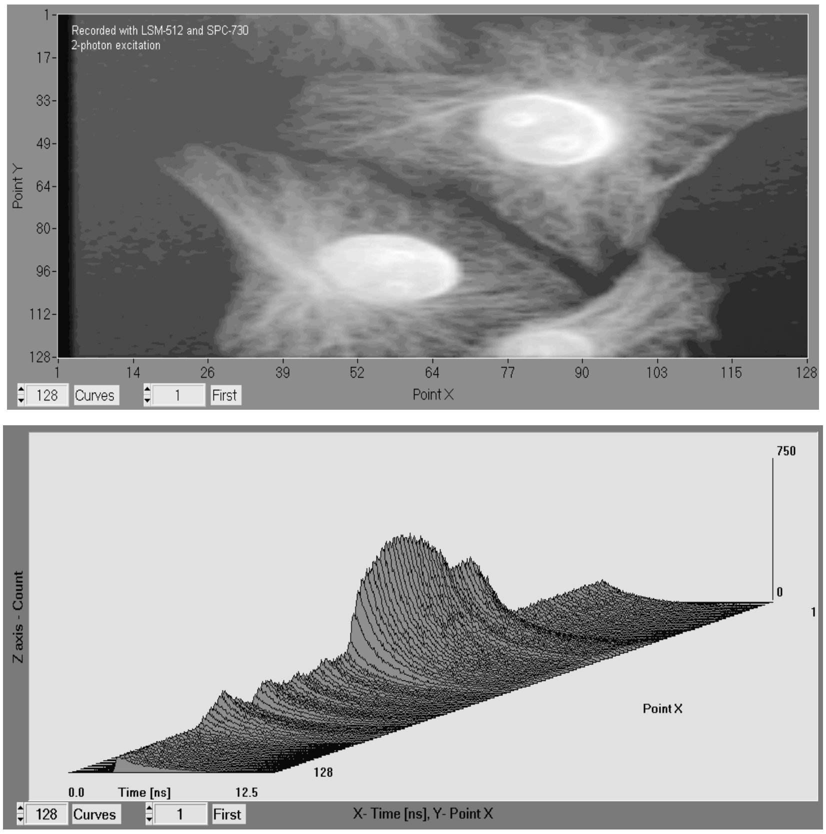
The single photon pulses from the PMT in the microscope are fed to the CFD input of the SPC module. The SYNC input gets a synchronisation signal from the laser from a photodiode which is usually built in either in the laser or in the scanning head of the microscope. To synchronise the imaging process in the SPC module with the scanning in the microscope, the Line Sync, Frame Sync and Pixel Clock pulses from the microscope are used. Because these signals are usually available from the microscope, no modifications in the microscope are required. Furthermore, because scanning microscopes usually have several detection channels with separate PMTs, the SPC module can work simultaneously with the standard image acquisition electronics of the microscope.



Connection of an SPC-7 Module to a Laser Scanning Microscope

The built-in PMTs of the scanning microscope are usually not optimal for TCSPC applications. However, most microscopes use small PMTs which give an acceptable instrument response in the TCSPC mode. Nevertheless, for best resolution an MCP PMT should be used in one of the detection channels of the microscope. Compared the price of the laser microscope the cost for the MCP is more than justified.

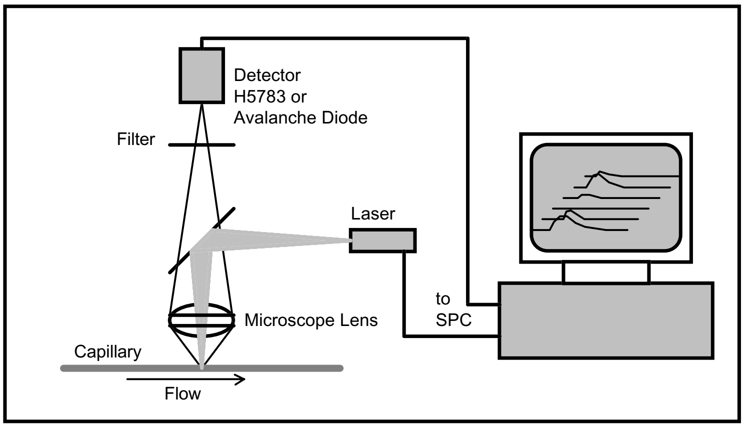
The figure below shows an image obtained with a Zeiss LSM 510 NLO Laser Scanning Microscope and an SPC-730 module. The image consist of 128 x 128 pixels containing a 256 point decay curve each. In the lower part of the figure the decay curves over a 16 pixel wide horizontal stripe of the image are shown.



TCSPC recording of cells (Zeiss LSM 510 NLO, SPC-730, two-photon excitation
Upper part: Image integrated over all 256 points of time scale
Lower part: Decay curves of a horizontal 16 pixel wide stripe of the image

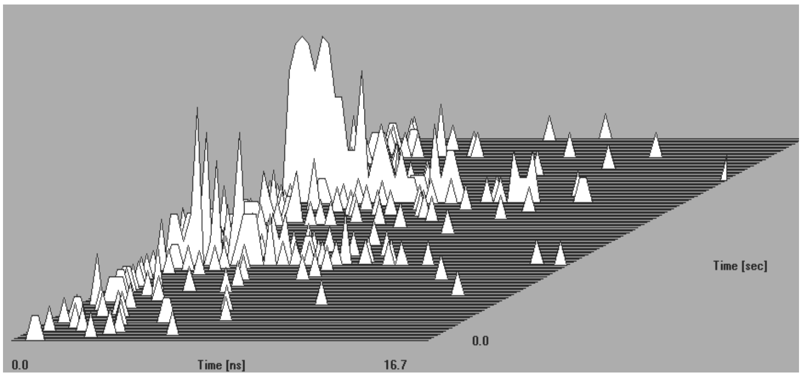
Single Molecule Detection

A typical setup to detect single molecules is shown in the figure below.



The molecules to be detected flow through a capillary. A microscopically small spot of the capillary is illuminated by the laser through a microscope lens. The fluorescence light is collected by the same lens and fed to the detector. The dye molecules travel through the laser focus within a few ms or less. In this time a single molecule can perform some 10^4 excitation and emission cycles. This is enough to record an approximate decay curve which allows to identify the molecule.

The figure below shows a typical result obtained with diode laser excitation.



Basically, single molecule detection is possible with all SPC versions. However, the SPC-40x/43x and SPC-600/630 modules are superior to other SPC modules due to their dual (or FIFO) memory architecture, their short collection times and more flexible memory data structure.

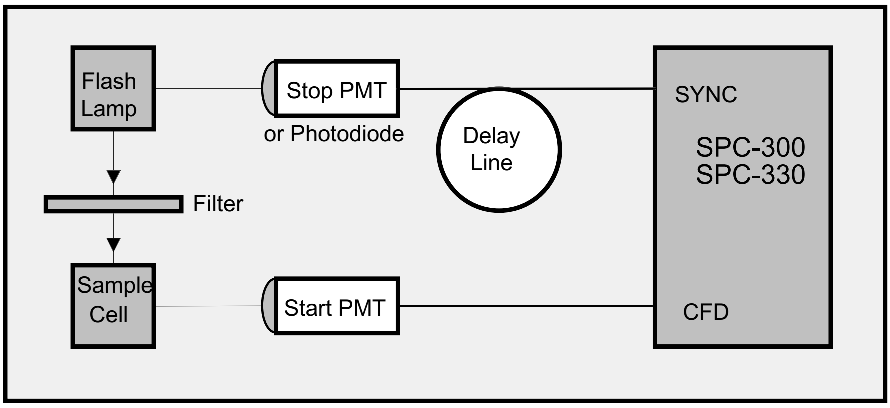
The dual memory (SPC-400/430, SPC-600/630) is used to alternately swap between the two memories and read the data from one memory while the measurement writes new data into the other one. By restricting the number of points per decay function to 64 the collection time per curve can be reduced to <1 ms while maintaining continuous recording without gaps between subsequent decay curves.

In the FIFO Mode (SPC-4x1, -4x2 or SPC-600/630) the full information (time within the excitation pulse sequence and time from the start of the measurement) is stored for each individual photon and continuously read by the software. The results are stored to the hard disk.

Measurements at low pulse repetition rates

All bh SPC modules are optimised for applications with high repetition rate laser light sources. Due to the 'reversed start/stop' principle and the proprietary AD conversion method the SPC modules in such applications achieve a much higher count rate and a lower differential nonlinearity than conventional NIM systems.

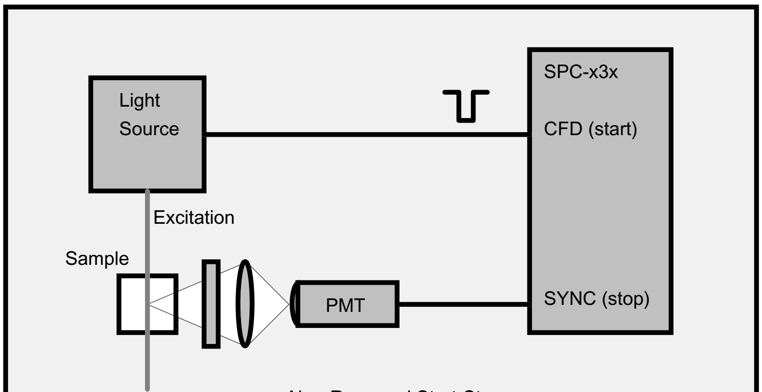
It is, however, possible to use the SPC modules also at repetition rates <100 kHz i.e. for nanosecond flash lamps or diode pumped solid state lasers. In these cases a stop pulse has to be provided after the last photon to be detected. This can be achieved by sending the synchronisation pulse from the laser through a delay line. The figure below shows a simple arrangement for fluorescence decay measurements with ns flash lamp excitation.



The Stop-PMT works at relatively low gain (not in the photon counting range!) and derives a SYNC pulse for the SPC module from the lamp pulse. This pulse is delayed by a cable (e.g. RG 174, 5 ns/m). The delay must be greater than the greatest time to be measured. The frequency divider in the SYNC channel is set to 1 (see 'System Parameters'). Thus the time measurement is done in the same way as with high repetition rate sources - from the photon pulse to the next SYNC pulse arriving at the module.

Non-Reversed Start-Stop

The SPC-x30 modules and the SPC-134 can be used for standard (non-reversed) start-stop operation. The PMT is connected to the ‘SYNC’ input, the pulse from the light source to the ‘CFD’ input. An example is given in the figure below.



Non-Reversed Start-Stop

Non-reversed start-stop operation can be can be convenient for low repetition rates of the light source. It avoids the delay line in the SYNC (stop) line. However, the SPC software expects reversed start stop so that the time axis appears reversed. Furthermore, the SYNC channel is designed for high repetition rate rather than for timing by PMT pulses. Therefore the timing performance can be worse than for the (normal) reversed operation.

Software

Overview

Single SPC modules come with the ‘SPC Standard Software’, a comfortable software package that allows for measurement parameter setting, measurement control, step motor control, loading and saving of measurement and setup data, and data display and evaluation in 2-dimensional and 3-dimensional modes. For data processing with other software packages a conversion to ASCII and Edinburgh Instruments format is included. The SPC Standard Software is available for Windows 3.1 and Windows 95/98/NT.

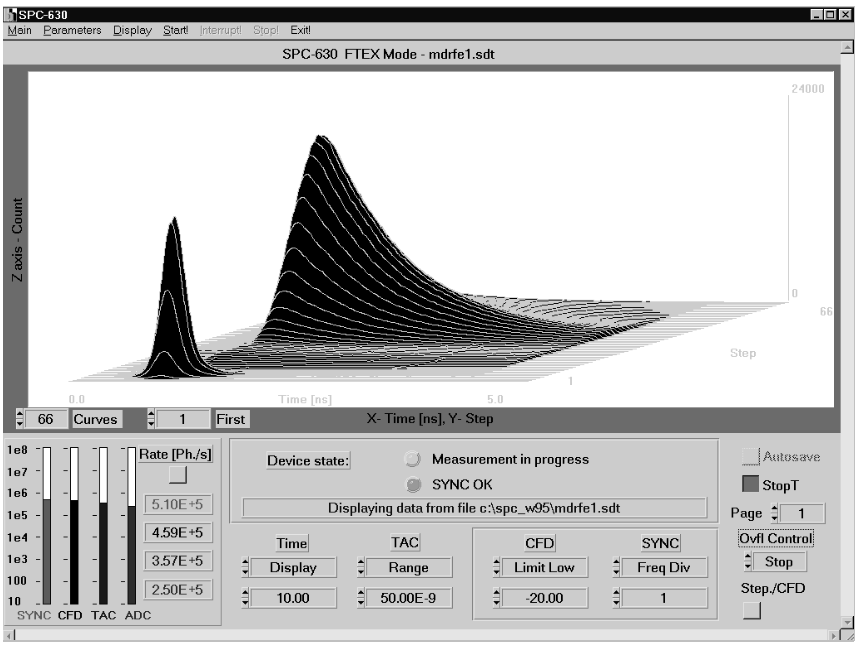
For the SPC-134 ‘TCSPC Power Package’ or for parallel operation of several SPC-6 or SPC-7 modules the ‘Multi SPC Software’ is required. The Multi SPC software includes all functions of the SPC Standard Software, but the module parameters, display functions and data management are structured for up to four modules. The Multi SPC software works with all PCI modules (SPC-6, SPC-7, SPC-134), but not with the ISA modules. The Multi SPC software is available only for Windows 95/98 and Windows NT.

To facilitate the development of user-specific software a DLL library for Windows 95 and Windows NT is available. However, before you start into the laborious project of creating your own SPC software, we recommend to check carefully whether the functions of the standard software can solve your problem.

The computer must be a IBM compatible 486 or Pentium machine. For convenient working a machine with 300 MHz or more is recommended (yet not required). The SPC Standard Software requires 32 Mb of memory and about 2 Mb hard disk space. However, to store the measurement data files much more hard disk space can be required.

You can use the SPC Standard Software and the Multi SPC Software without an SPC module. The software will display a warning that the module is not present. After selecting the desired module type from a list you can start the software in a ‘Simulation’ mode which emulates the SPC device memory in the PC memory. In this mode you can load, display and store data and do everything with the exception of a true measurement.

After starting the SPC software the main menu shown below appears.



The main menu contains the following items:

Menu Bar

Main Parameters Display Start Interrupt Stop Exit

Under these items the following functions are accessible:

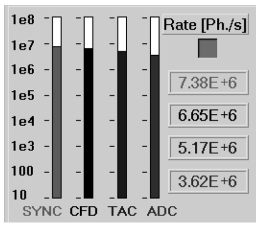
Main:	Load, Save, Convert, Print
Parameters:	Display Parameters, Trace Parameters, Adjust Parameters
Display:	Evaluation of curves
Start:	Start measurement
Interrupt:	Interrupt measurement, measurement can be re-started
Stop:	Stop and finish measurement
Exit:	Exit program

Curve Window

In the curve window the measurement results are displayed. The curves on the screen are referred to as 'Traces'. Trace definition, trace style and the scaling of the coordinates are set by the 'Trace Parameters' and the 'Display Parameters'.

The SPC-4x1/4x2 and the SPC-6x0 and -134 in the FIFO mode do not build up histograms in their memories like the other SPC modules. To display results, the SPC software analyses the incoming photon data and builds histograms in intervals set by the parameter ‘Display Time’. For each routing channel (detector) an individual curve can be displayed (see also ‘Trace Parameters’). The display of the curves consumes an appreciable part of the computing power, therefore we recommend to switch off the display if a high data throughput is required.

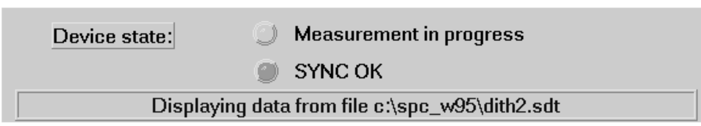
Count Rate Display



The rate display informs about the count rates the CFD, the TAC the ADC and the SYNC rate (SPC-x3x versions only). The CFD rate represents all pulses with an amplitude greater than 'CFD Limit Low'. The TAC rate is the working rate of the TAC. It is slightly smaller than the CFD rate because the TAC is not started by pulses exceeding 'CFD Limit High' and by pulses falling into the dead time. 'ADC Rate' is the conversion rate of the ADC. It represents all events inside the selected TAC window. In the SPC-3 modules the count rate display is active only when the measurement is running. The count rate display can be switched off to increase the display update rate.

Device State

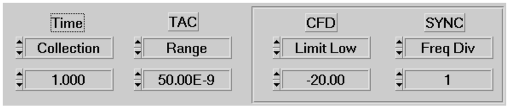
'Device state' informs about the current action of the device.



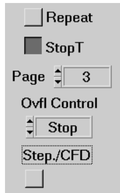
The most important state messages are

Collecting Data:	Measurement started but not finished
Displaying Data:	Measurement finished, final result is displayed
Displaying data from file:	Displayed data were loaded from an SPC data file
No SYNC:	No synchronisation signal
SYNC OK:	Synchronisation signal present
SYNC Overload:	Synchronisation amplitude too high
FIFO Overflow:	The FIFO is full, not all photons are recorded (SPC-4x1, -4x2 and SPC-6x0 only)

System Parameter Settings



The essential parameters of the measurement are accessible directly from the main menu. They can be changed during the measurement (see also ‘System Parameters’).



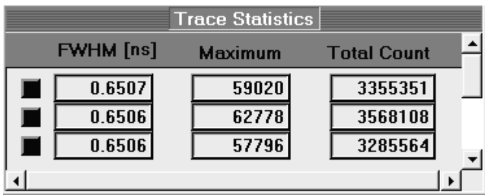
Time: Collection Time, Display Time, Repeat Time
TAC: Range, Gain, Offset, Limit Low, Limit High
CFD: ZC Level, Hold, Limit Low, Limit High (SPC-x00 only)
SYNC: Freq Divider, ZC Level, Holdoff, Threshold (SPC-x30 only)
Ovfl Control: None, Stop on Overflow, Correct Overflow
Page: Memory area (destination) for measurement data
Repeat: Repeat measurement
Stop T: Stop after Collection Time

By the switch 'Step.Dev/CFD' the CFD and SYNC part can be replaced with a window for stepping motor control.

Not all parameters are available in all operation modes or in all module types (please see ‘System Parameters’).

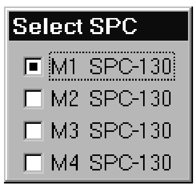
Trace Statistics

By the switch 'View Trace Statistics' a window is opened in which the FWHM values, the overall counts and the peak counts are displayed for all active traces. The window can be placed anywhere in the main window. In the oscilloscope mode, the trace statistics display is a convenient means to adjust the system for maximum resolution or count efficiency.



Module Select (Multi SPC Software)

If the Multi SPC Software is used (e.g. for the SPC-134 or for a dual SPC-6 or SPC-7 configuration) the parameter settings can be different for different modules. The parameters shown in the main window belong to the only one of the modules that is selected in the ‘Select SPC’ panel. This small panel can be placed anywhere in the screen area.

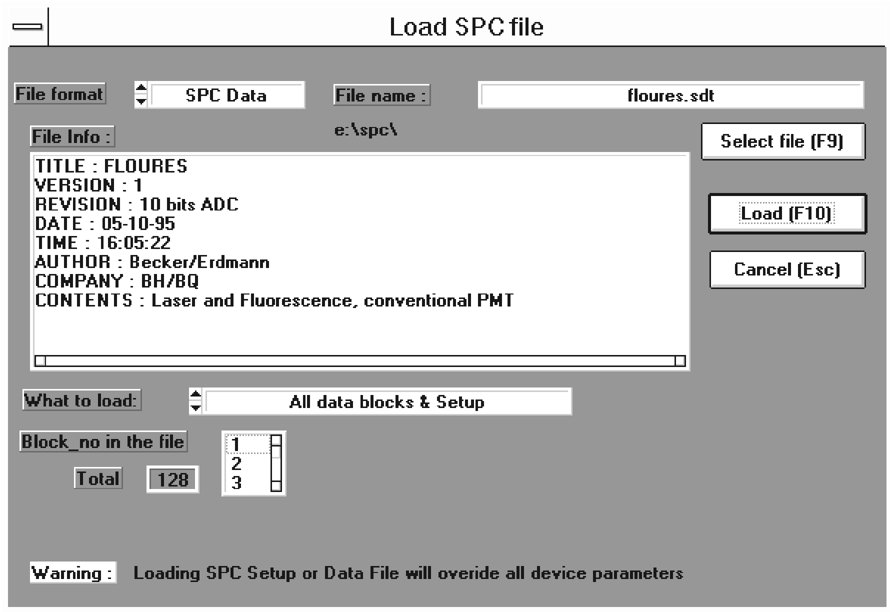


Main

Under ‘Main’ the functions for loading, saving and converting data and the print functions are available.

Load

The ‘Load’ menu is shown in the figure below.



In the ‘Load’ menu the following functions are available:

Data and Setup File Formats

You can chose between ‘SPC Data’ and ‘SPC Setup’. The selection refers to different file types. With ‘SPC Data’, files are loaded that contain both measurement data and system parameters. Thus the load operation restores the complete system state as it was in the moment of saving.

If you chose ‘SPC Setup’, files are loaded that contain the system parameters only. The load operation sets the system parameters, but the actual measurement data is not influenced. Files for ‘SPC Data’ have the extension ‘.sdt’, files for ‘SPC Setup’ the extension ‘.set’.

For the SPC-4x1/4x2 FIFO memory modules only ‘SPC Setup’ is available. The data files created in this mode cannot be loaded back into the module. (To display such files please see ‘Convert’)

File Name / Select File

The name of the data file to be loaded can be either typed into the ‘File Name’ field or selected from a list. To select the file from the list, ‘Select File’ opens a dialog box that displays the available files. These are ‘.sdt’ files or ‘.set’ files depending on the selected file format. Furthermore, in the ‘Select File’ box you can change to different directories or drives.

File Info, Block Info

After selecting the file an information text is displayed which was typed in when the data was saved. With ‘Block Info’ information about single data blocks (curves) is displayed. The blocks are selected in the ‘Block no in the file’ list.

Load / Cancel

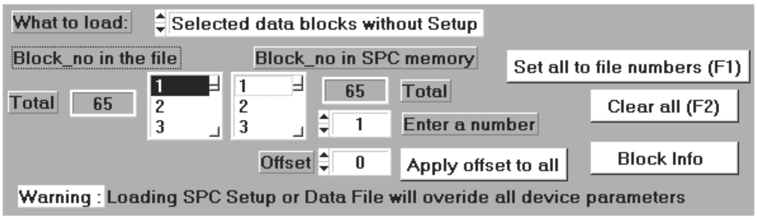
Loading of the selected file is initiated by 'Load'. 'Cancel' rejects the loading and closes the 'Load' menu.

Loading selected Parts of a Data File

Under 'What to Load' the options 'All data blocks & setup', 'Selected data blocks without setup' or 'Setup only' are available. The default setting is 'All data blocks & setup', which loads the complete information from a previously saved data file. 'Setup only' loads the setup data only, the measurement data in the SPC memory remains unchanged.

With 'Selected data blocks without setup' a number of selected curves or data sets out of a larger .sdt file can be loaded. A data set is a number of curves that was measured with the same hardware parameters, e.g. the decay curves of all pixels of a 'Scan' mode measurement.

For 'Selected data blocks without setup' the lower part of the 'Load' menu changes as shown in the figure below.

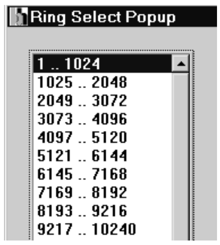


The list 'Block no in the file' shows the curves (or data sets) available in the file. Under 'Block no in the memory' the destination of the data blocks (curves / sets of curves) in the memory is shown. With 'Set all to file numbers' the destination in the memory can be set to the same block numbers as in the file. To set the destination of the data to locations different from the block numbers in the file, click on the a block number in the 'Block no in the memory' list and change it in the 'Enter Number' field. 'Clear all' clears the 'Block no in the memory' list.

For the SPC-134 or other multi-SPC systems operated by the Multi-SPC Software, the block designator contains the module number and a curve number (module_curve).

'Apply offset to all' loads data with a constant offset referred to the file block numbers. It can be used to conveniently load large data blocks to a memory location different from the location in the file.

In the SPC software versions for Windows 95 and Windows NT a sequence of blocks can be selected by pressing the 'Shift' key and clicking on the start and stop number.



Creating the 'Block No' list can take some time, especially on slow computers. Therefore, the for high number of blocks list is created on demand only by the 'Detail' button. When the list is switched on, a menu can be opened from which the location in the block number list can be selected in groups of 1024 blocks.

'Block Info' opens a new window which gives information about the data in a selected data block. An example for the block information window is given in the section 'Trace Parameters'.

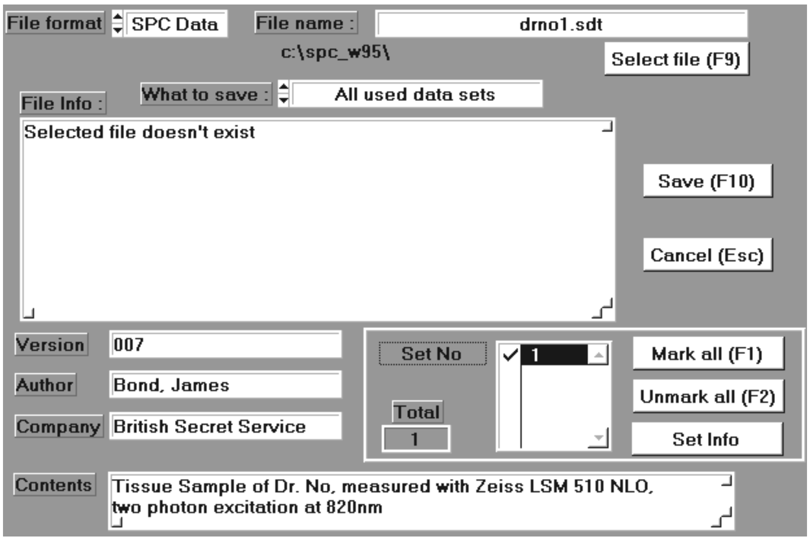
Loading Files from older Software Versions

Older software versions usually contain less or other system parameters than newer ones. Therefore, loading older files into a newer software (or vice versa) can cause warnings about missing or unknown parameters. To load the file, press the 'Continue' button until the file is loaded. Unknown parameters are ignored and missing parameters are replaced by their default values. To avoid further problems with such a file, we recommend to save it in the current software version (use option 'All used data blocks').

Save (Non-FIFO Versions or Non-FIFO Modes only)

The 'Save' menu is available for the Non-FIFO Versions or Non-FIFO Modes only. In the FIFO mode the data is continuously saved to the hard disk during the measurement.

The 'Save' menu is shown in the figure below.



In the 'Save' menu the following options are available:

File Format

You can chose between 'SPC Data' and 'SPC Setup'. The selection refers to different file types. With 'SPC Data' files are created which contain measurement data and system parameters as well. Thus the complete state is restored when the file is loaded. If you chose 'SPC Setup' files are created that contain the system parameters only. When loading such files the current measurement data is not influenced.

Files created by 'SPC Data' have the extension '.sdt', files created by 'SPC Setup' have the extension '.set'.

File Name

The name of the data file to which the data will be saved can be either typed into the 'File Name' field or - if it already exists - be selected from a list. To select the file from the list, 'Select File' opens a dialog box that displays the available files. These are '.sdt' files or '.set' files depending on the file format selected. Furthermore, in the 'Select File' box you can change to different directories or drives.

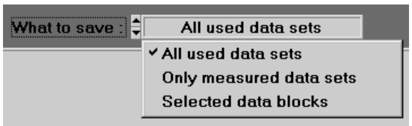
File Info

After selecting the file an information text can be typed into the ‘File info window’. If you have selected an existing file you can edit the existing file information. When you load the file later on, this text is displayed. This will help to identify the correct file before loading.

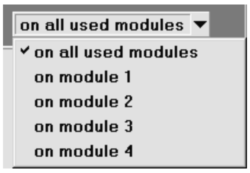
Save / Cancel

Saving of the selected file is started by ‘Save’ or F10. ‘Cancel’ rejects the saving and closes the ‘Save’ menu.

Selecting the data to be saved



Under ‘What to Save’ the options ‘All used data sets’, ‘Only measured data sets’ or ‘Selected data blocks’ are available. Furthermore, for the SPC-134 or other systems operated by the Multi-SPC software a module can be selected the data of which is to be saved. The default setting is ‘All used data sets’ and ‘All used Modules’, which loads all data which is in the memory of the SPC module. This can be measured data, calculated data or data loaded from another file.



‘All used data sets’ and ‘Only measured data sets’

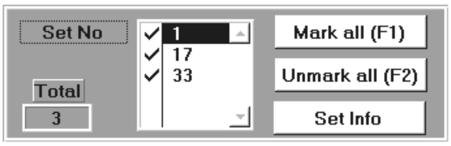
A ‘Data Set’ is the result of a single measurement, e.g.

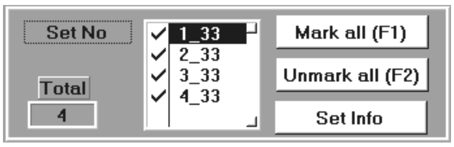
- a decay curve measured by a single detector in the ‘Single’ mode
- the decay curves measured in a multi-detector configuration in the ‘Single’ or f(t,x,y) mode
- a sequence of decay curves measured in the f(t,T) or f(t,ext) mode
- the time-resolved spectra obtained for the 8 time windows of the fi(T) or fi(ext) mode
- the decay curves for the pixels of an image recorded in the ‘Scan’ modes

‘All used data sets’ saves all data, i.e. measurement results obtained in the current session, results loaded from a file, and results created by the 2D and 3D data operations.

‘Only measured data sets’ saves only the data which was obtained by **measurements** in the current session. Data loaded from files or results of data operations are **not** saved.

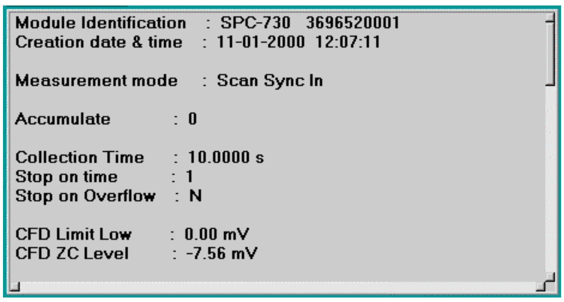
The start curve numbers of the available data sets are shown in the lower part of the ‘Save’ panel (figure right). For the SPC-134 or other multi-SPC systems operated by the Multi-SPC Software, the data set designator contains the module number and the start curve of the data set (module_data set).





By default, all data sets of all modules are marked. If you do not want to save all data sets you can unmark sets which are not to be saved.

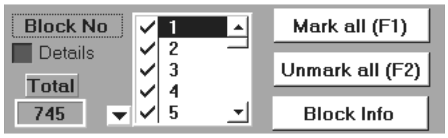
Selecting a data set in the list and clicking on ‘Set Info’ opens a new window which gives information about the data in the selected data set. The window is shown in the figure right. It contains the SPC module type and serial number, the date, and the system parameters used to measure the selected data set.



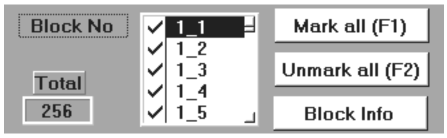
Selected data blocks

With ‘Selected data blocks’ a single curve or number of selected curves can be saved. This option is used to create files of selected curves from larger data sets, e.g. to save selected curves of a ‘Scan’ measurement for processing by an external data analysis program.

The list ‘Block No’ shows the individual curves which are available in the memory. The desired curves are selected (or deselected) from this list by a mouse click into the marked area. ‘Mark all’ selects all curves, ‘Unmark all’ deselects all curves.



Selecting Data Blocks, SPC-3 through -7

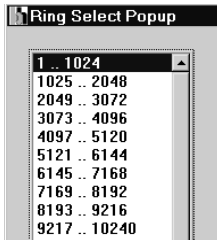


Selecting Data Blocks, SPC-134

For the SPC-134 or other multi-SPC systems operated by the Multi-SPC Software, the block designator contains the module number and a curve number (module_curve).

In the SPC software versions for Windows 95 and Windows NT a sequence of blocks can be selected by pressing the ‘Shift’ key and clicking on the start and stop number.

Creating the ‘Block No’ list can take some time, especially on slow computers. Therefore, for high number of blocks the list is created on demand by the ‘Detail’ button. When the list is switched on, a menu can be opened from which the location in the block number list can be selected in groups of 1024 blocks.



‘Set Info’ opens a new window which gives information about the data in a selected data block. An example for this window is given above for ‘All used data sets’.

Convert (Non-FIFO Versions or Non-FIFO Modes)

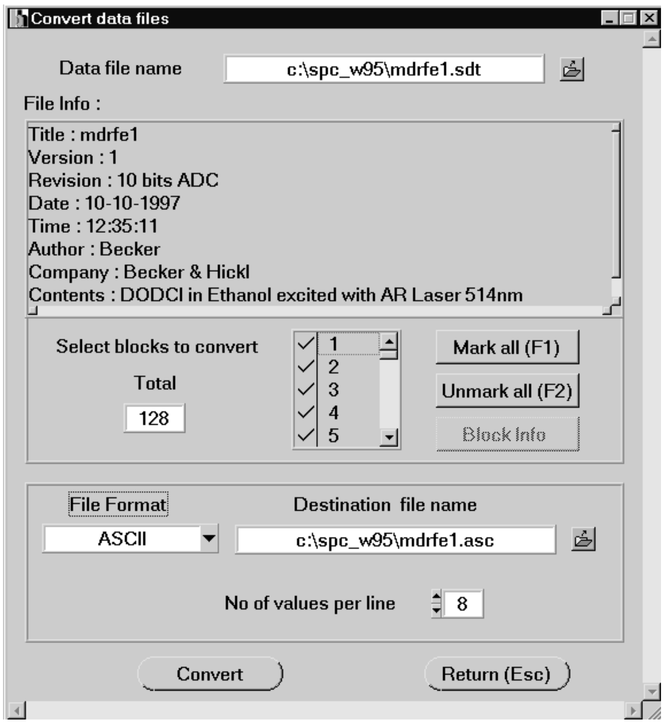
The ‘Convert’ functions are used to convert SPC data files into ASCII data files or into the file format of the Edinburgh Instruments data analysis software. The ‘Convert’ menu is shown in the figure below.

After selecting the source file, the file information is displayed which was typed in when the file was saved by the ‘Save’ function.

By ‘Select blocks to convert’ special blocks (curves) from the source file can be selected for conversion. At the beginning all curves of the source file are marked. Thus, no selection is required if all blocks of the source file are to be converted.

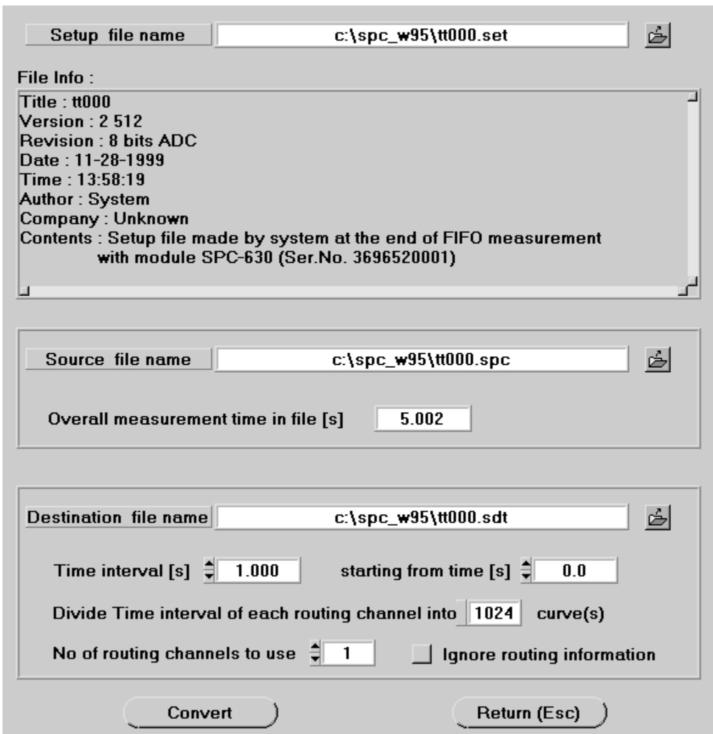
The output file format can be ‘ASCII’, ‘ASCII with Setup’ or ‘EI’. ‘ASCII’ converts the measurement data only. ‘ASCII with Setup’ converts the SPC system parameters and the measurement data. For the measurement data part the number of data values per line can be specified. ‘EI’ converts into the format of the Edinburgh Instruments data analysis software.

The entering of the destination file name is optional. If no destination file name is entered the source file name is used with the extension .ASC.



Convert (FIFO Versions or FIFO Mode of the SPC-6)

The ‘Convert’ functions are used to convert SPC FIFO data files (.spc) into .sdt data files of the SPC Standard Software. The ‘Convert’ for the FIFO mode menu is shown below.



To convert SPC FIFO data files into SPC Standard Software files both the setup data and the measurement data is required. Therefore, after each FIFO mode measurement a setup (.set) file is created which has the same name as the last data file. The name of this setup file must be specified in the upper part of the 'Convert' menu. The 'File Info' displays information about the associated measurement.

In the central part of the menu the FIFO data file is specified. 'Overall Measurement Time' informs about the time over which the measurement has been run.

The lower part specifies the SPC Standard Software file to be created. The file name is given under 'Destination file name'.

SPC FIFO measurements can run over very long times and contain data from several routing channels (detectors). Therefore, parameters are provided to control the structure of the destination file.

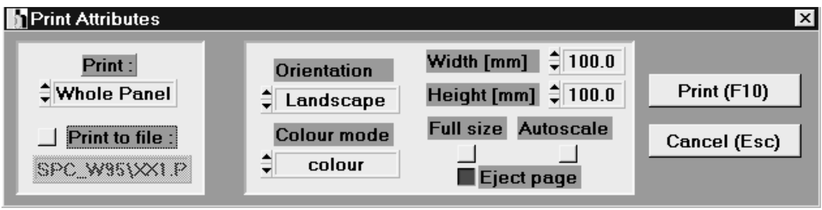
With 'Time Interval' and 'Starting from Time' a time interval can be selected out of the 'Overall measurement time' of the FIFO measurement. This time interval can be divided into a number of subsequent curves by 'Divide Time Interval of each Routing Channel into ... Curves'. If only one routing channel (one detector) was used this gives a data file which can be displayed in the 'Continuous Flow' or f(t,T) mode of the SPC Standard Software.

If several routing channels were used for the measurement different options of the conversion are available. By 'Ignore Routing Information', the data of all detector channels are merged into one detector channel of the converted data. Or, by reducing 'No of Routing Channels to use' to a value smaller than suggested, only the data of some channels (starting from Channel 1) is converted.

If the converted data contain data for several routing channels a set of subsequent curves is created for each channel. To display these data, the f(t,x,y) mode with a suitable setting of 'Routing Channels X' and 'Routing Channels Y' is recommended.

Print

The 'Print' function prints the actual screen pattern on the printer. You can print either the whole panel or the visible part only. 'Portrait' or 'Landscape' selects the orientation on the sheet. The dimensions are set by 'Autoscale', 'Full Size' or 'Size X' and 'Size Y'.



If you want to create a printer file of a screen pattern you can use the 'Print to File' option. If you select a postscript compatible printer the result is a postscript file which can be loaded into many text and image processing programs.

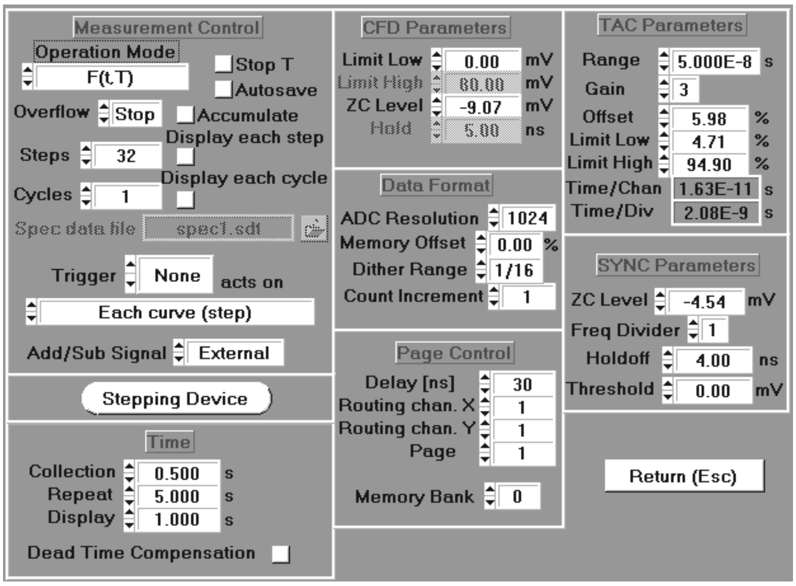
However, another (often more convenient) possibility to save a screen pattern is the 'print screen' key. When this key is pressed, Windows stores the screen pattern to the clipboard from where it can be loaded into an image processing program (Photo Paint, PhotoShop etc.).

Parameters

Under 'Parameters' the System Parameters, Display Parameter, Trace Parameter and Adjust Parameter menus are accessible. The System Parameters control the settings of the SPC module hardware. The Display Parameters are used to configure the curve window and to select the scales, the Trace Parameters define which information the curves contain and in which colour they are displayed, and the Adjust Parameters are used to adjust the module hardware.

System Parameters

The System Parameters control all settings of the SPC module hardware. The system parameter menu is shown in the figure below.

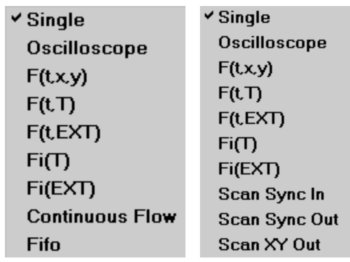


Measurement Control

The measurement control part of the system parameters menu contains the operation mode and the most important measurement control parameters. Due to the different SPC module types and operation modes the measurement control part of the menu changes with the module type and with the operation mode selected.

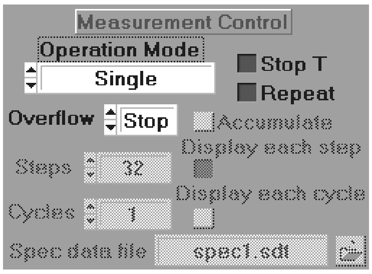
Operation Modes

The SPC modules allow a wide variety of operation modes. Most of them are available in all SPC modules (except the SPC-401/431/402/432 which work in the FIFO mode only). Some operation modes (e.g. 'Continuous Flow', 'FIFO', or 'Scan' can be used in special modules only. The software automatically recognises the module type and offers the available modes.



SPC-6x0 SPC-7x0

Single (All SPC Modules)



After starting the measurement in the 'Single' mode a single measurement cycle is performed. With the SPC-3/4/6 modules up to 128, with the SPC-5 and SPC-7 modules up to 16384 curves can be measured simultaneously if the measurement is controlled by the appropriate routing signals.

The photon collection is controlled by the parameters ‘Stop T’, ‘Repeat’ and the options under ‘Overflow’. The measurement stops

- at the end of 'Collection Time' if 'Stop T' is set
- at the first overflow if 'Stop Ovfl' is set

If both stop conditions are set the measurement stops in both cases. Without any stop condition the measurement will run until it is stopped by the operator. If the results run out of the data range 0...65535 the overrunning parts are clipped.

To collect more than 65535 photons the 'Correct Overflow' function is provided. With 'Correct Overflow', the measurement data is transferred to the PC memory at each overflow and added to the data already present there. Then the measurement data memory is cleared and the measurement is re-started. When the collection time is over the result is divided by the number of overflows and written back to the measurement memory. The resulting data has 16 bits and a maximum of 65535 again, but the standard deviation is reduced by the square root of the number of overflows. The 'Correct Overflow' function is available in the 'Single' mode only.

During the measurement intermediate results are shown on the screen in intervals of 'Display Time'. Up to eight curves can be displayed. The numbers of the curves are specified in the 'Trace Parameters'.

By activating the ‘Repeat’ button the measurement can be repeated in intervals of ‘Repeat Time’ (see ‘System Parameters’, ‘Times’) .

Oscilloscope (All SPC Modules)

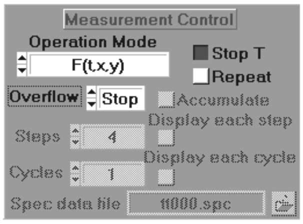
In the 'Oscilloscope Mode' the measurement is repeated automatically at the maximum available speed. The photon collection is controlled by the parameters ‘Collection Time’, ‘Stop T’, and the Stop Condition under ‘Overflow’. The measurement cycles are finished

- at the end of 'Collection Time' if 'Stop T' is set
- at the first overflow if 'Stop Ovfl' is set

The result is displayed on the screen at the end of each measurement cycle. Note that at least one stop condition must be set to complete the measurement cycle and to display the data. Several curves can be measured simultaneously if the measurement is controlled by the appropriate routing signals. Up to eight curves can be displayed during the measurement. The numbers of these curves are specified in the 'Trace Parameters'.

f(t,x,y) Mode (SPC-3x0, SPC-4x0, SPC-5x0, SPC-6x0, SPC-7x0)

The f(t,x,y) mode is used for measurements with external control of the curve number, e.g. with a multichannel detector. The measurement simultaneously records as many curves as detector channels are present (up to 128 for the SPC-3x0/4x0/6x0), up to 16 384 for the SPC-5x0/7x0).



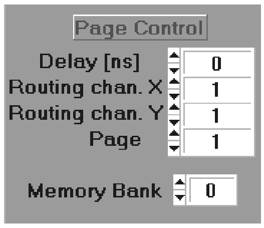
The photon collection is controlled by the parameters ‘Stop T’, ‘Repeat’ and ‘Stop Overflow’. The measurement stops

- at the end of 'Collection Time' if 'Stop T' is set
- at the first overflow if 'Stop Ovfl' is set as overflow option.

If both stop conditions are set the measurement stops in either case. Without any stop condition the measurement runs until it is stopped by the operator. If the results run out of the data range 0...65535 the overrunning parts are clipped. Thus, the measurement runs as in the 'single' mode, but the results are displayed as a three-dimensional figure.

The curve number in which a particular photon is stored is controlled via an externally applied ‘Routing Signal’. The Routing Signal is read with a selectable ‘Latch Delay’ after the corresponding photon was detected (see ‘Page Control’).

To set the correct relation between the display and the spatial arrangement of the detector channels the parameters 'Routing Channels X' and 'Routing Channels Y' are used (see ‘Page Control’). These parameters specify the number of rows and columns of the detector channels. If both 'Routing Channels X' and 'Routing Channels Y' are greater than one, three different 3D display modes are possible. These are

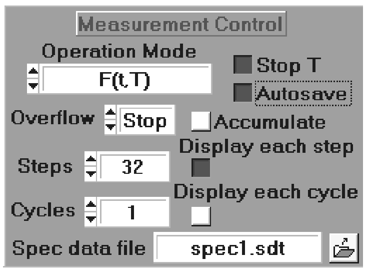


- an f(t,x) display within a selectable Y window
- an f(t,y) display within a selectable X window
- an f(x,y) display within a selectable time window.

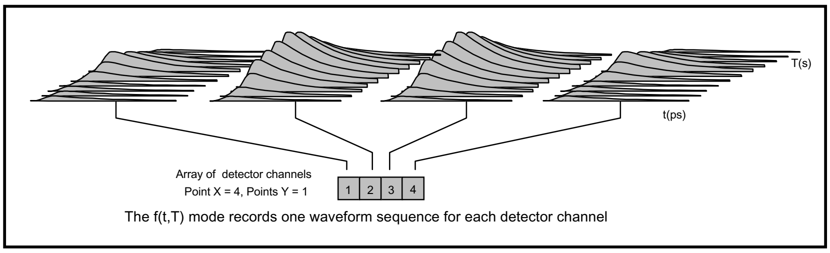
The mode of the three-dimensional display is selected in the 'Display Parameters'. The windows are set in the 'Window Parameters'. The displayed curves are the average (not the sum) of the curves in the selected X, Y or t window.

f(t,T) Mode (All SPC Modules)

The measurement of a single curve is repeated in intervals of 'Repeat Time'. The measured curves are stored one after another in the memory of the SPC module. The measurement steps are controlled by the stop conditions 'Stop T' and 'Stop Ovfl' as in the 'Single' mode. During the particular measurement steps the intermediate results are displayed in intervals of 'Display Time'. Furthermore, the result is displayed after each step if 'Display after each Step' is switched on. Note that this requires a certain time which can be greater than the desired repeat time. In the f(t,T) mode only one memory page is available.



The f(t,T) mode can be used in conjunction with the routing function. If several detector channels are active (Routing Channels X > 1 or Routing Channels Y > 1) a sequence of waveforms is recorded for each detector channel (figure below).



The f(t,T) mode records one waveform sequence for each detector channel

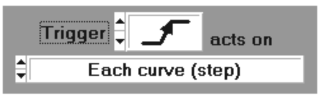
The maximum number of steps - or curves measured one after another - depends on the module type, the ADC Resolution and the number of Routing Channels used. Some examples are given in the table below.

Module Type	ADC Resolution	Routing Channels	Steps	Module Type	ADC Resolution	Routing Channels	Steps
SPC-7	4096	1	1024	SPC-6, SPC-134	4096	1	64
	4096	8	128		4096	8	8
	256	1	16384		256	1	1024
	256	8	2048		256	8	128
SPC-5	4096	1	1024	SPC-4	4096	1	32
	4096	8	128		4096	8	4
	256	1	16384		256	1	512
	256	8	2048		256	8	16
SPC-3-12	64 to 4096	1	32	SPC-3-10	64 to 1024	1	128
	64 to 4096	8	4		64 to 1024	8	16

When the specified number of steps - or curves measured one after another - has been completed the measurement stops and the result is displayed as a three-dimensional figure. When the display is in the ‘Curve’ mode the finite screen resolution does not allow to display more than 128 curves. Therefore, a specified block of curves out of a larger data set can be displayed. The block is specified by 'curves' (number of curves, <128) and 'first' (first curve to be displayed) in the main window.

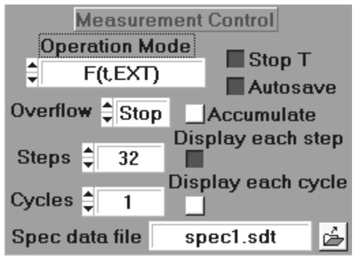
More than the maximum number of curves for the given module type can be measured by using the 'Autosave' function. If 'Autosave' is switched on, the measurement is repeated after the selected number of steps and the results are stored to a file. The file name includes a 3 digit number which is incremented after each new measurement. Thus each new measurement yields a new data file. This action is continued until the specified number of ‘Cycles’ is reached or the measurement is stopped by the operator.

Another option to repeat the whole recording sequence is the ‘Accumulate’ function. If ‘Accumulate’ is switched on, the recording of the specified number of steps - or curves measured one after another - is repeated and the results are accumulated in the SPC memory. The action is continued until the specified number of ‘Cycles’ is reached or the measurement is stopped by the operator.



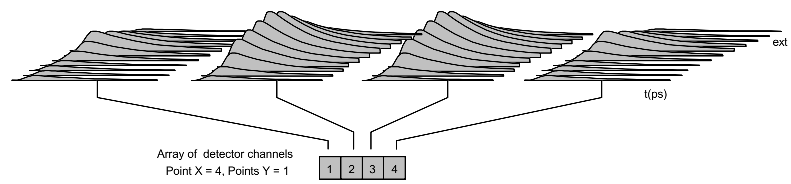
For the SPC-6, SPC-7 and SPC-134 modules, the f(t,T) mode can be controlled by the ‘Measurement Trigger’ (please see also ‘Routing and Control Signals’). The trigger action is defined under ‘Measurement Trigger’. It is possible to trigger the start of the sequence (i.e. each accumulation cycle) or the recording of each individual decay curve. The triggered f(t,T) mode is an excellent method to investigate transient changes in the decay functions after a stimulation event.

f(t,EXT) Mode (All SPC Modules)



In the f(t,EXT) mode the measurement of a single curve is repeated for different settings of an externally variable parameter. This may be the wavelength setting of a monochromator or the position of the detector. The measured curves are stored one after another in the memory. The measurement steps are controlled by the stop conditions 'Stop T' and 'Stop Ovfl' as in the 'Single' mode. To control the external parameter the stepping motor controller STP-240 is used (see data sheet or www.becker-hickl.de). The STP-240 is an additional PC module which is controlled directly by the SPC software. The device is configured by the file STP.CFG which includes minimum and maximum values for the position, step width, motor speed, the unit of the controlled parameter etc. (see STP-240 description). During the particular measurement steps the intermediate results are displayed in intervals of 'Display Time'. Furthermore, the result is displayed after each step if 'Display after each Step' is switched on. Note that this requires a certain time which may increase the measurement time. In the f(t,EXT) mode only one memory page is available.

The f(t,ext) mode can be used in conjunction with the routing function. If several detector channels are active (PointsX or PointsY>1) a sequence of waveforms is recorded for each detector channel (figure below).



The f(t,ext) mode records one waveform sequence for each detector channel

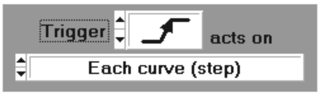
The maximum number of steps - or curves measured one after another - depends on the module type, the ADC Resolution and the number of Routing Channels used. Some examples are given in the table below.

Module Type	ADC Resolution	Routing Channels	Steps	Module Type	ADC Resolution	Routing Channels	Steps
SPC-7	4096	1	1024	SPC-6	4096	1	64
	4096	8	128		4096	8	8
	256	1	16384		256	1	1024
	256	8	2048		256	8	128
SPC-5	4096	1	1024	SPC-4	4096	1	32
	4096	8	128		4096	8	4
	256	1	16384		256	1	512
	256	8	2048		256	8	16
SPC-3-12	64 to 4096	1	32	SPC-3-10	64 to 1024	1	128
	64 to 4096	8	4		64 to 1024	8	16

When the specified number of steps - or curves measured one after another - has been completed the measurement stops and the result is displayed as a three-dimensional figure. When the display is in the ‘Curve’ mode the finite screen resolution does not allow to display more than 128 curves. Therefore, a specified block of curves out of a larger data set can be displayed. The block is specified by 'curves' (number of curves, <128) and 'first' (first curve to be displayed) in the main window.

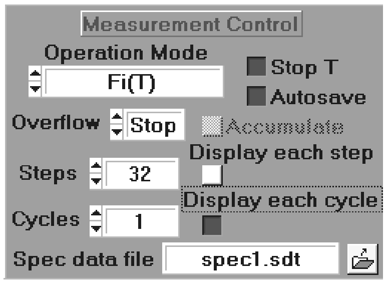
More than the maximum number of curves for the given module type can be measured by using the 'Autosave' function. If 'Autosave' is switched on, the measurement is repeated after the selected number of steps and the results are stored to a file. The file name includes a 3 digit number which is incremented after each new measurement. Thus each new measurement yields a new data file. This action is continued until the specified number of ‘Cycles’ is reached or the measurement is stopped by the operator.

Another option to repeat the whole stepping procedure is the ‘Accumulate’ function. If ‘Accumulate’ is switched on, the recording of the specified number of steps - or curves measured one after another - is repeated and the results are accumulated in the SPC memory. The action is continued until the specified number of ‘Cycles’ is reached or the measurement is stopped by the operator.



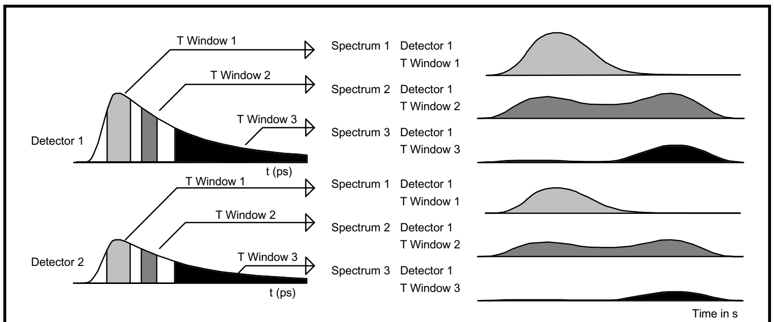
For the SPC-6, SPC-7 and SPC-134 modules, the f(t,ext) mode can be controlled by the ‘Measurement Trigger’ (please see also ‘Routing and Control Signals’). The trigger action is defined under ‘Measurement Trigger’. It is possible to trigger the start of the sequence (i.e. each accumulation cycle) or the recording of each individual decay curve.

fi(T) Mode (All SPC Modules)



The ‘fi’ modes are used to record time resolved spectra. The measurement of a single waveform is repeated in intervals of 'Repeat Time'. The counts in the channels of each curve are averaged within selectable time intervals (see ‘Window Intervals’). The results of the averaging represent the intensities in the selected windows. The subsequent values are displayed as a function of time. Up to eight time intervals can be selected to generate up to eight spectra for each detector channel (see 'Window Intervals'). The number of curve points is specified by the parameter 'Steps'.

The Fi(T) mode can be used in conjunction with a router or a multichannel detector head. The number of detector channels is specified by ' Routing Channels X' or ' Routing Channels Y'.



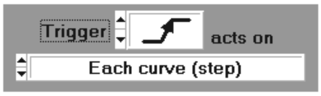
Spectrum Scan Mode fi(T) with Routing
For each T Window and each detector channel a spectrum is calculated

The maximum number of detector channels depends on the number of active time windows. For the SPC300/330, the product of the number of detector channels and time windows can be up to 128 for the 12 bit versions and 32 for the 10 bit versions. For the SPC-4x0 to SPC-7x0, the product depends on the ADC resolution and can be from 32 (Resolution 4096) to 1024 (Resolution 64). The display of the results is controlled by the ‘Trace Parameters’.

If 'Autosave' is switched on, the measurement is repeated after the selected number of 'Steps' and the results are stored to a file. The file name includes a 3 digit number which is incremented after each new measurement. Thus each new measurement yields a new data file.

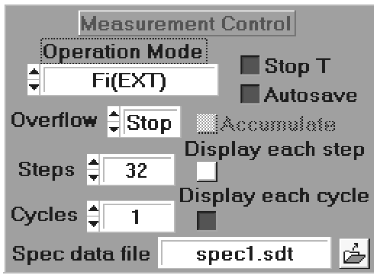
The action is continued until the specified number of ‘Cycles’ is reached or the measurement is stopped by the operator.

Intermediate results can be displayed by ‘Display each Step’ or ‘Display each Cycle’.



For the SPC-6, SPC-7 and SPC-134 modules, the fi(T) mode can be controlled by the ‘Measurement Trigger’ (please see also ‘Routing and Control Signals’). The trigger action is defined under ‘Measurement Trigger’. It is possible to trigger the start of the sequence (i.e. each accumulation cycle) or the recording of each step of the spectrum.

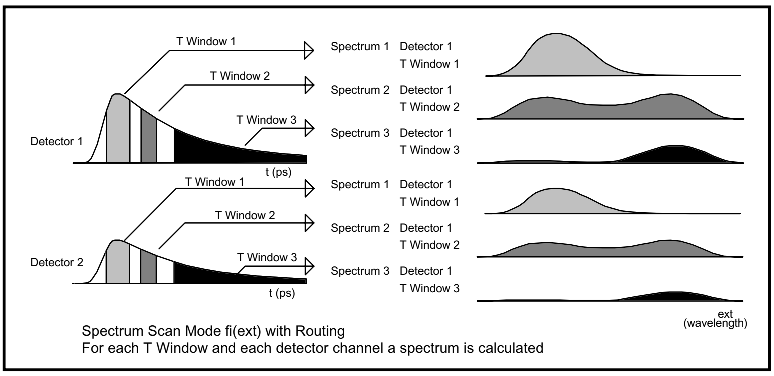
fi(EXT) Mode (All SPC Modules)



The ‘fi’ modes are used to record time resolved spectra. The measurement of a single waveform is repeated in intervals of 'Repeat Time'. The counts in the channels of each curve are averaged within selectable time intervals (see ‘Window Intervals’). The results of the averaging represent the intensities in the selected windows. The subsequent values are displayed as a function of an external parameter, usually the wavelength. Up to eight time intervals can be selected to generate up to eight spectra for each detector channel (see 'Window Intervals'). The number of curve points is specified by the parameter 'Steps'.

To control the external parameter the stepping motor controller STP-240 is used (see data sheet or www.becker-hickl.de). The STP-240 is an additional PC module which is controlled directly by the SPC software. The device is configured by the file STP.CFG which includes limiting values for the position, step width, motor speed, the unit of the controlled parameter etc. (see STP-240 description).

The Fi(EXT) mode can be used in conjunction with a router or a multichannel detector head. The number of detector channels is specified by 'Routing Channels X' and 'Routing Channels Y'.

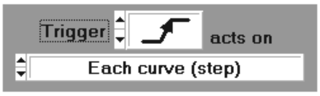


Spectrum Scan Mode fi(ext) with Routing
For each T Window and each detector channel a spectrum is calculated

The maximum number of detector channels depends on the number of active time windows. For the SPC300/330, the product of the number of detector channels and time windows can be up to 128 for the 12 bit versions and 32 for the 10 bit versions. For the SPC-400/430, the product depends on the ADC resolution and can be from 32 (Resolution 4096) to 1024 (Resolution 64). The display of the results is controlled by the Trace Parameters.

If 'Autosave' is switched on, the measurement is repeated after the selected 'Steps' number and the results are stored to a file. The file name includes a 3 digit number which is incremented after each new measurement. Thus each new measurement yields a new data file. The action is continued until the specified number of ‘Cycles’ is reached or the measurement is stopped by the operator.

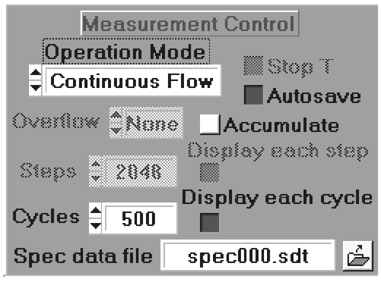
Intermediate results can be displayed by ‘Display each Step’ or ‘Display each Cycle’.



For the SPC-6, SPC-7 and SPC-134 modules, the fi(ext) mode can be controlled by the ‘Measurement Trigger’ (please see also ‘Routing and Control Signals’). The trigger action is defined under ‘Measurement Trigger’. It is possible to trigger the start of the sequence (i.e. each accumulation cycle) or the recording of each individual decay curve.

Continuous Flow Mode (SPC-4x0, SPC-6x0 and SPC-134 only)

The 'Continuous Flow' mode is targeted at single molecule detection in a continuous flow setup and other applications which require a large number of curves to be recorded in well-defined (usually short) time intervals. Unlike f(t,T), the ‘Continuous Flow’ mode is strictly hardware controlled and thus provides an extremely accurate recording sequence.



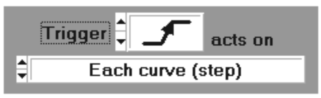
In the 'Continuous Flow' mode, decay curves are measured in intervals of 'Collection Time'. The measurement is repeated while the measurement system switches through all memory pages of both memory banks of the SPC-400/430, SPC-600/630 or SPC-134. While the measurement is running in one memory bank, the results of the other bank are read and stored to the hard disk. Thus, an virtually unlimited number of decay curves can be recorded without time gaps between subsequent recordings.

The number of curves in each memory bank - and consequently in each file - depends on the ADC resolution selected and the module type:

SPC-4x1/4x2:	ADC Resolution	4096	1024	256	64
	Curves / Memory Bank	32	128	512	2048
SPC-6x0:	ADC Resolution	4096	1024	256	64
	Curves / Memory Bank	64	2568	1024	4096
SPC-134:	ADC Resolution	4096	1024	256	64
	Curves / Memory Bank	64	2568	1024	4096

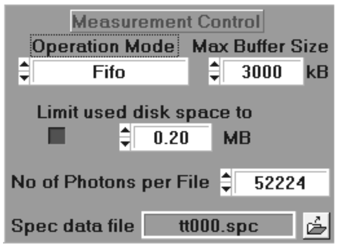
The Continuous Flow Mode can be used with the routing function. For each collection time interval the decay curves for all detector channels are measured simultaneously and stored in the memory. The number of curves per memory bank is reduced correspondingly.

The measurement stops when the specified number of ‘Cycles’ has been reached, i.e. ‘Cycles’ memory banks have been measured and the same number of data files have been created.



For the SPC-6 and SPC-134 modules, the Continuous Flow mode can be controlled by the ‘Measurement Trigger’ (please see also ‘Routing and Control Signals’). The trigger action is defined under ‘Measurement Trigger’. It is possible to trigger the start of the complete sequence, the start of the next memory bank or the recording of each individual decay curve.

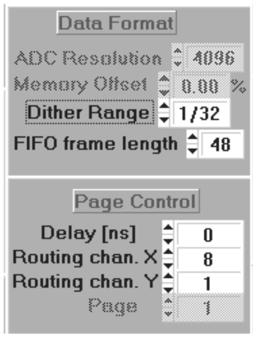
FIFO Mode (SPC-4x1/4x2 , SPC-6x0 and SPC-134only)



The 'FIFO' mode is available in the SPC-4x1/4x2, the SPC-600/630 and the SPC-134 only. This mode is used for single molecule investigations by the ‘BIFL’ method. For each photon the time within the laser pulse sequence and the time from the start of the experiment is stored. The memory is configured as a FIFO (First In First Out) buffer. During the measurement, the FIFO is continuously read by the device software and the results are stored to the hard disk of the computer.

Data from the FIFO mode can easily reach sizes of tens or hundreds of megabytes. The maximum used disk space can be limited by pressing the ‘Limit Disk Space’ button and specifying the amount of data. The measurement is stopped when the given disk space has been filled.

The overall measurement data can be divided into several subsequent data files. The current file is closed and a new file is created when a specified number of photons has been recorded (‘No of Photons per File’). The file names contain a 3-digit number which is automatically incremented for each subsequent file.



For the SPC-600/630, two different data formats are available. For the SPC-401/431, the SPC-402/432 and the SPC-134 the data format is fixed.

	FIFO Frame Length byte	Bytes/Photon	ADC Resolution channels	Macro Time Resol. bit	Routing channels
SPC-6	48	6	4096	24	256
SPC-6	32	4	256	16	8
SPC-4x1	48	6	4096	24	256
SPC-4x2	32	4	256	16	8
SPC-134	32*	4	4096	12	8

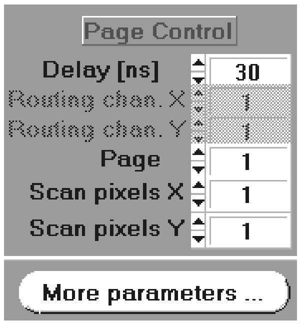
* Each of the four TCSPC channels delivers its own data file

The entry of each photon contains the time channel in which is was recorded, the macro time in the moment of its detection, and the detector channel where it was detected. The number of detector channels is fixed to 256 for the 6 byte mode and 8 for the 4 byte mode. If only one detector is used the detector channel number will be always ‘0’ (for detector No. 1).

By ‘Maximum Buffer Size’ a software buffer is specified which stores the data before they are saved to the hard disk. As long as the overall number of photons for the measurement is not very high (some 10^6) the buffer size should be made large enough to accept all photons of the measurement. Usually, the buffer size can be as large as 10 Mb for a computer with 32 Mb RAM. For very long recordings (the usual case for BIFL measurements) a small buffer size yields the highest data throughput.

For the SPC-600/630 and the SPC-134 the ‘Measurement Trigger’ is available also in the FIFO mode and can be used to start the measurement by an external trigger signal.

Scan Sync Out Mode (SPC-7x0 and SPC-5x5 only)

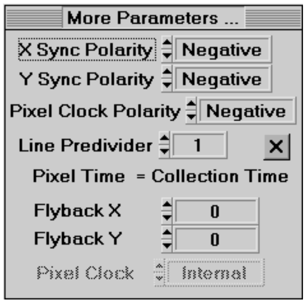


The ‘Scan Sync Out’ mode is used to record time resolved images with the SPC-505/535 and the SPC-700/730 modules. TheSPC-505 and SPC-535 are special versions of the SPC-500/530. The SPC-5x5 and the SPC-7x0 in the ‘Scan Sync Out’ control the destination curve number internally and deliver signals to control an external scanning device. For each pixel of the scanned image a complete waveform is recorded. The dwell time for each pixel is ‘Collection Time’. The maximum number of pixels depends on the ADC resolution selected:

ADC Resolution	64	256	1024	4096
No of Pixels (SPC-5)	16384	16384	4096	1024
No of Pixels (SPC-7)	65536	16384	4096	1024

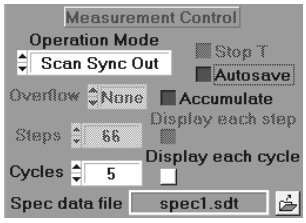
The scan can be either one-dimensional or two-dimensional. The number of steps in X- and Y-direction is specified by the parameters ‘Scan Pixels X’ and ‘Scan Pixels Y’ in the ‘Page Control’ Part of the system parameters.

The scanning parameters are defined under ‘More Parameters’. The meaning of the scanning parameters is listed below:



X Sync Polarity:	Polarity of X Sync Pulses, (H/L or L/H)
YSync Polarity:	Polarity of Y Sync Pulses, (H/L or L/H)
Pixel Clock Polarity:	Polarity of Pixel Clock Pulses, (H/L or L/H)
Line Predivider:	Values >1 combine several lines of the scanner into 1 line of the result
Flyback X:	Flyback time of the scanner for the X axis, defined as multiples of ‘Collection Time’.
Flyback Y:	Flyback time of the scanner for the Y axis, defined as multiples of ‘Collection Time’.

Additional control parameters are available under ‘Measurement Control’. The scanning action can be repeated for a specified number of ‘Cycles’ either by the ‘Autosave’ or ‘Accumulate’ function. With ‘Autosave’ each scan is stored in an independent data file. With ‘Accumulate’ the results are accumulated in the SPC memory.



The ‘Measurement Trigger’ is available in the scan modes. It acts as a start of the measurement and of each Accumulation or Autosave cycle.

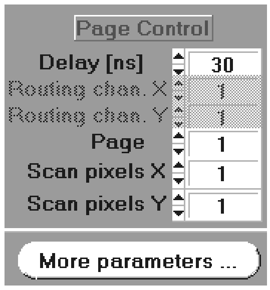
Scan Sync In Mode (SPC-7x0 and SPC-5x6 only)

The ‘Scan Sync In’ mode is designed to record images with scanners which deliver synchronisation pulses to the SPC module. Scan Sync In is the mode used for lifetime imaging with laser scanning microscopes. It can be used with ultrafast scanners which deliver video-like synchronisation signals.

The SPC-505/535 and the SPC-7x0 in the ‘Scan Sync Out’ mode use the synchronisation pulses from the scanner to control their internal destination curve number. For each pixel of the scanned image a complete waveform is recorded. The parameter ‘Collection Time’ defines the overall image recording time. The measurement stops at the end of the next frame after the collection time has expired.

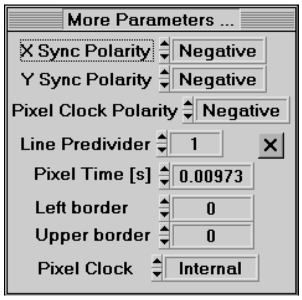
The maximum number of pixels depends on the ADC resolution selected:

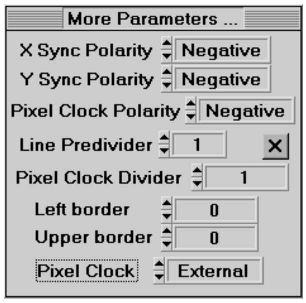
ADC Resolution	64	256	1024	4096
No of Pixels (SPC-5)	16384	16384	4096	1024
No of Pixels (SPC-7)	65536	16384	4096	1024



The number of pixels in X- and Y-direction is specified by the parameters ‘Scan Pixels X’ and ‘Scan Pixels Y’ in the ‘Page Control’ Part of the system parameters.

The scanning parameters are defined under ‘More Parameters’. The meaning of the scanning parameters is listed below:

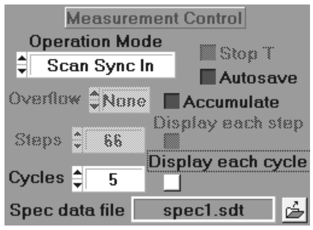




X Sync Polarity:	Polarity of X Sync Pulses, (H/L or L/H)
YSync Polarity:	Polarity of Y Sync Pulses, (H/L or L/H)
Pixel Clock Polarity:	Polarity of Pixel Clock Pulses, (H/L or L/H)
Line Predivider:	Predivider for X Sync. Values >1 merge several lines of the scanner into one line of the result.
Pixel Clock Divider:	Divider for ‘Pixel Clock External’, values >1 merge several pixels of the scanner into 1 pixel of the result.
Pixel Time:	For ‘Pixel Clock Internal’ only. Dwell Time per pixel for ‘Pixel Clock Internal’ Within one line, the pixel number is counted up in fixed time intervals set by ‘Pixel Time’.
Pixel Clock Predivider:	For ‘Pixel Clock External’ only. For Predivider > 1 several subsequent pixels of the scanner are combined into one result pixel.
Upper Border:	Number of lines which are not recorded at the start of each frame. Used to zoom into the image without changing the scanner operation.
Left Border:	Number of pixels which are not recorded at the start of each line. Used to zoom into the image without changing the scanner operation.
Pixel Clock:	The source of the pixel clock can be external (from the scanner) or internal. The internal pixel clock is derived from the system clock of the SPC board. Internal pixel clock required that the Xsync frequency from the scanner be constant and stable.

For video-compatible scanning (64us per line) the number of pixels recorded per line is

Pixel Time ns	400	800	1600	3200
Pixels / Line	160	80	40	20



The number of lines in the recorded image is:

Line Predivider	1	2	4	8
Lines / Frame	256	128	64	32

The image recording can be repeated for a specified number of ‘Cycles’ either by the ‘Autosave’ or ‘Accumulate’ function. With ‘Autosave’ each scan is stored in an independent data file. With ‘Accumulate’ the results are accumulated in the SPC memory.

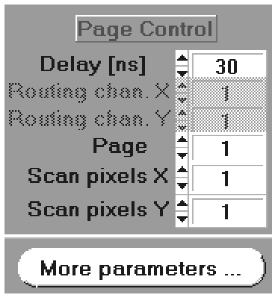
The ‘Measurement Trigger’ is available in the scan modes of the SPC-700/730. It acts as a start of the measurement and of each Accumulation or Autosave cycle.

Scan XY Out Mode (SPC-700/730 only)

The ‘Scan XY Out’ mode is used to record time resolved images with the SPC-700/730 modules. The SPC-7x0 in the ‘Scan Sync Out’ controls the destination curve number internally and delivers digital X and Y position signals to an external scanning device. For each pixel of the scanned image a complete waveform is recorded. The dwell time for each pixel is ‘Collection Time’. The maximum number of pixels depends on the ADC resolution selected:

ADC Resolution	64	256	1024	4096
No of Pixels	16384	16384	4096	1024

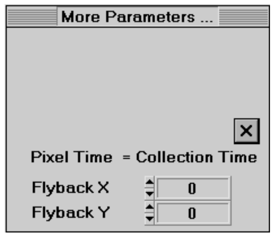
The scan can be either one-dimensional or two-dimensional. The number of steps in X- and Y-direction is specified by the parameters ‘Scan Pixels X’ and ‘Scan Pixels Y’ in the ‘Page Control’ Part of the system parameters.



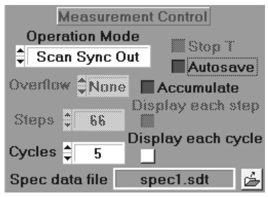
The scanning parameters are defined under ‘More Parameters’. The meaning of the scanning parameters is listed below:

Flyback X: Flyback time of the scanner for the X axis, defined as multiples of ‘Collection Time’. After the X position signal has switched back to the ‘0’ position the operation is suspended for the ‘Flyback X’ time to give the scanner mirror time to settle.

Flyback Y: Flyback time of the scanner for the Y axis, defined as multiples of ‘Collection Time’. After the Y position signal has switched back to the ‘0’ position the operation is suspended for the ‘Flyback Y’ time to give the scanner mirror time to settle.



Additional control parameters are available under ‘Measurement Control’. The scanning action can be repeated for a specified number of ‘Cycles’ either by the ‘Autosave’ or ‘Accumulate’ function. With ‘Autosave’ each scan is stored in an independent data file. With ‘Accumulate’ the results are accumulated in the SPC memory.



The ‘Measurement Trigger’ is available in the scan modes of the SPC-700/730. It acts as a start of the measurement and of each Accumulation or Autosave cycle.

Control Parameters (Non-FIFO Modules or Non-FIFO Modes)

The effect and availability of the measurement parameters depend on the module type and the selected operation mode. Therefore, the parameter description below should be understood as an overview and should be seen in conjunction with the section ‘Operation Modes’.

Stop Ovfl

With 'Stop Ovfl' the measurement stops at the first overflow in the measurement system. In conjunction with the ‘Count Increment’ parameter 'Stop Ovfl' can be used to record different curves with the same height of the maximum disregarding the pulse shape or light intensity.

Corr Ovfl

The 'Correct Overflow' function is used to record data with more than 65535 photons/channel. If 'Correct Overflow' is set the data is transferred to the PC memory when an overflow occurs. The data is added to the data which is already present there and the memory of the measurement system is cleared. The measurement is then restarted until the collection time is over or the measurement is stopped by the operator. At the end the result in the PC memory is divided by the number of overflows and transferred back to the measurement system memory. The result has 16 bits again, but the standard deviation of the data is reduced by the square root of the number of overflows. The 'Correct Overflow' function is available in the 'Single' mode only. It acts on the active traces only (see 'Trace Parameters').

Repeat

If 'Repeat' is set the measurement repeats automatically in intervals of 'Repeat Time'.

Autosave

'Autosave' is used to repeat the measurement and to store the results into subsequent data files. ‘Autosave’ is not available in all operation modes. Please refer to section ‘Operation Modes’.

Accumulate

‘Accumulate’ is used to repeat a measurement and to accumulate the results in the SPC memory. ‘Accumulate’ is not available in all operation modes. Please refer to section ‘Operation Modes’.

Stop T

With 'Stop T' set the measurement is stopped at the end of 'Collection Time'.

Steps

'Steps' is the number of subsequently measured curves in the operation modes f(t,T), f(t,Ext). In the fi modes, ‘Steps’ is the number of subsequently measured curves, which are converted into one point of the result curve each. Please refer to section ‘Operation Modes’.

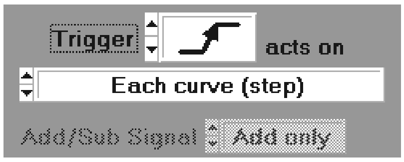
Cycles

Measurements consisting of several ‘Steps’ (sets of subsequently measured curves) can be repeated and stored to subsequent data files or accumulated in the SPC memory. ‘Cycles’ gives the number of measurements to be stored or accumulated. Please refer to section ‘Operation Modes’.

Display after each step

If 'Display after each step' is switched on, in the operation modes f(t,T) and f(t,EXT) the intermediate results are displayed when the data collection for a new curve has finished.

Measurement Trigger



The SPC-6, SPC-7 and the SPC-134 modules have a ‘Measurement Trigger’. Depending on the measurement mode it is used to trigger a measurement (Single, Oscilloscope), the start of a measurement sequence (f(t,T), Continuous Flow), the next step of a sequence (Continuous Flow), the start of the next accumulation cycle (f(t,T) etc. The function of the trigger for the particular mode is described under ‘Operation Modes’. The trigger condition can be set to ‘Rising Edge’, ‘Falling Edge’ or ‘None’. If the trigger is not used the trigger condition must be ‘None’.

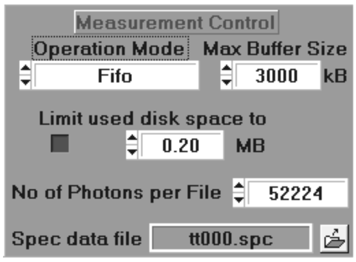
The trigger input is shared with the ‘Add/Sub’ line used for lock-in-SPC. Therefore, the trigger is not available when the Add/Sub signal is used and vice versa.

Add / Sub Signal

The Add / Sub signal is used for Lock-in SPC, i.e. to externally control whether a photon is added or subtracted. The Add / Sub signal shares one pin of the control connector with the Measurement Trigger signal. Therefore, the Add/Sub signal is not available when the trigger is used and vice versa. Add / Sub should be set to ‘Add Only’ when it is not used.

Control Parameters (FIFO Modules or FIFO Modes)

Maximum Buffer Size



By ‘Maximum Buffer Size’ a software buffer is specified which stores the data before they are saved to the hard disk. As long as the overall number of photons for the measurement is not very high (some 10^6) the buffer size should be made large enough to accept all photons of the measurement. One photon occupies 4 bytes for the SPC-401/431 and 2 bytes for the SPC402/432. For the SPC-6 modules, the number of bytes is determined by ‘FIFO Frame Length’ (see ‘Page Control’). Usually, the buffer size can be as large as 10 Mb for a computer with 32 Mb RAM.

For very long recordings (the usual case for BIFL measurements) a small buffer size yields the highest data throughput.

Limit Disk Space to

Data from the FIFO mode can easily reach sizes of tens or hundreds of megabytes. The maximum used disk space can be limited by pressing the ‘Limit Disk Space’ button and specifying the amount of data. The measurement is stopped when the given disk space has been filled.

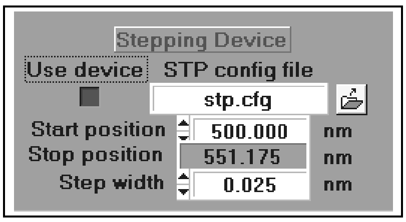
No of Photons per File

The overall measurement data can be divided into several subsequent data files. The current file is closed and a new file is created when a specified number of photons has been recorded (‘No of Photons per File’). The file names contain a 3-digit number which is automatically incremented for each subsequent file.

Data file name

In the FIFO Mode one or more data files are created which contain the data of the subsequently recorded photons. These measurement data files have the extension ‘.spc’. At the end of the measurement, a setup data file is generated which contains the hardware and software parameter used. The setup data file has the same name as the last measurement data file and has the extension ‘.set’.

Stepping Device (Non-FIFO Modes only)



Under 'Stepping Device' the parameters of the (optional) step motor controller are accessed.

Use Stepping Device

This parameters switches the software part for the stepping device on and off. If no stepping device is present in the system, the parameter must be 'off'.

STP Config file

The step motor control is configured by the specified file. By default the file 'STP.CFG' is used. To vary the drive parameters several configuration files may be created and selected by 'STP config file'.

Start Position

This parameter specifies the start position of the drive. It can be set within the limits set by the configuration file. The unit for the start position is also taken from this file.

End Position

The end position is calculated from the selected start position and step width.

Step width

The step width of the drive is selected with 'Step width'. It can be set within the limits set by the configuration file. The unit for the step width is also taken from this file.

Timing Control Parameters

Collection Time (Non FIFO Modes Only)

In most operation modes 'Collection Time' is the overall time of a measurement. In the ‘Scan Sync Out’ and ‘Scan XY Out’ modes ‘Collection Time’ is the time to acquire one pixel of the image. In the SPC-3 modules, the collection time interval is dead-time compensated. It automatically increases by the time intervals in which the system is 'blind' due to the processing of a detected photon. In the SPC-4, SPC-5, SPC-6 and SPC-7 modules the dead time compensation can be switched on or off.

Repeat Time (Non FIFO Modes Only)

If 'Repeat' is set in the 'single' mode the measurement is repeated after 'Repeat Time'. In the modes f(t,T) and fi(t,T) the particular measurement cycles are started in intervals of 'Repeat Time'. Values smaller than 'Collection time' are rejected by the software. This is, however, no guarantee that the duration of the measurement cycle is shorter than 'Repeat Time' because the collection time interval can be dead-time compensated. If the current measurement cycle is not finished when 'Repeat Time' is over the next measurement will start when the current one is complete. If an exact repeat time is important, choose a repeat time significantly greater than collection time.

Display Time (Non-FIFO Modes)

In the 'Single', f(t,x,y) and f(t,T) modes intermediate results are displayed on the screen in intervals of 'Display Time'. Because the measurement is stopped to read and display the results you should chose 'Display Time' not shorter than necessary in order not to increase the measurement time.

Display Time (FIFO Modes)

In the FIFO mode intermediate results are displayed only if 'Display Time' is set > 1 s. In this case the software analyses the photon data when writing to the hard disk and builds up histograms in intervals set by the parameter ‘Display Time’. Because the data is written to the hard disk only when the software buffer is full the actual display rate can change with the ‘Buffer Size’ and the count rate. The display consumes considerable computing power and therefore reduces the average photon count rate that can be stored to the hard disk. We recommend to switch the display off by ‘Display Time <1 s’ for measurements that require maximum speed.

Dead Time Compensation On/Off (SPC-4, -5, -6, -7 and SPC-134)

The ‘Dead Time Compensation’ function increases the collection time intervals by the sum of the dead time caused by the processing of all recorded photons. Thus, a linear intensity scale is achieved up to high count rates. In the SPC-4, -5, -6 and -7 modules the dead time compensation can be switched off by the ‘Dead Time Compensation’ button.

The ‘Dead Time Compensation’ has no meaning in the FIFO Modes.

CFD Parameters

Limit Low

This is the lower discriminator level, i.e. the threshold of the CFD. Pulses with amplitudes smaller than 'Limit Low' are not counted. The parameter range for 'Limit Low' is 5 mV to 80 mV for SPC-x00 modules and -20 mV to -500 mV for SPC-x30 modules.

Limit High (SPC-x00 only)

'Limit High' is the upper discriminator level. Pulses with amplitudes greater than 'Limit High' are not counted. They do, however contribute to the displayed CFD count rate due to the structure of the CFD (see 'Constant Fraction Discriminator'). 'Limit High' is available for the SPC-x00 modules only. The range for 'Limit High' is 5 mV to 80 mV.

ZC Level

'ZC Level' is the comparator threshold of the zero cross trigger in the CFD. The value has a range of -10 mV to +10 mV for the SPC-x00 modules and -100 mV to +100 mV for the SPC-x30 modules.

Hold (SPC-x00 only)

When the CFD has detected a pulse within the window 'Limit Low' to 'Limit High' this information is valid for the selected 'Hold' time only. The parameter is normally set to 5ns. Longer values may be useful for detectors with rise times greater than 5ns. 'Hold' is available for the SPC-x00 modules only.

SYNC Parameters

ZC Level

'ZC Level' is the threshold of the zero cross trigger in the SYNC channel. The value has a range of -10 mV to +10 mV for the SPC-x00 modules and -100 mV to +100 mV for the SPC-x30 modules.

Freq Div

'Freq Div' is the frequency divider ratio in the SYNC channel. The setting determines the number of signal periods covered by the result. Important note: Freq Div must be set to 1 for measurements at low repetition rates.

Holdoff

When the SYNC has triggered the detection of an new trigger pulse is rejected for the 'Holdoff' time. 'Holdoff' is used to avoid multiple triggering by pulse ringing or reflections.

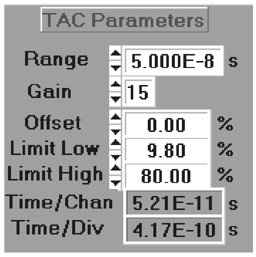
The 'Holdoff' range is from 4 ns to 16 ns. Please make sure that you don't set Holdoff greater than the period of your SYNC signal. This can produce non-equidistant internal synchronisation signals with correspondingly wrong measurement results.

Threshold (SPC-x30 only)

Input pulses with amplitudes smaller than the selected 'Threshold' are rejected by the SPC-x30 SYNC circuits. The range is from -20 mV to - 500 mV. The parameter is available for SPC-x30 modules only.

TAC Parameters

Range



'Range' is the overall length of the time window that can be measured. Values from 50 ns to 2 us are available. Internally the setting is done in five steps along with a 12 bit fine adjustment within the steps. Therefore virtually any value between 50 ns and 2 us is available.

Gain

'Gain' is the gain of the TAC signal amplifier. Consequently, the time scale is stretched if settings greater than one are used. Values of 1 to 15 are available.

Offset

With 'Offset' the displayed time range is shifted on the TAC characteristic. The result is shifted in X direction on the screen. 'Offset' can be set to 0...100 % of the overall TAC range. However, the remaining part of the TAC characteristic (from 'Offset' to 100%) should be long enough to fill the display window for the selected TAC Gain. The resolution of 'TAC Offset' is 12 bit or 4096 discrete values.

Limit Low

The TAC contains a window discriminator to suppress events outside a selected time interval. 'Limit Low' sets the lower limit of this interval. 'Limit Low' can be selected from 0% to 100% of the display window, but not higher than 'Limit High'.

Limit High

The TAC contains a window discriminator to suppress events outside a selected time interval. 'Limit High' sets the upper limit of this interval. 'Limit High' can be selected from 0% to 100% of the display window, but not lower than 'Limit Low' .

Time/Ch

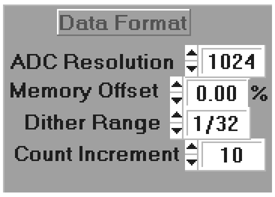
This value is the time per channel. It is displayed for information only. It is calculated from the settings of TAC Range, TAC Gain and ADC Resolution.

Time/div

This value is the time per division. It is displayed for information only. It is calculated from the settings of TAC Range, TAC Gain and ADC Resolution.

Data Format

ADC Resolution (Non-FIFO Modes)



This parameter is the resolution of the AD converter or the number of time channels. Due to the different memory structure of the SPC-300/330 and SPC-4, -5, -6, -7 and -134 modules 'Resolution' has different effects depending on the module type.

In the SPC-300 and SPC-330 modules 'Resolution' can be set from 64 to 1024 for 10 bit (-10) modules and from 64 to 4096 for 12 bit (-12) modules. 'Resolution' acts on the display of the data only. The measurement always yields data with 1024 or 4096 channels. If a reduced resolution is selected the data of adjacent channels is averaged and displayed as one data point. Thus the channels can contain more than 65535 photons if not the maximum resolution is used. Furthermore, the resolution can be changed even after the measurement to inspect the results with different resolutions.

In the SPC-4, -5, -6 and -7 modules and in the SPC-134 'Resolution' can be 64, 256, 1024 and 4096. The parameter does not only control the display of the data, but also the data structure in the memory. Consequently, for lower resolution settings more curves can be stored in the memory than in the SPC-300/330 modules. Furthermore, the SPC-5 and -7 have a much bigger memory. The number of curves available in these modules is given below:

SPC-134				
ADC Resolution	64	256	1024	4096
No of Curves	8192	2048	256	642
No of curves addressed by external routing signal	128	128	128	64

SPC-400/430				
ADC Resolution	64	256	1024	4096
No of Curves	4096	1024	128	32
No of curves addressed by external routing signal	128	128	128	32

SPC-500/530				
ADC Resolution	64	256	1024	4096
No of Curves	16384	16384	4096	1024
No of curves addressed by external routing signal	16384	16384	4096	1024

SPC-600/630, SPC-134				
ADC Resolution	64	256	1024	4096
No of Curves	8192	2048	256	642
No of curves addressed by external routing signal	128	128	128	64

SPC-700/730				
ADC Resolution	64	256	1024	4096
No of Curves (Scan Sync IN/Out)	65536	16384	4096	1024
No of curves addressed by external routing signal	16384	16384	4096	1024

ADC Resolution (FIFO Modes)

In the FIFO mode the ADC resolution is 256 or 4096. For the SPC-6 the resolution can be selected by ‘FIFO Frame Length’. For the SPC-4x1 and the SPC-134 the resolution is fixed to 4096, for the SPC-4x2 to 256.

Memory Offset (Non-FIFO Modes only)

When the Lock-in capability of the bh SPC modules is used negative result values can occur. To avoid a clipping of these values at zero the baseline can be shifted to values greater than zero with 'Memory Offset'.

Dither Range

'Dither Range' controls the ADC error correction used in the SPC modules (see section 'ADC Error Correction'). Greater values of 'Dither Range' improve the differential nonlinearity. At the same time the unusable parts of the ADC characteristic increase.

The parameter is given in points for the SPC300/330 and in a fraction of the overall ADC range for the SPC-4, -5, -6 and -7 modules. For the SPC-300/330 we recommend to use a value of 64 for 10 bit modules and 256 for 12 bit modules. For the other modules 1/16 or 1/8 is the best choice.

Count Increment (Non-FIFO Modes only)

'Count Increment' is the value which is added in the memory at the detection of each photon. Values greater than one will cause the measurement to proceed faster. Although this will not give any improvement of accuracy it can be used to get a higher curve in the oscilloscope mode or to get a 'stop on overflow' at less than 65535 counts. Furthermore, an appropriate Count Increment in conjunction with ‘Stop Overflow’ can be used to normalise curves to the same maximum value independently of the pulse shape and the count rate.

The parameter may look unusual for you at first glance, especially if you are familiar with conventional NIM TCSPC systems. It is, however, a convenient means to make the measurement control more flexible.

FIFO Frame Length (SPC-6 in the FIFO Mode)

This parameter sets the data format for the SPC-600/630 in the FIFO Mode. For the SPC-4x1, the SPC-4x2 and the SPC-134 the FIFO Frame Length is fixed.

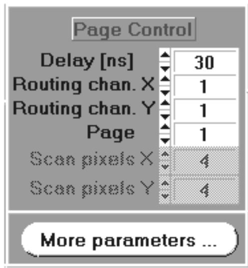
	FIFO Frame Length byte	Bytes/Photon	ADC Resolution channels	Macro Time Resol. bit	Routing channels
SPC-6	48	6	4096	24	256
SPC-6	32	4	256	16	8
SPC-4x1	48	6	4096	24	256
SPC-4x2	32	4	256	16	8
SPC-134	32*	4	4096	12	8

* Each of the four TCSPC channels delivers its own data file

Page Control

The memory of the SPC-300/330 module has space for up to 128 curves (32 curves for 12 bit modules). For the SPC-4, -5, -6 and -7 modules the number of curves depends on the module type and the ‘ADC Resolution’ and can be much higher (see ‘ADC Resolution’). In some of the measurement modes (e.g. f(t,x,y) or ‘Scan’ modes) the measurement data consist of a number of curves which are related to the individual detector channels or pixels of the scanned image. The Page Control parameters are provided to define the number and the spatial arrangement of the detector channels or the number and arrangement of the pixels of the image. If the number of curves per measurement is less than 50% of the module memory size the memory can hold the results of several measurements. In this case the memory is divided into several ‘Pages’ that hold the data of one measurement each.

Routing Channels X, Routing Channels Y



For multichannel measurements ‘Routing Channels X' and 'Routing Channels Y' are the number of rows and columns of the detector channels. To demonstrate the effect of the parameters some examples for the SPC-300/330 are given below.

1. Only one curve is recorded with a single channel detector. 'Routing Channels X' and 'Routing Channels Y' are set to 1. Thus the memory has 128 pages (32 pages for 12 bit modules) which hold one measurement or one curve each.
2. Four curves are recorded simultaneously by using four detectors and a 2 bit routing signal. For this measurement 'Routing Channels X'=4 and 'Routing Channels Y'=1 is set. Thus 32 pages are available (8 pages for 12 bit modules) with four curves each. The input of the routing signal will be automatically configured to accept 2 bits.
3. A multichannel detector with 8 rows and 8 columns is used. 'Routing Channels X' and 'Routing Channels Y' have to be set to 8 both. This yields 2 pages with 64 curves each. (Note that this measurement is not possible with an SPC-3x00-12 module which has 32 curves only.) The input of the routing signal is configured to accept 6 bits.

The product 'Routing Channels X' * 'Routing Channels Y' is always rounded to even 2^n values. For example, 'Routing Channels X'=9 and 'Routing Channels Y'=1 yields 16 curves per page and 8 pages in a SPC-3x0 10 bit module.

Scan Pixels X, Scan Pixels Y (Scan Modes)

These parameters are used for the ‘Scan’ modes of the SPC-5x5, -5x6 and SPC-7 modules. Channels X' and 'Routing Channels Y' are the number of pixel rows and columns in the scanned image. They act in the same way as 'Routing Channels X' and 'Routing Channels Y' for the f(t,x,y) mode.

Page (Non-FIFO Modes)

Page is the memory block in which the result of the measurement is stored. The page size is 'Routing Channels X' * 'Routing Channels Y' or ‘Scan Pixels X’ * ‘Scan Pixels Y’, rounded to the next greater 2^n value. If the page size is less than 50% of the module memory the memory is divided into several ‘Pages’ which hold the results of one measurement each.

Delay (Not for SPC-134)

'Delay' determines the moment when the routing and control signals for multichannel measurements are read. The delay is referred to the pulse at the CFD input. 'Latch Delay' has a range from 0 to 255ns. Note that an internal latch delay of 5..10ns and the cable delays must be taken into account. Furthermore, values greater than 100ns reduce the maximum count rate of the device. ‘Delay’ is not available for the SPC-134 modules.

Memory Bank (SPC-400/430, SPC-600/630 and SPC-134 in NON-FIFO Modes)

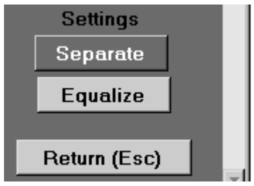
The SPC-400/430, the SPC-600/630 and the SPC-134 have a dual memory. 'Memory Bank' switches between the two memories.

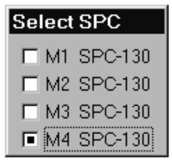
More Parameters

Depending on the module type and the operation mode special parameters (e.g. to control a scanner) are available. These parameters are described under the ‘Operation Modes’ for these modules.

Parameter Management for Multi-SPC Configurations

For Multi-SPC systems (such as the SPC-134) each module has its own system parameters, and the currently displayed System Parameter Panel refers to one of the modules only. To specify the module to which the parameters refer a small 'Select SPC' panel is present and can be conveniently placed anywhere in the screen area.

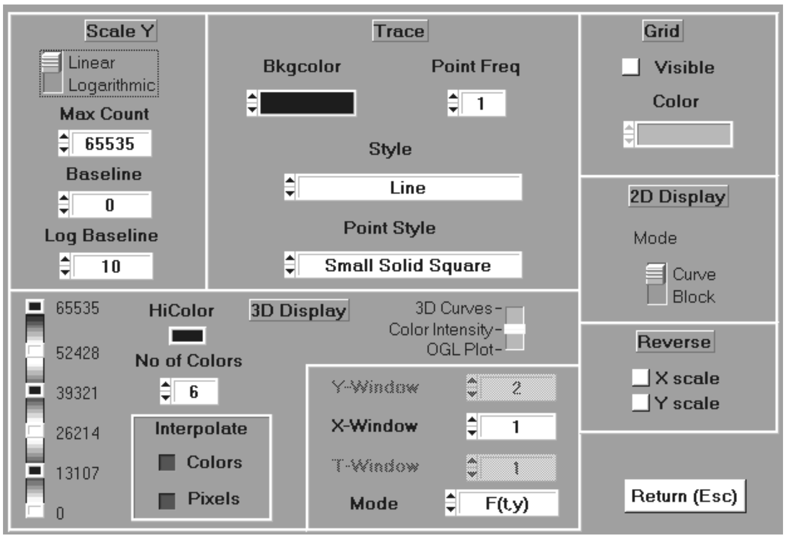




Furthermore, you can use the 'Separate / Common' button to decide whether subsequent parameter changes should be for all module or for the specified module only. If you want to set the same parameters for all modules, click on the 'Equalise' button. The parameters for the current module are then transferred into all other modules. If a parameter is has not the same value in different modules it is highlighted by a different colour in the system parameter panel.

Display Parameters

The layout of the curve display is controlled by the display parameters. The display parameter menu is shown in the figure below.



General Display Parameters

Scale Y

Under 'Scale Y' you can switch between a linear or a logarithmic display of the curves. Furthermore, the curve window can be set to a fraction of the maximum number of photons.

Linear / Logarithmic: Linear or logarithmic Y-scale
Max Count: Upper limit of the display range at linear or logarithmic scale
Basln: Lower limit of the display range for linear scale
Log Basln: Lower limit of the display range for logarithmic scale

Trace

Bkgcolor: Background colour of the curve window.

Style: Display style of the curves. The styles 'Line', 'Points Only' and 'Connected Points' are available.

Point Freq: At values >1 each n-th point is displayed only. 'Point Freq' has no influence if 'Line' is selected.

Grid

Visible: Toggles the grid on and off.
Color: Grid colour.

Reverse

Reversing both axis of the display can be achieved by the two buttons ‘X scale’ and ‘Y scale’. In the standard modes ‘single’ or ‘oscilloscope’ reversing is normally switched off. However, if the results of scan operations (spectra or images) are displayed, the ‘reverse’ buttons can be used to swap the image into the desired orientation. ‘Reverse’ works in all display modes. It acts on the display only, not on the data in the memory.

2D Display Parameters

Curve: Each curve (trace) on the screen is related to one curve in the memory which is set by the 'Trace Parameters'.

Block: Each curve (trace) on the screen is the average of several curves in the memory. The relation is set by the 'Trace Parameters' and the 'Window Intervals'. The block mode of the display is used to display multichannel measurements in the 2D display mode.

Curve Mode and Block Mode have no meaning in the FIFO Mode. The parameters are not available in this mode.

3D Display Parameters

To display results obtained in the f(t,x,y), f(t,ext) or f(t,T) mode three different three-dimensional display modes are provided. The parameters are not available in the FIFO Mode.

The ‘3D Display’ part of the display parameter menu changes with the display mode selected.

The ‘3D Curves’ mode displays the results as a set of curves. The Y axis represents the number of photons, the X and Z axis the parameters x, y, t or EXT.

The ‘Colour Intensity’ Mode transforms the light intensity into a grey or colour scale. The X and Y axis represents two of the parameters x, y, t or EXT.

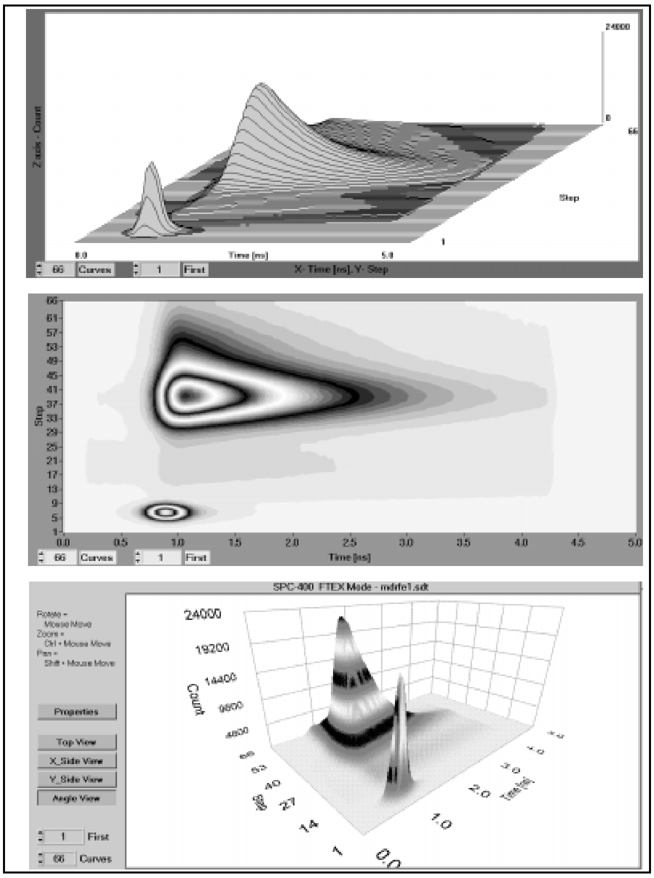
The ‘OGL Plot’ mode shows the results as a curved and coloured surface with the number of photons as Y axis and either x, y, t or EXT as X and Z axis. The styling possibilities in the OGL plot are manifold. However, if the amount of data is high, the OGL plot can be very slow. The OGL plot is available in the Windows 95/98/NT version of the SPC software only.

Examples for the three display modes are shown in the figure below.

3D Curves

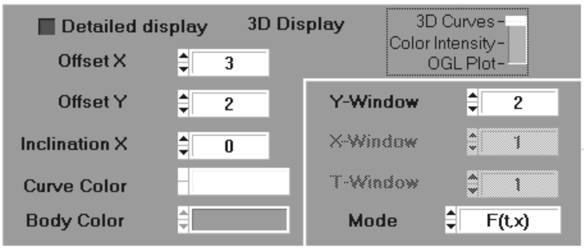
Colour Intensity Mode

OGL Plot



3D Curve Mode Parameters

The ‘3D Display’ part of the display parameter menu changes with the display mode selected. When the 3 D display is switched to ‘3D Curves’ the display parameters are as shown in the figure below.



Offset X: Offset X is the shift in X direction between subsequent curves in the three-dimensional display

Offset Y: Offset Y is the shift in Y direction between subsequent curves in the three-dimensional display

Inclination X: This parameter determines the inclination of the X axis of the three-dimensional display.

Curve Color: Colour of the curves

Body Color: The 'mountains' in the three-dimensional display can be painted with a colour different from the background colour.

The X, Y and T windows and the ‘Mode’ setting are used to select subsets of 4-dimensional data sets (please see also ‘Window Intervals’).

f(t,x): 3-dimensional display of waveforms recorded in a spatially 2-dimensional (x,y) measurement. It displays waveforms with subsequent X values. Each displayed waveform is the average of all curves within the selected 'YWindow'. (see 'Window Intervals')

f(t,y): 3-dimensional display of waveforms recorded in a spatially 2-dimensional (x,y) measurement. It displays waveforms with subsequent Y values. Each displayed waveform is the average of all curves within the selected 'XWindow'. (see 'Window Intervals')

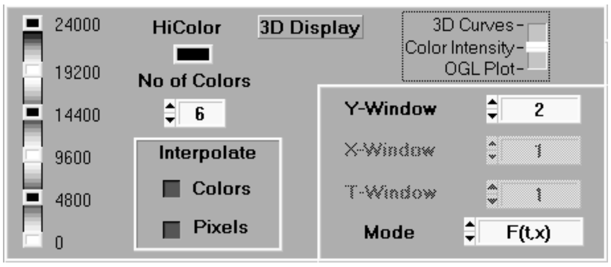
f(x,y): 3-dimensional display of waveforms recorded in a spatially 2-dimensional (x,y) measurement. Each point represents the average intensity within the selected 'T window'. (see 'Window Parameters')

Y-Window: Y window in the f(t,x) display mode. Up to 8 Y Windows are available.
X-Window: X window in the f(t,y) display mode. Up to 8 X Windows are available.
T-Window: T window in the f(x,y) display mode. Up to 8 T Windows are available.

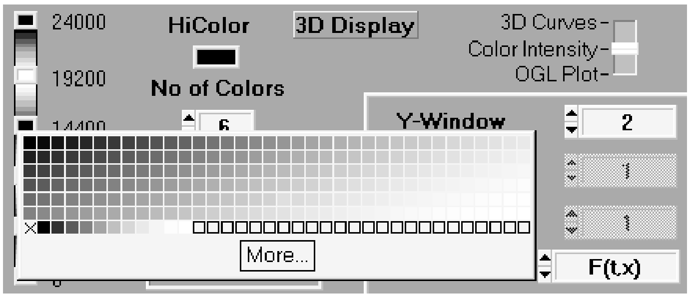
Detailed Display: In the ‘Detailed Display’ mode all points of the result curves are displayed. For a high number of curves and high ADC resolution this can be very time-consuming. Furthermore, under Windows 3.1 the memory problems can arise. Therefore, a compressed display style is available by switching off the ‘Detailed Display’ function.

Colour-Intensity and OGL Mode Parameters

When the display mode is switched to ‘Colour Intensity’ or ‘OGL Plot’ the display parameters are as shown below.



The colours of the display are assigned to the number of photons by the colour bar on the left side. The scale of the colour bar is set by the parameters under ‘Scale Y’ (MaxCount, Baseline, Log Baseline, Linear/Logarithmic). The number of different colours is set by ‘No of Colors’. The colours are selected by clicking on the exaggerated fields in the colour bar. This opens a colour table (see figure below) from which the colours can be selected.



For image areas with photon numbers exceeding the upper end of the colour bar ‘HiColor’ is used. This colour is set in the same way as the colours in the bar.

The ‘Interpolate’ function is used to provide intermediate colours (‘Color’ button) and to smooth images between the pixels (‘Pixels’ button).

The X, Y and T windows and the ‘Mode’ setting are used to select subsets of 4-dimensional data sets.
f(t,x): 3-dimensional display of waveforms recorded in a spatially 2-dimensional (x,y) measurement. It displays waveforms with subsequent X values. Each displayed waveform is the average of all curves within the selected 'YWindow'. (see 'Window Intervals')

f(t,y): 3-dimensional display of waveforms recorded in a spatially 2-dimensional (x,y) measurement. It displays waveforms with subsequent Y values. Each displayed waveform is the average of all curves within the selected 'XWindow'. (see 'Window Intervals')

f(x,y): 3-dimensional display of waveforms recorded in a spatially 2-dimensional (x,y) measurement. Each point represents the average intensity inside the selected 'T window'. (see 'Window Parameters')

Y-Window: Y window in the f(t,x) display mode. Up to 8 Y Windows are available.
X-Window: X window in the f(t,y) display mode. Up to 8 X Windows are available.
T-Window: T window in the f(x,y) display mode. Up to 8 T Windows are available.

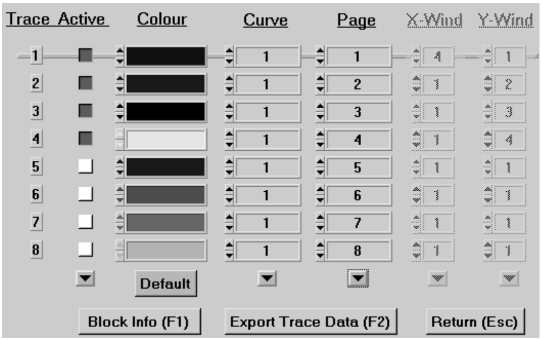
Special OGL Plot Parameters

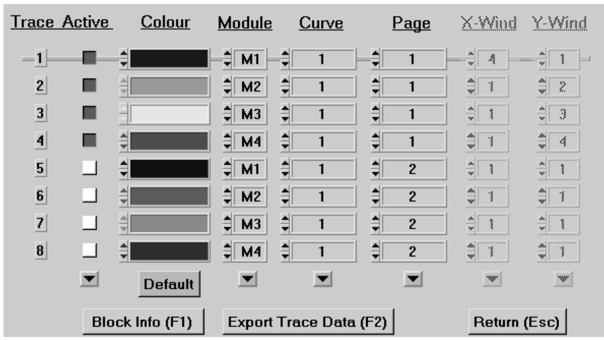
More OGL Plot parameters are available via the ‘Properties’ near the display window when the OGL plot is active. These parameters are not normally needed for typical TCSPC applications. Let your children help you to try out all settings!

Trace Parameters

Trace Definitions

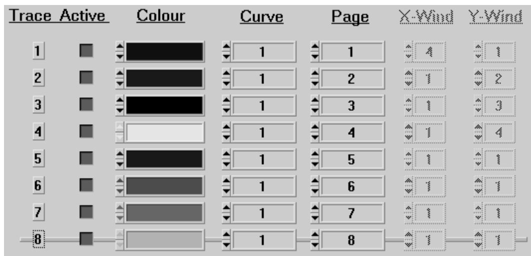
Up to eight different curves can be simultaneously displayed in the curve window and in the ‘2D Display’. These curves can be the measured waveforms, time resolved spectra measured in the fi modes, data loaded from a data file or - in the ‘Block Mode’ of the 2D display - averaged data from several curves from a multichannel or ‘Scan’ mode measurement. The curves on the screen are referred to as 'Traces'. The Trace Parameters define which information the traces contain and in which colour they are displayed. The Trace Parameter panels for the SPC Standard Software and for the Multi SPC Software are shown in the figure below.





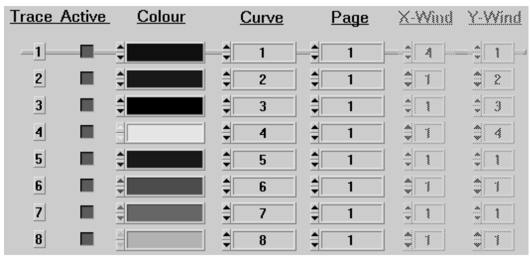
To each trace a module number (for Multi SPC), a curve number, a page number and an X Window, a Y Window and a T windows is related (please see ‘Window Parameters’). The curve number is used in the curve mode, the windows are used in the block mode of the display (please see ‘Display Parameters’). With 'active' a particular trace can be switched on or off. We recommend to switch off traces that are not needed. This increases the speed of the display. The meaning of the trace parameters is demonstrated by some examples.

The setting shown in the figure right is normally used for single detector measurements. The eight ‘pages’ contain the results of eight individual measurements. The results are displayed together on the screen. Other pages can be selected depending on the module type and the used ADC resolution.



Trace Parameters for Single Detector Measurement

The next figure shows the trace parameters as they are used for multi-detector measurements or for measurements in the ‘Scan’ modes of the SPC-7. The 2D Display is in the ‘Curve Mode’ and shows the first eight detector channels or the first eight pixels of the scanned image. Other curve numbers can be used within the used number of detector channels or pixels.

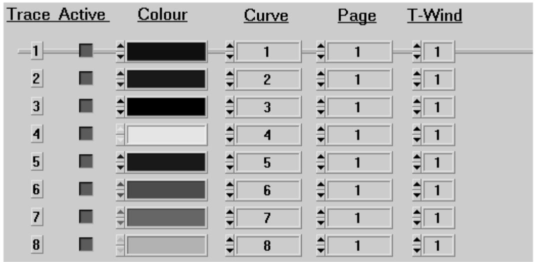


Trace parameters for Multichannel Measurement (Curve Mode)

If the 'Block Mode' of the 2D display is used the trace parameter window is as shown in the figure right. In this mode, the 2D display shows curves that represent the average of several detector channels or pixels of the recorded image. The channels are selected by the ‘X Window’ and the ‘Y Window’ (for definition see ‘Window Parameters’). For the setting shown right averaged decay curves in the first eight X windows and the first Y Window are displayed. Other combinations of X and Y windows can be used depending on the number of detector channels, pixels and windows defined in the Window Parameters.

Trace Parameters for Multichannel Measurement, Block Mode

The Trace Parameters are also used to display time-resolved spectra recorded by the ‘Spectrum’ modes fi(T) and fi(ext). These modes record spectra in the 8 ‘T Windows’ for each detector channel. (Please see ‘System Parameters’, ‘Operation Modes’ and ‘Window Parameters’) With the setting shown in the figure right, the spectra recorded in the T Windows 1 to 4 are displayed for the detector channels defined by ‘Curve’.

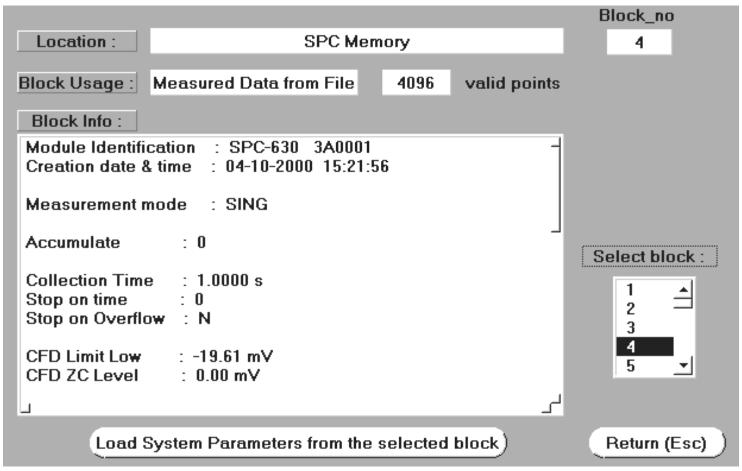


Trace Parameters for Spectrum Modes

Note: If you activate traces that display curves without valid data erratic data may appear. The reason is, that the measurement data memory is not cleared at the start of the program. This is done intentionally to have a chance of saving valuable data after a program crash or an unwanted exit. The data in the SPC memory will normally survive the crash or the exit and can be saved after rebooting the computer and restarting the SPC software. (Save with option ‘selected data blocks’)

Block Info

The ‘Block Info’ button opens a window containing detailed information about a selected data block. This includes the type and the number of the modules used to measure these data and the corresponding system parameters. The Block Info window is shown in the figure below.



Export of Trace Data

The measurement data contained in a selected trace can be exported into an ASCII file. Pressing the 'Export Trace Data' button opens dialog box to choose a file name and to start the conversion.

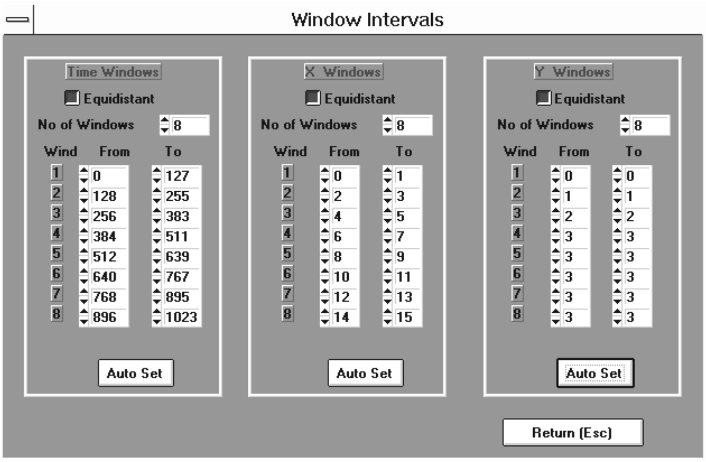
Exporting trace data is possible also in the 'Block Mode' of the display. In this case the trace data are calculated by averaging the set of curves selected for this trace.

Exporting trace data is convenient if selected parts of a 'Scan' or 'Multichannel' measurement are to be processed by an external data analysis program. For exporting larger data sets, please see 'Convert'.

Window Intervals

The window intervals are used to define subsets of multichannel and 'Scan' mode measurement data and to define the time windows of time resolved spectra. These parameters are not used for the FIFO mode.

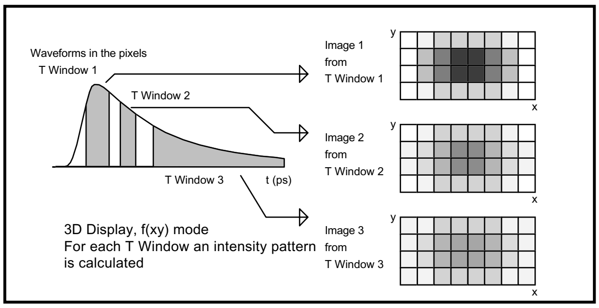
The window interval menu is shown in the figure below.



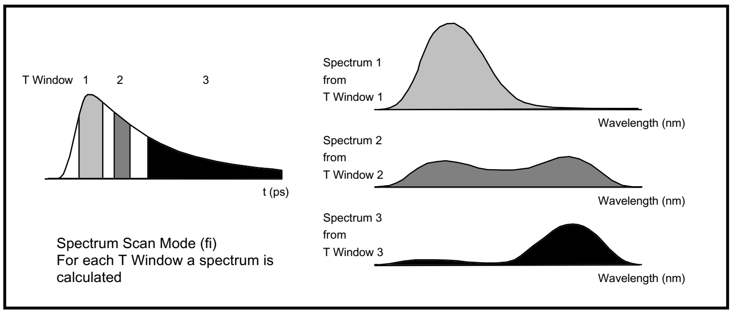
Time Windows

In the 'Time Windows' panel time intervals for calculating average intensities of the selected parts of the waveforms are defined. The time windows are used by the 3D display modes and by the spectrum modes fi(ext) and fi(t).

The 3 D display modes are used to display the results of f(t,x,y) or 'Scan' modes. These modes deliver a two-dimensional (x,y) array of points containing one waveform each. The results are four-dimensional data cubes with x, y, t and the photon number for each point. To display these results, one of the variables x, y, t is fixed and the result is displayed as a function of the other two variables. For the f(x,y) mode of the 3 D display, the 'Time Windows' define t intervals in which the photon numbers are averaged and displayed as a function of x and y. The figure below shows how a 4x8 pixel intensity pattern is derived from the 4x8 waveforms.



In the Spectrum Modes (‘fi’ modes) the measurement of a single waveform is repeated in intervals of 'Repeat Time' for different settings of an external parameter. From the waveform of each measurement step average intensities are calculated within the ‘T Windows’. The results of the averaging (i.e. the intensities) are displayed as a function of time or of the external parameter (e.g. wavelength). Up to eight time intervals can be selected to generate up to eight result curves for each detector channel. The principle is shown in the figure below.

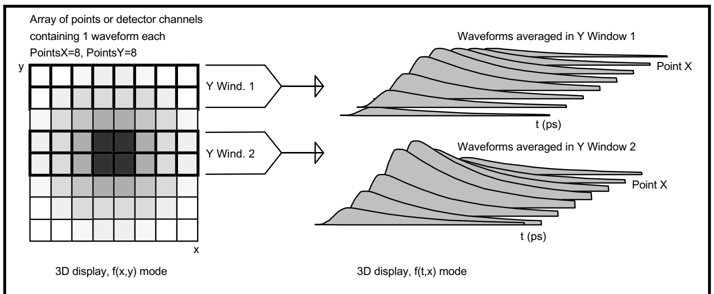


The spectrum modes can be used with routing. In this case the individual sets of spectra with different T Windows are calculated for each detector channel. (Please see also ‘X Windows, Y Windows’ and ‘System Parameters’, ‘Routing Channels X’ and ‘Routing Channels Y’.)

X Windows, Y Windows

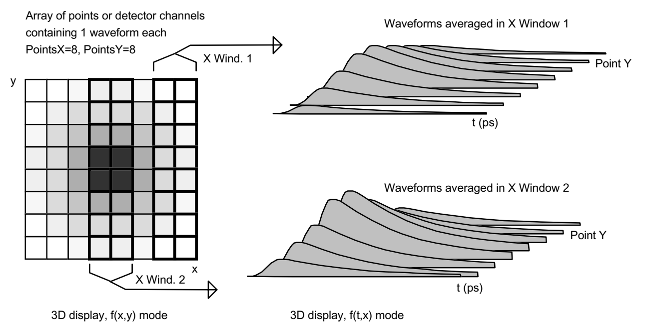
In the 'X Windows' and ‘Y Windows’ panels are used to define spatial (x,y) intervals in ‘f(t,x,y)’, or ‘Scan’ mode results. Furthermore, they are used to display a particular detector channel (or a set of detector channels) if the f(t,T), f(t,ext), fi(T), fi(ext) or Continuous Flow modes are used with routing.

In the figure below, two horizontal stripes of waveform channels were selected from a 8x8 pixel array of an ‘f(t,x,y)’ or ‘Scan’ mode measurement. The waveforms are displayed as functions of t and x (3D display mode f(t,x). Depending on the ‘Y Window’ settings and the Y window selected, up to 8 such waveform patterns exist.



Selection of waveforms from a 2-dimensional array, f(t,x) display

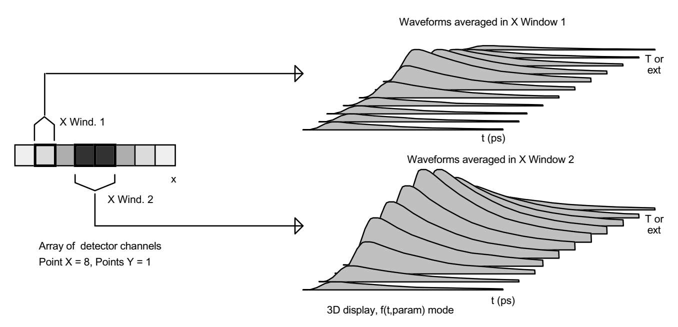
In the next figure, two vertical stripes were selected from the same 8x8 pixel array. Now, the waveforms are displayed as functions of t and y (3D display mode f(t,y). Depending on the 'X Window' settings and the X window selected, up to 8 such waveform patterns exist.



Selection of waveforms from a 2-dimensional array, f(t,y) display

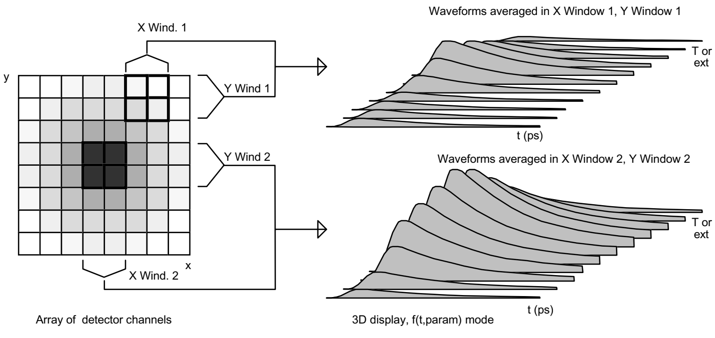
The X and Y window are also used to display a particular detector channel (or a set of detector channels) if the fi(T), fi(ext), f(t,T), f(t,ext) or Continuous Flow modes are used with routing. In the fi modes up to 8 spectra for the 8 different time windows are recorded for each detector channel.

The (t,T), f(t,ext) and Continuous Flow modes produce a sequence of waveforms for each detector channel. Since the data of only one detector channel can be displayed at the same time, the actual channel is defined by the X and Y windows. Depending on 'Routing Channels X' and 'Routing Channels Y' in the System Parameters, the detector array can be one-dimensional (Routing Channels X = 1 or Routing Channels Y = 1) or 2-dimensional (Routing Channels X > 1 and Routing Channels Y > 1). The selection of a data subset from a linear array of 8 detectors is shown in the next figure.



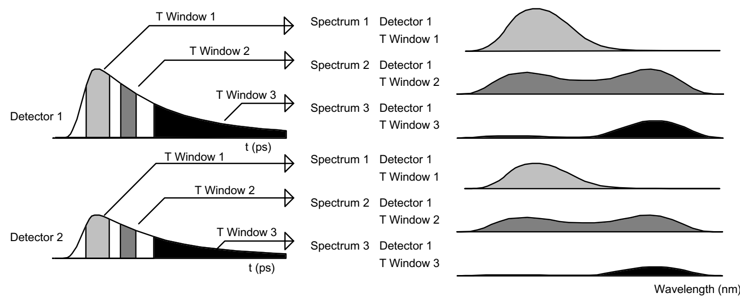
Selection of waveforms from a 1-dimensional detector array
f(t,T), f(t,ext) or Continuous Flow mode, f(t,param) display

For a 2-dimensional detector array, a data subset is displayed for the detector channels which are both inside the X Window and the Y Window:



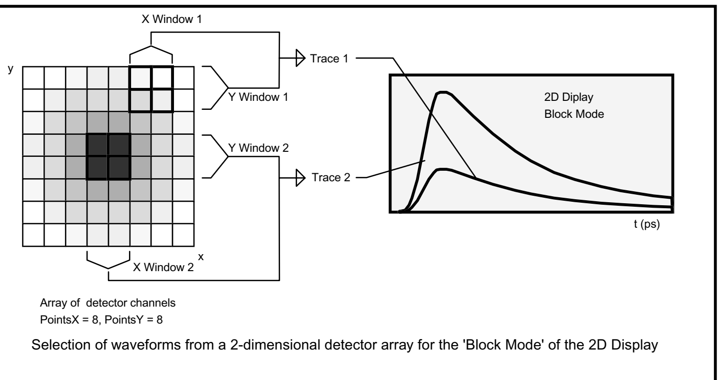
Selection of waveforms from a 2-dimensional detector array
f(t,T), f(t,ext) or Continuous Flow mode, f(t,param) display

The influence of the X and Y Windows on an fi(T) or fi(ext) measurement is shown in the next figure. As shown under 'T Windows', the fi modes produce 8 spectra for the 8 'Time Windows'. If the fi mode is used with a router 8 spectra for each routing channel can be produced. The number of detector channels is defined in the by 'Routing Channels X' and 'Routing Channels Y' in the 'System Parameters'. Depending on these settings, several X and Y windows can be defined. The spectra are displayed by the 2D display. Controlled by the 'Trace Parameters' any combination of 'T Window', 'X Window' and 'Y Window' can be used to define a trace in the display.



Spectrum Scan Mode (fi) with Routing
For each T Window and each detector channel a spectrum is calculated

To display single curves or waveforms averaged over several waveform channels the 'Block Mode' of the 2D display can be used. In the Block Mode of the 2D display mode traces are defined which represent the average of waveforms within the selected X and Y window (see 'Trace Parameters').



Selection of waveforms from a 2-dimensional detector array for the 'Block Mode' of the 2D Display

Auto Set Function

For all windows up to eight intervals can be defined. The intervals can be defined manually or set automatically by the 'Auto Set' function. To control 'Auto Set' the following options are provided.

Equidistant: The available window range is divided into eight equal intervals. If the number of points cannot divided by 8 (this can happen for X and Y) the last window can be bigger than the windows 1 to 7.

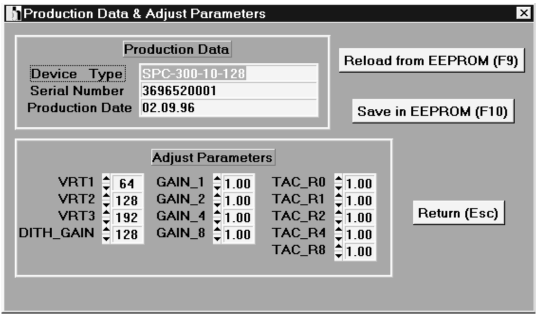
Non Equidistant: The start values of the intervals are set by hand. The end values are set by the autoset function in a way that the intervals fit close together.

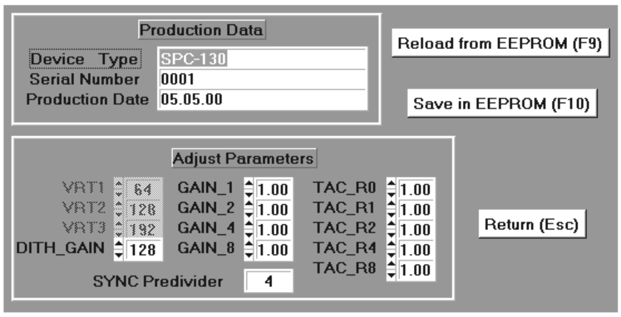
No of Windows: This is the number of windows to be set by the autoset function.

Adjust Parameters

Most of the required hardware adjustments in the SPC modules are done by the software. The adjust values are accessible via the adjust parameters menu. The adjust values are stored not in a file, but in an EEPROM on the SPC module. To change the adjust parameters a certain knowledge about the SPC hardware is required. Wrong inputs may seriously deadjust the module. Therefore you can change the adjust parameters, but not save them to the EEPROM. The changed adjust values are used by the device, but they will be replaced by the original values after restarting the SPC software.

The Adjust Parameters for SPC-3 through SPC-7 and for the SPC-134 modules are shown in the figure below.





Production Parameters

This area contains manufacturing information about the particular module. The information is used by the software to recognise different module versions. Please do not change these parameters.

Adjust Values

VRT1...VRT3 (Voltage of Resistor Tap, SPC-3 through SPC-7)

These parameters adjust the wide scale linearity of the ADC. Imagine the ADC characteristic as a rubber band that is fixed at the zero point and the full scale point. At 1/4, 1/2 and 3/4 of this band other bands are fixed which draw the ADC characteristic up or down. The default values are VRT1=192, VRT2=128 and VRT3=64.

Dither Gain

This parameter changes the gain of the DAC in the error correction part of the ADC (see 'ADC error correction'). To adjust this parameter, a short pulse is measured in a slow TAC range with the maximum value of 'Dither Width'. 'Dither Gain' is adjusted to get a minimum pulse width. The range of the parameter is from 0 to 255, the default setting is 128.

Gain1, Gain2, Gain4, Gain8

These parameters correct the values of 'TAC Gain'. Internally 'TAC Gain' is set by the combination of four binary graded resistors. Therefore, only four parameters are used to set all 15 gain steps. 'Gain1' corrects the Gain=1 value, 'Gain2' the Gain=2 value and so on. If the gain is correct for 1,2,4 and 8 also the other values are correct (dynamic errors neglected). The default values are 1, greater values increase the TAC Gain, smaller values decrease the TAC Gain.

TAC_R0 toTAC_R8

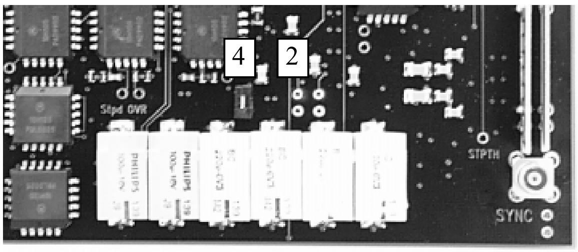
These Parameters correct 'TAC Range'. The parameters act on the following Range settings:

TAC_R0	50ns to <100ns
TAC_R1	1000ns to <2000ns
TAC_R2	500ns to <1000ns
TAC_R4	200ns to <500ns
TAC_R8	100ns to <200ns

The default setting is 1. Values >1 increase Range, i.e. decrease the width of a signal, values <1 decrease Range, i.e. increase the with of a signal. Values from 0.9 to 1.1 are accepted.

SYNC Predivider (SPC-134 only)

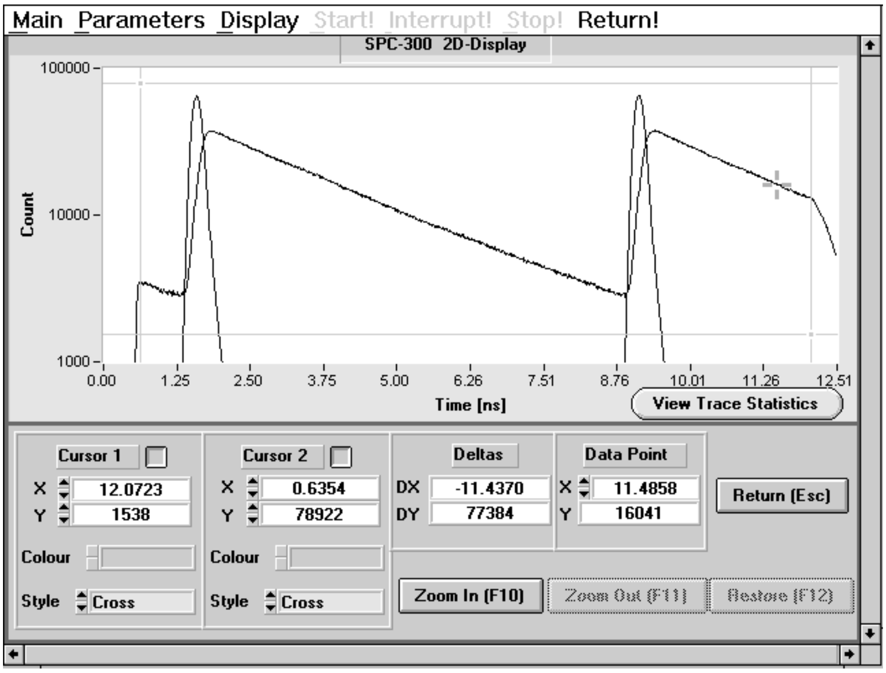
In the SPC-134 modules the SYNC signal is divided by 2 or by 4 before it is fed into the SYNC Rate Counter. The divider ration is set by a jumper on the board and is normally 4. ‘SYNC Predivider’ must correspond to the jumper setting to get correct count rate results.



Display Routines

Display 2D

'Display 2D' incorporates functions for inspection and evaluation of the measured data. Under 'Display 2D' the traces defined in the 'Trace Parameters' are displayed. The 2D display is shown in the figure below.



The display style (linear/logarithmic, window limits, curve style, background and grid colours) is set in the display parameters. Furthermore, a 'Block Mode' is provided to define traces as averages of several curves of a multichannel measurement.

Two cursor lines are available to select curve points and to display the data values numerically. The scale can be changed in both axis by zooming the area inside the cursor lines. The cursor settings and the zoom state is stored when leaving the display routine. Thus the display will come up with the same settings when it is left and entered again. Note that the cursor settings are stored in the scale units (i.e. ns, counts), not as pixel values. Thus the cursor settings will change if TAC range or TAC gain are changed.

When the 'Display 2D' is active, the 2D Data operations can be accessed via the 'Display' menu and selection of '2D Data Processing'.

From 'Display 2D' the 'Display Parameters', the 'Trace Parameters' and the 'Print' function can be accessed directly.

Cursors

The two cursors are used to select and measure curve points and to set the range for zooming the displayed data.

With 'Style' you can select whether a cursor is a horizontal line, a vertical line or a cross of a vertical and a horizontal line. For each cursor the X-Position (vertical cursor), the Y-Position (horizontal cursor) or both (crossed line cursor) are displayed. Under 'Deltas' the differences between the cursor values are displayed.

The colours of the cursors are set by 'Colors'.

The cursors can be moved with the mouse or with the keyboard. When the keyboard is used, the cursor is selected with 'page up' and 'page down' and shifted with the cursor keys. By pressing the cursor keys together with the 'shift' key a fine stepping is achieved.

Data Point

In addition to the cursors, the 'Data Point' can be used to measure data values. The data point is a small cross that can be shifted across the screen by the mouse. When releasing the mouse key the data point drops to the next true data location of the nearest trace. At the same time X and Y values are displayed.

Zoom Function

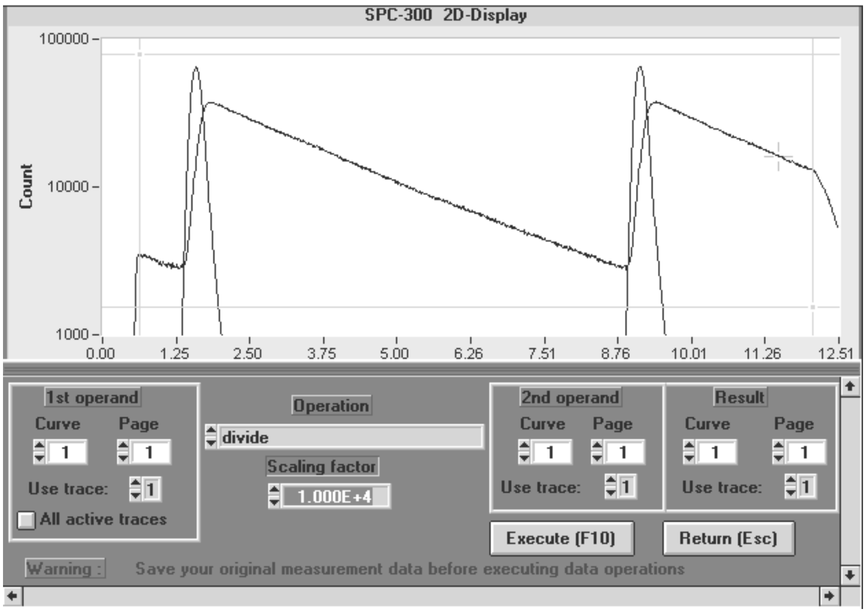
'Zoom in' magnifies the area inside the two cursors to the whole screen width. If the cursors are vertical lines the magnification occurs in X-direction. If the cursors are horizontal the scale is magnified in Y-direction. For crossed line cursors zooming is done in both directions stretching the rectangle between the cursor to the full screen.

'Zoom Out' restores the state before the last zoom action. This includes not only the zoom state but also the other display parameters such as 'linear' or 'logarithmic'.

'Restore' will restore the state as it had been when entering the 'Zoom' function.

2D Data Processing

When the 'Display 2D' is active, the 2D Data operations can be accessed via the 'Display' menu and selection of '2D Data Processing'. In this case the lower part of the screen is replaced by the data processing window. In this window the source of the operands, the operation and the destination of the result can be selected. All operations refer to the range inside the cursors. The data processing window is shown in the figure below.



1st operand

At this place the curve number of the first operand is specified. This can be done either by 'Curve' and 'Page' or by selecting one of the active traces via 'use trace'. If an active trace is selected, 'Curve' and 'Page' is set according to the values in the trace parameters. 'Curve' and 'Page' are displayed in the colour of the selected trace. The selected operation is applied to all active traces at once, if 'all active traces' is selected.

Operation

'Operation' selects the operation to be applied to the operands. To keep the result inside the data range of the measurement memory (0...65535) the result is multiplied by the 'Scaling Factor'. This factor can be set to any floating point number.

2nd operand

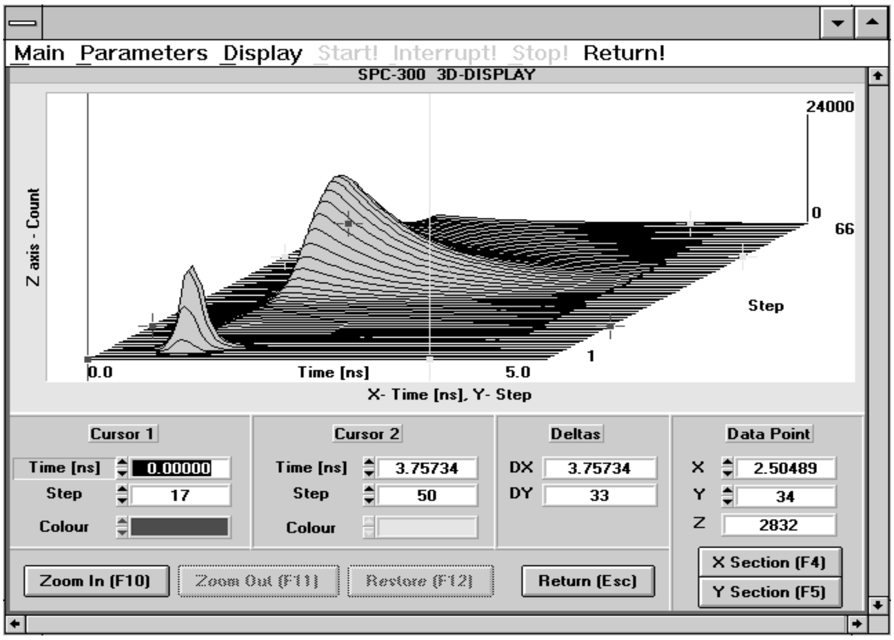
At this place the curve number of the second operand has to be specified. This can be done either by 'Curve' and 'Page' or by selecting one of the active traces via 'use trace'. If an active trace is selected, 'Curve' and 'Page' is set according to the values in the trace parameters. 'Curve' and 'Page' are displayed in the colour of the selected trace.

Result

At this place the curve number of the result has to be specified. This can be done either by 'Curve' and 'Page' or by selecting one of the active traces via 'use trace'. If an active trace is selected, 'Curve' and 'Page' is set according to the values in the trace parameters. 'Curve' and 'Page' are displayed in the colour of the selected trace.

Curve Display 3D

'Curve Display 3D' is used to display the results of the f(t,T), f(t,EXT) and f(t,x,y) modes. The display style depends on the settings of the 'Display Parameters'. Both the ‘3D Curve’ mode and the ‘Colour Intensity’ modes are available. When the 'Display 3D' is active, the 3D Data operations can be accessed via the 'Display' menu and selection of '3D Data Processing'. The Display Parameters can be accessed directly via the menu bar. Furthermore, the 'Print' function is accessible. The 3D curve display is shown in the figure below.



Cursors

The cursors are used to select and to measure the values of selected points. They are also used to define the range for zooming and the range for the three-dimensional data processing operations.

Data Point

The 'Data Point' is an additional means to measure single points of the three-dimensional data set. The cross-shaped marker is moved over the data by the mouse or by the cursor keys of the keyboard.

If controlled by the mouse, a horizontal movement shifts the data point across the actual curve. A vertical movement causes the data point to change to the next curve. Controlling the data point by the mouse requires some experience. Therefore the data point can also be moved by the cursor keys of the keyboard. 'Left' and 'right' shift the data point on the current curve, 'up' and 'down' cause it to jump to the next curve.

Note that the data point can be set to invisible curve parts. To avoid confusion the data should displayed in a way that the interesting parts are clearly visible (see 'Display Parameters', '3D Display').

Zoom Function

'Zoom in' magnifies the area inside the cursors to the whole available display width.

'Zoom Out' restores the state before the last ‘Zoom in’ action. This includes not only the zoom state but also the other display parameters as 'linear' or 'logarithmic'.

'Restore' will restore the state of the moment when the 'Zoom' function was entered.

3D Data Processing

When the 'Display 3D' is active, the 3D Data operations can be accessed via the 'Display' menu and selection of '3D Data Processing'. In this case the lower part of the screen is replaced by the data processing window. In this window the desired operation can be selected. All operations refer to the range defined by the cursors. During the operation the original data is replaced by the result. Therefore, we recommend to store the original data to a file before starting an operation.

Start, Interrupt, Stop

Start

'Start' starts the measurement in the selected operation mode. During the measurement the main menu remains active and the results are shown in the curve window. The rate display gives information about the count rates in the CFD, the TAC and the ADC. The CFD rate represents all pulses with an amplitude greater than 'CFD Limit Low'. The TAC rate is the working rate of the TAC. It is slightly smaller than the CFD rate because the TAC is not started by pulses exceeding the 'CFD Limit High'. 'ADC Rate' is the conversion rate of the ADC. It represents all events inside the selected TAC window.

When a measurement is run with the SPC-401/431/402/432 or in the FIFO mode of the SPC-600/630 one or more data files are created which contain the data of the subsequently recorded photons. These measurement data files have the extension ‘.spc’. At the end of the measurement, a setup data file is generated which contains the hardware and software parameter used. The setup data file has the same name as the last measurement data file and has the extension ‘.set’.

The most important system parameters can be changed during the measurement. The effect becomes visible with the display of the next result.

Interrupt

'Interrupt' interrupts a running measurement. This can be required to change system parameters or to adjust the external experimental set-up. After selecting 'Start' the measurement will proceed from the interrupted state.

Stop

'Stop' aborts a running measurement. After stopping the results are displayed as they were present in the moment of stopping. Note that the measurement cannot be re-started after using 'Stop'.

Exit

The SPC software is left by 'Exit'. When the program is left, the system parameters are saved in a file 'auto.set'. This file is automatically loaded at the next program start. So the system will come up in the same state as it was left before. If you do not want to save the last settings you can reject the writing of a new auto.set file by switching off the 'save data on exit' knob.

If you forgot to save your measurement data when exiting the program, re-enter the SPC software immediately. The data will be still present in the SPC device memory. However, if you switched off 'save data on exit' the system parameters are replaced by the older ones.

Data file structure

Depending on the selected action in the 'Save' routine .SET or .SDT files are generated. SET-files contain the system, trace and display parameters only. SDT-files contain the parameters and the measurement data. Both file types have the same structure with the difference that the SET-files do not contain the measurement data. With the introduction of the SPC-400 and SPC-430 modules and a new Windows software in 1997 the data file structure has been extended . The new data files contain a separate block information and separate system parameters for each curve. Both data file structures are described below.

DOS Software and Windows Software SPC-300 V 1.6 and earlier

All files start with '*IDENTIFICATION'. Then the text information follows which was typed in when the data was saved. The end of this part is marked with '*END'.

Under '*BODY' the system parameters follow. These are divided into the system parameters, display parameters, trace parameters and window parameters. Each parameter is identified by its name and its parameter type. Then the parameter values follows. This structure allows adding of new parameters in future software versions without loosing compatibility.

The end of the system parameters is identified by '*END' again. The SET-files end at this place. In the SDT-files the measurement data follow. The begin of each curve is identified by '*BLOCK1' ...'*BLOCK128'. The data values are unsigned short integers of Borland C++. The structure of a typical file is given in the following list.

```
*IDENTIFICATION
            ID          :  SPC Setup & Data File
            TITLE       :  LED1
            VERSION     :   1
            REVISION    :  10 bits ADC
            DATE        :  08-31-94
            TIME        :  17:38:47
            AUTHOR      :   Becker
            COMPANY :   B&H
            CONTENTS  :    green LED, XP1702 at 1.7kV
*END
*BODY
            SYS_PARA_BEGIN:
            #PR [PR_PDEV,X,0]
            #SP [SP_CFD_LH,F,80.0]
            #SP [SP_TAC_OF,F,9.499390]
            #DI [DI_3DC2C,I,14]
            SYS_PARA_END:
            TRACE_PARA_BEGIN:
            #TR #0 [1,2,1,1,4,1,1]
            .
            #TR #7 [0,14,1,8,1,1,1]
            TRACE_PARA_END:
            WIND_PARA_BEGIN:
            #WI #0 *NO *0 [0,0]
            .
            #WI #2 *NO *7 [56,63]
            WIND_PARA_END:
*END
*BLOCK1
       short                curvepoint[0]
       short                curvepoint[1]
       .                    .
       short                curvepoint[n]
                  .
*BLOCK128
       short                curvepoint[0]
       short                curvepoint[1]
       .                    .
       short                curvepoint[n]
*END
```

SPC Standard Software Version 2.0 to 6.9

The Windows software versions 2.0 to 6.9 used a new data file structure with improved flexibility. In the new file structure the hardware setup data of individual data blocks is stored if these blocks have been measured with different hardware settings.

The data files consist of

- a file header which contains structural data used to find the other parts of the file
- the file information which was typed in when the file was saved
- the system setup data for hardware and software
- one or more measurement description blocks which contain the system parameters corresponding to the particular data blocks
- data blocks containing one curve each, along with information to which measurement description block they correspond.

File Header (binary)

All SPC data files start with a file header which contains information about the location and the length of the other parts of the file. The header file variables are shown in the table below.

short	revision	software revision number (lower 4 bits = 10 decimal)
long	info offset	offset of the info part which contains general information (Title, date, time, contents etc.)
short	info length	length of the info part
long	setup_offs	offset of the setup data (system parameters, display parameters, trace parameters etc.)
short	setup_length	length of the setup data
long	data_block_offset	offset of the first data block (one data block contains one curve)
short	no_of_data_blocks	number of data blocks
long	data_block_length	length of one data block
long	meas_desc_block_offset	offset to 1st. measurement description block (system parameters connected to data blocks)
short	no_of_meas_desc_blocks	number of measurement description blocks
short	meas_desc_block_length	length of the measurement description blocks
unsigned short	header_valid	valid: 0x5555, not valid: 0x1111
unsigned long	reserved1	
unsigned short	reserved2	
unsigned short	chksum	checksum of file header

File Info

This part contains the general information which has been typed in when the data was saved. The info part is stored in ASCII. An example is given below.

```
*IDENTIFICATION
    ID          : _SPC Setup & Data File_
    Title       : startup
    Version     : 007
    Revision    : 1
    Date        : 10-10-1997
    Time        : 12:29:01
    Author      : Bond, James
    Company     : Unknown
    Contents    : Dye sample from Dr. No
*END
```

Setup

The setup block contains all the system parameters, display parameters, trace parameters etc. It is used to set the SPC system (hardware and software) into the same state as it was in the moment when the data file was stored. The values are stored together with an identifier of the particular parameter. This method allows to maintain compatibility between different SPC versions. If a parameter is missing in the setup part, a default value is used when the file is loaded. A typical setup part is shown below.

```
*SETUP
SYS_PARA_BEGIN:
#PR [PR_PDEV,I,0]
#PR [PR_PPORT,I,2]
#PR [PR_PWHAT,I,0]
#PR [PR_PF,B,0]
#PR [PR_PFNAME,S,IMAGE.PRT]
#PR [PR_PORIEN,I,1]
#PR [PR_PEJECT,B,1]
#PR [PR_PWIDTH,F,100]
#PR [PR_PHEIGH,F,100]
#PR [PR_PFULL,B,1]
#PR [PR_PAUTO,B,1]
#PR [PR_STP_FN,S,STP.CFG]
#PR [PR_SAVE_T,I,2]
#SP [SP_MODE,I,0]
#SP [SP_CFD_LL,F,-20]
#SP [SP_CFD_LH,F,80]
#SP [SP_CFD_ZC,F,0]
#SP [SP_CFD_HF,F,5]
#SP [SP_SYN_ZC,F,-9.8267717]
#SP [SP_SYN_FD,I,4]
#SP [SP_SYN_FQ,F,-20]
#SP [SP_SYN_HF,F,4]
#SP [SP_TAC_R,F,5.0000001e-08]
#SP [SP_TAC_G,I,1]
#SP [SP_TAC_OF,F,9.4993896]
#SP [SP_TAC_LL,F,14.90196]
#SP [SP_TAC_LH,F,84.705879]
#SP [SP_TAC_TC,F,4.8828126e-11]
#SP [SP_TAC_TD,F,6.2500001e-09]
#SP [SP_ADC_RE,I,1024]
#SP [SP_EAL_DE,I,30]
#SP [SP_NCX,I,1]
#SP [SP_NCY,I,1]
#SP [SP_PAGE,I,1]
#SP [SP_COL_T,F,100.01]
#SP [SP_REP_T,F,100.01]
#SP [SP_DIS_T,F,0.99899995]
#SP [SP_REPEAT,B,0]
#SP [SP_STOPT,B,1]
#SP [SP_OVERFL,C,S]
#SP [SP_WL_STA,F,300]
#SP [SP_WL_STO,F,362]
#SP [SP_WL_STE,F,2]
#SP [SP_EXTST,B,0]
#SP [SP_STEPS,I,32]
#SP [SP_OFFSET,F,0]
#SP [SP_YWIN_N,I,8]
#SP [SP_XWIN_N,I,8]
#SP [SP_TWIN_N,I,8]
#SP [SP_X_EQU,B,1]
#SP [SP_Y_EQU,B,1]
#SP [SP_T_EQU,B,1]
#SP [SP_DITH,I,64]
#SP [SP_EN_INT,B,0]
#SP [SP_INCR,I,64]
#SP [SP_DAES,B,1]
#SP [SP_SPE_FN,S,SPEC1.SDT]
#SP [SP_CYCLES,U,1]
#SP [SP_DAEC,B,0]
#SP [SP_MEM_BANK,I,0]
#SP [SP_DTCOMP,B,1]
#DI [DI_SCALE,I,0]
#DI [DI_MAXCNT,L,65535]
#DI [DI_LBLINE,L,100]
#DI [DI_BLINE,L,0]
#DI [DI_GRID,B,0]
#DI [DI_GCOL_F,I,8]
#DI [DI_GCOL_B,I,0]
#DI [DI_TRACE,I,0]
#DI [DI_BOD_C,I,3]
#DI [DI_2DDIS,I,0]
#DI [DI_2DTRNO,I,1]
#DI [DI_3DOFFX,I,4]
#DI [DI_3DOFFY,I,4]
#DI [DI_3DINCX,I,0]
#DI [DI_3DCOL,I,15]
#DI [DI_3DMODE,I,3]
#DI [DI_YWIN,I,2]
#DI [DI_XWIN,I,1]
#DI [DI_TWIN,I,1]
#DI [DI_PSTYLE,I,9]
#DI [DI_PFREQ,I,1]
#DI [DI_CUR,B,0]
#DI [DI_RATE,B,1]
#DI [DI_2DC1,B,1]
#DI [DI_2DC2,B,1]
#DI [DI_2DC1C,I,1]
#DI [DI_2DC2C,I,5]
#DI [DI_2DC1S,I,0]
#DI [DI_2DC2S,I,0]
#DI [DI_3DC1C,I,12]
#DI [DI_3DC2C,I,14]
#DI [DI_SIZE,I,1]
SYS_PARA_END:
TRACE_PARA_BEGIN:
#TR #0 [1,15,1,1,4,1,1]
#TR #1 [0,9,1,2,1,2,1]
#TR #2 [0,10,1,3,1,3,1]
#TR #3 [0,14,1,4,1,4,1]
#TR #4 [0,9,1,5,1,1,1]
#TR #5 [0,12,1,6,1,1,1]
#TR #6 [0,13,1,7,1,1,1]
#TR #7 [0,11,1,8,1,1,1]
 TRACE_PARA_END:
WIND_PARA_BEGIN:
#WI #0 *NO *0 [0,0]
#WI #0 *NO *1 [0,0]
#WI #0 *NO *2 [0,0]
#WI #0 *NO *3 [0,0]
#WI #0 *NO *4 [0,0]
#WI #0 *NO *5 [0,0]
#WI #0 *NO *6 [0,0]
#WI #0 *NO *7 [0,0]
#WI #1 *NO *0 [0,0]
#WI #1 *NO *1 [0,0]
#WI #1 *NO *2 [0,0]
#WI #1 *NO *3 [0,0]
#WI #1 *NO *4 [0,0]
#WI #1 *NO *5 [0,0]
#WI #1 *NO *6 [0,0]
#WI #1 *NO *7 [0,0]
#WI #2 *NO *0 [0,127]
#WI #2 *NO *1 [128,255]
#WI #2 *NO *2 [256,383]
#WI #2 *NO *3 [384,511]
#WI #2 *NO *4 [512,639]
#WI #2 *NO *5 [640,767]
#WI #2 *NO *6 [768,895]
#WI #2 *NO *7 [896,1023]
 WIND_PARA_END:
*END
```

Measurement Description Blocks

Each data block can (but need not) have its own system (hardware) parameter set which can differ from the setup parameters. In the block header of each data block a corresponding measurement description block is specified. Therefore the number of measurement description blocks can vary from one (if all stored data blocks are measured with the same hardware parameters) to the number of saved data blocks (if all blocks are measured with different hardware parameters). The number, the length and the location of the measurement description blocks is stored in the file header at the beginning of the file.

The information in the measurement description blocks is used for the 'Block Info' function in the Load, Save and Trace Parameter menus. If the button 'Use System Parameters from the Selected Block' is pressed, the system parameters are replaced by the data in the measurement description block.

The measurement description blocks are stored in a binary format. The structure is shown below.

```
char time[9];          /* time of creation */
char date[11];         /* date of creation */
char mod_ser_no[16];  /* serial number */
short   meas_mode;
float   cfd_ll;
float   cfd_lh;
float   cfd_zc;
float   cfd_hf;
float   syn_zc;
short   syn_fd;
float   syn_hf;
float   tac_r;
short   tac_g;
float   tac_of;
float   tac_ll;
float   tac_lh;
short   adc_re;
short   eal_de;
short   ncx;
short   ncy;
unsigned short  page;
float   col_t;
float   rep_t;
short   stopt;
char    overfl;
short   use_motor;
short   steps;
```

```
float    offset;
short    dither;
short    incr;
short    mem_bank;
char     mod_type[16];   /* module type */
float    syn_th;
short    dead_time_comp;
short    polarity_l;
short    polarity_f;
short    polarity_p;
short    linediv;
short    accumulate;
int      flbck_y;
int      flbck_x;
int      bord_u;
int      bord_l;
float    pix_time;
short    pix_clk;
short    trigger;
int      scan_x;
int      scan_y;
int      scan_rx;
int      scan_ry;
short    fifo_typ;
int      epx_div;
int      mod_type_code;
```

Data Blocks

Each data block contains the data of one curve. The number, the length and the location of the data blocks is contained in the file header at the beginning of the data file.

Each data block can (but need not) be measured with different hardware parameters. Therefore, for each block a data block header is provided, which specifies a corresponding measurement description block. Furthermore the header contains a block number, the offset of the data block from the beginning of the file, the offset to the next data block and an information about the data in the block (none, measured, loaded from file, calculated, simulated).

short	block_no	number of the block in the file, from 0 to no_of_data_blocks-1
long	data_offs	offset of the data block from the beginning of the file
long	next_block_offs	offset to the data block header of the next data block
unsigned short	block_type	0: unused 1: measured 2: data from file 3: calculated data 4: simulated data
short	meas_desc_block_no	Number of the measurement description block corresponding to this data block
unsigned long	reseved1	
unsigned long	reserved2	

The data of the block specified by the block header is stored as shown below. It follows directly after the data block header.

```
short     curvepoint[0]
short     curvepoint[1]
.         .
.         curvepoint[data_block_length-1]
```

SPC Standard Software Version 7.0 and later
Multi-SPC Software Version 7.0 and later

With the introduction of the SPC-134 and the increased resolution of the SPC-7 scanning modes a modification of the file structure became necessary. The changes were required to identify the individual modules of a multi-SPC system and to save more than 65565 curves of a scan measurement. Older files of the SPC versions 2.0 to 6.9 are compatible with the new structure. However, loading files of version 7.0 or later into old software versions can (but need not) cause problems.

As in the previous version, the data files consist of

- a file header which contains structural data used to find the other parts of the file
- the file information which was typed in when the file was saved
- the system setup data for hardware and software
- one or more measurement description blocks which contain the system parameters corresponding to the particular data blocks
- data blocks containing one curve each, along with information to which measurement description block they correspond.

File Header (binary)

The SPC data files start with a file header which contains information about the location and the length of the other parts of the file. The new header file allows for a higher number of data blocks in file and different block sizes:

short	revision	software revision number (lower 4 bits = 11(decimal))
long	info offset	offset of the info part which contains general information (Title, date, time, contents etc.)
short	info length	length of the info part
long	setup_offs	offset of the setup data (system parameters, display parameters, trace parameters etc.)
short	setup_length	length of the setup data
long	data_block_offset	offset of the first data block
short	no_of_data_blocks	no_of_data_blocks valid only when in 0 .. 0x7ffe range, if equal to 0x7fff the field 'reserved1' contains valid no_of_data_blocks
long	data_block_length	length of the longest data block in the file
long	meas_desc_block_offset	offset to 1st. measurement description block (system parameters connected to data blocks)
short	no_of_meas_desc_blocks	number of measurement description blocks
short	meas_desc_block_length	length of the measurement description blocks
unsigned short	header_valid	valid: 0x5555, not valid: 0x1111
unsigned long	reserved1	reserved1 now contains no_of_data_blocks
unsigned short	reserved2	
unsigned short	chksum	checksum of file header

File Info

This part contains the general information which has been typed in when the data was saved. The info part is stored in ASCII. An example is given below.

```
*IDENTIFICATION
    ID          : _SPC Setup & Data File_
    Title       : startup
    Version     : 007
    Revision    : 1
    Date        : 10-10-1997
    Time        : 12:29:01
    Author      : Bond, James
    Company     : Unknown
    Contents    : Dye sample from Dr. No
*END
```

Setup

The setup block contains all the system parameters, display parameters, trace parameters etc. It is used to set the SPC system (hardware and software) into the same state as it was in the moment when the data file was stored. The values are stored together with an identifier of the particular parameter. This method allows to maintain compatibility between different SPC versions. If a parameter is missing in the setup part, a default value is used when the file is loaded. A typical setup part is shown below.
For Multi SPC Systems the system parameters section contains subsections for module parameters which are separate for the individual modules.

```
SYS_PARA_BEGIN:
#PR [PR_PDEV,I,0]
#PR [PR_PPORT,I,2]
#PR [PR_PWHAT,I,0]
#PR [PR_PF,B,0]
#PR [PR_PFNAME,S,IMAGE.PRT]
#PR [PR_PORIEN,I,1]
#PR [PR_PEJECT,B,1]
#PR [PR_PWIDTH,F,100]
#PR [PR_PHEIGH,F,100]
#PR [PR_PFULL,B,1]
#PR [PR_PAUTO,B,1]
#PR [PR_STP_FN,S,STP.CFG]
#PR [PR_SAVE_T,I,2]
#SP [SP_MODE,I,0]
#SP [SP_CFD_LL,F,-20]
#SP [SP_CFD_LH,F,80]
#SP [SP_CFD_ZC,F,0]
#SP [SP_CFD_HF,F,5]
#SP [SP_SYN_ZC,F,-9.8267717]
#SP [SP_SYN_FD,I,4]
#SP [SP_SYN_FQ,F,-20]
#SP [SP_SYN_HF,F,4]
#SP [SP_TAC_R,F,5.0000001e-08]
#SP [SP_TAC_G,I,1]
#SP [SP_TAC_OF,F,9.4993896]
#SP [SP_TAC_LL,F,14.90196]
#SP [SP_TAC_LH,F,84.705879]
#SP [SP_TAC_TC,F,4.8828126e-11]
#SP [SP_TAC_TD,F,6.2500001e-09]
#SP [SP_ADC_RE,I,1024]
#SP [SP_EAL_DE,I,30]
#SP [SP_NCX,I,1]
#SP [SP_NCY,I,1]
#SP [SP_PAGE,I,1]
#SP [SP_COL_T,F,100.01]
#SP [SP_REP_T,F,100.01]
#SP [SP_DIS_T,F,0.99899995]
#SP [SP_REPEAT,B,0]
#SP [SP_STOPT,B,1]
#SP [SP_OVERFL,C,S]
#SP [SP_WL_STA,F,300]
#SP [SP_WL_STO,F,362]
#SP [SP_WL_STE,F,2]
#SP [SP_EXTST,B,0]
#SP [SP_STEPS,I,32]
#SP [SP_OFFSET,F,0]
#SP [SP_YWIN_N,I,8]
#SP [SP_XWIN_N,I,8]
#SP [SP_TWIN_N,I,8]
#SP [SP_X_EQU,B,1]
#SP [SP_Y_EQU,B,1]
#SP [SP_T_EQU,B,1]
#SP [SP_DITH,I,64]
#SP [SP_EN_INT,B,0]
#SP [SP_INCR,I,64]
#SP [SP_DAES,B,1]
#SP [SP_SPE_FN,S,SPEC1.SDT]
#SP [SP_CYCLES,U,1]
#SP [SP_DAEC,B,0]
#SP [SP_MEM_BANK,I,0]
#SP [SP_DTCOMP,B,1]
#DI [DI_SCALE,I,0]
#DI [DI_MAXCNT,L,65535]
#DI [DI_LBLINE,L,100]
#DI [DI_BLINE,L,0]
#DI [DI_GRID,B,0]
#DI [DI_GCOL_F,I,8]
#DI [DI_GCOL_B,I,0]
#DI [DI_TRACE,I,0]
#DI [DI_BOD_C,I,3]
#DI [DI_2DDIS,I,0]
#DI [DI_2DTRNO,I,1]
#DI [DI_3DOFFX,I,4]
#DI [DI_3DOFFY,I,4]
#DI [DI_3DINCX,I,0]
#DI [DI_3DCOL,I,15]
#DI [DI_3DMODE,I,3]
#DI [DI_YWIN,I,2]
#DI [DI_XWIN,I,1]
#DI [DI_TWIN,I,1]
#DI [DI_PSTYLE,I,9]
#DI [DI_PFREQ,I,1]
#DI [DI_CUR,B,0]
#DI [DI_RATE,B,1]
#DI [DI_2DC1,B,1]
#DI [DI_2DC2,B,1]
#DI [DI_2DC1C,I,1]
#DI [DI_2DC2C,I,5]
#DI [DI_2DC1S,I,0]
#DI [DI_2DC2S,I,0]
#DI [DI_3DC1C,I,12]
#DI [DI_3DC2C,I,14]
#DI [DI_SIZE,I,1]
#MP0 [MP_CFD_LL,F,0]
#MP0 [MP_CFD_LH,F,39.843136]
#MP0 [MP_CFD_ZC,F,-7.5590553]
#MP0 [MP_CFD_HF,F,5]
#MP0 [MP_SYN_ZC,F,-4.5354333]
#MP0 [MP_SYN_FD,I,1]
#MP0 [MP_SYN_FQ,F,-19.607843]
#MP0 [MP_SYN_HF,F,4]
#MP0 [MP_TAC_LL,F,7.8431373]
#MP0 [MP_TAC_LH,F,90.588234]
#MP0 [MP_TRIGGER,I,0]
#MP0 [MP_TAC_OF,F,9.8039217]
#MP1 [MP_CFD_LL,F,0]
#MP1 [MP_CFD_LH,F,39.843136]
#MP1 [MP_CFD_ZC,F,-7.5590553]
#MP1 [MP_CFD_HF,F,5]
#MP1 [MP_SYN_ZC,F,-4.5354333]
#MP1 [MP_SYN_FD,I,1]
#MP1 [MP_SYN_FQ,F,-19.607843]
#MP1 [MP_SYN_HF,F,4]
#MP1 [MP_TAC_LL,F,7.8431373]
#MP1 [MP_TAC_LH,F,90.588234]
#MP1 [MP_TRIGGER,I,0]
#MP1 [MP_TAC_OF,F,9.8039217]
SYS_PARA_END:
TRACE_PARA_BEGIN:
#TR #0 [1,15,1,1,4,1,1]
#TR #1 [0,9,1,2,1,2,1]
#TR #2 [0,10,1,3,1,3,1]
#TR #3 [0,14,1,4,1,4,1]
#TR #4 [0,9,1,5,1,1,1]
#TR #5 [0,12,1,6,1,1,1]
#TR #6 [0,13,1,7,1,1,1]
#TR #7 [0,11,1,8,1,1,1]
 TRACE_PARA_END:
WIND_PARA_BEGIN:
#WI #0 *NO *0 [0,0]
#WI #0 *NO *1 [0,0]
#WI #0 *NO *2 [0,0]
#WI #0 *NO *3 [0,0]
#WI #0 *NO *4 [0,0]
#WI #0 *NO *5 [0,0]
#WI #0 *NO *6 [0,0]
#WI #0 *NO *7 [0,0]
#WI #1 *NO *0 [0,0]
#WI #1 *NO *1 [0,0]
#WI #1 *NO *2 [0,0]
#WI #1 *NO *3 [0,0]
#WI #1 *NO *4 [0,0]
#WI #1 *NO *5 [0,0]
#WI #1 *NO *6 [0,0]
#WI #1 *NO *7 [0,0]
#WI #2 *NO *0 [0,127]
#WI #2 *NO *1 [128,255]
#WI #2 *NO *2 [256,383]
#WI #2 *NO *3 [384,511]
#WI #2 *NO *4 [512,639]
#WI #2 *NO *5 [640,767]
#WI #2 *NO *6 [768,895]
#WI #2 *NO *7 [896,1023]
 WIND_PARA_END:
*END
```

Measurement Description Blocks

Each data block can (but need not) have its own system (hardware) parameter set which can differ from the setup parameters. In the block header of each data block a corresponding measurement description block is specified. Therefore the number of measurement description blocks can vary from one (if all stored data blocks originate from only one measurement) to the number of saved data blocks (if all blocks are measured with different hardware parameters). The number, the length and the location of the measurement description blocks is stored in the file header at the beginning of the file.

The information in the measurement description blocks is used for the 'Block Info' or ‘Set Info’ function in the Load, Save and Trace Parameter menus. If the button 'Use System Parameters from the Selected Block' is pressed, the system parameters are replaced by the data in the measurement description block.

The measurement description blocks are stored in a binary format. The structure is shown below.

```
char  time[9];          /* time of creation */
char  date[11];         /* date of creation */
char mod_ser_no[16];  /* serial number */
short    meas_mode;
float    cfd_ll;
float    cfd_lh;
float    cfd_zc;
float    cfd_hf;
float    syn_zc;
short    syn_fd;
float    syn_hf;
float    tac_r;
short    tac_g;
float    tac_of;
float    tac_ll;
float    tac_lh;
short    adc_re;
short    eal_de;
short    ncx;
short    ncy;
unsigned short  page;
float    col_t;
float    rep_t;
short    stopt;
char     overfl;
short    use_motor;
short    steps;
float    offset;
short    dither;
short    incr;
short    mem_bank;
char     mod_type[16];   /* module type */
float    syn_th;
short    dead_time_comp;
short    polarity_l;
short    polarity_f;
short    polarity_p;
short    linediv;
short    accumulate;
int      flbck_y;
int      flbck_x;
int      bord_u;
int      bord_l;
float    pix_time;
short    pix_clk;
short    trigger;
int      scan_x;
int      scan_y;
int      scan_rx;
int      scan_ry;
short    fifo_typ;
int      epx_div;
int      mod_type_code;
```

Data Blocks

With the software version 7.0 the data block header was changed to make possible a higher number of data blocks and a variable block size.

Each data block can now contain a ‘Data Set’ i.e. the data of several curves which were obtained in one measurement. The number and the location of the data blocks is contained in the file header at the beginning of the data file. The length of the block is contained in the block header.

The data block header contains the data block number, the offset of the data block from the beginning of the file, the offset to the next data block and an information about the data in the block (measured block, block loaded from file, etc.), and a reference to the corresponding measurement description block:

short	block_no	number of the block in the file valid only when in 0 .. 0x7ffe range, if equal to 0x7fff lblock_no (old software version - reserved1) field contains valid number of the block in the file
long	data_offs	offset of the data block from the beginning of the file
long	next_block_offs	offset to the data block header of the next data block
unsigned short	block_type	0: unused 1: measured block 2: flow data 3: data block from file 4: calculated data block 5: simulated data block, 11(hex): measured data set 13(hex): data set from file 14(hex): calculated data set 15(hex): simulated data set,
short	meas_desc_block_no	Number of the measurement description block corresponding to this data block
unsigned long	lblock_no	reserved1 now contains number of the block in the file*
unsigned long	block_length	reserved2 now contains block(set) length in bytes

* The field ‘lblock_no’ contains the data block / data set number in the bits 0 to 23 and the module number (0 to 3) in the bits 24 to 25.

The data of the set specified by the block header is stored as shown below. It follows directly after the data block header:

```
short       curvepoint[0][0]
short       curvepoint[0] [1]
.           .
.           curvepoint[0] [adc_re -1]
short       curvepoint[1][0]
short       curvepoint[1] [1]
.           .
.           curvepoint[1] [adc_re -1]
.
short       curvepoint[n][0]
short       curvepoint[n] [1]
.           .
.           curvepoint[n] [adc_re -1]
```

The number of curves in the set depends on the measurement parameters, e.g. measurement mode, no of routing bits etc. The number of curves in the block is equal to ‘block_length’ (from the block header) divided by adc_re (from the corresponding measurement description block).

FIFO File Structure, Version 2.0 to 6.9

When a measurement is run with the SPC-4x1, -4x2 or the SPC-6x0 in the FIFO Mode one or more data files are created which contain the data of the subsequently recorded photons. These measurement data files have the extension '.spc'. At the end of the measurement, a setup data file is generated which contains the hardware and software parameter used. The setup data file has the same name as the last measurement data file and has the extension '.set'.
The structures of the measurement data and setup files are described below.

Setup Files

For each measurement, a setup data file is generated which contains the hardware and software parameter used for this measurement. The setup files are compatible to that of the SPC Standard Software.

The setup data files consist of

- a file header which contains structural data used to find the other parts of the file
- the file information which was typed in when the file was saved
- the system setup data for hardware and software

File Header

The files start with a file header which contains information about the location and the length of the other parts of the file. The information is stored in a binary format. The file header variables are shown in the table below. The header is used for setup files and data files of the SPC Standard Software as well. Therefore, not all parameters contained in the header are used for the SPC FIFO setup files.

short	revision	software revision number
long	info offset	offset of the info part which contains general information (Title, date, time, contents etc.)
short	info length	length of the info part
long	setup_offs	offset of the setup data (system parameters, display parameters, trace parameters etc.)
short	setup_length	length of the setup data
long	data_block_offset	offset of the first data block (one data block contains one curve)
short	no_of_data_blocks	number of data blocks
long	data_block_length	length of one data block
long	meas_desc_block_offset	offset to 1st. measurement description block (sytem parameters connected to data blocks)
short	no_of_meas_desc_blocks	number of measurement description blocks
short	meas_desc_block_length	length of the measurement description blocks
unsigned short	header_valid	valid: 0x5555, not valid: 0x1111
unsigned long	reserved1	
unsigned short	reserved2	
unsigned short	chksum	checksum of file header

Info

This part contains the general information which was automatically generated by the FIFO software.
The info part is stored in ASCII. An example is given below.

```
*IDENTIFICATION
    ID          : _SPC Setup & Data File_
    Title       : startup
    Version     : 007
    Revision    : 1
    Date        : 10-10-1997
    Time        : 12:29:01
    Author      :
    Company     :
    Contents    : Setup file made by system at the end of FIFO measurement wuth module SPC-630 (Ser. No. 360021)
*END
```

Setup Block

The 'setup' block contains all the system parameters, display parameters, trace parameters etc. It is used to set the SPC system hardware and software into the same state as it was in the moment when the data file was stored. The values are stored together with an identifier of the particular parameter. This method allows to maintain compatibility between different SPC versions. If a parameter is missing in the setup part, a default value is used when the file is loaded. A typical setup part is shown below.

```
*SETUP
SYS_PARA_BEGIN:
#PR [PR_PDEV,I,0]
#PR [PR_PPORT,I,2]
#PR [PR_PWHAT,I,0]
#PR [PR_PF,B,0]
#PR [PR_PFNAME,S,IMAGE.PRT]
#PR [PR_PORIEN,I,1]
#PR [PR_PEJECT,B,1]
#PR [PR_PWIDTH,F,100]
#PR [PR_PHEIGH,F,100]
#PR [PR_PFULL,B,1]
#PR [PR_PAUTO,B,1]
#PR [PR_STP_FN,S,STP.CFG]
#PR [PR_SAVE_T,I,2]
#SP [SP_MODE,I,0]
#SP [SP_CFD_LL,F,-20]
#SP [SP_CFD_LH,F,80]
#SP [SP_CFD_ZC,F,0]
#SP [SP_CFD_HF,F,5]
#SP [SP_SYN_ZC,F,-9.8267717]
#SP [SP_SYN_FD,I,4]
#SP [SP_SYN_FQ,F,-20]
#SP [SP_SYN_HF,F,4]
#SP [SP_TAC_R,F,5.0000001e-08]
#SP [SP_TAC_G,I,1]
#SP [SP_TAC_OF,F,9.4993896]
#SP [SP_TAC_LL,F,14.90196]
#SP [SP_TAC_LH,F,84.705879]
#SP [SP_TAC_TC,F,4.8828126e-11]
#SP [SP_TAC_TD,F,6.2500001e-09]
#SP [SP_ADC_RE,I,1024]
#SP [SP_EAL_DE,I,30]
#SP [SP_NCX,I,1]
#SP [SP_NCY,I,1]
#SP [SP_PAGE,I,1]
#SP [SP_COL_T,F,100.01]
#SP [SP_REP_T,F,100.01]
#SP [SP_DIS_T,F,0.99899995]
#SP [SP_REPEAT,B,0]
#SP [SP_STOPT,B,1]
#SP [SP_OVERFL,C,S]
#SP [SP_WL_STA,F,300]
#SP [SP_WL_STO,F,362]
#SP [SP_WL_STE,F,2]
#SP [SP_EXTST,B,0]
#SP [SP_STEPS,I,32]
#SP [SP_OFFSET,F,0]
#SP [SP_YWIN_N,I,8]
#SP [SP_XWIN_N,I,8]
#SP [SP_TWIN_N,I,8]
#SP [SP_X_EQU,B,1]
#SP [SP_Y_EQU,B,1]
#SP [SP_T_EQU,B,1]
#SP [SP_DITH,I,64]
#SP [SP_EN_INT,B,0]
#SP [SP_INCR,I,64]
#SP [SP_DAES,B,1]
#SP [SP_SPE_FN,S,SPEC1.SDT]
#SP [SP_CYCLES,U,1]
#SP [SP_DAEC,B,0]
#SP [SP_MEM_BANK,I,0]
#SP [SP_DTCOMP,B,1]
#DI [DI_SCALE,I,0]
#DI [DI_MAXCNT,L,65535]
#DI [DI_LBLINE,L,100]
#DI [DI_BLINE,L,0]
#DI [DI_GRID,B,0]
#DI [DI_GCOL_F,I,8]
#DI [DI_GCOL_B,I,0]
#DI [DI_TRACE,I,0]
#DI [DI_BOD_C,I,3]
#DI [DI_2DDIS,I,0]
#DI [DI_2DTRNO,I,1]
#DI [DI_3DOFFX,I,4]
#DI [DI_3DOFFY,I,4]
#DI [DI_3DINCX,I,0]
#DI [DI_3DCOL,I,15]
#DI [DI_3DMODE,I,3]
#DI [DI_YWIN,I,2]
#DI [DI_XWIN,I,1]
#DI [DI_TWIN,I,1]
#DI [DI_PSTYLE,I,9]
#DI [DI_PFREQ,I,1]
#DI [DI_CUR,B,0]
#DI [DI_RATE,B,1]
#DI [DI_2DC1,B,1]
#DI [DI_2DC2,B,1]
#DI [DI_2DC1C,I,1]
#DI [DI_2DC2C,I,5]
#DI [DI_2DC1S,I,0]
#DI [DI_2DC2S,I,0]
#DI [DI_3DC1C,I,12]
#DI [DI_3DC2C,I,14]
#DI [DI_SIZE,I,1]
SYS_PARA_END:
TRACE_PARA_BEGIN:
#TR #0 [1,15,1,1,4,1,1]
#TR #1 [0,9,1,2,1,2,1]
#TR #2 [0,10,1,3,1,3,1]
#TR #3 [0,14,1,4,1,4,1]
#TR #4 [0,9,1,5,1,1,1]
#TR #5 [0,12,1,6,1,1,1]
#TR #6 [0,13,1,7,1,1,1]
#TR #7 [0,11,1,8,1,1,1]
 TRACE_PARA_END:
WIND_PARA_BEGIN:
#WI #0 *NO *0 [0,0]
#WI #0 *NO *1 [0,0]
#WI #0 *NO *2 [0,0]
#WI #0 *NO *3 [0,0]
#WI #0 *NO *4 [0,0]
#WI #0 *NO *5 [0,0]
#WI #0 *NO *6 [0,0]
#WI #0 *NO *7 [0,0]
#WI #1 *NO *0 [0,0]
#WI #1 *NO *1 [0,0]
#WI #1 *NO *2 [0,0]
#WI #1 *NO *3 [0,0]
#WI #1 *NO *4 [0,0]
#WI #1 *NO *5 [0,0]
#WI #1 *NO *6 [0,0]
#WI #1 *NO *7 [0,0]
#WI #2 *NO *0 [0,127]
#WI #2 *NO *1 [128,255]
#WI #2 *NO *2 [256,383]
#WI #2 *NO *3 [384,511]
#WI #2 *NO *4 [512,639]
#WI #2 *NO *5 [640,767]
#WI #2 *NO *6 [768,895]
#WI #2 *NO *7 [896,1023]
 WIND_PARA_END:
*END
```

Measurement Data Files (SPC-401/431, SPC-6 FIFO 4096 Channels)

The information about the subsequent photons is stored one after another in the measurement data file. For each photon 6 bytes are used. The structure of these data is shown in the table below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	ADC[7]	ADC[6]	ADC[5]	ADC[4]	ADC[3]	ADC[2]	ADC[1]	ADC[0]
Byte 1	0	GAP	MTOV	INVALID	ADC[11]	ADC[10]	ADC[9]	ADC[8]
Byte 2	MT[23]	MT[22]	MT[21]	MT[20]	MT[19]	MT[18]	MT[17]	MT[16]
Byte 3	R[7]	R[6]	R[5]	R[4]	R[3]	R[2]	R[1]	R[0]
Byte 4	MT[7]	MT[6]	MT[5]	MT[4]	MT[3]	MT[2]	MT[1]	MT[0]
Byte 5	MT[15]	MT[14]	MT[13]	MT[12]	MT[11]	MT[10]	MT[9]	MT[8]

ADC[11:0]	ADC Data (Micro Time)
R [7:0]	Routing Signals (inverted)
MT[23:0]	Macro Time [µs]
GAP	1 = Possible recording gap due to FIFO Full. There may be (and most likely is) a gap in the recording preceding this photon.

MTOV	1 = Macro Timer Overflow. Since the capacity of the macro timer is limited to 24 bit it will overflow each 2^{24} µs. The software which processes the data file has to add these 2^{24} µs to its internal macro time value on each MTOV =1.
INVALID	1 = Data Invalid. All data for this photon except the MTOV bit is invalid. The INVALID bit is set if the 'Count Enable' bit at the SPC routing connector was '0', i.e. if a router is connected and there is no valid routing information for this photon.

Measurement Data Files (SPC-402/432, SPC-6 FIFO 256 Channels)

The information about the subsequent photons is stored one after another in the measurement data file. For each photon 4 bytes are used. The structure of these data is shown in the table below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	ADC[7]	ADC[6]	ADC[5]	ADC[4]	ADC[3]	ADC[2]	ADC[1]	ADC[0]
Byte 1	MT[7]	MT[6]	MT[5]	MT[4]	MT[3]	MT[2]	MT[1]	MT[0]
Byte 2	MT[15]	MT[14]	MT[13]	MT[12]	MT[11]	MT[10]	MT[9]	MT[8]
Byte 3	INVALID	MTOV	GAP	0	R[2]	R[1]	R[0]	MT[16]

ADC[7:0]	ADC Data (Micro Time)
R [2:0]	Routing Signals (inverted)
MT[16:0]	Macro Time [µs]
GAP	1 = Possible recording gap due to FIFO Full. There may be (and most likely is) a gap in the recording preceding this photon.
MTOV	1 = Macro Timer Overflow. Since the capacity of the macro timer is limited to 24 bit it will overflow each 2^{17} * 50ns. The software which processes the data file has to add these 2^{17} * 50ns to its internal macro time value for each macro time overflow.
INVALID	1 = Data Invalid. All data for this photon except the MTOV bit is invalid. The INVALID bit is set if the 'Count Enable' bit at the SPC routing connector was '0', i.e. if a router is connected and there is no valid routing information for this photon.

Due to the high macro time resolution and the limited number of macro time bits in the SPC-402/432 a macro time overflow occurs each 6.5 ms. Therefore, it can happen that no photon is recorded between two subsequent macro time overflows. To enable the processing software to maintain a correct macro time for the rest of the measurement an entry in the measurement data file is provided if overflows occurred between two subsequent photons. This entry is marked by 'MTOV = 1' and 'INVALID = 1' and contains the number of macro time overflows which occurred since the last photon was recorded. The structure of this entry is shown below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	CNT[7]	CNT[6]	CNT[5]	CNT[4]	CNT[3]	CNT[2]	CNT[1]	CNT[0]
Byte 1	CNT[15]	CNT[14]	CNT[13]	CNT[12]	CNT[11]	CNT[10]	CNT[9]	CNT[8]
Byte 2	CNT[23]	CNT[22]	CNT[21]	CNT[20]	CNT[19]	CNT[18]	CNT[17]	CNT[16]
Byte 3	INVALID(1)	MTOV(1)	--	0	CNT[27]	CNT[26]	CNT[25]	CNT[24]

CNT[27:0]   Number of macro time overflows which occurred without recording photons

FIFO File Structure, Version 7.0 and later

With the changes introduced in the version 7.0 of the SPC Standard Software and the Multi-SPC-Software also the file header and setup block section of the FIFO files has changed.
The structures of the measurement data and setup files are described below.

Setup Files

For each measurement, a setup data file is generated which contains the hardware and software parameter used for this measurement. The setup files are compatible to that of the SPC Standard Software.

The setup data files consist of

- the file header which contains structural data used to find the other parts of the file
- the file information which was typed in when the file was saved
- the system setup data for hardware and software

File Header

The files start with a file header which contains information about the location and the length of the other parts of the file. The information is stored in a binary format. The file header variables are shown in the table below. The header is used for setup files and data files of the SPC Standard Software as well. Therefore, not all parameters contained in the header are used for the SPC FIFO setup files.

short	revision	software revision number (lower 4 bits = 11(decimal))
long	info offset	offset of the info part which contains general information (Title, date, time, contents etc.)
short	info length	length of the info part
long	setup_offs	offset of the setup data (system parameters, display parameters, trace parameters etc.)
short	setup_length	length of the setup data
long	data_block_offset	offset of the first data block
short	no_of_data_blocks	no_of_data_blocks valid only when in 0 .. 0x7ffe range, if equal to 0x7fff the field 'reserved1' contains valid no_of_data_blocks
long	data_block_length	length of the longest data block in the file
long	meas_desc_block_offset	offset to 1st. measurement description block (system parameters connected to data blocks)
short	no_of_meas_desc_blocks	number of measurement description blocks
short	meas_desc_block_length	length of the measurement description blocks
unsigned short	header_valid	valid: 0x5555, not valid: 0x1111
unsigned long	reserved1	reserved1 now contains no_of_data_blocks
unsigned short	reserved2	
unsigned short	chksum	checksum of file header

Info

This part contains the general information which was automatically generated by the FIFO software.
The info part is stored in ASCII. An example is given below.

```
*IDENTIFICATION
    ID          : _SPC Setup & Data File_
    Title       : startup
    Version     : 007
    Revision    : 1
    Date        : 10-10-1997
    Time        : 12:29:01
    Author      :
    Company     :
    Contents    : Setup file made by system at the end of FIFO measurement wuth module SPC-630 (Ser. No. 360021)
*END
```

Setup Block

The ‘setup’ block contains all the system parameters, display parameters, trace parameters etc. It is used to set the SPC system hardware and software into the same state as it was in the moment when the data file was stored. The values are stored together with an identifier of the particular parameter. This method allows to maintain compatibility between different SPC versions. If a parameter is missing in the setup part, a default value is used when the file is loaded. A typical setup part is shown below.

```
SYS_PARA_BEGIN:
#PR [PR_PDEV,I,0]
#PR [PR_PPORT,I,2]
#PR [PR_PWHAT,I,0]
#PR [PR_PF,B,0]
#PR [PR_PFNAME,S,IMAGE.PRT]
#PR [PR_PORIEN,I,1]
#PR [PR_PEJECT,B,1]
#PR [PR_PWIDTH,F,100]
#PR [PR_PHEIGH,F,100]
#PR [PR_PFULL,B,1]
#PR [PR_PAUTO,B,1]
#PR [PR_STP_FN,S,STP.CFG]
#PR [PR_SAVE_T,I,2]
#SP [SP_MODE,I,0]
#SP [SP_CFD_LL,F,-20]
#SP [SP_CFD_LH,F,80]
#SP [SP_CFD_ZC,F,0]
#SP [SP_CFD_HF,F,5]
#SP [SP_SYN_ZC,F,-9.8267717]
#SP [SP_SYN_FD,I,4]
#SP [SP_SYN_FQ,F,-20]
#SP [SP_SYN_HF,F,4]
#SP [SP_TAC_R,F,5.0000001e-08]
#SP [SP_TAC_G,I,1]
#SP [SP_TAC_OF,F,9.4993896]
#SP [SP_TAC_LL,F,14.90196]
#SP [SP_TAC_LH,F,84.705879]
#SP [SP_TAC_TC,F,4.8828126e-11]
#SP [SP_TAC_TD,F,6.2500001e-09]
#SP [SP_ADC_RE,I,1024]
#SP [SP_EAL_DE,I,30]
#SP [SP_NCX,I,1]
#SP [SP_NCY,I,1]
#SP [SP_PAGE,I,1]
#SP [SP_COL_T,F,100.01]
#SP [SP_REP_T,F,100.01]
#SP [SP_DIS_T,F,0.99899995]
#SP [SP_REPEAT,B,0]
#SP [SP_STOPT,B,1]
#SP [SP_OVERFL,C,S]
#SP [SP_WL_STA,F,300]
#SP [SP_WL_STO,F,362]
#SP [SP_WL_STE,F,2]
#SP [SP_EXTST,B,0]
#SP [SP_STEPS,I,32]
#SP [SP_OFFSET,F,0]
#SP [SP_YWIN_N,I,8]
#SP [SP_XWIN_N,I,8]
#SP [SP_TWIN_N,I,8]
#SP [SP_X_EQU,B,1]
#SP [SP_Y_EQU,B,1]
#SP [SP_T_EQU,B,1]
#SP [SP_DITH,I,64]
#SP [SP_EN_INT,B,0]
#SP [SP_INCR,I,64]
#SP [SP_DAES,B,1]
#SP [SP_SPE_FN,S,SPEC1.SDT]
#SP [SP_CYCLES,U,1]
#SP [SP_DAEC,B,0]
#SP [SP_MEM_BANK,I,0]
#SP [SP_DTCOMP,B,1]
#DI [DI_SCALE,I,0]
#DI [DI_MAXCNT,L,65535]
#DI [DI_LBLINE,L,100]
#DI [DI_BLINE,L,0]
#DI [DI_GRID,B,0]
#DI [DI_GCOL_F,I,8]
#DI [DI_GCOL_B,I,0]
#DI [DI_TRACE,I,0]
#DI [DI_BOD_C,I,3]
#DI [DI_2DDIS,I,0]
#DI [DI_2DTRNO,I,1]
#DI [DI_3DOFFX,I,4]
#DI [DI_3DOFFY,I,4]
#DI [DI_3DINCX,I,0]
#DI [DI_3DCOL,I,15]
#DI [DI_3DMODE,I,3]
#DI [DI_YWIN,I,2]
#DI [DI_XWIN,I,1]
#DI [DI_TWIN,I,1]
#DI [DI_PSTYLE,I,9]
#DI [DI_PFREQ,I,1]
#DI [DI_CUR,B,0]
#DI [DI_RATE,B,1]
#DI [DI_2DC1,B,1]
#DI [DI_2DC2,B,1]
#DI [DI_2DC1C,I,1]
#DI [DI_2DC2C,I,5]
#DI [DI_2DC1S,I,0]
#DI [DI_2DC2S,I,0]
#DI [DI_3DC1C,I,12]
#DI [DI_3DC2C,I,14]
#DI [DI_SIZE,I,1]
#MP0 [MP_CFD_LL,F,0]
#MP0 [MP_CFD_LH,F,39.843136]
#MP0 [MP_CFD_ZC,F,-7.5590553]
#MP0 [MP_CFD_HF,F,5]
#MP0 [MP_SYN_ZC,F,-4.5354333]
#MP0 [MP_SYN_FD,I,1]
#MP0 [MP_SYN_FQ,F,-19.607843]
#MP0 [MP_SYN_HF,F,4]
#MP0 [MP_TAC_LL,F,7.8431373]
#MP0 [MP_TAC_LH,F,90.588234]
#MP0 [MP_TRIGGER,I,0]
#MP0 [MP_TAC_OF,F,9.8039217]
#MP1 [MP_CFD_LL,F,0]
#MP1 [MP_CFD_LH,F,39.843136]
#MP1 [MP_CFD_ZC,F,-7.5590553]
#MP1 [MP_CFD_HF,F,5]
#MP1 [MP_SYN_ZC,F,-4.5354333]
#MP1 [MP_SYN_FD,I,1]
#MP1 [MP_SYN_FQ,F,-19.607843]
#MP1 [MP_SYN_HF,F,4]
#MP1 [MP_TAC_LL,F,7.8431373]
#MP1 [MP_TAC_LH,F,90.588234]
#MP1 [MP_TRIGGER,I,0]
#MP1 [MP_TAC_OF,F,9.8039217]
SYS_PARA_END:
TRACE_PARA_BEGIN:
#TR #0 [1,15,1,1,4,1,1]
#TR #1 [0,9,1,2,1,2,1]
#TR #2 [0,10,1,3,1,3,1]
#TR #3 [0,14,1,4,1,4,1]
#TR #4 [0,9,1,5,1,1,1]
#TR #5 [0,12,1,6,1,1,1]
#TR #6 [0,13,1,7,1,1,1]
#TR #7 [0,11,1,8,1,1,1]
 TRACE_PARA_END:
WIND_PARA_BEGIN:
#WI #0 *NO *0 [0,0]
#WI #0 *NO *1 [0,0]
#WI #0 *NO *2 [0,0]
#WI #0 *NO *3 [0,0]
#WI #0 *NO *4 [0,0]
#WI #0 *NO *5 [0,0]
#WI #0 *NO *6 [0,0]
#WI #0 *NO *7 [0,0]
#WI #1 *NO *0 [0,0]
#WI #1 *NO *1 [0,0]
#WI #1 *NO *2 [0,0]
#WI #1 *NO *3 [0,0]
#WI #1 *NO *4 [0,0]
#WI #1 *NO *5 [0,0]
#WI #1 *NO *6 [0,0]
#WI #1 *NO *7 [0,0]
#WI #2 *NO *0 [0,127]
#WI #2 *NO *1 [128,255]
#WI #2 *NO *2 [256,383]
#WI #2 *NO *3 [384,511]
#WI #2 *NO *4 [512,639]
#WI #2 *NO *5 [640,767]
#WI #2 *NO *6 [768,895]
#WI #2 *NO *7 [896,1023]
 WIND_PARA_END:
*END
```

Measurement Data Files (SPC-401/431, SPC-6 FIFO 4096 Channels)

The information about the subsequent photons is stored one after another in the measurement data file. For each photon 6 bytes are used. The structure of these data is shown in the table below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	ADC[7]	ADC[6]	ADC[5]	ADC[4]	ADC[3]	ADC[2]	ADC[1]	ADC[0]
Byte 1	0	GAP	MTOV	INVALID	ADC[11]	ADC[10]	ADC[9]	ADC[8]
Byte 2	MT[23]	MT[22]	MT[21]	MT[20]	MT[19]	MT[18]	MT[17]	MT[16]
Byte 3	R[7]	R[6]	R[5]	R[4]	R[3]	R[2]	R[1]	R[0]
Byte 4	MT[7]	MT[6]	MT[5]	MT[4]	MT[3]	MT[2]	MT[1]	MT[0]
Byte 5	MT[15]	MT[14]	MT[13]	MT[12]	MT[11]	MT[10]	MT[9]	MT[8]

ADC[11:0]	ADC Data (Micro Time)
R [7:0]	Routing Signals (inverted)
MT[23:0]	Macro Time [µs]
GAP	1 = Possible recording gap due to FIFO Full. There may be (and most likely is) a gap in the recording preceding this photon.
MTOV	1 = Macro Timer Overflow. Since the capacity of the macro timer is limited to 24 bit it will overflow each 2^{24} µs. The software which processes the data file has to add these 2^{24} µs to its internal macro time value on each MTOV =1.
INVALID	1 = Data Invalid. All data for this photon except the MTOV bit is invalid. The INVALID bit is set if the 'Count Enable' bit at the SPC routing connector was '0', i.e. if a router is connected and there is no valid routing information for this photon.

Measurement Data Files (SPC-402/432, SPC-6 FIFO 256 Channels)

The information about the subsequent photons is stored one after another in the measurement data file. For each photon 4 bytes are used. The structure of these data is shown in the table below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	ADC[7]	ADC[6]	ADC[5]	ADC[4]	ADC[3]	ADC[2]	ADC[1]	ADC[0]
Byte 1	MT[7]	MT[6]	MT[5]	MT[4]	MT[3]	MT[2]	MT[1]	MT[0]
Byte 2	MT[15]	MT[14]	MT[13]	MT[12]	MT[11]	MT[10]	MT[9]	MT[8]
Byte 3	INVALID	MTOV	GAP	0	R[2]	R[1]	R[0]	MT[16]

ADC[7:0]	ADC Data (Micro Time)
R [2:0]	Routing Signals (inverted)
MT[16:0]	Macro Time [µs]
GAP	1 = Possible recording gap due to FIFO Full. There may be (and most likely is) a gap in the recording preceding this photon.
MTOV	1 = Macro Timer Overflow. Since the capacity of the macro timer is limited to 24 bit it will overflow each 2^{17} * 50ns. The software which processes the data file has to add these 2^{17} * 50ns to its internal macro time value for each macro time overflow.
INVALID	1 = Data Invalid. All data for this photon except the MTOV bit is invalid. The INVALID bit is set if the 'Count Enable' bit at the SPC routing connector was '0', i.e. if a router is connected and there is no valid routing information for this photon.

Due to the high macro time resolution and the limited number of macro time bits in the SPC-402/432 a macro time overflow occurs each 6.5 ms. Therefore, it can happen that no photon is recorded between two subsequent macro time overflows. To enable the processing software to maintain a correct macro time for the rest of the measurement an entry in the measurement data file is provided if overflows occurred between two subsequent photons. This entry is marked by 'MTOV = 1' and 'INVALID = 1' and contains the number of macro time overflows which occurred since the last photon was recorded. The structure of this entry is shown below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	CNT[7]	CNT[6]	CNT[5]	CNT[4]	CNT[3]	CNT[2]	CNT[1]	CNT[0]
Byte 1	CNT[15]	CNT[14]	CNT[13]	CNT[12]	CNT[11]	CNT[10]	CNT[9]	CNT[8]
Byte 2	CNT[23]	CNT[22]	CNT[21]	CNT[20]	CNT[19]	CNT[18]	CNT[17]	CNT[16]
Byte 3	INVALID(1)	MTOV(1)	--	0	CNT[27]	CNT[26]	CNT[25]	CNT[24]

CNT[27:0] Number of macro time overflows which occurred without recording photons

Measurement Data Files (SPC-134)

The information about the subsequent photons is stored one after another in the measurement data file. For each photon 2 words (4 bytes) are used. The structure of these data is shown in the table below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	MT[7]	MT[6]	MT[5]	MT[4]	MT[3]	MT[2]	MT[1]	MT[0]
Byte 1	ROUT[3]=0	ROUT[2]	ROUT[1]	ROUT[0]	MT[11]	MT[10]	MT[9]	MT[8]
Byte 2	ADC[7]	ADC[6]	ADC[5]	ADC[4]	ADC[3]	ADC[2]	ADC[1]	ADC[0]
Byte 3	INVALID	MTOV	GAP	0	ADC[11]	ADC[10]	ADC[9]	ADC[8]

INVALID 1 = Data Invalid. All data for this photon except the MTOV bit is invalid. The INVALID bit is set if the 'Count Enable' bit at the SPC routing connector was '0', i.e. if a router is connected and there is no valid routing information for this photon.

MTOV 1 = Macro Timer Overflow. Since the capacity of the macro timer is limited to 12 bit it will overflow each 2^{12} * 50ns. The software which processes the data file has to add this time to its internal macro time value on each MTOV =1.

ADC[11:0] ADC Data (Micro Time)

ROUT[3:0] Routing signals (inverted)

MT[11:0] Macro Time [50 ns]

GAP 1 = Possible recording gap due to 'FIFO Full'. There may be (and most likely is) a gap in the recording preceding this photon.

Due to the high macro time resolution and the limited number of macro time bits in the SPC-134 a macro time overflow occurs each 0.2 ms. Therefore, it can happen that no photon is recorded between two subsequent macro time overflows. To enable the processing software to maintain a correct macro time for the rest of the measurement an entry in the measurement data file is provided if overflows occurred between two subsequent photons. This entry is marked by 'MTOV = 1' and 'INVALID = 1' and contains the number of macro time overflows which occurred since the last photon was recorded. The structure of this entry is shown below.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 0	CNT[7]	CNT[6]	CNT[5]	CNT[4]	CNT[3]	CNT[2]	CNT[1]	CNT[0]
Byte 1	CNT[15]	CNT[14]	CNT[13]	CNT[12]	CNT[11]	CNT[10]	CNT[9]	CNT[8]
Byte 2	CNT[23]	CNT[22]	CNT[21]	CNT[20]	CNT[19]	CNT[18]	CNT[17]	CNT[16]
Byte 3	INVALID(1)	MTOV(1)	--	0	CNT[27]	CNT[26]	CNT[25]	CNT[24]

CNT[27:0] Number of macro time overflows which occurred without recording photons

Trouble Shooting

Although we believe that our SPC modules work reliably tests can be recommended after an accident such as overvoltage, mechanical stress or another extreme situation. Furthermore, if a measurement setup does not work as expected a test of the SPC module can help to find out the reason. However, the best strategy **before a test is required,** is: **Avoid damage to the module**!

How to Avoid Damage

The best way to avoid any trouble is to avoid conditions that can cause damage to the SPC module. The most dangerous situations are described below.

Electrostatic Discharge

Electrostatic discharge can damage the module when it is inserted or removed from a computer or when it is touched for other reasons. It happens when your body is electrically charged and you touch a sensitive part of the SPC module. To avoid damage due to electrostatic discharge we recommend to follow the rules given below:

Before inserting an SPC module is into a computer, you should touch the computer at a metallic (grounded) part to drain a possible charge of your body.

When the module is taken from its packaging box it should be touched at first at the front panel.

Before bringing the module into contact with the computer touch both the module at the front panel and a metallic part of the computer.

When taking a module from a computer touch a metallic part of the computer before touching the SPC module.

There are extreme situations where sparks are crackling when touching anything. Such an environment should be avoided when handling any electronic parts. Or, if this is not possible, it is not ridiculous to take off shoes and socks when handling sensitive electronic devices.

Overvoltage at the signal inputs

Damaging the signal inputs is the most expensive accident, because the CFD or the SYNC hybrid circuit has to be replaced in this case. Therefore:

Never connect a photomultiplier to the SPC module when the high voltage is switched on! Never connect a photomultiplier to the SPC module if the high voltage was switched on before with the PMT output left open! Never use switchable attenuators between the PMT and the SPC! Never use cables and connectors with bad contacts! The same rules should be applied to photodiodes that are operated at supply voltages above 20V. The reason is as follows: If the PMT output is left open while the HV is switched on, the output cable is charged by the dark current to a voltage of some 100V. When connected to the SPC the cable is discharged into the SPC input. The energy stored in the cable is sufficient to destroy the input amplifier. Normally the limiter diodes at the input will prevent a destruction, but the action will stress the diodes enormously. Therefore, don't tempt fate!

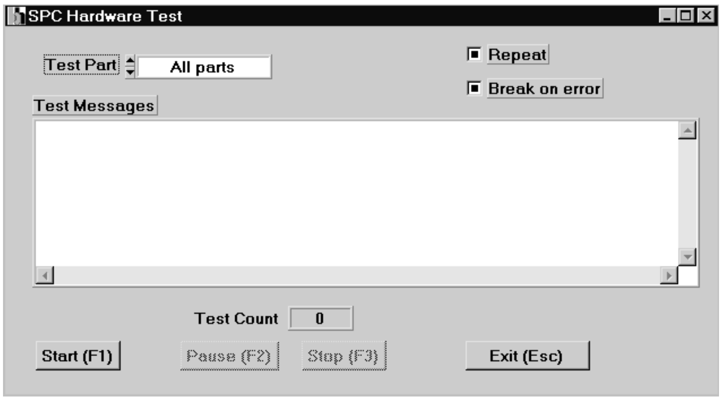
To provide maximum safety against damage we recommend to connect a resistor of about 10 kOhm from the PMT anode to ground inside the PMT case and as close to the PMT anode as possible. This will prevent cable charging and provide protection against damage due to bad contacts in connectors and cables.

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

Please be careful when working with low repetition rate lasers. Some of these lasers deliver so high pulse energies, that a photodiode can switch into a breakthrough state and deliver an extremely high current for hundreds of ns. Even PMTs can deliver pulses of several 100 mA if they are hit by the laser pulse. For maximum safety, use preamplifiers when working with such lasers.

Testing the Module by the SPC Test Program

If you suspect any problems with the bus interface, the timing and control circuits or the memory of an SPC module, run the 'SPC Test' program delivered with the SPC Standard Software. The main panel of this program is shown below.

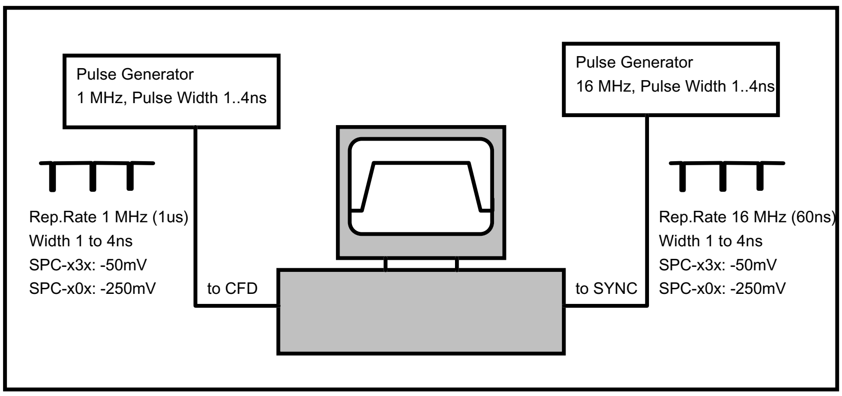


Switch on 'All Parts', 'Repeat' and 'Break on Error' and start the test. If the program performs several test loops (indicated by 'Test Count') without indicating an error you may be sure that the bus interface, the timing and control circuits and the memory of the module work correctly. Depending on the type of the SPC module and the speed of the computer, it can take some minutes to run one test loop.

If an error is displayed, check that the module is inserted correctly and that there is no address conflict (See next section).

Test for Basic Function and for Differential Nonlinearity

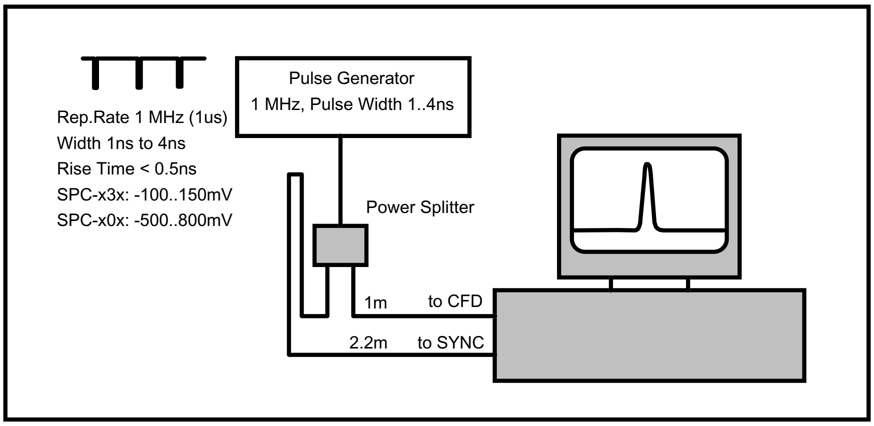
This test requires two pulse generators with a pulse width of 1 to 4 ns and a repetition rate of 16 MHz and 1 MHz respectively. **Don't** use diode laser controllers for SYNC generation. The test setup is shown below.



It is important that the two pulse generators are really independent. Therefore, keep the generators and the cables well apart.

Test for Time Resolution

The time resolution of the SPC modules is tested in the setup shown below.



Frequently Encountered Problems

The module is not found by the SPC software

ISA modules: Check the address in the SPC.INI file and the setting of the DIP switch on the SPC module (See ‘Changing the Module Address’). Try another address to be sure that the problem is not caused by an address conflict with another module.

All modules: Check that the module is correctly inserted. Especially when moving the computer the module can work loose. Furthermore, the connectors have some longitudinal play which can cause problems in the PCI connectors. Make sure that the bus connector is clean. If necessary, clean with ethanol, isopropanol or acetone.

No SYNC Rate or ‘No Sync’

Check the SYNC signal. Is the polarity of the pulses correct? Is the baseline of the pulses correct? Check the signal with an oscilloscope (300 MHz or more). Don’t forget to switch the oscilloscope to 50 Ω, DC.

For SPC-x30 modules the polarity of the pulses must be negative. For SPC-x00 modules, make sure that the SYNC input is configured for the right polarity.

Check that the delay lines for shaping the zero cross are inserted (see ‘Configuring the CFD and SYNC Inputs’).

Check the SYNC parameters. For –00 modules set ‘SYNC ZC’ to –10mV. For –30 modules, set ‘SYNC Threshold’ to –20mV and change ‘SYNC ZC’ between –100mV and +100mV.

SPC-134: Sync Rate Jumper missing (see ‘Adjust Parameters’)

Wrong SYNC Rate

SYNC Rate too high: This problem is usually caused by reflections and ringing at the SYNC line. Check the Sync signal. For –00 modules set ‘SYNC ZC’ to –10mV. For –30 modules, increase ‘SYNC Threshold’. Increase ‘SYNC Holdoff’.

SYNC Rate too low: Check the SYNC parameters. For –00 modules set ‘SYNC ZC’ to –10mV. For –30 modules, set ‘SYNC Threshold’ to –20mV and change ‘SYNC ZC’ between –100mV and +100mV.

SPC-134: Sync rate jumper setting does not conform with the Adjust Parameters

No CFD Rate

Check the detector and the preamplifier. For –00 modules, make sure that the pulse polarity is correct and that the pulse amplitude is between 20 mV and 80 mV. For –00 modules, make sure that the pulses are negative. Check the CFD parameters.

Check that the delay lines for shaping the zero cross are inserted (see ‘Configuring the CFD and SYNC Inputs’).

No TAC Rate or TAC rate much lower than CFD Rate

Check that the delay lines for shaping the zero cross are inserted (see ‘Configuring the CFD and SYNC Inputs’).

Check the CFD parameters. Change ‘CFD ZC’. For a wrong zero cross setting it can happen that the leading edge discriminator in the CFD responds, but the zero cross discriminator does not find a zero cross. In this case a CFD rate is displayed, but there are no CFD output pulses to trigger the TAC.

SPC-00: CFD input amplitude too high or ‘CFD Limit High’ too low. The majority of the input pulses are above the upper CFD Threshold.

No ADC Rate

If the ADC rate is zero or extremely low the reason is almost always a SYNC problem.

For SPC-00 modules:

Set SYNC ZC to –10 mV. Check the SYNC signal. Is there a baseline offset? For offset signals it can happen that the baseline is above the ‘SYNC OK' level, but there is no part of the signal that crosses the ‘SYNC ZC’ level. The module then indicates ‘SYNC OK’, but the internal SYNC Rate is zero. Check that the delay lines for shaping the zero cross are inserted (see ‘Configuring the CFD and SYNC Inputs’).

For SPC-30 modules:

Check the SYNC signal. Is there a baseline offset? Check the SYNC parameters. Change ‘SYNC ZC’. For a wrong zero cross setting it can happen that the leading edge discriminator in the SYNC responds, but the zero cross discriminator does not find a zero cross. In this case a SYNC rate is displayed, but there are no SYNC output pulses to stop the TAC.

For SYNC repetition rates lower than 20 MHz:

Make sure that the SYNC pulses arrive **after** the detector pulses and within a time not greater than the selected ‘TAC Range’. Otherwise the TAC is not stopped, detects an ‘Outrange’ condition and resets itself without starting the ADC. What you see in this case are only some background events, not the signal photons.

Check the TAC Parameters Limit High, Limit Low and TAC Offset.

ADC Rate, but no TAC Rate

During FIFO measurement: Normal effect if no photons are detected. The ADC rate comes from the conversions which are forced by macro time overflows.

All rates present, but no curves on the screen

Check the Trace Parameters. Are you displaying the curve(s) which you are measuring? ‘Page’ must have the same setting as in the main window. Is the measured curve switched ‘active’? Is the colour of the curve different from the background colour?

Check the Display Parameters. ‘Reverse Y scale’ should be off, ‘Baseline’ should be 0. ‘Bkgcolor’ must be different from the colour of the measured curve.

Check the System Parameters. For a simple test measurement, the operation mode should be ‘Oscilloscope’ or ‘Single’. For the Oscilloscope mode ‘Stop T’ and a reasonable ‘Collection Time’ must be set. For the ‘Single’ mode, a display time of less than 1 second should be set. ‘Routing Channels X’ and ‘Routing Channels Y’ should be 1. ‘Memory Offset’ should be 0.

If the module has a measurement trigger (SPC-6, -7, SPC-134), the trigger condition **must be ‘none’** as long as no trigger is used (‘More Parameters’).

If a router is used: Make sure that the detector signal is connected to the router. Make sure that the timing cable from the router is connected to the SPC **and** the router is connected via the Sub-D cable. The detector signal **must** be connected to via the router as long as the router is connected via the Sub-D cable. Connecting the detector directly to the SPC **does not** work as long as the router is connected via the Sub-D cable.

Curve on the screen does not change when measured

You display another curve than you are measuring. Check the trace parameters as described above.

Noise in the measured curves is bigger than expected, ‘Chi Square’ too high

Check the ‘Count Increment’ parameter in the System Parameters. Set ‘Count Increment’ = 1 for precision measurements.

Ripple or waves in the curves

Check the ‘Dither Range’ parameter in the System Parameters. The function of this parameter is described under ‘ADC with Error Correction’.

Check your SYNC signal. Is the amplitude correct? Is the risetime short enough to maintain clean triggering?

Keep the cables to the SYNC and the CFD input well separated.

Try with slightly different ‘CFD Zero Cross’ and ‘SYNC Zero Cross’. If the zero cross level is too close to the true signal baseline the zero cross triggers respond to spurious signals which can impair the timing accuracy.

Make sure that there is no electrical noise from your laser. Especially diode lasers often are radio transmitters rather than light sources.

SPC-7, Scan Sync in Mode: Measurement doesn’t finish

Check the Xsync, Ysync and PixlClk signals. One of the signals is missing.

Bad Time Resolution

Check whether the SYNC and CFD inputs are configured correctly (see ‘Configuring the CFD and SYNC inputs’).

Check your setup for ground loops. Grounding different system components (computer, PMT, HV power supply, monochromator, etc.) at different ground systems can induce considerable noise current in the ground lines. This current is transformed into the signal lines and can degrade the timing performance.

Disconnect network cables. Long network cables work as antennas and introduce noise into the system.

Check the SYNC signal with an oscilloscope for risetime and amplitude jitter.

Check the detector signal for background noise. With the HV of the PMT switched off, there should be no CFD count rate for a CFD limit low above 10..20 mV.

Is the pulse amplitude sufficient? For the SPC-x00 versions the amplitude of the majority of pulses should be above 40mV, for the SPC-0x30 versions above 100 mV to get optimum resolution. Check by changing the 'CFD limit low' parameter.

Be careful when checking the resolution with a scattering solution. Multiple scattering can broaden the pulses by several 100 ps. The solution should look clear under normal daylight, but show a distinct scattering effect in the laser beam. On the other hand, don't use the Raman scattering of pure water. Although clearly detectable, this is too weak to exclude errors by the fluorescence of contamination. Surprisingly, scattering the laser at a piece of paper often gives good results. However, the best way to test the resolution is to send the laser beam through a set of filters directly to the detector.

Bad Shape of System Response, Double Pulses

Check the optical system for scattered light and multiple reflections.

SPC-00: The amplitude of the majority of the detector pulses must be less than 'CFD limit Low'. Otherwise it can happen that you detect a refection of the detector pulses rather than the pulses themselves.

With active modelockers: Make sure that there is no pickup from the modelocker frequency. This can cause non-equidistant SYNC pulses.

Fan does not work

If the fan doesn't work you have most likely shorted the +12V at the sub-D connector and burned the connection on the SPC module. Although there is no immediate danger of overheating under normal temperature conditions, the module should be repaired as soon as possible. Remember that a photodiode or a detector supplied by the 12V from the sub-D connector may not work correctly.

Assistance through bh

Software updates, new manual versions and application notes about new applications are available from our web site www.becker-hickl.de. Furthermore, we are pleased to support you in all problems concerning the measurement of fast electrical or optical signals. This includes discussions of new applications, the installation of the SPC modules, their application to your measurement problem, the technical environment and physical problems related to short time measurement techniques. Simply call us or send us an email.

Should there be a problem with your SPC module, please contact us. To fix the problem we ask you to send us a data file (.sdt) of the questionable measurement or (if a measurement is not possible) a setup file (.set) with your system settings. Furthermore, please add the following information:

Description of the Problem
SPC Module Type and Serial Number
Software Version
Detector type, Operating voltage of the detector, PMT Cathode type
Preamplifier type, Gain, Bandwidth etc.
Laser System: Type, Repetition Rate, Wavelength, Power
SYNC Signal Generation: Photodiode, Amplitude, Rise Time
Optical System: Basic Setup, Sample, Monochromator
System Connections: Cable Lengths, Ground Connections. Add a drawing if necessary.
Environment: Possible Noise Sources
Your personal data: E-mail, Telephone Number, Postal Address

The fastest way is to send us an email with the data file(s) attached. We will check your system settings and – if necessary – reproduce your problem in our lab. We will send you an answer within one or two days.

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Specification

SPC-300/330-10, SPC-300/330-12

Photon Channel	SPC-300	SPC-330
Principle	Constant Fraction Discriminator	
Time Resolution (FWHM / RMS, electr.)	13 ps / 7 ps	6 ps / 3 ps
Opt. Input Voltage Range	± 10 mV to ± 80 mV	- 50 mV to - 1 V
Lower Threshold	5 mV to 80 mV	- 20 mV to - 500 mV
Upper Threshold	5 mV to 80 mV	-
Zero Cross Adjust	-10 mV to + 10 mV	- 100 mV to + 100 mV

Synchronisation Channel	SPC-300	SPC-330
Principle	Constant Fraction Discriminator	
Opt. Input Voltage Range	± 10 mV to ± 50 mV	- 50 mV to - 1 V
Threshold	-	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz	
Frequency Divider	1-2-4-8-16	
Zero Cross Adjust	-10 mV to + 10 mV	-20 mV to + 20 mV

Time-to-Amplitude Converter / ADC	-10 Versions	-12 Versions
Principle	Ramp Generator / Biased Amplifier	
TAC Ramp Range	50 ns to 2 us	
Biased Amplifier Gain	1 to 15	
Biased Amplifier Offset	0 to 100% of TAC Range	
Time Range incl. Biased Amplifier	3.3 ns to 2 us	
min. Time / Channel	3.24 ps	813 fs
TAC Window Discriminator	Any Window inside the TAC Range	
ADC Principle	50 ns Flash ADC with Error Correction	
Diff. Nonlinearity	< 2% rms	

Data Acquisition	-10 Versions	-12 Versions
Dead Time	200 ns	
max. Number of Curves in Memory	128	32
max. Number of Detector Channels	128	32
Number of Time Channels / Curve	64 to 1024	64 to 4096
Counts / Channel (dep. on No. of Ch.)	2^{20} - 4 to 2^{16}-1	2^{24} -16 to 2^{16-1}
Overflow Control	none / stop / correct and repeat	
Collection Time	10 ms to 1000 s	
Display Interval Time	10 ms to 1000 s	
Repeat Time	10 ms to 1000 s	
Curve Control (internal)	Software Control	
Curve Control (external Routing)	7 bit TTL	5 bit TTL
Add/Sub (Lock-in) Control	1 bit TTL	1 bit TTL
Count Enable Control	1 bit TTL	1 bit TTL
Control Signal Latch Delay	0 to 255 ns	

Operation Environment	
Computer System	PC Pentium ,486 or 386 with Coprocessor
Bus Connector	ISA 16 bit
Power Consumption	20 W at +5V, 0.7 W at +12V
Dimensions	337 mm x 120 mm x 32 mm

SPC-400/430

Photon Channel	SPC-400	SPC-430
Principle	Constant Fraction Discriminator	
Time Resolution (FWHM / RMS, electr.)	13 ps / 7 ps	7 ps / 4 ps
Opt. Input Voltage Range	± 10 mV to ± 80 mV	- 50 mV to - 1 V
Lower Threshold	5 mV to 80 mV	- 20 mV to - 500 mV
Upper Threshold	5 mV to 80 mV	-
Zero Cross Adjust	-10 mV to + 10 mV	- 100 mV to + 100 mV

Synchronisation Channel	SPC-400	SPC-430
Principle	Constant Fraction Discriminator	
Opt. Input Voltage Range	± 10 mV to ± 50 mV	- 50 mV to - 1 V
Threshold	-	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz	
Frequency Divider	1-2-4-8-16	
Zero Cross Adjust	-10 mV to + 10 mV	-100 mV to + 100 mV

Time-to-Amplitude Converter / ADC

Principle	Ramp Generator / Biased Amplifier
TAC Range	50 ns to 2 us
Biased Amplifier Gain	1 to 15
Biased Amplifier Offset	0 to 100% of TAC Range
Time Range incl. Biased Amplifier	3.3 ns to 2 us
min. Time / Channel	813 fs
TAC Window Discriminator	Any Window inside TAC Range
ADC Principle	50 ns Flash ADC with Error Correction
Diff. Nonlinearity	< 2% rms

Data Acquisition

Dead Time	125 ns			
max. Count Rate (for infinite detector count rate)	8 MHz			
max. Number of Curves in Memory	2048	512	128	32
max. Number of Detector Channels	128	128	128	32
Number of Time Channels / Curve	64	256	1024	4096
Counts / Channel (Continuous Flow Mode)	2^{16}-1			
Counts / Channel (Single Mode)	2^{32}-1			
Overflow Control	none / stop / repeat and correct			
Collection Time	0.1 ms to 1000 s			
Display Interval Time	10ms to 1000 s			
Repeat Time	0.1 ms to 1000 s			
Curve Control (internal)	Programmable Hardware Sequencer			
Curve Control (external Routing)	7 bit TTL			
Add/Sub (Lock-in) Control	1 bit TTL			
Count Enable Control	1 bit TTL			
Control and Routing Signal Latch Delay	0 to 255 ns			

Operation Environment

Computer System	PC Pentium, AT-486 or AT-386 with math. Coprocessor
Bus Type	ISA 16 bit
Power Consumption	20 W at +5 V, 1 W at +12 V
Dimensions	full size AT card: 337 mm x 120 mm

SPC-401/431, SPC-402/432

Photon Channel	SPC-401/402	SPC-431/432
Principle	Constant Fraction Discriminator	
Time Resolution (FWHM / RMS, electr.)	13 ps / 7 ps	8 ps / 4 ps
Opt. Input Voltage Range	± 10 mV to ± 80 mV	- 50 mV to - 1 V
Lower Threshold	5 mV to 80 mV	- 20 mV to - 500 mV
Upper Threshold	5 mV to 80 mV	-
Zero Cross Adjust	-10 mV to + 10 mV	- 100 mV to + 100 mV

Synchronisation Channel	SPC-401/402	SPC-431/432
Principle	Constant Fraction Discriminator	
Opt. Input Voltage Range	± 10 mV to ± 50 mV	- 50 mV to - 1 V
Threshold	-	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz	
Frequency Divider	1-2-4-8-16	
Zero Cross Adjust	-10 mV to + 10 mV	-100 mV to + 100 mV

Time-to-Amplitude Converter / ADC

Principle	Ramp Generator / Biased Amplifier
TAC Range	50 ns to 2 us
Biased Amplifier Gain	1 to 15
Biased Amplifier Offset	0 to 100% of TAC Range
Time Range incl. Biased Amplifier	3.3 ns to 2 us
min. Time / Channel	813 fs at 12 bit ADC Resolution
TAC Window Discriminator	Any Window inside TAC Range
ADC Principle	50 ns Flash ADC with Error Correction
Diff. Nonlinearity	< 2% rms

Data Acquisition	SPC-401/431	SPC-402/432
Dead Time	150 ns	
Output Data Format (ADC/Macrotime/Routing)	12/24/8	8/17/3
No. of Data File Bytes per Photon	6	4
FIFO Buffer Capacity (photons)	64 k	128k
Macro Timer Resolution	1 us / 24 bit	50ns / 17 bit
Curve Control (external Routing)	8 bit TTL	3 bit TTL
Count Enable Control	1 bit TTL	
Routing Signal Latch Delay	0 to 255 ns	

Operation Environment

Computer System	PC Pentium or 486
Bus Connector	ISA 16 bit
Power Consumption	approx. 20 W at +5V, 0.7 W at +12V
Dimensions	337 mm x 120 mm x 32 mm

SPC-500/530

Photon Channel

Photon Channel	SPC-500	SPC-530
Principle	Constant Fraction Discriminator	
Time Resolution (FWHM / RMS, electr.)	13 ps / 7 ps	7 ps / 4 ps
Opt. Input Voltage Range	± 10 mV to ± 80 mV	- 50 mV to - 1 V
Lower Threshold	5 mV to 80 mV	- 20 mV to - 500 mV
Upper Threshold	5 mV to 80 mV	-
Zero Cross Adjust	-10 mV to + 10 mV	- 100 mV to + 100 mV

Synchronisation Channel

Synchronisation Channel	SPC-500	SPC-530
Principle	Constant Fraction Discriminator	
Opt. Input Voltage Range	± 10 mV to ± 50 mV	- 50 mV to - 1 V
Threshold	-	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz	
Frequency Divider	1-2-4-8-16	
Zero Cross Adjust	-10 mV to + 10 mV	-100 mV to + 100 mV

Time-to-Amplitude Converter / ADC

Principle	Ramp Generator / Biased Amplifier
TAC Range	50 ns to 2 us
Biased Amplifier Gain	1 to 15
Biased Amplifier Offset	0 to 100% of TAC Range
Time Range incl. Biased Amplifier	3.3 ns to 2 us
min. Time / Channel	813 fs
TAC Window Discriminator	Any Window inside TAC Range
ADC Principle	50 ns Flash ADC with Error Correction
Diff. Nonlinearity	< 2% rms

Data Acquisition

Dead Time		330ns	
max. Number of Curves in Memory	16384	4096	1024
max. Number f Detector Channels	16384	4096	1024
Number of Time Channels / Curve	256	1024	4096
Counts / Channel		2^{16}-1	
Counts / Channel ('Single' mode, repeat and acquire)		2^{32}-1	
Overflow Control		none / stop / repeat and acquire	
Collection Time		0.1 ms to 1000 s	
Display Interval Time		10ms to 1000 s	
Repeat Time		0.1 ms to 1000 s	
Curve Control (external Routing)		14 bit TTL	
Count Enable Control		1 bit TTL	
Control Signal Latch Delay		0 to 255 ns	

Operation Environment

Computer System	PC Pentium, AT-486 or AT-386 with math. Coprocessor
Bus Type	ISA 16 bit
Power Consumption	20 W at +5 V, 1 W at +12 V
Dimensions	full size AT card: 337 mm x 120 mm

SPC-505/535 and SPC-506/536

(All other parameters same as for SPC-500/530)

Data Acquisition

Dead Time		330ns	
max. Number of Curves in Memory	16384	4096	1024
max. Number f Detector Channels	16384	4096	1024
Number of Time Channels / Curve	256	1024	4096
Counts / Channel		2^{16}-1	
Counts / Channel ('Single' mode, repeat and acquire)		2^{32}-1	
Overflow Control		none / stop / repeat and acquire	
Collection Time		0.1 ms to 1000 s	
Display Interval Time		10ms to 1000 s	
Repeat Time		0.1 ms to 1000 s	

Curve Control	SPC-505/535	SPC-506/536
Routing	Internal Hardware Sequencer	external
Routing Signals	Output of Scanner Control Signals PixelClock, FlybackX, FlybackY (TTL/CMOS)	Input for TV Sync Signals XSync, YSync (TTL/CMOS)
Count Enable Control	1 bit TTL/CMOS	
Add/Subtract	1 bit TTL/CMOS	
Latch Delay (for Count Enable and ADD)	0 to 255 ns	

SPC-600/630

Photon Channel	SPC-600	SPC-630
Principle	Constant Fraction Discriminator	
Time Resolution (FWHM / RMS, electr.)	13 ps / 7 ps	8 ps / 5 ps
Opt. Input Voltage Range	± 10 mV to ± 80 mV	- 50 mV to - 1 V
Lower Threshold	5 mV to 80 mV	- 20 mV to - 500 mV
Upper Threshold	5 mV to 80 mV	-
Zero Cross Adjust	-10 mV to + 10 mV	- 100 mV to + 100 mV

Synchronisation Channel	SPC-600	SPC-630
Principle	Constant Fraction Discriminator	
Opt. Input Voltage Range	± 10 mV to ± 50 mV	- 50 mV to - 1 V
Threshold	-	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz	
Frequency Divider	1-2-4-8-16	
Zero Cross Adjust	-10 mV to + 10 mV	-100 mV to + 100 mV

Time-to-Amplitude Converter / ADC

Principle	Ramp Generator / Biased Amplifier
TAC Range	50 ns to 2 us
Biased Amplifier Gain	1 to 15
Biased Amplifier Offset	0 to 100% of TAC Range
Time Range incl. Biased Amplifier	3.3 ns to 2 us
min. Time / Channel	813 fs
TAC Window Discriminator	Any Window inside TAC Range
ADC Principle	50 ns Flash ADC with Error Correction
Diff. Nonlinearity	< 2% rms

Data Acquisition (Histogram Mode)

Dead Time	125ns			
max. Number of Curves in Memory	4096	1024	256	64
max. Number of Detector Channels	128	128	128	32
Number of Time Channels / Curve	64	256	1024	4096
max. Counts / Channel	2^{16}-1			
Overflow Control	none / stop / repeat and correct			
Collection Time	0.1 ms to 10000 s			
Display Interval Time	10ms to 1000 s			
Repeat Time	0.1 ms to 1000 s			
Curve Control (internal)	Programmable Hardware Sequencer			
Curve Control (external Routing)	7 bit TTL			
Add/Sub (Lock-in) Control	1 bit TTL			
Count Enable Control	1 bit TTL			
Control Signal Latch Delay	0 to 255 ns			

Data Acquisition (FIFO / BIFL Mode)

ADC Resolution	12 bit	8 bit
Dead Time	150 ns	125 ns
Output Data Format (ADC / Macrotime / Routing)	12 / 24/ 8	8 / 17 / 3
FIFO buffer Capacity (photons)	128 k	256 k
Macro Timer Resolution	1 us, 24 bit	50ns, 17 bit
Curve Control (external Routing)	8 bit TTL	3 bit TTL
Count Enable Control	1 bit TTL	
Routing Signal Latch Delay	0 to 255 ns	

Operation Environment

Computer System	PC Pentium or 486
Bus Connector	PCI
Power Consumption	approx. 20 W at +5V, 0.7 W at +12V
Dimensions	312 mm x 122 mm x 28 mm

SPC-700/730

Photon Channel

Photon Channel	SPC-700	SPC-730
Principle	Constant Fraction Discriminator	
Time Resolution (FWHM / RMS, electr.)	13 ps / 7 ps	7 ps / 4 ps
Opt. Input Voltage Range	± 10 mV to ± 80 mV	- 50 mV to - 1 V
Lower Threshold	5 mV to 80 mV	- 20 mV to - 500 mV
Upper Threshold	5 mV to 80 mV	-
Zero Cross Adjust	-10 mV to + 10 mV	- 100 mV to + 100 mV

Synchronisation Channel

Synchronisation Channel	SPC-700	SPC-730
Principle	Constant Fraction Discriminator	
Opt. Input Voltage Range	± 10 mV to ± 50 mV	- 50 mV to - 1 V
Threshold	-	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz	
Frequency Divider	1-2-4-8-16	
Zero Cross Adjust	-10 mV to + 10 mV	-100 mV to + 100 mV

Time-to-Amplitude Converter / ADC

Principle	Ramp Generator / Biased Amplifier
TAC Range	50 ns to 2 us
Biased Amplifier Gain	1 to 15
Biased Amplifier Offset	0 to 100% of TAC Range
Time Range incl. Biased Amplifier	3.3 ns to 2 us
min. Time / Channel	813 fs
TAC Window Discriminator	Any Window inside TAC Range
ADC Principle	50 ns Flash ADC with Error Correction
Diff. Nonlinearity	< 2% rms for 90% of TAC Range

Data Acquisition

Dead Time (stop to next photon)	180ns			
Number of Time Channels / Curve	64	256	1024	4096
max. Number of Curves in Memory, ext. Routing	16384	16384	4096	1024
max. Number of Curves in Memory, int. Routing	65536	16384	4096	1024
max. Scanning Area, int. Routing	256 x 256	128 x 128	64 x 64	32 x 32
max. Number of Detector Channels	16384	16384	4096	1024
Counts / Channel	2^{16}-1			
Counts / Channel ('Single' mode, repeat and acquire)	2^{32}-1			
Overflow Control	none / stop / repeat and acquire			
Collection Time	0.1 ms to 1000 s			
Display Interval Time	10ms to 1000 s			
Repeat Time	0.1 ms to 1000 s			
Curve Control (Internal Routing)	up to 16385 Curves			
Curve Control (Passive Scanning)	14 bit TTL or SYNC Pulses from Scanner to SPC			
Scanning Control (Active Routing)	14 bit TTL or Sync Pulses from SPC to Scanner			
Count Enable Control	1 bit TTL			
Control Signal Latch Delay	0 to 255 ns			

Operation Environment

Computer System	PC Pentium or 486
Bus Connector	PCI
Power Consumption	approx. 20 W at +5V, 0.7 W at +12V
Dimensions	312 mm x 122 mm x 28 mm

SPC-134

Photon Channels

Principle	Constant Fraction Discriminator (CFD)
Time Resolution (FWHM / RMS, electr.)	8 ps / 5 ps
Opt. Input Voltage Range	- 50 mV to - 1 V
Lower Threshold	- 20 mV to - 500 mV
Upper Threshold	-
Zero Cross Adjust	- 100 mV to + 100 mV

Synchronisation Channels

Principle	Constant Fraction Discriminator (CFD)
Opt. Input Voltage Range	- 50 mV to - 1 V
Threshold	- 20 mV to -500 mV
Frequency Range	0 to 200 MHz
Frequency Divider	1-2-4
Zero Cross Adjust	-100 mV to + 100 mV

Time-to-Amplitude Converters / ADCs

Principle	Ramp Generator / Biased Amplifier
TAC Range	50 ns to 2 us
Biased Amplifier Gain	1 to 15
Biased Amplifier Offset	0 to 100% of TAC Range
Time Range incl. Biased Amplifier	3.3 ns to 2 us
min. Time / Channel	813 fs
ADC Principle	50 ns Flash ADC with Error Correction
Diff. Nonlinearity	< 2% rms

Data Acquisition

Dead Time	125ns			
max. Number of Curves in Memory (per module)	4096	1024	256	64
Number of Time Channels / Curve	64	256	1024	4096
max. Counts / Channel	2^{16}-1			
Overflow Control	none / stop / repeat and correct			
Collection Time	0.1 ms to 10000 s			
Display Interval Time	10ms to 1000 s			
Repeat Time	0.1 ms to 1000 s			
Curve Control (internal)	Programmable Hardware Sequencer			
Count Enable Control	1 bit TTL			
Measurement Trigger	TTL			

Operation Environment

Computer System	PC Pentium
Bus Connectors	PCI
Used PCI Slots	4
Power Consumption per Module	approx. 18 W at +5V, 2 W at +12V
Dimensions	225 mm x 125 mm x 85 mm

Absolute Maximum Ratings (for all SPC modules)

Current into the SYNC and CFD inputs	100 mA (DC)
	500 mA (pulse, <1us)
Voltage at the routing and control inputs / outputs	-0.5V ... +5.5 V
Currents at the	
+5V output	200 mA
-5V output	200 mA
+12V output	100 mA
-12V output	100 mA
Supply Voltage at the ISA Connector	
Vcc (+5V)	-0.5 ... +5.5 V
Vpp (+12V)	-0.5 ... +13 V
Signal Voltages at the ISA connector	-0.5 ... +5.5 V
Ambient temperature	0°C ... +40°C

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