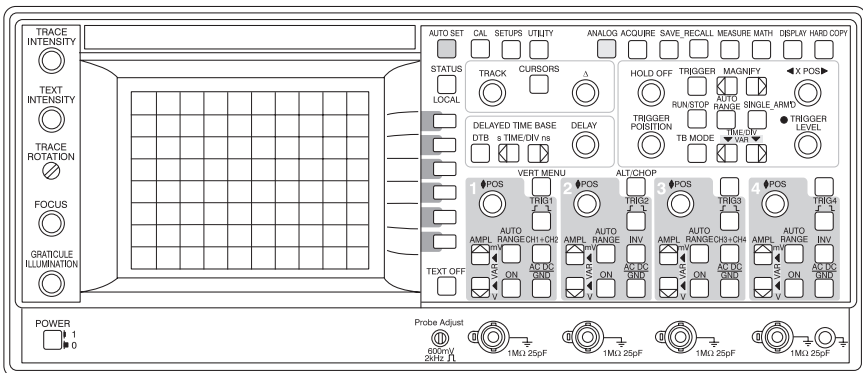# Autoranging CombiScope™ Instrument

PM3370B-PM3380B-PM3390B
PM3384B-PM3394B

MATH+ Users Manual   *2/1- Nov-1998*

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1 INTRODUCTION

The MATHPLUS option gives your oscilloscope the added mathematical capability to make complex waveform measurements/decisions. For example, you can make "PASS/FAIL" measurements in an automated test environment, mathematically manipulate realtime and/or stored waveforms (addition, subtraction, multiplication, ...) , establish amplitude qualified cursors, and more.

This manual describes all mathematic functions that were described in the Users Manuals as well as additional mathematic functions and pass/fail testing.

In addition to the basic instrument functions described in the Users Manuals, Mathplus provides the following:

-   Four more mathematical functions (integration, differentiation, fast Fourier transformation analysis, and histogram analysis).

-   Probe scaling for scaling the input sensitivity and for presetting the dimension of the acquired trace.

-   Pass/fail testing for testing waveforms against reference templates and calculated measurement results against preset limits. The action on a fail situation can be selected as beep, save, stop, or hard copy. A hard-wired output of the Fail condition is available.

-   Measurement statistics to display additional statistic measurement results on the screen.

-   Amplitude qualified cursors for timing measurements with time cursors automatically positioned relative to the signals: max peak, min peak, high level, or low level.

-   Multiple-shot mode for capturing up to 200 (50 in 2 channel version) consecutive single shot acquisitions (if the memory extension installed).

-   Varying the X POSITION of a stored trace allowing compensation for delay in measurement cables of different lengths.

2 MATHEMATICS

2.1 INTRODUCTION

Most oscilloscopes, including most Digital Storage Oscilloscopes, limit their capabilities to the display of amplitude (in volts), versus time. In addition to the traditional oscilloscope functions, the Autoranging CombiScopes™ allow you to mathematically change the contents of each memory location. You can use the mathematics functions to calculate new waveforms from other traces that serve as input data.

The following section describes the mathematical functions implemented in your oscilloscope.

Note: The External Trigger input traces of the 2 channel versions can not be used as source for the mathematics functions.

The two mathematic functions (MATH 1 and MATH 2) are independent waveform processes. Both offer a choice of eight mathematical functions (add, subtract, multiply, filter, integration, differentiation, fast Fourier transformation analysis, and histogram analysis processes). These can be used in series or in parallel. The add, subtract, and multiply functions always require two source traces to operate; the other functions require only one source trace.

Acquired traces or stored traces can be used as source for mathematical operations and can be selected by using the Δ control in the ' MATH >> MATH 1' or 'MATH >> MATH 2' submenu. For best results, the source traces must be within the dynamic range of the scope. Inactive traces or empty memory locations cannot be used and the screen will display the message "INVALID SELECTION".

The result of MATH 1 is always stored in memory location 'm1'. The result of MATH 2 is always stored in memory location 'm2'. When used for mathematical functions, existing memory locations are overwritten. (Use the 'Copy' function to save important traces in another memory location, before using the mathematical functions.)

Independent operation enables separate processes to be performed at the same time. When the result of a mathematical function is placed in a register memory, functions can be chained together. An example is Ch1∗Ch2, with the result being

integrated to measure power. In this example, MATH 1 is the multiply function with the product placed in m1 and MATH 2 is the integration process, integrating the contents of m1, and placing the result in m2. The mathematical functions are performed on traces with differing units. Channel 1 shows volts over time, channel 2 shows current over time expressed in Ampères. The resulting trace of the multiplication fuction is expressed in Watts and gives the power over time. The units for the integrated trace are Joules.

Notes: -   *The mathematical functions give useful results only if there is no conflict between the units. For example, you cannot add ampères to volts.*
              -    *The trigger delay and the timebase setting of the two traces must be equal. This is always guaranteed if the traces were acquired at the same time (i.e., they are elements of the same register).*
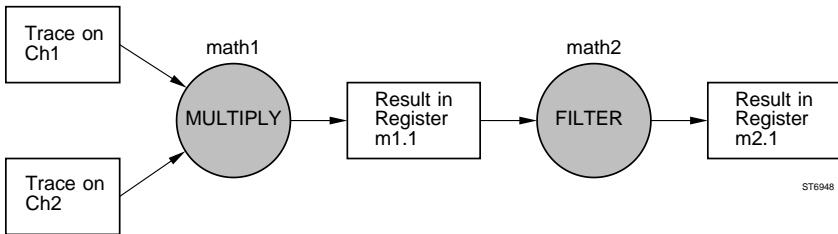
Figure 2.1   Example of chained mathematical functions

Note: Appendix A gives the complete menu structure of the MATH menu.

Remote commands:

CPL: QW (Command to query a waveform).

Refer to the Operating Guide for full details

2.2 DEFINITIONS

An example that can be used with the formulas given below, the Probe Adjust signal was sampled and the trace data was sent to a personal computer using the RS-232-C serial interface and the Query Waveform command of CPL. The settings used and the most important elements of the response received were as follows:

Settings
Attenuator	200 mV/div	
Coupling	DC	
Offset	-1.5 div = -300 mV offset.	
Timebase	200 μs/div	
Delay	-2.50 div = 500 μs pretrigger view	

Data

SYMBOL	PARAMETER	VALUE	TYPE
Yu	Y-units	V	string
Xu	X-units	s	string
Yz	Y-zero	0.3	number
Xz	X-zero	-0.0005	number
Yr	Y-resolution	3.125e-005	number
Xr	X-resolution	4e-006	number
Yrng	Y-range	65535	number
dT-corr	dT-correction	4688E-04	number
N	sample count	512	number
Y[1]	sample 1	9603	binary
Y[2]	sample 2	9612	binary
. . . .	. . . . .	. . . . .	. . . .
Y[N]	sample N	-9599	binary

The following paragraphs give some definitions and formulas that enable you to interpret the preceding data. The same definitions, symbols, and formulas will be used to describe the discrete mathematical functions of the Mathplus processing functions.

Definitions You can describe a waveform using two one- dimensional arrays that contain wave sample information: **S[1...N]** and **T[1...N]**. In both arrays the index "n" (range : 1...N) corresponds to the sample number. Data in the "S" array represents the amplitude of the waveform in volts of each sample, Data in the "T" array represents the sample time in seconds of each sample.

A waveform is sometimes expressed in other units. For example, an FFT waveform gives a range of frequencies (T[1]...T[N]; expressed in Hz) for the signal amplitude of these frequency components (S[1]...S[N], expressed in dB).

Formulas:

S[n]   S[n] is the value of sample n, expressed in Y- units.
             Y-units are usually volts.

$$S[n] = (Yz + (Y[n] \times Yr)) \times Yu$$

Sensitivity Usually the sensitivity is expressed in volt/div. In the oscilloscope,
             the range of the Y[n] values (Yrng) always equals 2^16 = 65535,
             which corresponds with 10.24 divisions on the screen. This gives a
             maximum vertical resolution of 6400 'levels' per division.
             Sensitivity is expressed in Y-units/division.

$$Sensitivity = 6400 \times Yr \times \frac{Yu}{div}$$

Offset   Offset is the vertical screen position of the signal ground level,
             indicated by "1-" (excluding Y-pos shift). The offset can be adjusted
             with the front panel Y POS controls. For calculated traces, the
             offset can be adjusted with the delta controls in the MATHematics
             menu.
             Offset is expressed in Y-units (volts).

$$Offset = -Yz \times Yu$$

NOTE: *Traces can also be positioned with the Y-pos control in the RECALL*
             menu, but this does not affect the offset. The reason is that Y-pos
             is a pure display function, which does not affect the signal sampling
             nor the calculation of a trace using a mathematics function.

T[n]   T[n] is the sample moment, expressed in X-units.
             X-units are usually seconds.

$$T[n] = (Xz + (n-1) \times Xr) + (dT - corr \times Xr) \times Xu$$

Timebase   In case of a sampled signal the horizontal scale is called the
             timebase. The timebase setting is usually expressed in seconds/
             division. Without magnification or compression, the oscilloscope
             always displays 50 samples per horizontal division.

$$Timebase = 50 \times Xr \times \frac{Xu}{div}$$

NOTE: *The horizontal scale can differ, like the FFT scale. In this case it is*
             expressed in X-units per division.

Delay The time delay between the trigger and the moment that the first
sample is taken. If the delay is negative, the first sample is taken
before the trigger. This is called pretrigger view. In pretrigger view,
the trigger point (horizontal position of which T[n]=0) is indicated on
the screen. The delay or the position of the trigger point can be
adjusted with the TRIGGER POSITION control.
Delay is usually expressed in X-units (seconds).

$$Delay = -(Xz + (dT - corr \times Xr)) \times Xu$$

$$Triggerposition = (Xz + (dT - corr \times Xr)) \times Xu$$

These values can also be expressed in divisions:

$$Delay = \left(\frac{-(Xz + (dT - corr \times Xr))}{Xr}\right) \times \frac{1}{50} \times div$$

$$Triggerposition = \left(\frac{(Xz + (dT - corr \times Xr))}{Xr}\right) \times \frac{1}{50} \times div$$

NOTE: *The X-POS control in the RECALL menu can also be used to
position traces horizontally, but this does not affect the delay or
signal sampling because X-POS is purely a display function.*

2.3   ADD

Description:

The ADD function performs a point-to-point addition of two traces, related to the two ground levels (indicated as '-'). The result of the ADD function is a new trace in a different register. The resulting trace can be scaled, and offset can be added for positioning.

NOTE: The front panel keys CH1+CH2 (or CH3+CH4) can also be used to
         display additional <u>active</u> traces of the sums of these channels. But you
         can use the mathematical ADD function even after a single shot or on
         stored traces.

Scaling is used to fit the resultant trace onto the screen. The TRACK control adjusts scaling.
Vertical positioning is called offset. It offsets each sample in the resultant trace with a value so that the trace can be "moved" vertically. The Δ control adjusts the vertical positioning.
The scale factor and the offset factor are displayed in the 'MATH SCALE' menu. Pressing the 'autoscale' softkey automatically selects the settings so the trace continues to fit onto the screen even if the input signals use the full dynamic range of the oscilloscope.

The amplitude settings are also used by the mathematical functions to obtain correct results if the settings of the two sources are different.

Either newly acquired traces or previously stored traces can be used as the sources for this process. The cursor controls are used to select sources. The resulting trace is automatically written into a register memory (m1 for math1 or m2 for math2).

To see the result more clearly, press the 'DISPLAY SOURCE on/off' softkey to turn off the two source traces.
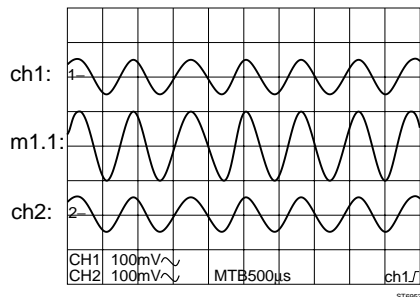

*Figure 2.2   Trace m1.1 is the result of
                the ADD function*
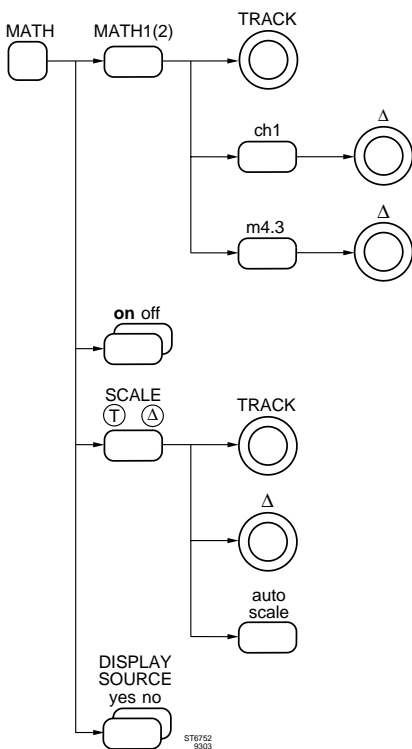
Mathematical description:

$$Sr = S_1 + S_2 \qquad \text{where Sr is the result}$$

Discrete mathematical formula:

$$Sr[n] = S_1[n] + S_2[n]$$

For an explanation of the symbols, refer to Section 2.2.

Key sequence:

MATH — MATH1(2) — TRACK	Control to select the ADD function.
ch1 — Δ	Control to select the first source trace.
m4.3 — Δ	Control to select the second source trace.
on off	Toggle softkey to switch the ADD function on or off.
SCALE (T) (Δ) — TRACK	Control to adjust the scale factor.
Δ	Control to adjust the offset factor.
auto scale	Toggle softkey to select autoscaling.
DISPLAY SOURCE yes no	Toggle softkey to switch the source traces on and off.

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2.4   SUBTRACT

Description:

The SUBTRACT function performs a "point-from-point" subtraction of two traces, related to the two ground levels (indicated as '-'). The result of the SUBTRACT function is a new trace in a different register. The resulting trace can be scaled and offset can be added for positioning.

NOTE: The front panel keys CH1+CH2 (or CH3+CH4) can also be used to display additional <u>active</u> traces of the subtraction of these channels. But you can use the mathematical SUBTRACT function even after a single shot or on stored traces.

Scaling is used to fit the resultant trace onto the screen. The TRACK control adjusts scaling.
Vertical positioning is called offset. It offsets each sample in the resultant trace with a certain value so that the trace can be "moved" vertically. The Δ control adjusts the vertical positioning.
The scale factor and the offset factor are displayed in the 'MATH SCALE' menu. Pressing the 'autoscale' softkey automatically selects the settings so the trace continues to fit onto the screen even if the input signals use the full dynamic range of the oscilloscope.

The amplitude settings are also used by the mathematical functions to obtain correct results if the settings of the two sources are different.

Either newly acquired traces or previously stored traces can be used as the sources for this process. The cursor controls are used to select sources. The resulting trace is automatically written into a register memory (m1 for math1 or m2 for math2).

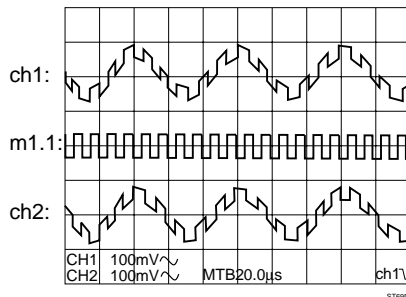To see the result more clearly, press the 'DISPLAY SOURCE on/off' softkey to turn off the two source traces.

Figure 2.3   Trace m1.1 is the result of the SUBTRACT function
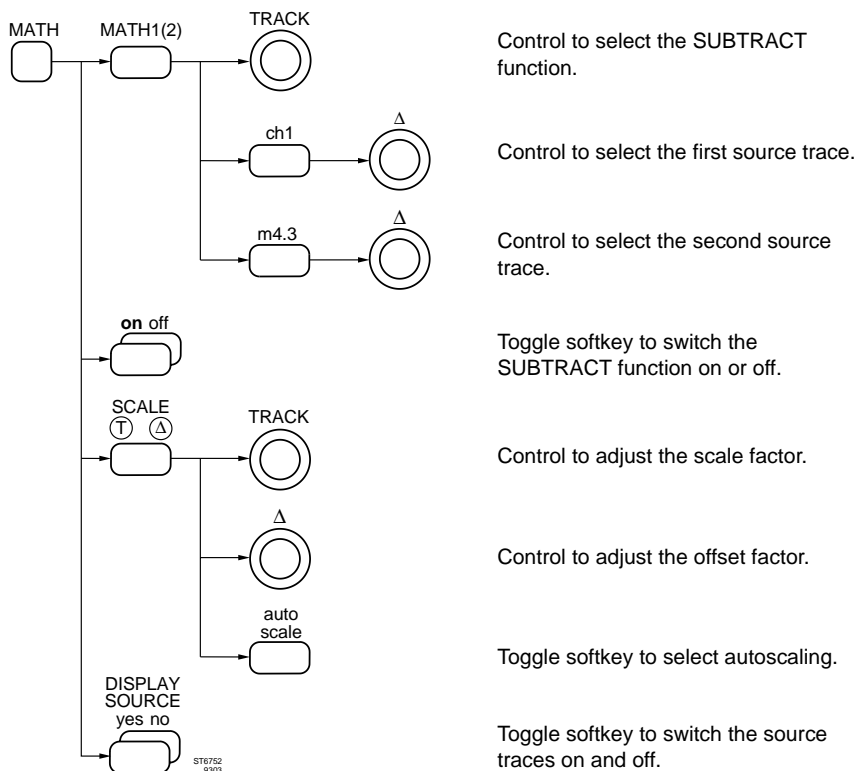
Mathematical description:

$Sr = S_1 - S_2$ where Sr is the result

Discrete mathematical formula:

$Sr[n] = S_1[n] - S_2[n]$

For an explanation of the symbols, refer to Section 2.2.

Key sequence:

MATH MATH1(2) TRACK		Control to select the SUBTRACT function.
ch1 Δ		Control to select the first source trace.
m4.3 Δ		Control to select the second source trace.
on off		Toggle softkey to switch the SUBTRACT function on or off.
SCALE Ⓣ Ⓐ TRACK		Control to adjust the scale factor.
Δ		Control to adjust the offset factor.
auto scale		Toggle softkey to select autoscaling.
DISPLAY SOURCE yes no		Toggle softkey to switch the source traces on and off.

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2.5   MULTIPLY

Description:

The MULTIPLY function performs a point-to-point multiplication of two traces. The value of each data point is related to ground. The result of the MULTIPLY function is a new trace in a different register. The resulting trace can be scaled, and offset can be added for positioning.

If the source traces are expressed in different units, the result will be automatically expressed in correct units. For example, a volt multiplied by an ampere will result in watts.

Scaling is used to fit the resultant trace onto the screen. The TRACK control adjusts scaling.
Vertical positioning is called offset. It offsets each sample in the resultant trace offset with a certain value so that the trace can be "moved" vertically. The Δ control adjusts vertical positioning.
The scale factor and the offset factor are displayed in the 'MATH SCALE' menu. Pressing the 'autoscale' softkey automatically selects the settings so the trace continues to fit onto the screen even if the input signals use the full dynamic range of the oscilloscope.

Either newly acquired traces or previously stored traces can be used as the sources for this process. The cursor controls are used to select sources. The resulting trace is automatically written in a register memory (m1 for math1 or m2 for math2).

To see the result more clearly, press the 'DISPLAY SOURCE on/off' softkey to turn off the two source traces.

One example of using the MULTIPLY function is the measurement of dissipated power, by taking the voltage across a device and multiplying it by the current through the same device. Refer to section 9.2 for an application example of multiplying a voltage trace and a current trace using the proper units.
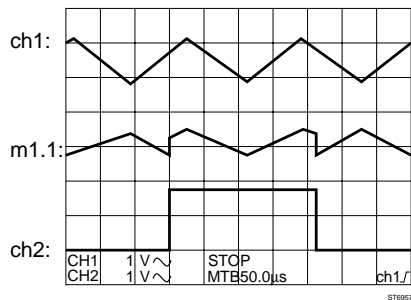

Figure 2.4   Trace m1.1 is the result of the MULTIPLY function
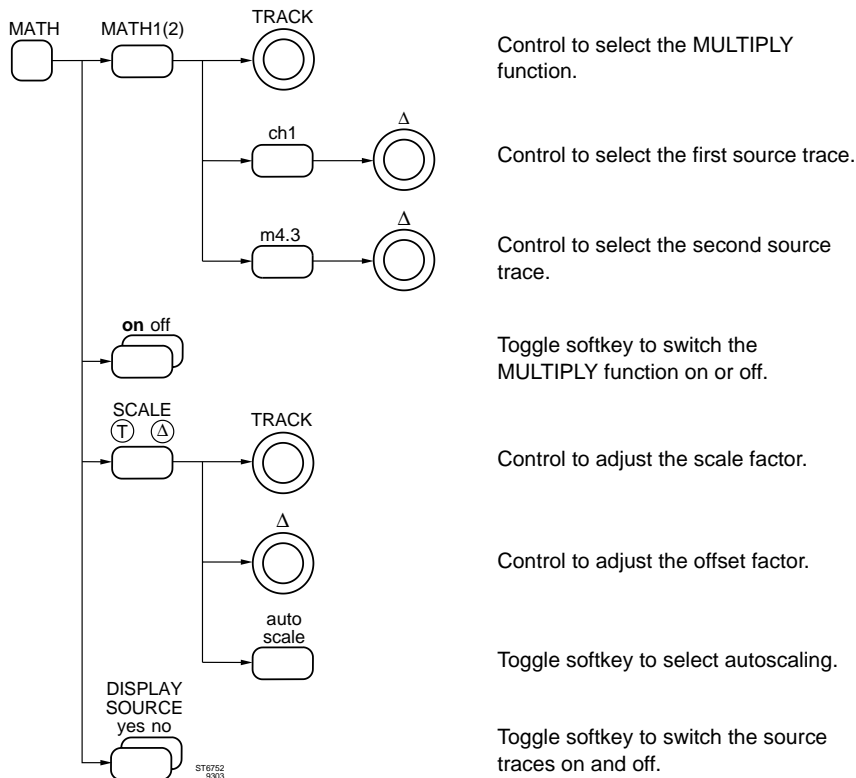
Mathematical description:

$Sr = S_1 \times S_2$ where Sr is the result

Discrete mathematical formula:

$Sr[n] = S_1[n] \times S_2[n]$

For an explanation of the symbols, refer to paragraph 2.2

Key sequence:

MATH	MATH1(2)	TRACK	Control to select the MULTIPLY function.

Control to select the MULTIPLY function.

Control to select the first source trace.

Control to select the second source trace.

Toggle softkey to switch the MULTIPLY function on or off.

Control to adjust the scale factor.

Control to adjust the offset factor.

Toggle softkey to select autoscaling.

Toggle softkey to switch the source traces on and off.

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2.6   FILTER

Description:

The FILTER function is a waveform MATH function. It is a post- acquisition
algorithm that can be used for low-pass filtering or as display smoothing. The cut-
off frequency of the low-pass filter can be adjusted and the resulting trace can be
stored as a new trace in a separate register. This implies that the original
waveform or trace is never disturbed by the process, allowing you to "experiment"
with different filter factors.

A typical use of this digital low pass filter is to suppress noise even after a (single
shot) acquisition. Since the FILTER function is a post acquisition process, it can
also be used on single event waveforms.

Any newly acquired traces or previously stored traces can be used as sources for
the filter process. The filtering is performed on all traces of a selected source
register.
The resulting trace(s) are automatically written in memory location m1 for math1
or m2 for math2 and are instantly displayed on the screen.

For each sample point of the trace, a
weighed sum is calculated over a
window of K samples (convolution). K
is adjusted with the Δ control. The
window width K is displayed in the
'MATH FILTER PARAM' menu. The
resulting cut-off frequency is the result
of the sample rate set by the timebase
and the window. While the window is
being adjusted, the -3dB point is
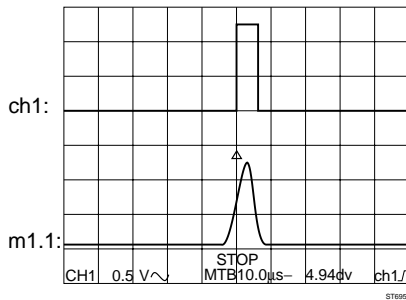displayed in the bottom area of the
screen.

Figure 2.5   *Figure 2.5 Trace m1.1 is
the result of the FILTER
function*

Discrete mathematical formula:

$$Sr[n] \;=\; \sum_{k=\frac{-(K-1)}{2}}^{k=\frac{+(K-1)}{2}} S_1[n+k] \times F[k]$$

where: K is the window width (value may be between 3 and 41)
          k is the convolution index
          n is the sample point index
          F[k] is the filter function used for the convolution

The used filter function is given below. The sum of the components of the filter function is always 1, so that the signal amplitude will not be affected.
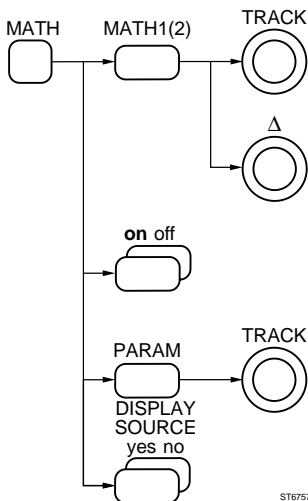
$$F[k] \;=\; \frac{1 - \cos\left(\dfrac{\pi + 2\pi k}{(K+1)}\right)}{(K+1)}$$

In case of a window width K = 3, the filter values are:

          F[-1] = 0,250
          F[0] = 0,500
          F[1] = 0,250

For an explanation of the symbols refer to Section 2.2.

Key sequence:

Control to select the FILTER function.

Control to select the source signal.

Toggle softkey to switch the FILTER function on or off.

Control to select the number of samples for the filter window.

Toggle softkey to switch the display of the source trace on or off.

2.7   INTEGRATE

Description:

The INTEGRATE function performs a numerical integration process on a trace.
The horizontal area for the integration can be adjusted and the result is stored as
a trace in a register. This trace can be scaled and positioned.

Scaling is used to fit the resultant trace onto the screen. Scaling is adjusted with
the TRACK control.
Vertical positioning is called offset. It offsets each sample in the resultant trace
with a certain value so that the trace can be "moved" vertically. The Δ control
adjusts the vertical positioning.
The scale factor and the offset factor are displayed in the 'MATH INTEGR
PARAM' menu.
Pressing the 'autoscale' softkey automatically selects settings that are optimal for
typical applications as pulse power measurements.

Either newly acquired traces or previously stored traces can be used as the
source for the integration process. The integration is performed on all traces of
the selected source register, and the resulting traces are automatically written to
a register memory (m1 for math1 or m2 for math2) and instantly displayed on the
screen.

The process can be done on a full trace, but also on a part of the trace (limited
area). You can adjust the TRACK control for the left limitation and the Δ control for
the right limitation. The AREA submenu also allows adjustment of the 'base line'
used for the integration. Usually the base line is positioned at the GND level, but
sometimes it is necessary to adjust the level because of offset of the input signal.

Two vertical cursors mark the trace
interval related to the time; the
horizontal cursor acts as an indication
for the offset compensation. The cross
sections of cursors are positioned at
the result trace, giving a direct readout
of the pulse power. Refer to paragraph
9.3 for an example that shows PROBE
scaling (in amperes), MULTIPLY to
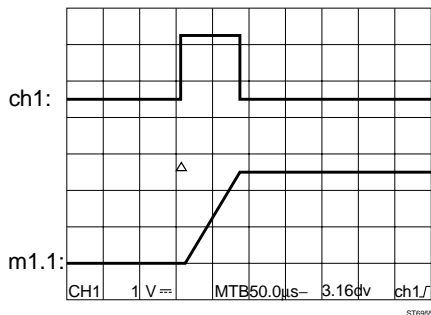measure power, and INTEGRATION
to integrate pulse power.

*Figure 2.6   Trace m1.1 is the result of
                   the INTEGRATE function*

Mathematical description:

$$Sr(t) = \int_o^t S_1(t)dt$$ were Sr(t) is the result

Discrete mathematical formula:

$$Sr[n] = \sum_{k=0}^{k=n} (S_1[n] - (-X_1 z)) \times X_1 r$$ in $X_1 u$ x $Y_1 u$ units

where: $S_1[n]$ is the value of the source trace
           $-X_1 z$ is the offset of the source trace, related to ground
           k is the sample point index
           $X_1 r$ is the horizontal resolution of the source expressed in X1u units

The formula can be expressed in the sample values (Y1[n] in stead of S1[n]) with the following conditions:
- The offset (-Yrz) will initially be equal to the offset of the input trace (-$Y_1 z$), but may be adjusted with the offset control in the menu. This means that on screen, the ground marker of the source and result are initially positioned at the same level.
- The scale will have an initial value that is best for most applications. The scale is selected as a value in the 1- 2-5 range and is related to the timebase setting and the sensitivity.
- The autoscale function sets the scale and offset factors back to the initial values.

Key sequence:
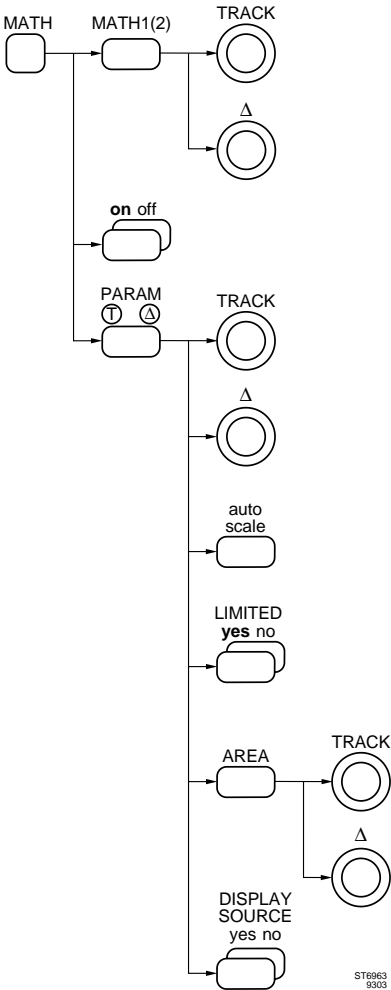
Key sequence	Description
MATH → MATH1(2) → TRACK	Control to select the INTEGRATE function.
Δ	Control to select the source signal.
on off	Toggle softkey to switch the INTEGRATE function on or off.
PARAM Ⓣ Ⓐ → TRACK	Control to adjust the scale factor.
Δ	Control to adjust the offset factor.
auto scale	Toggle softkey to select the autoscaling.
LIMITED **yes** no	Toggle softkey to switch area limitation on or off.
AREA → TRACK	Control to adjust the left limitation
Δ	Control to adjust the right right limitation
DISPLAY SOURCE yes no	Toggle softkey to switch the display of the source trace on or off.

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2.8   DIFFERENTIATE

Description:

The DIFFERENTIATE function performs a numerical differentiation process on a trace. The result is stored as a new trace in a different register. The result trace can be scaled and positioned.

Scaling is used to fit the resultant trace onto the screen. The TRACK control adjusts scaling.
Vertical positioning is called offset. It offsets each sample in the resultant trace offset with a certain value so that the trace can be "moved" vertically. The Δ control adjusts the vertical positioning.
The scale factor and the offset factor are displayed in the 'MATH DIF PARAM' menu.
Pressing the 'autoscale' softkey automatically selects preset values that are optimal for typical applications.

Either newly acquired traces or previously stored traces can be used as sources for the differentiation process. Differentiation is performed on all traces of the selected source register, and the resulting traces are automatically written in a register memory (m1 for math1 or m2 for math2) and instantly displayed on the screen.

The menu allows adjustment of the window width (also called differential distance). The window selection adjustment and discrete mathematical formulas are described in the following paragraphs.
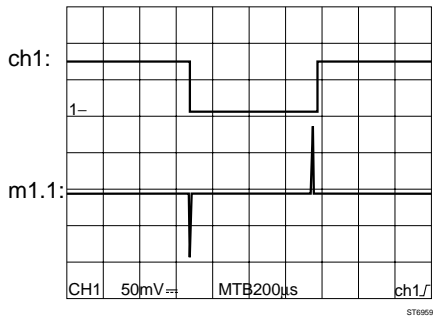

Figure 2.7   Trace m1.1 is the result of the DIFFERENTIATE function

Mathematical description:

$$Sr(t) = \frac{d}{dt} \times S_1(t) = \frac{S_1\left(t + \frac{dT}{2}\right) - S_1\left(t - \frac{dT}{2}\right)}{dT}$$

In the formula, dT is the differential distance, which can be selected in the menu. In theory, the smaller the dT, the more accurate the result. However, if the input signal is noisy, the result becomes even more noisy. The choice of dT setting, therefore, will depend on the input signal. The best setting is the smallest dT value that will output the most acceptable signal.

The used differential distance can be calculated from the number of samples in the window (K) and the sample distance (Xr = horizontal resolution).

$$dT = (K-1) \times Xr \qquad \text{in Xu units; usually seconds}$$

Discrete mathematical formula:

$$Sr[n] = \frac{S_1\left[n + \frac{(K-1)}{2}\right] - S_1\left[n - \frac{(K-1)}{2}\right]}{(K-1) \times Xr}$$

expressed in Y_1u/X_1u units

Where: n   Is the sample point index
        K   Is the window width
        $S_1[n]$ Is the value of sample n of the source trace
        Sr[n]   Is the value of sample n of the result trace

The formula can be expressed in the sample values (Y1[n] in stead of S1[n]), with the following conditions:
-   The offset (-Yrz) will initially be equal to the offset of the input trace (-Y_1z), but may be adjusted with the offset control in the menu. This means that on screen, the ground marker of the source and result are initially positioned at the same level.
-   The scale will have an initial value that is best for most applications. The scale is selected as a value in the 1- 2-5 range and is related to the timebase setting and the sensitivity.
-   The autoscale function sets the scale and offset factors back to the initial values.

Key sequence:
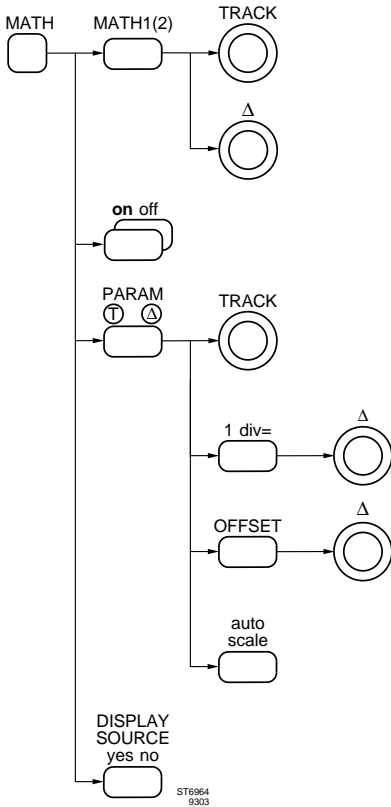
Key	Description
MATH → MATH1(2) → TRACK (○)	Control to select the DIFFERENTIATE function.
Δ (○)	Control to select the source signal.
on off	Toggle softkey to switch the DIFFERENTIATE function on or off.
PARAM Ⓣ Ⓓ → TRACK (○)	Control to select the number of samples for the window.
1 div= → Δ (○)	Control to adjust the scale factor.
OFFSET → Δ (○)	Control to adjust the offset factor.
auto scale	Toggle softkey to select the autoscaling.
DISPLAY SOURCE yes no	Toggle key to switch the display of the source trace on or off.

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2.9   FAST FOURIER TRANSFORMATION (FFT)

Description:

The FAST FOURIER TRANSFORMATION (FFT) function transforms an amplitude waveform from the time domain into the frequency domain. The resultant is a waveform, showing the power spectrum of the original trace. The horizontal axis of the FFT is the frequency axis; the vertical axis gives the amplitude of the frequency components found.
With the use of a high speed Digital Signal Processor (DSP), the complex waveform processing takes only a fraction of the time it would take on an average PC or on older measurement equipment.

Typical applications of FFT are in distortion tests, bandwidth and crosstalk measurements, signal purity analysis, and noise spectrum measurements.

The FFT function can be performed on any waveform in the acquisition system or in memory.
Both the source and the resultant waveform are single traces. The resultant trace is automatically written in either m1.1 (for math1) or in m2.1 (for math2) and is instantly displayed on screen.
Since the FFT process requires additional memory to store the 'imaginary' and 'real' parts of the FFT waveform, the oscilloscope must be set to an acquisition length up to 2K (or 8K when the extended memory option is installed). This is selected by TB-MODE, ACQ LENGTH, 4ch @ .. pts. These real and imaginary waveforms cannot be accessed by the user.

In general, any FFT algorithm assumes the source waveform is a representative part of a continuous, repetitive signal. As such, all signal components in the source signal should be described by a full number of cycles. During processing, the waveform memory content is repeatedly analyzed as if it represents different cycles. Thus any incomplete cycle results in a phase and amplitude jump in the waveform at the location where the beginning and the end of the memory content are supposed to come together (see figure 2.8).
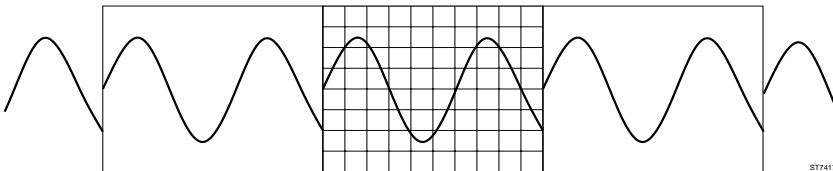

Figure 2.8   Repeated waveform

This results in frequency components, called side-lobes, in the FFT display that do not really originate from the signal under test. To reduce this influence of incomplete cycles, different steps can be taken. These steps are known as 'windowing' and as 'zero filling' (see below).

Horizontal resolution of FFT

The horizontal scale (frequency scale, in Hz) of the FFT display depends on the setting of the timebase and the number of samples of the source trace. The standard setting for an acquisition record is 50 points per division. The minimum and maximum value of the scale can easily be calculated.

Minimum frequency
The lowest frequency component (f_{min}) that can be discovered in a source trace, has a single period filling the entire acquisition record. This frequency can be calculated from the horizontal resolution (sample distance) of the source trace (Xr) and the number of samples in a record N (acquisition length).

$$Xr = \text{Timebase setting}/50 = Tb/50$$

$$f_{min} = 1/(N \times Xr) = 50/(N \times Tb)$$

Maximum frequency
Every sinewave is defined by at least 2 points. So the highest frequency that can be determined in the FFT can be derived from Timebase (Tb);

$$f_{max} = (50/2)/Tb = 25/Tb$$

Resolution
The resolution of the FFT is the smallest frequency step (f_r) that can be made in a FFT result record containing N samples. So the resolution gets higher when f_r gets smaller.

$$f_r = f_{max}/N = (25/Tb)/N = 25/(N \times Tb)$$

This is half of the minimum frequency. Because the negative frequency component resulting from the FFT calculations is a mirror image of the positive ones, they can be omitted. So the positive side can be stretched over twice the area.

For a given timebase setting, the best possible frequency resolution can be obtained by selecting the longest possible acquisition record. With the Extended Memory option installed, record lengths up to 8k can be used.

Windowing

Windowing is a mathematical process that attenuates the parts of the waveform
that are at the beginning and the end of the record.
As a result, the FFT is calculated mainly from the part of the record that is near
the center. Thus incomplete cycles in the record have a reduced influence on the
width of the sidebands of frequency components in the FFT.
The first and last samples have a reduced influence or no influence on the FFT.
The window (FILTER) is selected in the MAThematics PARAMeter menu.

Rectangular window.
In fact, rectangular window equals no window. All samples are multiplied by 1.

Formula: $sample[n] = 1 \times sample[n]$

The major advantage of the rectangular window is its narrow main lobe. Using the
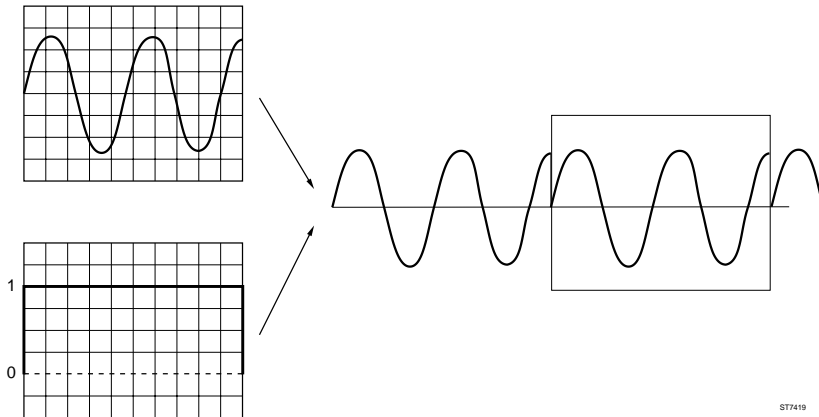rectangular window function provides the best frequency resolution.

Figure 2.9   Rectangular window

Hanning window.
The frequencies around the main lobe are considerably reduced compared to those passing through the rectangular window. The tradeoff for this lower noise floor is that the main lobe is wider. Therefore, you will not see frequencies close to the fundamental frequency.

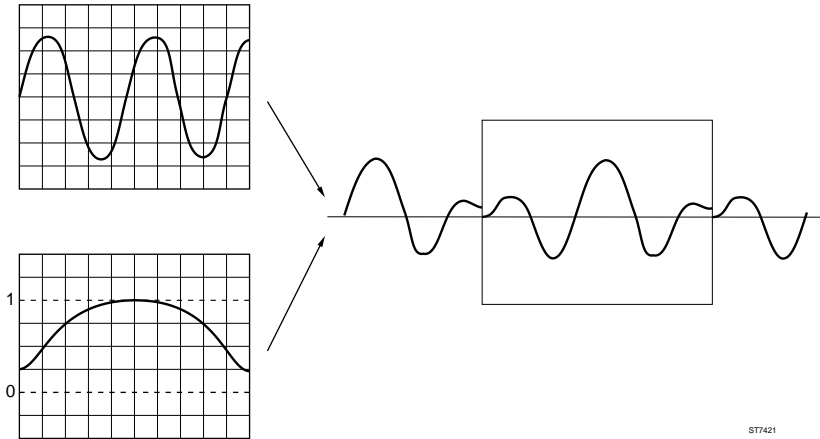Formula: $sample[n] = 0,5 \times sample[n] \times (1 - \cos(2\pi n / N))$
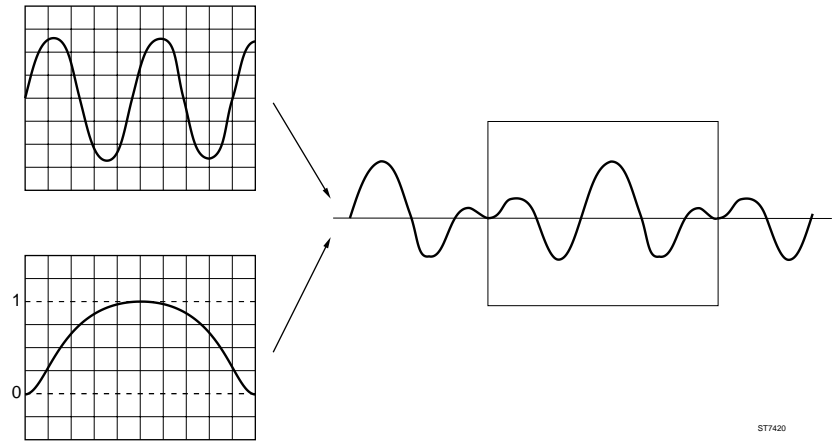
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Figure 2.10   Hanning window

Hamming window.
The main lobe is not as wide as it is with the Hanning window; therefore, the noise floor is a little higher. Frequencies closer to the fundamental can be seen without being drowned in noise.

Formula: $sample[n] = sample[n] \times (0{,}54 - 0{,}46\cos(2\pi n/N))$

Figure 2.11   Hamming window

Average
Average can be used to reduce the noise in the FFT result. This way more frequency components become visible.

Zero filling

Zero filling is used when the LIMITED function in the MATHematics PARAMeter menu is turned on. The number of samples selected in the AREA menu is replaced by samples of the value zero. Thus, at baseline level, the waveform in memory can be reduced to a full number of cycles and a number of 'empty' samples. This is mainly useful when you are using the rectangular window. The other windows already reduce the effect of incomplete cycles.
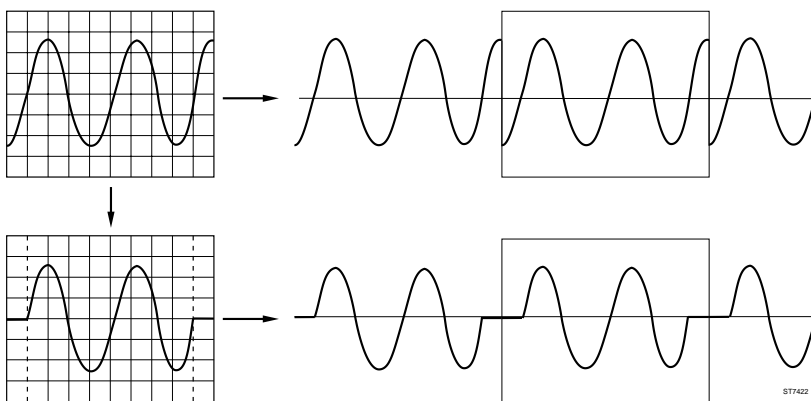

Figure 2.12   Zero filling

Cursor readout

There is only one cursor when the FFT result register is selected in the CURSORS menu. The cursor is used to find the frequency and the level of any component in the FFT result. Absolute or relative readout of the level is selected in the MATHematics PARAMeter. The dimension of the readout is selected in the CURSORS READOUT menu.

Relative
The X-axis is a frequency domain. The Y-axis is a dB domain. Both scales are linear. Vertical scaling is always 10 dB/div. The top of the screen is always 0 dB. The frequency component with the largest amplitude is the reference (0 dB) for the other components. Changes in the source amplitude have no immediate effect on the FFT display.

Absolute
The result of the FFT is processed to a power spectrum. The amplitude of the power spectrum is related to the amplitude of the input signal.

Power can be written as $P = U^2/R$. So, for those cases where input and output impedance are the same, the output voltage can be expressed as a relation to the input voltage.

$$dB = 10\log P_2/P_1 = 10\log U_2^{\,2}/U_1^{\,2} = 20\log U_2/U_1$$

However the dB does not automatically allow the expression of absolute levels. But, often a reference is made to a well known standard level, e.g., 1 μV or 1 mW. By doing so, absolute levels can be expressed as follows:

         dBμV   dB with respect to 1 μV
         dBm   dB with respect to 1 mW

When you use dBm, you must know the impedance of the system to be able to convert from mV to dBm. The most common and often used impedances are 600 ohms (LF telecom) and 50 ohms (RF).

Note: *This reference impedance selection does **not** imply that the input impedance of the oscilloscope is (or has to be) 50 ohm or 600 ohm.*

Note: *All voltage levels used in power calculations are in V*rms.

Reference level setting
The maximum displayed sinewave has an amplitude of 8 divisions p-p. This equals an amplitude of 8 / 2√2 = 2.828 div_rms. At 100 mV/div, this equals 282 mV_rms. Compared to 1 mW in 50 ohms (0 dBm), this results in a reference level of 2 dBm.

Because 0 dBm on a graticule line is a much more convenient value for a reference, all values are recalculated to this 0 dBm at the top of the screen. This results in the reference levels in the table below.

Attenuator setting	V_{rms}	dBm @ 50 ohms	Reference level dBm @ 600 ohms	dBμV
5 V/div	11.18 V	+ 34 dBm	23.2 dBm	141 dBμV
2 V/div	4.47 V	+ 26 dBm	15.2 dBm	133 dBμV
1 V/div	2.24 V	+ 20 dBm	9.2 dBm	127 dBμV
0.5 V/div	1.12 V	+ 14 dBm	3.2 dBm	121 dBμV
0.2 V/div	447 mV	+ 6 dBm	- 4.8 dBm	113 dBμV
0.1 V/div	224 mV	0 dBm	- 10.8 dBm	107 dBμV
50 mV/div	112 mV	- 6 dBm	- 16.8 dBm	101 dBμV
20 mV/div	44.7 mV	- 14 dBm	- 24.8 dBm	93 dBμV
10 mV/div	22.4 mV	- 20 dBm	- 30.2 dBm	87 dBμV
5 mV/div	11.2 mV	- 26 dBm	- 36.2 dBm	81 dBμV
2 mV/div	4.47 mV	- 34 dBm	- 44.2 dBm	73 dBμV

Other reference impedances

For other reference impedances X, a correction factor C_x, can be calculated and added to the dBm @50 ohm table.

$$C_x = 20\log\sqrt{(50\ \text{ohm}/X\ \text{ohm})} = 10\log 50/X$$

e.g. 75 Ω $C_{75} = 10\log 50/75 = -1{,}76dB$

So if a signal was measured in a 75 ohms system at +20 dBm where the measerement was based upon a 50 ohms system, the actual signal is then +20 dBm - 1.76 dBm = +18.24 dBm.
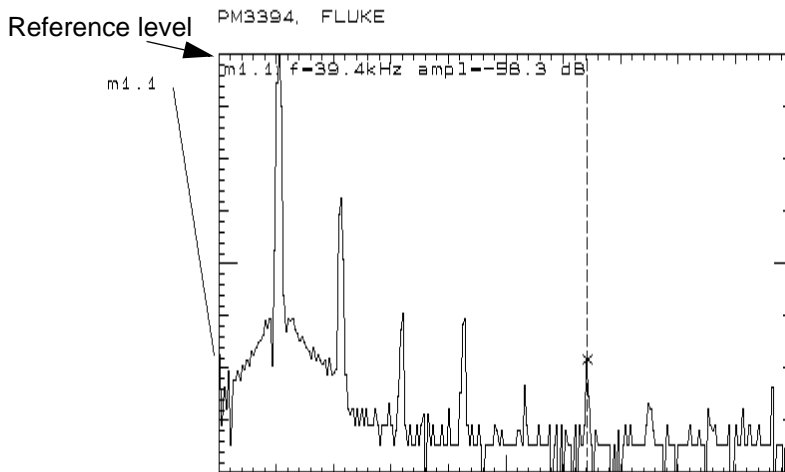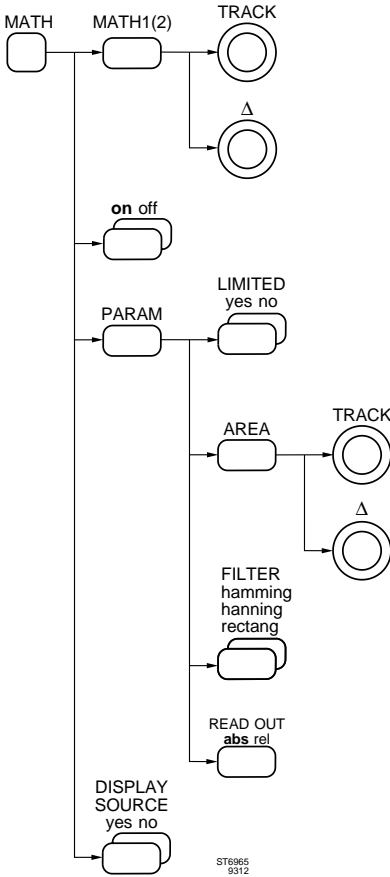
Reference level

Figure 2.13   FFT reference level

Key sequence:

MATH → MATH1(2) → TRACK (○)	Control to select the FFT function.
Δ (○)	Control to select the source signal.
on off	Toggle softkey to switch the FFT function on or off.
PARAM → LIMITED yes no	Toggle softkey to switch the area limitation on or off.
AREA → TRACK (○)	Control to adjust the left limit.
Δ (○)	Control to adjust the right limit.
FILTER hamming hanning rectang	Toggle softkey to select a FFT window.
READ OUT **abs** rel	Toggle softkey to select absolute or relative cursor readout.
DISPLAY SOURCE yes no	Toggle key to turn the display of the source trace on or off.

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CURSORS   on off
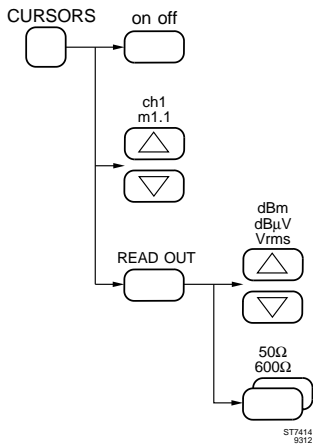
Softkey to turn the cursors off.

ch1
m1.1

Softkey pair to select the source register for cursor readout. Memory location m1.1 is the result register of the MATH1 function, and m2.1 the result register of the MATH2 function.

READ OUT

dBm
dBμV
Vrms

Softkey pair to select the dimension of the cursor readout result.

50Ω
600Ω

Toggle softkey to select the reference impedance of 50 ohms or 600 ohms.

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2.10 HISTOGRAM

Description:

The HISTOGRAM function calculates an amplitude density graph of a trace.

Typical use of the histogram function is data transmission, e.g., in telecommunication.

The result of the histogram function is a new trace in a different register. The new trace is automatically scaled between -2 and +3 divisions.

Either newly acquired traces or previously stored traces can be used as the source for the histogram process. The result and the source are a single trace. The resulting trace is automatically written as the first trace in a register memory (m1.1 for math1 or m2.1 for math2) and is instantly displayed on the screen.

In the histogram the horizontal axis represents the voltage levels (called 'classes'). The vertical axis represents the number of times each voltage level was present in the source trace. (The number of occurrences is sometimes also called density.) The result is always presented with a resolution of 512 'classes' and is put into the first 512 samples of a trace.
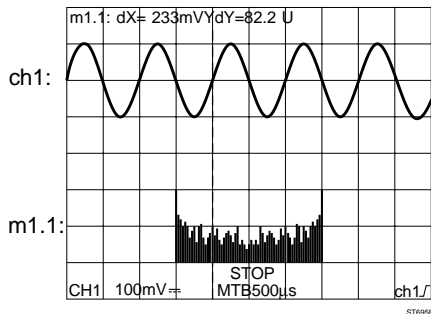

Figure 2.14   Trace m1.1 is the result of the HISTOGRAM function

If cursors are used, only one cursor is displayed; it shows a marker on the crossing point of the resulting trace. The corresponding density is then displayed in the top area of the screen (expressed in %).

NOTES: -   *If averaging is not used, the result will effectively contain only 256 classes, which is equal to the ADC resolution (2^{8}bit).*
-   *If the trace length of the source is higher, the vertical resolution of the result will increase. The more samples that are taken, the higher the accuracy of the statistics.*
-   *The calculation of a histogram requires a lot of memory; therefore, the histogram function cannot be performed in the 4K and 8K modes (or in the 16 and 32k modes if the memory expansion option is installed). The .2 .3 and .4 traces of the result trace are used by the calculation algorithm.*

Key sequence:
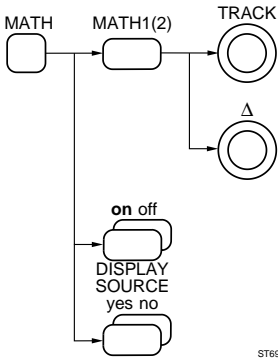
MATH → MATH1(2) → TRACK	Control to select the HISTOGRAM function.
Δ	Control to select the source signal.
on off — DISPLAY	Toggle key to switch the HISTOGRAM function on or off.
SOURCE yes no	Toggle key to switch the display of the source trace on or off.

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3 PROBE SCALING

Description:

The 'UTILITY PROBE SCALE menu' has been expanded in the Mathplus option.
This menu now offers the capability of probe scaling and can be used for the
mathematic functions.
This menu is reached via the key sequence: 'UTILITY >> PROBE >> PROBE
CORR >> SCALE'.

For each channel (incl. EXT TRIG on 2 channel models) you can select a scale
factor and the unit.
The following units can be selected: V (volts), A (amperes), Ω (ohm), W (watt), J
(joule), C (degrees centigrade), K (kelvin), P (pascal), m (meter) or U (unit). The
scale factor is a floating-point value with an exponent, and can be selected with
the Δ control. Cursor readouts, mathematics and measurements, are performed
and displayed in the proper units.

When performing mathematical processes to one or two signals, the instrument
automatically adapts the unit and exponent of the new trace type.

Example: A current (A) is applied to Ch1, and a voltage (V) is applied to Ch2. The
resulting trace of the multiply function will automatically have a 'W' indication as unit.
After integration the result will be the energy and will be expressed in joule (J).

The 'scale on/off' softkey sets the predefinition for all channels on or off.

Key sequence:

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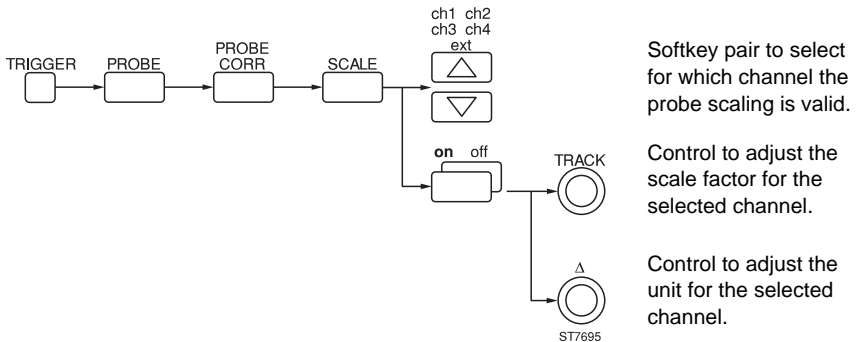
4   PASS/FAIL TESTING

Description:

In addition to the basic measurements (MEAS1 and MEAS2), the MEASURE menu has been expanded with a PASS/FAIL testing facility. This allows you to test waveforms against reference templates (envelope) and calculated measurement results against preset limits. The screen displays the result of the test (PASS or FAIL). The action on a fail situation is user selectable. The action can be beep, save, stop, and hard copy. The scope also provides a hardware output. Pass/fail testing is very useful for semi-automated test applications (ATE). No visual interpretations of displays are needed.

To enter the pass/fail testing mode, select 'PASS/FAIL' from the MEASURE menu. The menu displays the choices, and you use a softkey to select the TEST menu or the ACTION menu. Pressing the 'on/off' softkey switches off the menu again, and you can activate the pass/fail action by pressing the 'run/stop' softkey (run activated).

Pass/fail test
You can select one of the four pass/fail TEST modes: envel, meas1, meas2, or cursor.

- Envel
Envelope pass/fail testing can be used for comparing a waveforms against a reference template (envelope). Either newly acquired traces or previously stored traces can be used as reference waveforms. Adjust the Δ control to select the source waveform. When the test trace exceeds the limits of the template during testing, the scope will act as selected in the 'ACTION' menu.
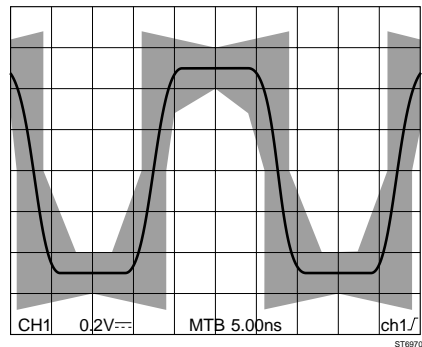

Figure 4.1   Create envelope for pass/fail testing

Envelope pass/fail testing cannot use the External Trigger channel or its memory location (mx.e) in the 2 channel versions. When you acquire the reference waveform in the envelope mode, you can use it directly as a template. When you need a user- defined template, select the 'EDIT ENVELOPE' softkey to enter the edit mode. In this menu you use a horizontal shift softkey pair and a vertical softkey pair to define the envelope from the selected source waveform. When you use a trace from a protected register memory, the EDIT CONFIRM menu is activated first to overrule the register protection.

A second option is to draw a template without the use of a source trace. Then press the 'DRAW' softkey to enter the DRAW ENVELOPE mode. The envelope register must be cleared first. This is done in the DRAW CONFIRM menu that is displayed when necessary.

In the DRAW ENVELOPE menu you can draw the upper and lower limit of the template by turning the TRACK control and Δ control to find the VERT POS and HOR POS of the selected limit. One horizontal and one vertical cursor display the two positions and the crossing of the two cursors mark a point on the template. Press the CONNECT softkey to define the first point and continue with ACCEPTing next points until the template is completed.

If necessary you can store and protect entire libraries of templates (for example, the CCITT standardized masks) in the internal register memory of the oscilloscope.

- Meas1

Pass/fail testing is done by comparing the calculated results of measurement 1 against preset limits. To enter the defined test range mode, select 'RANGE' from the DEFINE TEST menu. The menu now displays the choices, and you use a softkey to select one of the three following test range modes:

>limit   gives a fail condition for all values higher than the selected limit. You adjust this limit with the TRACK control.

<limit   gives a fail condition for all values lower than the selected limit. You adjust this limit with the TRACK control.

range   gives a fail condition for all values outside the selected range. You adjust the upper limit with the TRACK control, and the lower limit with the Δ control.

- Meas2

Pass/fail testing by comparing the calculated results of measurement 2 against preset limits.

- Cursor

Pass/fail testing is done by comparing a cursor readout against preset limits. The cursor readout to be tested can be selected :

ΔV the voltage difference between the cursors.

V1   the absolute voltage with respect to ground.

ΔT the time difference between the cursors.

$1/\Delta T$ the calculated frequency.

To enter the 'define test range mode', select 'RANGE' from the DEFINE TEST
menu. The menu now displays the choices, and you use a softkey to select one
of the three test range modes:

>limit   gives a fail condition for all values higher than the selected limit. You
                adjust this limit with the TRACK control.

<limit   gives a fail condition for all values lower than the selected limit. You
                adjust this limit with the TRACK control.

range   gives a fail condition for all values outside the selected range. You
                adjust the upper limit with the TRACK control, and the lower limit with
                the Δ control.

The pass/fail testing on cursors is very useful in combination with the Amplitude
Qualified Cursor mode. Refer to Chapter 6.

Pass/Fail Action
The action on a fail situation can then
be off, beep, stop, save, or hard copy.
To enter the Pass/fail action mode,
select the 'ACTION' softkey from the
PASS/FAIL TESTING menu. The
menu now displays the choices, and
you use a softkey pair to select one of
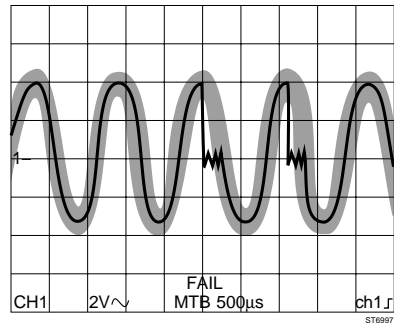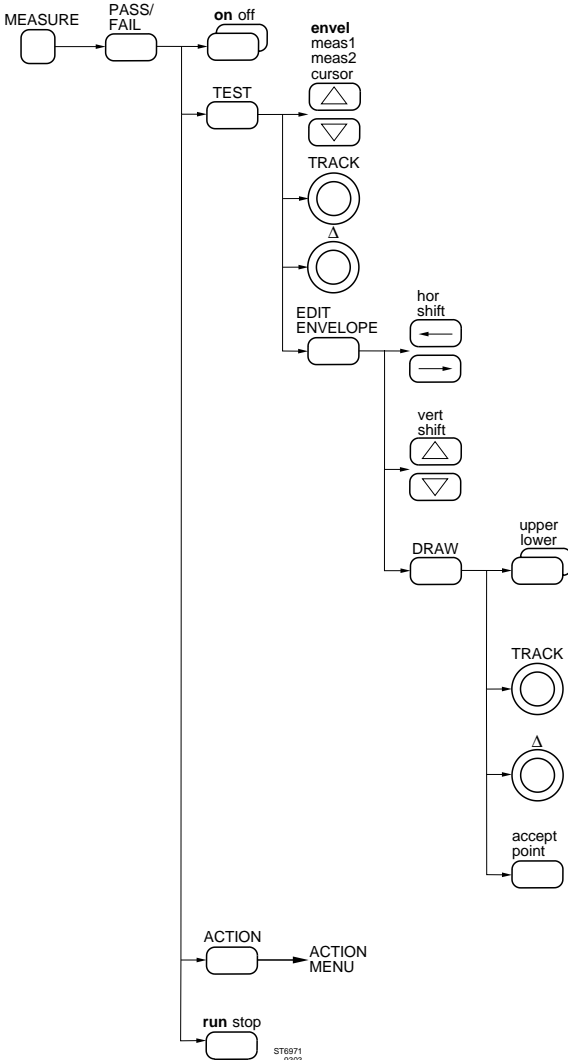the following actions in a fail
conditions:

Figure 4.2   Waveform: pass/fail

- off   No reaction on a fail condition.

- beep   An audilbe signal warning of a fail condition.

- stop   Stop of signal acquisition; the screen displays the "fail trace". This
               mode can be used to automatically capture the first violating
               waveform.

- save   The "fail trace" is automatically written in a selected register memory
               location. The TRACK control selects the register memory. Memory
               locations reserved for External Trigger View signals (mx.e) cannot be
               used. Of course, the destination register memory may not be protected
               if it is used to save the fail waveform. The save mode is used to
               automatically store the latest (most recent) fail situation.

- hcopy   A hard copy of the "fail trace" is made to a printer or a plotter.

In addition to one of the five fail actions, pin 4 of the RS- 232-C output connector can become LOW on a fail condition. You must then set the 'HW-OUT yes/no' menu selection to 'yes' and you must also select '3-wire' in the UTILITY >> RS232 SETUP menu. You can use this line to control an external device.

Key sequence:

Envelope testing:

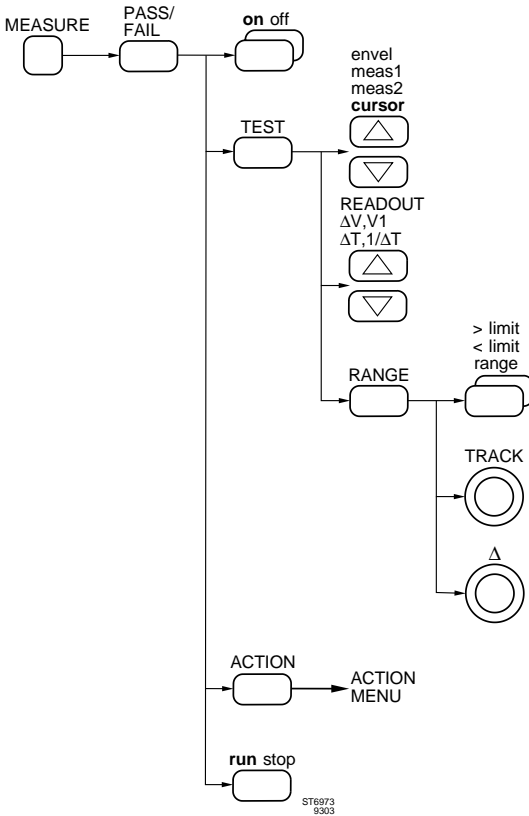|	
MEASURE — PASS/FAIL — **on** off	Toggle softkey to switch pass/fail testing on and off.
TEST — **envel** meas1 meas2 cursor △ ▽	Softkey pair to select envelope testing.
TRACK ◯	Control to select the envelope register.
Δ ◯	Control to select the register as source for the template.
EDIT ENVELOPE — hor shift ← →	Softkey pair to create horizontal limits in the template.
vert shift △ ▽	Softkey pair to create vertical limits in the template.
DRAW — upper lower	Toggle softkey to select the upper or lower limit for the user-defined template.
TRACK ◯	Control to adjust vertical position.
Δ ◯	Control to adjust horizontal position.
accept point	Softkey to accept the determined point.
ACTION — ACTION MENU	Softkey to activate the ACTION menu, see below.
run stop	Toggle softkey to start the pass/fail testing.

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Measure testing:

Toggle softkey to switch pass/fail testing on and off.

Softkey pair to select measure testing.

Toggle softkey to switch between >limit, <limit or range condition for testing.
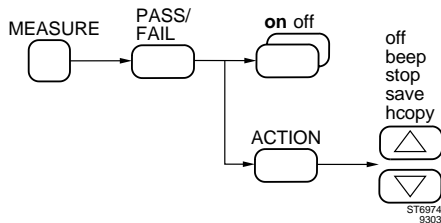
Control to adjust upper limit.

Control to adjust lower limit.

Softkey to activate the ACTION menu; see below.

Toggle softkey to start the pass/fail testing.

Cursors testing:

MEASURE → PASS/FAIL → **on** off	Toggle softkey to switch pass/fail testing on and off.
TEST → envel meas1 meas2 **cursor** △ ▽	Softkey pair to select cursor testing.
READOUT △V,V1 △T,1/△T △ ▽	Softkey pair to switch between ΔV, V1, ΔT, or 1/ΔT readout.
RANGE → > limit < limit range	Toggle softkey to switch between >limit, <limit, or range condition for testing.
TRACK ◯	Control to adjust upper limit.
△ ◯	Control to adjust lower limit.
ACTION → ACTION MENU	Softkey to activate the ACTION menu; see below.
run stop	Toggle softkey to start the pass/fail testing.

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Action menu:

MEASURE → PASS/FAIL → **on** off	Toggle softkey to switch pass/fail testing on and off.
ACTION → off beep stop save hcopy △ ▽	Softkey pair to switch between off, beep, stop, save, or hardcopy action after fail condition.

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Remote commands:

CPL: PW (Command to program a waveform)
         QW (Command to query a waveform)

Refer to the Operating Guide for full details.

5 MEASUREMENT STATISTICS

Description:

In a standard oscilloscope you can perform two calculated measurements (MEAS1 and MEAS2). Once selected, the actual value of the measurement is instantly displayed in the top left corner of the screen. This measurement can be done on newly acquired traces or on stored traces. In 2 channel models only the input channels or their stored traces can be measured.

When you set the MEASURE >> STATIST menu selection to 'on', the screen displays three more values. These values are measured over the total number of acquisitions for that particular measurement and is updated instantly.

The additional statistic measurement values are as follows:

- absolute minimum value.

- absolute maximum value.

- mean value.

NOTE : When you use the statistic measurement in pass/fail testing, the testing is done on the mean value of the trace instead of the actual value.

Key sequence:
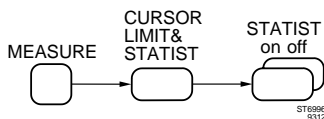
Toggle softkey to switch the statistic measurement on and off.

6   AMPLITUDE QUALIFIED CURSORS

Description:

The standard instrument is provided with two independent cursors that can be positioned on newly acquired signals or on previously stored traces. By using the cursors you can make fast and accurate amplitude (=), time ($||$), or both amplitude and time (#) measurements in digital and analog mode. You find a full description of these basic cursors functions in the Operating Guide.

The Mathplus option allows you to use **amplitude qualified cursors**. These enable highly automated timing measurements with time cursors automatically being positioned relative to the displayed traces. This is very useful for rise time measurements on signals with aberrations, measurements on a specific pulse in a pulse train, or various pulse width measurements.

The amplitude qualified cursors are activated with the key sequence 'CURSORS >> auto >> ...'. The cursor controls let you locate the horizontal cursors relative to reference levels (0% and 100%). These reference levels are displayed on the screen as dotted lines. The cursors then search horizontally for the point where the trace crosses the cursor level, and the cursors are positioned at these points. You can determine the condition of the cursor searching using the 'SEARCH' submenu. The cursor readout is at the top of the screen.

The 'SEARCH' feature enables you to find the n-th occurrence (n= 1,2,3 or Last) of the two amplitude qualified cursors independently. This allows you to measure on a specific pulse in a pulse train.

You can set each of the four reference levels for the amplitude qualified cursors (C1-0%, C1-100%, C2-0%, and C2- 100%) using the 'CURSORS SEARCH REF's' menu. The options that can be selected are :

-   min   the most negative trace value.

-   max   the most positive trace value.

-   high   the voltage level that corresponds with the top flat part of the trace.
         This eliminates the influences of overshoot or ringing on time
         measurements.

-   low   the voltage level that corresponds with the bottom flat part of the trace.
         This eliminates the influences of undershoot or ringing on time
         measurements.

- gnd   the ground level, indicated by "-".

- abs   the absolute voltage level. The TRACK control adjusts the level for the selected cursor. The menu displays this level.

Initially the readouts in the top text area are displayed in relative values (%). But you can press the READOUT softkey to change to absolute values (usually volts).

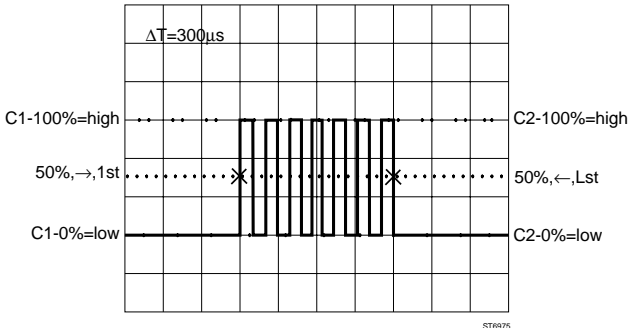For optimum visibility of trace detail, press the 'DISPLAY REF's on/off' softkey to turn off the reference cursors.

Figure 6.1   Measuring the width of a burst of pulses
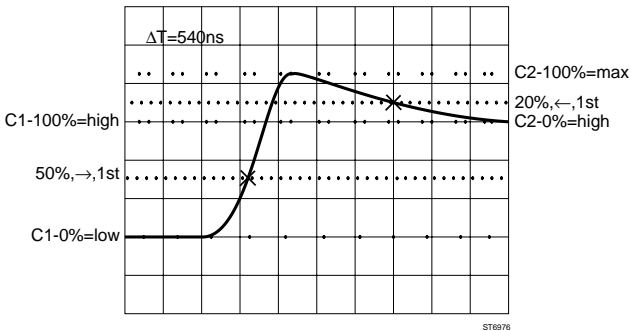
Figure 6.2   Measurement of recovery time from overshoot

Key sequence:
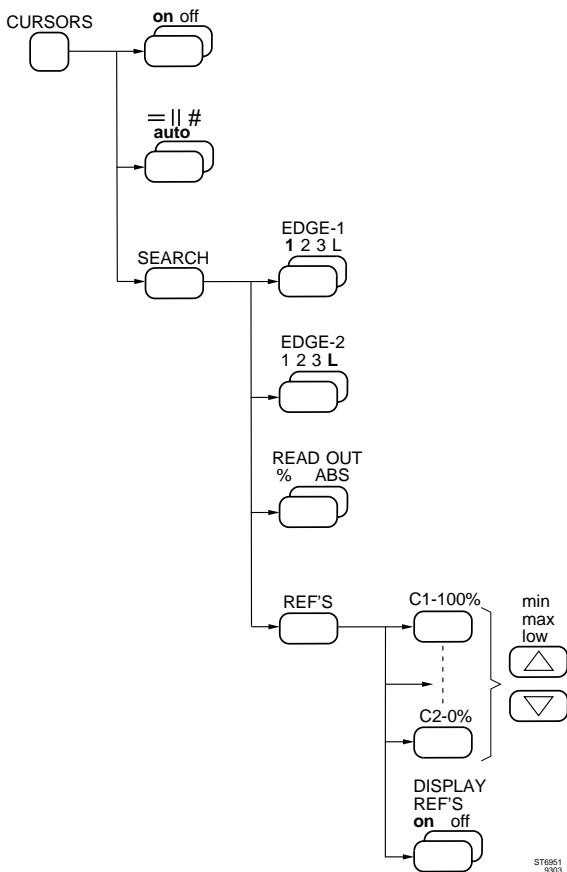
CURSORS → **on** off	Toggle function softkey to switch between cursors on and off.
= ‖ # **auto**	Toggle function softkey to switch between volts, time, mixed or amplitude qualified cursors.
SEARCH → EDGE-1 **1** 2 3 L	Toggle function softkey to select the occurrence of cursor C1.
EDGE-2 1 2 3 **L**	Toggle function softkey to select the occurrence of cursor C2.
READ OUT % ABS	Toggle function softkey to switch between relative or absolute readouts.
REF'S → C1-100% ... C2-0% → min max low △ ▽	Softkey pair to select between the cursor conditions. This can be done for all four reference conditions. If 'abs' is selected, the TRACK control adjusts the level.
DISPLAY REF'S **on** off	Toggle function softkey to turn the reference cursors on and off.

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Remote commands:

CPL:QM (command to query measured values)

Refer to the Operating Guide for full details.

7   MULTIPLE SHOT

Description:

The MATHPLUS option offers in addition to the three basic timebase modes (AUTO, TRIG, and SINGLE) the MULTIple shot mode. The mode selection is done in the TB MODE menu.

Multiple shot enables the 4 channel instruments, to perform up to 32 (200 for extended memory) consecutive single-shot acquisitions. The 2 channel instruments allow up to 16 (50 for extended memory) consecutive single-shot acquisitions. Pressing the SINGLE key resets the scope for single-shot operation; the trigger level is set to 0.5 division (indicated by T-). You can now select single-shot or multiple-shot mode in the TB MODE menu. From now on, the selected mode is used every time the SINGLE key is pressed.

In the multiple-shot mode, the acquisition is stored in the highest unprotected memory location. The scope then automatically rearms for the next acquisition and stores it in the memory location with the next lower index. This continues until the whole memory is filled or a protected memory location is met. Depending on the number of active channels and the selected memory configuration (acquisition @512, @2K,...), a single register can contain 1, 2, or 4 shots.

Key sequence:
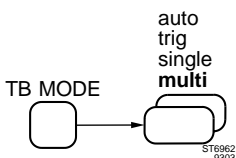
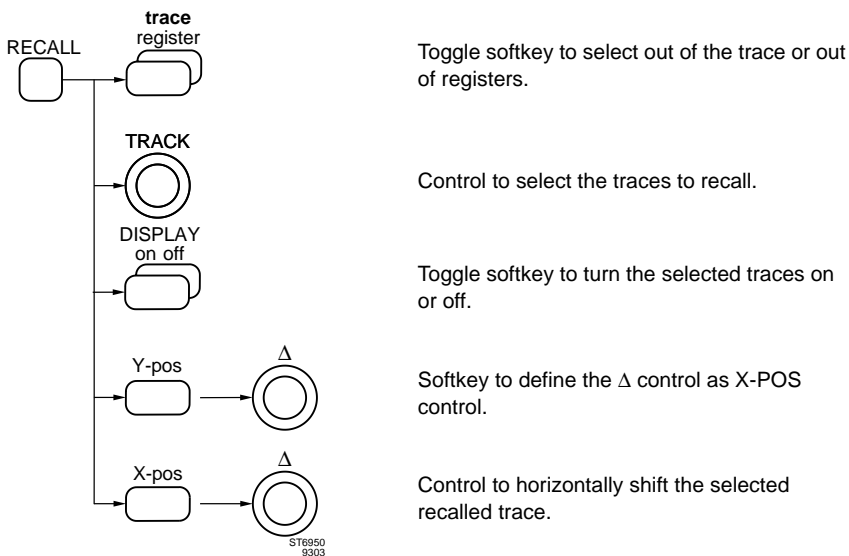|	
TB MODE → auto / trig / single / **multi** (ST6962 9303)	Softkey pair to select between the timebase modes including multiple shot.
SINGLE	Key to reset the MAIN TB in multiple-shot mode, with ARM'D indicator.

8   VARYING X POSITION

Description:

You can display previously stored traces at any time and in any combination.
When you recall multiple traces, the standard instrument version allows you to
vary the Y-POSition of a displayed stored register (e.g., m4) or trace (e.g., m4.1).
This is done with the Δ control in the 'RECALL REGISTER MEMORY' menu

When the Mathplus option has been installed, you can also vary the X-POSition
of a displayed stored trace. To enable this control, press the bottom softkey in the
RECALL REGISTER MEMORY menu and select 'trace' mode. Then select either
Y-POS or X-POS from the 'RECALL REGISTER MEMORY' menu to define the
function of the Δ control. A softkey selection in the 'RECALL REGISTER
MEMORY' menu defines the function of the Δ control, whether used for Y-POS or
for X-POS.

The X-POS feature is useful for observing and comparing stored traces that are
time related and for delay compensation of measurement cables of different
length.

Key sequence:

RECALL → **trace**/register	Toggle softkey to select out of the trace or out of registers.
TRACK	Control to select the traces to recall.
DISPLAY on off	Toggle softkey to turn the selected traces on or off.
Y-pos → Δ	Softkey to define the Δ control as X-POS control.
X-pos → Δ	Control to horizontally shift the selected recalled trace.

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9   APPLICATIONS

9.1   INTRODUCTION

Oscilloscopes have always enabled the electronics engineer to view electrical
signals. Up to now, this is usually limited to showing voltages measured in a
system.

The Autoranging CombiScope family of oscilloscopes can do many mathematical
operations, so that you can derive information from measurements that is not
obvious to see in the original traces.
This chapter gives examples of this mathematical processing, and provides the
explanation of how this type of processing expands the measurement capabilities
of the oscilloscope.

9.2   POWER MEASUREMENT

Oscilloscope measurements can be made of voltage or current, then circuit or
device power can be calculated from these measurements.
But, the Autoranging CombiScope family of multichannel oscilloscopes can
simultaneously measure both voltage and current and multiply waveforms, thus
calculating and displaying electrical power as a function of time.
This measurement will be reliable over a wide range of frequencies, irrespective
of the wave shapes of voltage and current. These measurements can be used in
systems equipped with switching components such as switch mode power
supplies where power can be a critical factor.
In Figure 9.1a, an ac voltage source V1 is loaded by a resistor Rload. This causes
current (I) to flow in the system.
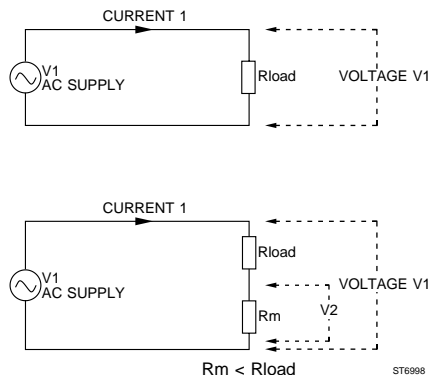

Figure 9.1   Basic set-up for
               Power Measurement

In Figure 9.2 a copy of the original oscilloscope screen is shown with part of the instruments setup information. The figure shows both signals: channel 1 (ch1) shows voltage V1 at a vertical deflection setting of 5 V/div (volts per division), channel 2 (ch2) shows the current. The channel 2 deflection setting is indicated as 0.2 A/div (amperes per division). This is achieved by changing the probe scaling of channel 2 to adapt for an external current-to-voltage conversion, giving one volt output per ampere input.

The conversion itself was achieved by placing a 1Ω measurement resistor Rm in series with the load and applying the voltage across this series resistor (see Figure 9.1b) as V2 to oscilloscope channel 2 (ch2).

Refer to Figure 9.2; it appears V1 (ch1) has an amplitude of 5.5 Vp, the current has a peak value of 222 mA.

The oscilloscope was set up to multiply this waveform information and to store the resultant waveform in memory 1 as channel 1 (m1.1).
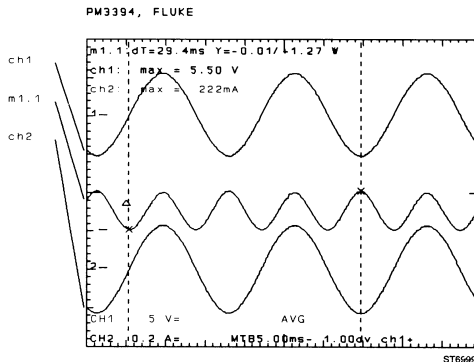
Figure 9.2   Oscilloscope screen showing the voltage (ch1) and current (ch2) waveforms together with the momentary power curve (m1.1)

NOTE: Multiplication at the ch1 and ch2 waveforms results in the center waveform displaying the momentary power. Cursor measurement on this power curve shows the peak power in the resistor is 1.27 Watts.

Use the following key-sequence to activate this multiplication process:
- Enter the MATH menu.
- Select MATH 1, m1 = >.
- Turn the TRACK control to select the multiplication operation to select ch1 and ch2.
- Press ENTER and turn on the mathematical operation.
- Change the display size and position if necessary.

Scaling and Scale factor

If the measurement resistor Rm has a value other than 1Ω, the current-to-voltage conversion ratio can be used for the scaling factor according to the following formula:

$$\text{SCALEfactor} \ = \ \frac{1}{Rm}$$

Example: Suppose a current of 2 amperes is flowing in the system. This current will cause a 2-volt signal across a 1 ohm resistor. If an oscilloscope with a vertical deflection setting of 1 V/div is used to measure this, the deflection indication of the oscilloscope should be 1 A/div instead of 1 V/div; signal amplitude will be 2 divisions. If the resistor is replaced by a 0.5Ω type, the voltage across it will be just 1 volt, giving a signal amplitude on screen of 1 division. The scaling factor should be set to 2.000 E00 to get a current reading of 2 A/div.

Use the following key sequence to change the readout of channel 2 to indicate A/div (amperes per division):
- Enter the UTILITY menu.
- Select PROBE >, PROBE CORRection >, SCALE > and select this function to work on channel 2, switch it ON.
- Use the Δ control to select another unit of measure for the channel 2 deflection factor, select UNITS A (= amperes).

9.3   INTEGRATION OF A WAVEFORM

The mathematical process of integration can be seen as the summation of all signal values of a waveform over time. In a sampled system like an oscilloscope, this comes down to the summation of all individual samples, including signs, over time. This allows you to measure the accumulated effect over time of individual events or individual parts of a signal. The resultant waveform expresses V∗s (voltseconds) as a function of time if the original curve is in volts per division or expresses Coulomb if the source waveform is in Amperes per division. Applications include measuring the charge stored in a device, being the integrated waveform of the current, measuring the dissipation as the integrated curve of power, and many more.

In Figure 9.3, channel 1 shows a current step of 8.92A that is used to charge a capacitor (ch1). As a result, the charge in the capacitor will increases linearly. Mathematical operation 2 is used to integrate the current waveform, resulting in a curve (m2.1) that represents the charge stored in the capacitor.

The vertical deflection of the processed curve has been set to give a scaling of 25 µC/div (micro-coulombs per division).
The cursors were used to measure the charge stored is 141 µC per cycle.
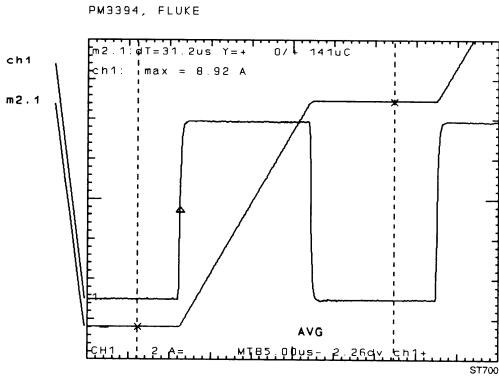

Figure 9.3   Waveforms showing step current (ch1) and charge stored in the capacitor (m2.1)

Key sequence is:
- Enter the MATH menu
- Press MATH 2
- Enter MATH 2 m2= > and use the TRACK control to select the integration process.
- Use the Δ control to select the acquisition as the source for the mathematical process and press ENTER.
- Set the on/off toggle to ON.
- Enter the PARAMeter submenu to change the vertical deflection setting to 25 µC/div or its position (OFFSET).
- Enter de CURSOR menu, select vertical cursors on m2.1, enter the READOUT submenu and switch over the V1&V2 readout.

9.4   POWER MEASUREMENT IN A SWITCH MODE POWER SUPPLY

The size and weight of electronic equipment is often dominated by the size and weight of the power supply it incorporates, so switch mode power supplies (SMPS) are used to make products smaller and more lightweight.
Because the size and weight of these power supplies in turn depends on their operating frequency, much effort is spent increasing the converter's frequency of operation.

The losses in efficiency due to the switches are the main limitation to this increase in frequency. Measurement of the losses is therefore of crucial importance in the design of SMPS.

In Figure 9.4, the power stage of a flyback type SMPS is shown. During the forward stroke, the transistors V1 and V2 conduct and charge the transformer, and increase the current through the transformer's primary winding. This causes the voltage across Rm to increase until it is high enough to fire V3. This switches off V1 and V2 for the duration of the flyback stroke, and forces the transformer to discharge via the secondary windings of the transformer.
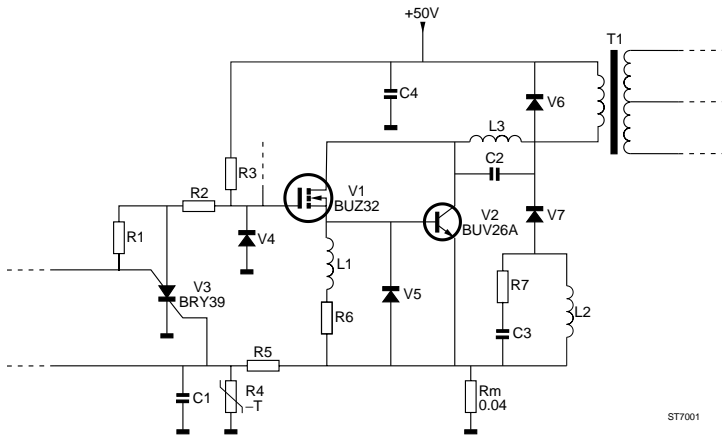

Figure 9.4   Power stage of a Switch Mode Power Supply

Losses occur mainly in the switcher components V1 and V2 due to their switching speed and are mainly during the phase where the transistors are switched on again. At that time the voltage over the transistors is high, and the current starts to increase.
These losses can easily be measured by applying the collector voltage of V2 and the voltage across Rm to the oscilloscope (see Figure 9.5).
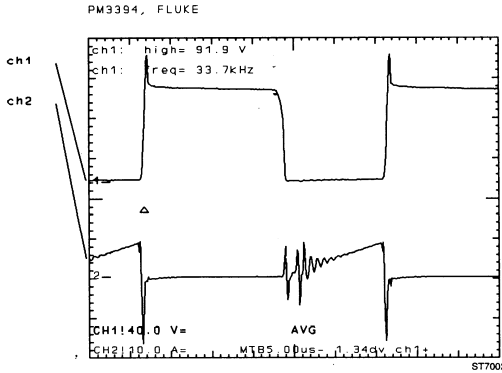
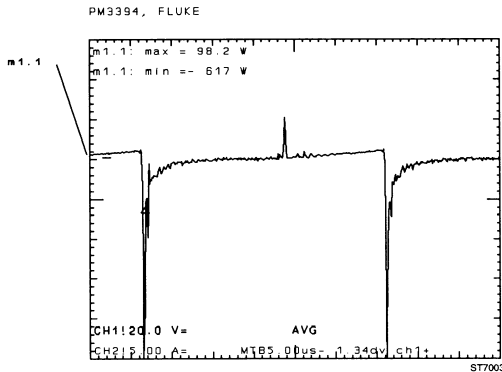*Figure 9.5   SMPS voltage (upper trace) and current waveforms*

Figure 9.6   Momentary Power as a function of time

The oscilloscope is used in the windows mode, that is, the two source traces are each displayed over half the vertical size of the screen (four divisions), thus giving an optimal use of the screen and good separation of the two traces while maintaining high vertical deflection settings. The vertical deflection readout is adapted to the new waveform display size.

Figure 9.6 shows the mathematically obtained resultant waveform; the measurements indicate the maximum peak is approximately 98.2W.

Also a negative (and much larger) peak can be seen in Figure 9.6. This peak corresponds to the power handled by the flyback diodes at the moment the flyback stroke starts. Since at that moment voltage and current are of opposite sign, a negative value is found. This negative sign indicates that the current does not go through the transistors. This power peak is therefore not handled by the

transistors and needs not to be taken into account where the power handling of the transistors is concerned.

The key-sequence to set up the oscilloscope for this power curve calculation is as follows:
- Attache probes measuring the collector voltage and the output current to the oscilloscope channels 1 and 2.
- Set the probe scaling for the current measurement on the appropriate channel.
- Enter the UTILITY menu.
- Select PROBE > and PROBE CORRection >.
- Select the channel that represents the current (here ch2).
- Press SCALE > and change the units into A (amperes) by using the Δ control and adapt for the value of the measurement resistor Rm by setting a SCALE factor equal to (1/Rm) with the TRACK control. Notice the vertical deflection indication changes according to the scale factor and units of measure used.
- Enter the MATH menu, select MATH 1, set up the mathematical operation 1 for multiplication using the TRACK control and select ch1 and ch2 as the source waveforms by means of the Δ control.
- Press ENTER and switch on (on/off) the mathematical operation. Now the SCALE sub-menu can be entered if the resultant waveform has to be changed in vertical size or offset (position).

Perform the following steps to measure the peak power:
- Select the MEASURE menu.
- Select measurement 1 and toggle the first softkey until the 'volt' mode is highlighted.
- Use the TRACK control to measure the MAXimum peak.
- Use the Δ control to do the measurement on m1.1.
- Press RETURN and switch on measurement 1.

MINimum peak can be measured in the same way as MEAS 2 to indicate the power peak handled by the diodes.

9.5 PULSE POWER OR DISSIPATED ENERGY MEASUREMENT

The power the transistors handle is converted into heat. The risk of damage to a component depends on the peak power that the component handles, and also on the total dissipation of the component. Too much dissipation will cause the temperature of the device to be too high.
The dissipation is proportional to the integral of the power curve over time.

The dissipation in the transistor takes place during the conducting phase (where the transistor is carrying current) and during the switching transitions. In Figure 9.7 was zoomed in on that part of the waveform of Figure 9.6.
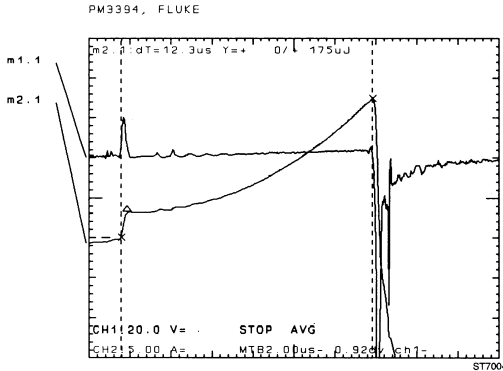

Figure 9.7   Power handling by the devices during the conducting phase of the SMPS

The power curve was derived from part of the signal and used as the source for an integration process.
The integrated waveform shows the accumulated pulse power, dissipated by the devices.
The cursors can be used on this waveform and give a read-out in joules (J), which is the equivalent of Ws (watt-seconds).
In order to know the total dissipation of the devices per second, we have to multiply the dissipation per cycle, which was found to be 175 μJ, and the number of cycles per second (33.7 KHz, see figure 9.5) and find 5.9W.

Once the instrument makes the power curve (described in the previous paragraph), the following key-sequence can be used to come to the integrated curve:
- Enter the MATH menu.
- Select MATH 2.
- Select MATH 2 m2= >.
- Select the integration operation by using the TRACK control.
- Use the Δ control to select the result of MATH 1 in memory 1 as the source for the operation.
- Press ENTER, switch the processing function on.
  If desired, select from the PARAMETER menu to change the offset of the curve or select a different vertical scaling for the resultant curve.

The integration process can also be performed in a limited area, that is, part of the source waveform can be neglected by indicating the process has to be performed over a limited area only. If you select this function is selected by setting 'LIMITED yes', a new AREA submenu comes available that allows you to use the cursors to isolate the part of the waveform that must be used for the integration process.
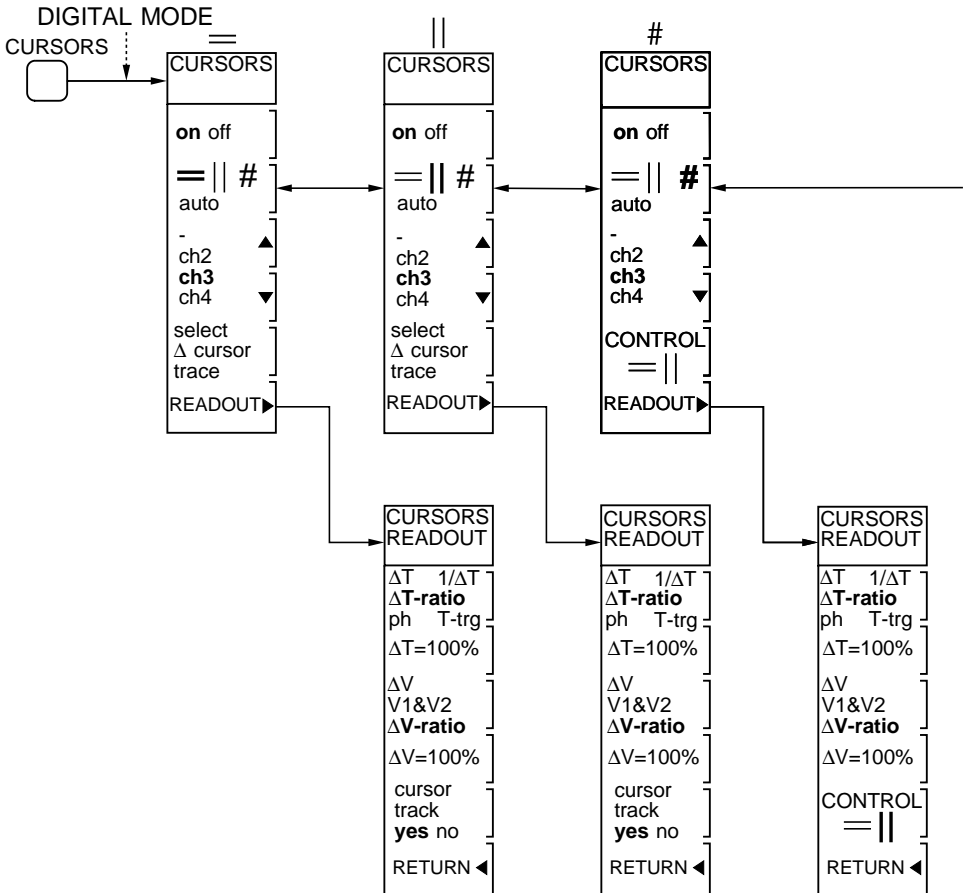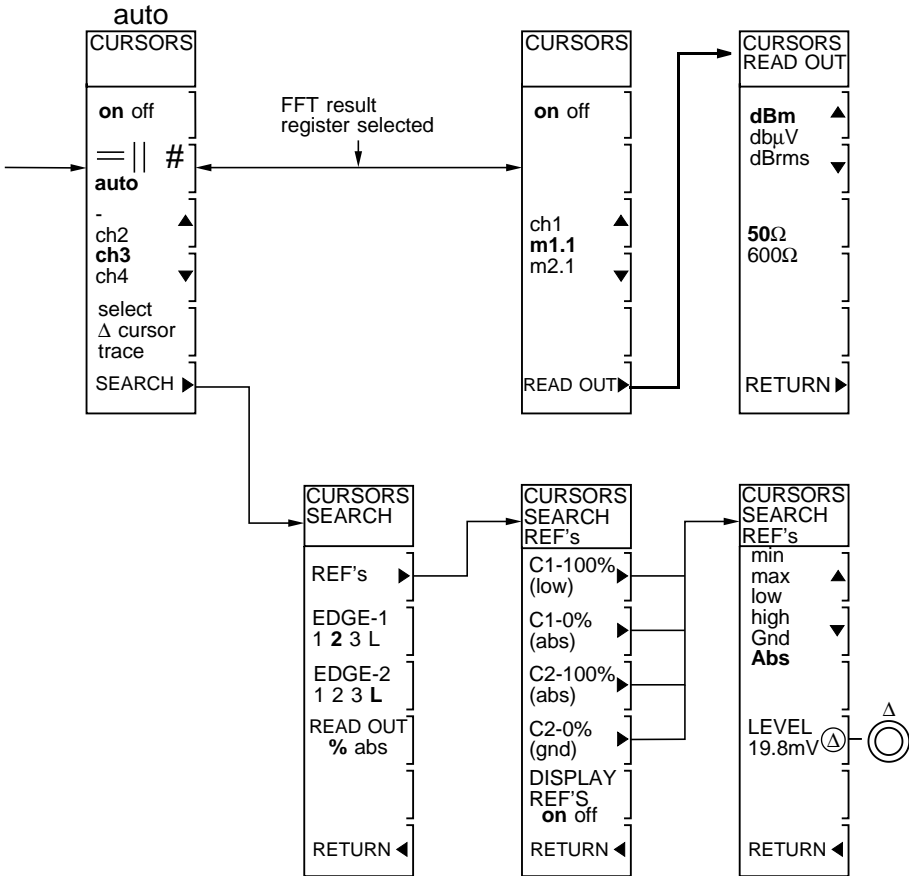
APPENDICES

Appendix A
MATHPLUS CURSORS menu
(Digital part only)

DIGITAL MODE

CURSORS

=

CURSORS

on off

= || #
auto

-
ch2
ch3
ch4

select
Δ cursor
trace

READOUT▶

||

CURSORS

on off

= || #
auto

-
ch2
ch3
ch4

select
Δ cursor
trace

READOUT▶

#

CURSORS

on off

= || **#**
auto

-
ch2
ch3
ch4

CONTROL
= ||

READOUT▶

CURSORS
READOUT

ΔT 1/ΔT
ΔT-ratio
ph   T-trg

ΔT=100%

ΔV
V1&V2
ΔV-ratio

ΔV=100%

cursor
track
yes no

RETURN◀

CURSORS
READOUT

ΔT 1/ΔT
ΔT-ratio
ph   T-trg

ΔT=100%

ΔV
V1&V2
ΔV-ratio

ΔV=100%

cursor
track
yes no

RETURN◀

CURSORS
READOUT

ΔT 1/ΔT
ΔT-ratio
ph   T-trg

ΔT=100%

ΔV
V1&V2
ΔV-ratio

ΔV=100%

CONTROL
= ||

RETURN◀

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CURSORS
on off
= ‖ #
auto
-
ch2 ▲
ch3
ch4 ▼
select
Δ cursor
trace
SEARCH ▶

FFT result
register selected

CURSORS
on off
ch1 ▲
m1.1
m2.1 ▼
READ OUT ▶

CURSORS READ OUT
dBm ▲
dbμV
dBrms ▼
50Ω
600Ω
RETURN ▶

CURSORS SEARCH
REF's ▶
EDGE-1
1 **2** 3 L
EDGE-2
1 2 3 **L**
READ OUT
% abs
RETURN ◀

CURSORS SEARCH REF's
C1-100% ▶
(low)
C1-0% ▶
(abs)
C2-100% ▶
(abs)
C2-0% ▶
(gnd)
DISPLAY
REF'S
on off
RETURN ◀

CURSORS SEARCH REF's
min
max ▲
low
high
Gnd ▼
Abs
LEVEL Ⓓ
19.8mV
Δ
RETURN ◀

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