

Characteristic features of the digital oscilloscopes; the main/window time base rev. 1

Purpose: Acquaintance with the main/window time base. Acquaintance with the specific features of a digital scope. Acquisition of a signal, using of the Averaging mode, using the Envelope mode, the effects that the sampling operation has on the measurements.

Summary of theory

The digital scope, unlike the analog scope, operates on the sampled signal. This operation mode allows the addition of more functions, specific to a digital system : storing and digital processing of the acquired samples. Despite these advantages, sampling the signal can generate problems. Sampling should be done according to the sampling theorem; when the theorem's conditions are not met, the phenomenon of *aliasing* in the frequency domain / under-sampling in the time domain appears, inaccurate measurements being obtained for certain parameters in this case.

The Tektronix TDS 1001 scope can operate at a maximum sampling frequency of 1GSamples / second ($F_{smax} = 1\text{GHz} = 1\text{GSa/s}$). During an acquisition cycle the scope acquires $N_s = 2500$ samples. An acquisition cycle corresponds to the time interval during which the display on the screen is done. The number of the displayed points depends on the resolution of the display. The display of the Tektronix TDS1001 scope has 320 points on the horizontal axis, amongst which, for the zone corresponding to the grid of the screen, 250 points are used. Consequently, the displayed image will be formed by 250 points, the rest of the samples being used for horizontal details of the image (zoom), measurements, etc.

Let T_s be the time interval between two acquired points (samples), and $N_x = 10$ the number of divisions of the grid, on the horizontal axis; for an image displayed on the screen, the following relation is true :

$$N_x \cdot C_x = N_s \cdot T_s \quad (1)$$

Because the acquired number of samples is fixed, it results that the scope has to modify its sampling frequency, when the horizontal deflection coefficient C_x is modified.

To the maximum sampling frequency, $F_{smax} = 1\text{GSa/s}$, corresponds a sampling period of $T_{smin} = 1\text{ns}$. From the equation (1), in this case, a deflection coefficient C_{xmin} is obtained :

$$C_{xmin} = \frac{N_s T_s}{N_x} = 250\text{ns/div} \quad (2)$$

For deflection coefficients lower than C_{xmin} , from equation (1), a sampling period lower than T_{smin} is obtained, meaning a sampling frequency greater than F_{smax} . Since such a frequency can not be achieved, the scope will operate, in this case, at F_{smax} , and it will reduce the number of acquired samples.

Consequently, for $C_x < C_{xmin}$, the scope will operate at its maximum sampling frequency ($F_s = F_{smax}$, $T_s = T_{smin}$ respectively), and the number of acquired samples will be smaller than 2500. If there are fewer samples than the number of samples necessary, the scope will "fill in" the gaps using the *interpolation*.

Acquisition modes for the digital scope Tektronix TDS1001

a) **SAMPLE** – the samples, are directly displayed. From the 2500 acquired samples, in the grid zone of the screen there are displayed only 250. The viewed image is refreshed after each acquisition cycle.

b) **PEAK DETECT** – does not use the frequency calculated according to the relation (1), but the maximum sampling frequency available; the memory of 2500 samples is used as follows: the maximum and the minimum values of the signal are stored, for 1250 sampling intervals, and these values are used for displaying the waveform. Consequently, there will be 1250 maximum values and 1250 minimum values. This simple mode can be used for the display of short time pulses, that

can be skipped in **SAMPLE** mode, when F_s calculated according to the relation (1) is small, meaning that T_s is high. The viewed image is refreshed after each acquisition cycle.

c) **AVERAGE** – the scope performs the averaging, according to the "fixed-window" procedure, on a number of M acquisition cycles, for each of the 2500 samples that form the image, obviously, satisfying the condition $C_x > C_{xmin}$. In this case, M can be :

$$M = 4, 16, 64, 128$$

At the end of each averaging operation (after M acquisition cycles) the video memory is refreshed. The number of cycles on which the averaging is done is selected from the **ACQUIRE -> Averages** menu.

RUN/STOP – as it was mentioned above, the scope resumes the operation of acquisition of the samples, at each new trigger moment. This operating mode is called the **RUN** mode.

The acquisition operation can be stopped by pressing the knob **RUN/STOP**. In this case, the scope keeps in its memory (and on the display) the set of 2500 samples acquired, previous to the moment the knob **RUN/STOP** was pressed and no further acquisition is performed. This operating mode is called the **STOP** mode. The alternance between the two modes can be done by successively pressing the **RUN/STOP** button. The selected operating mode is displayed in the top of the screen (**Trig'd** or **STOP**).

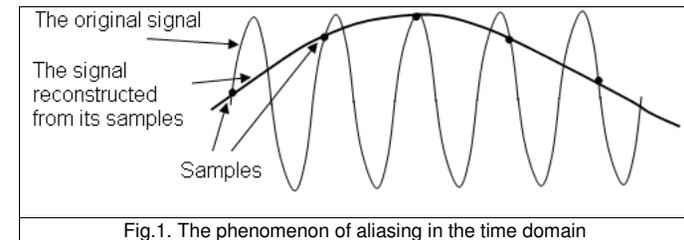
Display modes for the digital scope Tektronix TDS1001

A very useful display mode, specific to a digital scope, is the displaying of the image with **persistence**. In this mode, for a selected interval of time, on the display there are kept / stored all the images displayed in this time interval. This mode is useful because it allows viewing all the points through which the signal passes in the specified interval. This mode allows the viewing of the envelope of the signal, or the viewing of very short pulses. This is possible because, by storing the samples acquired during several acquisition cycles, the probability of detecting also the events that appear less frequently or for short time, increases. For the TDS1001 scope, the following intervals for the persistence of the image can be chosen: 1, 2, 5 seconds and infinity, respectively.

The effect of the aliasing in the time domain and in the frequency domain

• The effect of the aliasing in the time domain

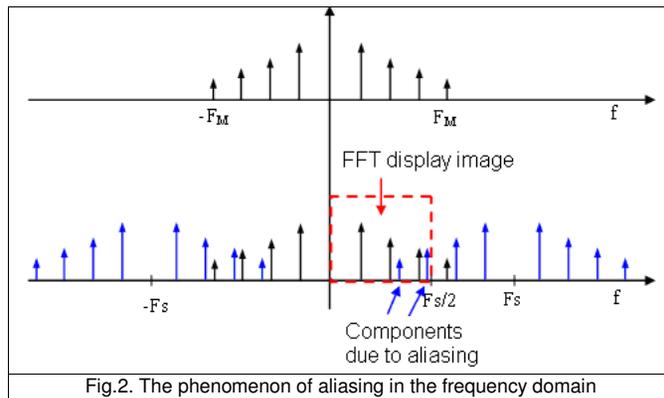
The aliasing appears when the signal is sampled with a frequency less than the frequency needed in order to allow the reconstruction of the signal from its samples. In this case, the reconstructed signal will differ from the original one. On the scope, this is equivalent to the displaying of a signal of frequency *smaller* than the frequency of the input signal and / or the displaying of an instable image.



• The effect of the aliasing in the frequency domain

The spectrum of the sampled signal is represented by *the periodic repeating in frequency*, with the period F_s , of the spectrum of the analog signal. Consequently, being F_M the maximum frequency from the spectrum (Fig. 2, top side), the spectrum from $(-F_M, F_M)$ can be also found in the interval $(F_s - F_M, F_s + F_M)$, etc (Fig.2, bottom right side). Therefore, to avoid the overlapping (the aliasing) of the 2 ranges, the second spectrum (the repeated one) should be at higher frequencies than the first spectrum, ie :

$$F_s - F_M \text{ (the min freq. from the second spectrum)} \geq F_M \text{ (max freq. from the first spectrum)}$$



This last equation leads to the condition $F_s \geq 2F_M$. This is the sampling theorem: the sampling frequency should be at least the double of the maximal frequency from the spectrum of the analog signal, otherwise the aliasing phenomenon will appear, the reconstruction of the original signal being impossible.

Because the spectrum of the sampled signal is periodic with the period F_s , and the spectrum of the real signals is symmetrical from zero, the scope displays the spectrum of the signal in the interval from 0 (most-left of the screen) to $F_s/2$ (most-right of the screen), represented in dotted line in Fig. 2 (bottom side). In the case of aliasing, the spectral components from the repeated spectrum will also be displayed, although they are not components of the original signal.

Operating modes with the main/window time base

The window time base allows the selection of a certain zone (window) from the image viewed with the main time base, and the viewing of the selected zone only. This way, one obtains an effect of a "time magnifier" (zoom) with adjustable position anywhere within the main time base.

The operating mode with the window time base can be selected from the **HORIZ MENU** -> **Window Zone**. From the **SEC/DIV** knob the horizontal deflection coefficient for the secondary time base can be adjusted. Its value appears on the screen in the field / next to the letter **W**. By adjusting the value of the deflection coefficient, the desired dimension for the window is adjusted. By selecting the softkey **Window**, the image in the window is zoomed full-screen.

Measurements

A. The study of the main/window time base

1. Measure the rise time of a rectangular signal. Generate a rectangular signal of frequency 10kHz. Adjust its amplitude so that the signal is between half of the second division (0%) and half of the seventh division (100%). Adjust, from **HORIZONTAL POSITION** knob the position of the arrow indicating the trigger moment, so that it is in the center of the screen. Select the operating mode with main/window time base (by pressing the **HORIZ MENU knob and selecting the field Window Zone**). On the screen, a dotted vertical line appears, and on the bottom of the screen appears, also, the field **W**, whose value represents the deflection coefficient of the window time base (C_{w}). By rotating the knob for the adjustment of the horizontal deflection coefficient, the value of the coefficient **W** (C_{w}) can be modified. By increasing **W** it can be observed that the dashed vertical line splits into two vertical lines, the area enclosed by the two lines representing the portion of the signal that will be displayed in the window. Position the window on the rising slope of the signal (the slope from the center of the screen), and view full-screen the selected area (by selecting **Window** from the menu on the screen). Adjust the deflection coefficient so that the measurement of the rise time is as accurate as possible.

B. Measurements using the average mode and the envelope mode (display with persistence of the image)

2. For the rectangular signal previously viewed, adjust the amplitude to $A=200\text{mV}$. Select the **main** time base. Use the vertical deflection coefficient $C_y=100\text{mV/div}$ to view the signal. View a number of periods between 2 and 4.

a) Measure, using the cursors, the peak-to-peak amplitude of the noise superimposed on the rectangular signal.

b) Measure the amplitude of the signal, using the average mode (**Acquire->Average**). Select 128 acquiring cycles for the averaging operation (**Averages->128**). What happens with the noise? Why?

c) Return in the **Sample** operating mode. Select the display with infinite persistence mode (**Display->Persist->Infinite**), and measure, again, the peak-to-peak amplitude of the noise. How does it change compared to the measurement from a? Why?

3. Modify the amplitude of the rectangular signal to 2V, and modulate this signal in amplitude (**SHIFT->AM**). The degree of modulation can be adjusted from **SWEEP SPAN** (pulled knob). Choose the deflection coefficients $C_y=500\text{mV/div}$, $C_x=250\mu\text{s/div}$ respectively. Return to the display without persistence. Adjust the trigger level until the image becomes triggered (the modulated sine can be observed, and not one or two black band(s)).

a) Measure the maximum and the minimum amplitude of the modulated signal.

b) Adjust the trigger level so that it reaches the average value of the signal (approximately the zero level, because the signal is symmetrical from zero - the image becomes untriggered as a consequence of this setting). Modify the horizontal deflection coefficient to $C_x=25\mu\text{s/div}$. Following the same steps as at point 2, measure the averaging value, A_{med} , of the amplitude of the signal (using the **Average** mode), and the maximum and the minimum variation of the amplitude (using the infinite persistence mode).

c) Calculate the value of the degree of modulation, using the measurements done before. Use the relation $A_{\max/\min} = A_{med} (1 \pm m)$.

C. Measurement of the sampling period

Measure the sampling period of the scope. Use the rectangular signal from point 3 (without the modulation - the **SWEEP SPAN knob pressed**) so that, on the screen, two to four periods of the signal can be viewed. Select the display without persistence and the acquiring mode **Acquire -> Peak Detect**. Adjust the horizontal deflection coefficient at $C_x=250\mu\text{s/div}$. Select the **STOP** mode, to stop the acquisition (by pressing the **RUN/STOP knob**). Detail the image, from the C_x adjusting knob, until it begins to be displayed as dots.

a) Measure, using the time cursors, the distance between two consecutive points (the sampling period).

b) Calculate the sampling period and the sampling frequency. Use the relation $N_x \cdot C_x = N_s \cdot T_s$, where C_x is the value before detailing the image ($250\mu\text{s/div}$), $N_s=1250$ samples, and T_s is the sampling period.

Remark 1 : The number of samples is half comparing to the **SAMPLE** mode, because there are 1250 maximum values and 1250 minimum values. The minimum values and the maximum values are displayed at intervals equal to T_s , both on the same horizontal position.

Remark 2 : In **RUN** mode, the scope adjusts T_s , depending on C_x , to consider the optimal number of samples. In **STOP** mode, the adjustment of C_x does not have the same effect, because the acquisition is stopped, and the image on the screen is a stored one (it is not refreshed). It is then possible to detail the image so that it can be viewed as individual dots / points, which was not possible in the **RUN** mode.

c) Repeat a and b for a deflection coefficient $C_{x1}=100\mu\text{s/div}$. What happens with the sampling frequency?

D. The effect of the sampling on the measurements in the time domain.

4. Return to **ACQUIRE->Sample**. Generate a rectangular signal of frequency 10kHz. Adjust the **HORIZONTAL POSITION knob** so that the position of the arrow which indicates the trigger

moment is in the center of the screen. Set $C_{x1}=100\mu\text{s}/\text{div}$. Select the **STOP** mode, to stop the acquisition of the signal. Detail the acquired image until the rise time becomes visible on the screen.

a) Measure the rise time t_{c1} .
 b) Return to the **RUN** mode. Set $C_{x2}=25\mu\text{s}/\text{div}$. Stop the acquisition of the image, by selecting the **STOP** mode. Following the steps from a, measure the rise time t_{c2} . What happens with the rise time? Compare the measured values with the value measured at 1. Explain what happened. (*Hint: Correlate them, also, with measurements done at 4 - the relationship between the measured rise time and the frequency used in the moment of the acquisition*).

5. Select the **RUN** mode. Generate a rectangular signal of frequency 10kHz and the amplitude 100mV. Observe that on the signal there is a high frequency noise superimposed. Set the deflection coefficient at $C_{x1}=100\mu\text{s}/\text{div}$. Stop the acquisition, choosing the **STOP** mode.

a) Detail the image (50 times approximately - C_x at least 50 times smaller) and measure, using the time cursors, the distance between two successive peaks of the noise T_{n1} . Choose the two nearest peaks.

b) Acquire a new signal (**RUN** mode). Set the deflection coefficient to $C_{x2}=25\mu\text{s}/\text{div}$, select the **STOP** mode, and repeat the measurement from a, obtaining T_{n2} .

c) Return in the **RUN** mode, and detail the image, until the distance between two peaks of the noise can be measured. Measure that distance, T_{n3} .

How can you explain the obtained results?

Remark: At c, because the noise is asynchronous with the signal, the image of the noise is not triggered. To view the image of the noise as stable as possible, adjust the trigger level at the peak level of the noise.

E. Measurement of the instability of the period of a signal

6. Input to the scope, a rectangular signal of $f=10\text{kHz}$ and the amplitude 1V. Choose C_x so that 3 - 6 periods of the signal are viewed. Adjust the **HORIZONTAL POSITION** knob so that the position of the arrow, indicating the trigger moment, is at the *leftmost side* of the screen. Set the trigger on rising slope (**Slope -> Rising**). Select and detail, using the window time base (as at 1), the first rising slope of the signal (that is after the slope used for trigger). Use a deflection coefficient for the secondary base, W , at least 50 times smaller than for the main time base. What happens with the rising slope of the signal?

a) Using the display with infinite persistence mode (**Display->Persist->Infinite**), measure the instability of the selected rising slope, ΔT_1 , ie, the width of the black band given by the left-right movement of the slope;

b) Return to the display with the Main (M) base; measure the instability of the second and the third rising slopes (ΔT_2 , ΔT_3). Pay attention! Use **the same** coefficient W as at a), otherwise the comparison is not valid. Verify the relations $\Delta T_2 < 2 \cdot \Delta T_1$ and $\Delta T_3 < 3 \cdot \Delta T_1$ respectively.

Why does the instability of the rising slope accentuate? Explain the result.

c) Calculate the relative instability of the period of the signal, $\varepsilon = \frac{\Delta T}{T} [\%]$. Consider the greater ΔT .

F. The effect of the aliasing in the frequency domain

7. Generate a **sinusoidal signal** of amplitude 2V and of frequency 600kHz. Set the vertical deflection coefficient at $C_y=1\text{V}/\text{div}$. View the spectrum of the signal (**MATH MENU->FFT**). Set the horizontal deflection coefficient at 125kHz/div.

a) Measure, using the frequency cursors, the value of the frequency of the signal. Determine which is the maximum frequency that the scope can display, for the selected deflection coefficient (the frequency corresponding to the most-right side of the screen). Which is the relation between this frequency and the sampling frequency (displayed in parenthesis next to the horizontal deflection coefficient)?

b) Set the value of the horizontal deflection coefficient at 50kHz/div. Measure the frequency of the signal in this case. How do you explain the obtained value? Which is the value of the sampling frequency in this case?

G. The effect of the aliasing in the time domain

8. Remember that the aliasing appears when sampling at a frequency less than the Nyquist frequency, and the aliased signal appears on a frequency less than the real one. More precisely, if the unknown signal has the frequency f_x , with $f_s/2 < f_x < f_s$, then, the aliased signal appears on the frequency

$$f_a = f_s - f_x \quad (3)$$

At the digital scope, this situation can appear at relatively high (slow) values of C_x , because the increasing of C_x means the increasing of T_s , according to relation (1), therefore, the decreasing of f_s . Observe that $f_{s \max}$ (for TDS1001, 1GSa/s) is valid only for low C_x , otherwise it decreases because N_s is relatively small (the oscilloscope does not have enough memory to store a lot of frequent samples).

a) Use $C_x = 5\text{ms}/\text{div}$. Set it on the scope (return in the time domain). Knowing $N_s = 2500$ pt, calculate the corresponding f_s .

b) observe that f_s is relatively low, so it is easy to exceed the Nyquist frequency; chose a signal of frequency $f_x > f_s/2$, near f_s , namely $f_x = 49.95\text{kHz}$. Set this frequency on the generator. Calculate the frequency of the aliased signal, f_a , corresponding to f_s previously calculated and to the relation (3).

c) without changing C_x , observe the frequency of the signal on the screen. Although the signal is unstable, it can be observed it is of low frequency. Using the menu **MEASURE -> TYPE Frequency**, measure the frequency f_{measured} of this signal. Use the **RUN/STOP** knob, to see a stable image, and draw it. Return in **RUN**. Observe if the measured aliased frequency f_{measured} corresponds to the calculated f_a .

d) the aliasing is an undesired phenomenon, because, in this case, the digital scope, displays a signal of a frequency totally different from the real one (the result of the measurement is also wrong). To determine if the signal was aliased, several methods can be used:

- observe that, adjusting the trigger level anywhere on the screen, the image does not become triggered, which is not a normal behaviour of the scope.
- in the right-most bottom side of the screen, the parameters of the trigger are displayed: the level, the slope (set by the user) and the frequency with which the signal intersects the trigger (measured). What is that frequency f_{trigger} ? Observe that it is very different from the measured frequency f_{measured} , thing that does not normally happen.
- observe that modifying C_x with only one step, right and / or left, the image changes radically (it contracts/expands more than 2 ... 2.5 times, as it should happen).
- use the Peak Detect mode, to detect the aliasing, because, in this operating mode, the sampling frequency increases and the relation for the aliased frequency f_a is not valid any more; return to $C_x = 5\text{ms}/\text{div}$, then select **ACQUIRE->Peak Detect**; observe that the image is very different from the one obtained in the Sample mode, this indicating an anomaly. Draw the image, and return to the Sample mode.

e) press **AUTOSET** to adjust the horizontal deflection coefficient at the automatically selected C_x' . Measure the real frequency of the signal, f_x . Which is the value of C_x' ? Which is the value of f_s' , corresponding to it? Explain whether or not the aliasing appears and give the reason why is so.

Remark 1. The possibility of aliasing is one of the disadvantages of the digital scope comparing to the analog one. However, the aliasing appears rarely, and it can be detected using

one of the methods mentioned above. At low (fast) values of C_x , the aliasing is unlikely to appear, because of the existence of the upper (analog) frequency of the input stages, which filter the signals of frequencies higher than the Nyquist frequency.

Example: at TDS1001, f_{3dB} is only 40MHz while $f_{smax} = 1GSa/s$ – so, as long as $f_{Nyquist} > 40MSa/s$, meaning $f_s > 80MSa/s$, the input stage has the role of an anti-aliasing filter. The low bandwidth of the analog stage, which is normally a disadvantage, now becomes an advantage from an anti-aliasing standpoint.

f) calculate C_{xmin} at which the filtering of 40MHz has this effect (based on relation (1)).

Remark 2. On the high-end digital scopes, with $N_s \gg 2500$ pt, the risk of the aliasing decreases, because f_s does not decrease as radically as C_x increases.

g) calculate N_s necessary so that f_s does not decrease under the value of 1GSa/s at $C_x \leq 5ms/div$, based on relation (1). Compare with N_s available on the TDS1001 !

H. Measurements with the double time base on a multi-level signal

9. Make the circuit from Fig.3. Use the supply set on 6V (*verify, using the voltmeter, the voltage and the polarity*). At the **CLOCK** input connect a TTL signal of frequency 20kHz. The signal is obtained from the TTL output of the generator (to activate it press **SHIFT+TTL** on the generator keyboard).

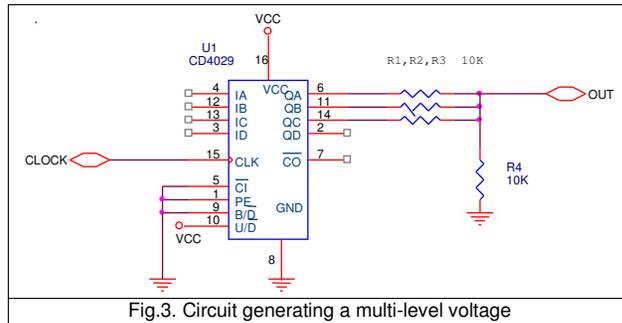


Fig.3. Circuit generating a multi-level voltage

QA, QB and QC are the outputs of a decadic counter on 4 bits ($Q_A=LSB$, $Q_D=MSB$). When in logical "1", each output produces a current through the respective resistance; summing these currents through R_4 determines a voltage on it, proportional to the number of outputs that are in logical "1". Consequently, the waveform from the OUT measurement point will have 4 possible voltage levels, depending on the number of the outputs which are simultaneously on "1" (0,1,2 or all 3).

a) Set, from the **HORIZONTAL POSITION**, the arrow that indicates the trigger moment, in the left-most side of the screen. View and draw, on the same image, the signals CLOCK, QA, QB, QC.

Pay attention! Because the scope does not have 4, but 2 channels, correctly and **identically** triggering the 4 signals (that can only be viewed 2 by 2), is essential, otherwise the temporal relation between them, when viewing the first two signals, and the last 2 signals, is lost ! The internal triggering (on CH1 or CH2) is not useful in this case.

Choose the external trigger (**Trig Menu-> Source -> Ext**), input QC on the plug EXT TRIG. Choose C_x so that minimum 10 periods of the signal are viewed on the screen, due to the fact that the counter is decadic (the waveform has a period equal to 10 periods of the CLOCK). Keep this signal connected to the EXT input when viewing all the four signals. Obviously, the signal from the EXT input is used for trigger, it can not be displayed !

Why is the image unstable if the CLOCK signal is used instead of QC ? Explain !

Hint: observe that the image is unstable when viewing a signal which has a greater period e (for example Qc) triggered with a signal which has a lower value period (for example, Clock), and,

when doing the opposite, the image is stable. If it is not yet stable, adjust the Holdoff time (HORIZ MENU->TRIG KNOB->HOLDOFF).

Explain why is the image stable when the period of the signal used for triggering is a multiple of the period of the viewed signal !

b) Return to the internal triggering (**Trig Menu-> Source -> CH1**). View and draw a period of the signal from the OUT output. What *trigger level* and what *slope* did you use for a stable image ? Mark on the image the corresponding level and slope.

Detail and measure, using the window time base, the rise time for one of the smallest voltage steps that appears in the viewed signal (choose one of the moments when this thing happens and **bold it** on the image of the main time base)

Observe that, because the respective event begins with a level and a slope *that can be found more than once* in a period of the signal from OUT, its view with the main time base is not possible, due to the fact that a triggering set that corresponds *only to that event* can not be uniquely defined.

This is the main application of the window time base : when the signal has a more complex form, with the main time base view a large area of the signal, triggered on an easy to trigger event (for example, the higher or the lowest level of the signal, that can be found only once within a period), even if that event is not interesting for the application, then, the interesting portion can be detailed, using the window time base, without re-adjusting the trigger.

Preparatory questions

1. Calculate the sampling frequencies for the scope TDS1001, if C_x has the values 10ms/div, 5 μ s/div, 100ns/div. Consider $N_x=10$ divisions and $N_s=2500$ samples displayed on the screen. The maximum sampling frequency is $F_{smax}=1GHz$.
2. The spectrum of a sinusoidal signal of frequency $f=500kHz$ is viewed. Which should the minimum sampling frequency be, so that the spectrum of the signal is correctly viewed ?
3. How does the oscilloscope work in the PEAK DETECT mode ?
4. How does the oscilloscope work in the AVERAGE mode ?
5. Which is the signification of the coefficient C_{xmin} for a digital scope ?
6. At which sampling frequency does the scope operate for $C_x < C_{xmin}$?
7. What is the relative error due to the resolution of the display, when measuring a rise time of 40 ns, using the scope Tektronix TDS1001 ($F_{smax}=1GHz$, and C_x is assumed to be as low as desired)?
8. Why is a short pulse disappearing, when operating in the SAMPLE mode, and it can appear wider in the PEAK DETECT mode, than in the SAMPLE mode ?
9. Can a deterministic parasitic signal of high frequency, synchronous with the useful signal and superimposed on it, be removed from the image in the AVERAGE mode ? But an asynchronous one? Justify your answer.
10. Determine the resolution when measuring time intervals using the cursors, if C_x has the values 1 μ sec/div, 0.02 μ s/div (given that the resolution is determined by the used sampling period, and the cursors can be moved step by step).
11. Determine the frequency measured on the display of the scope TDS 1001, in FFT mode, if the viewed signal has the frequency of $f=700kHz$, and the horizontal deflection coefficient is 50kHz/div?
12. A sinusoidal signal of frequency $f = 1MHz$ FFT mode is displayed as having a frequency of 500kHz. What is the sampling frequency used?
13. A sinusoidal signal of frequency $f = 2.5 MHz$ is viewed in the FFT mode with the sampling frequencies of $f_{s1}= 8MS/sec$, $f_{s2}= 4MS/sec$ and $f_{s3}= 2MS/sec$. Determine the *apparent / aliased* frequencies of the signal, that can be read on the display, in the case of each of the three FFT diagrams, and the correct sampling frequencies.