

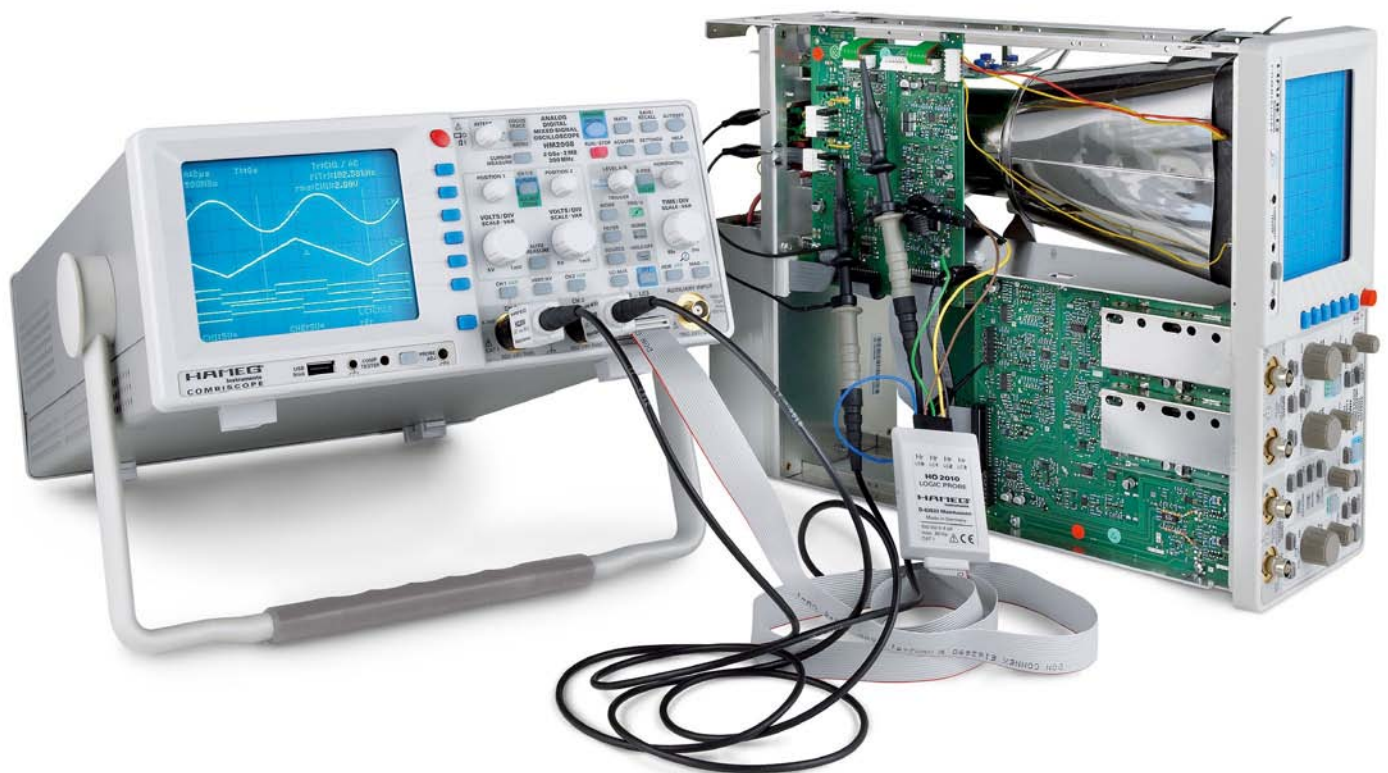
# HAMEG Oscilloscopes

Oscilloscopes cannot be replaced by any other measuring instruments ...

... because only oscilloscopes give a full representation of the measuring signal.

... because only oscilloscopes display signals versus time.

The importance of waveform representation becomes obvious when comparing oscilloscopes with alternatives to oscilloscopes: multi-meters and frequency counters. Both offer a much higher measuring accuracy, but the lack of waveform representation may obscure erroneous measurements.



As an example, erroneous measuring results will be obtained if pulse signals are being measured with duty cycles not exactly 1:1. This is especially the case when there are complex signals.

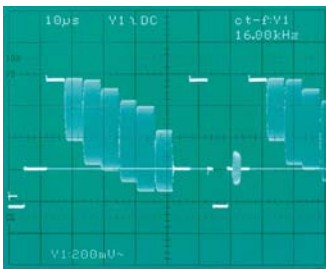
Comparable problems exist when measuring frequency, too. True measurements are based on the assumption that the signals are nearly ideal sine waves, triangles or square waves. Again complex signals will also lead to erroneous results.

A typical example of such a complex signal is a composite video signal. It contains 50 Hz field sync pulses, 15.625 kHz line sync pulses and the video signal with frequencies of a few Hertz up to about 5 MHz.

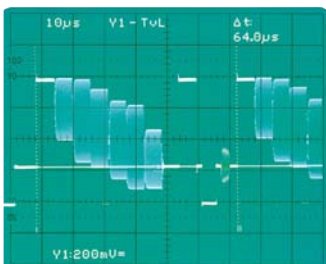
If a frequency counter is used to analyze such a signal, the accidental selection of the trigger level will determine which of the many frequencies will be displayed. Depending on the choice of trigger level, either the frequency of the sync pulses or of the video signal will be displayed. This can be easily demonstrated with the oscilloscopes HM504 or HM507. These instruments not only display the signal, they also contain a frequency counter. The choice of the trigger level is the same for oscilloscope and frequency counter, but if the frequency counter is used, the trigger level will not be visible.

Picture 1 displays a composite video signal. The trigger symbol is visible on the left of the display. In this example the trigger level was chosen at the level of the sync pulses. A frequency counter can neither determine nor display the trigger level; this is also true for the frequency counter in the oscilloscope mentioned. The result of the frequency measurement is displayed in the top right corner as [16.00 kHz]; the correct result would be 15.625 kHz (line frequency). The causes of this difference are the equalizing pulses preceding and following the field sync pulses and the half line offset of the frame sync pulses. If the cursors are used as demonstrated in picture number 2 the correct time for one line of 64.0 μs and that the correct line frequency of 15.625 kHz are obtained.

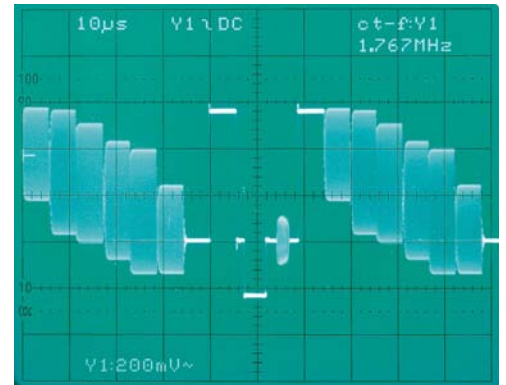
If the trigger level is moved into the area of the video rather than the line content



Picture 1: Composite video signal displayed on a HAMEG oscilloscope



Picture 2: Time measurement with cursor lines (HAMEG oscilloscope)



Picture 3: Frequency counter shows 1.76 MHz (HAMEG oscilloscope)

the differences will increase. Depending on the trigger level various different measurement results will be obtained. In picture 3 1.767 MHz are displayed, even though for this signal the frequency 4.43 MHz dominates. This erroneous measurement is caused by the fact that the 4.43 MHz color signal is not constantly available. In fact this signal is interrupted by sync pulses and other signals. Also in this case a correct result can only be obtained if the waveform is displayed with the cursors set to the correct points.

Without oscilloscope control of the signal to be measured, the measuring results of multimeters and frequency counters are not reliable especially in the case of complex signals. This concerns even „simple“ signals such as a 50 Hz line (mains) frequency which may become superimposed by noise and transients and thus be converted to complex signals.

The importance of signal wave form representation is consequently immense and with it the importance of oscilloscopes.

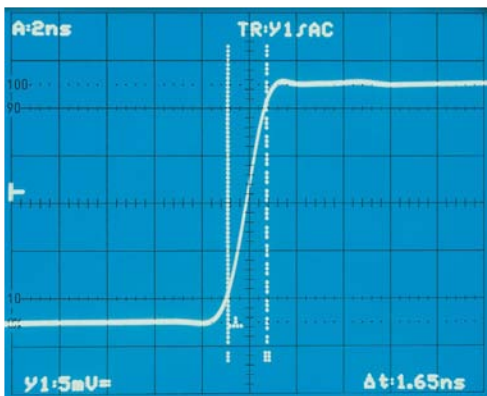
### Main purpose of oscilloscopes

The duty of an oscilloscope is to display a signal as faithfully as possible as it is present at the point of measurement.

Unfortunately, this requirement is fundamentally unrealizable, but HAMEG engineers succeed in creating instruments that give a fairly truthful representation of the signals. The main criteria that an oscilloscope has to fulfill are listed in the following.

### Rise time

The manufacturing costs of an oscilloscope are mainly influenced by the bandwidth or risetime of the instrument. As a rule the risetime of an oscilloscope should be less than one third of the risetime of the fastest signal to be measured. If the signal is very much faster than the oscilloscope, the oscilloscope will display its own risetime which is shown in picture 4.



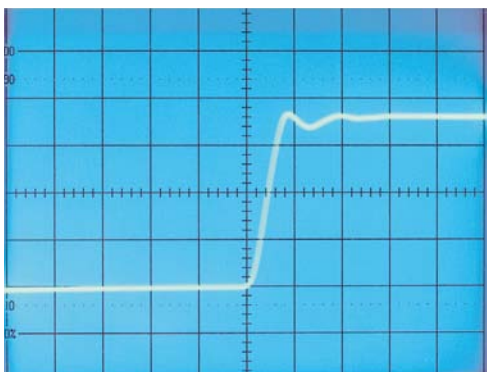
Picture 4: Square wave with risetime of less than 1 ns displayed on a HAMEG oscilloscope

### Overshoot

Faithful signal display requires that the oscilloscope does not contribute distortions like overshoots, ringing etc to the signal itself. In order to test the transient behavior of an oscilloscope a very fast, clean square wave signal is used.

Picture 5 shows the display of such a signal on an oscilloscope from an East Asia company.

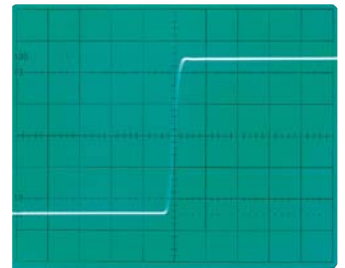
The user of such an oscilloscope has no way to discriminate whether the signal dis-



Picture 5: The same square wave displayed on a competitive oscilloscope which causes overshoot

tortion is inherent in the measuring signal or whether it is caused by the oscilloscope.

As can be seen in picture 6, a HAMEG oscilloscope with the same bandwidth, displaying the same signal as in picture 5, shows a perfectly clean step. Consequently, if a signal displayed on a HAMEG oscilloscope shows any distortion, the user will know that this distortion was not caused by the oscilloscope.

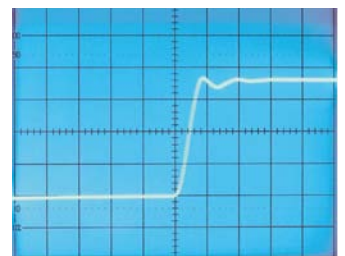


Picture 6: Step response of an excellent amplifier (HAMEG oscilloscope)

### Jitter

In picture 7 taken from the screen of a competitor's instrument, the jitter on the rising portion of the signal is obvious. The user can not discern whether this jitter was inherent in the signal or whether it is caused by the oscilloscope. However, in many applications the information about the jitter is important.

Of course, some jitter will be unavoidable, and in oscilloscopes jitter is caused e.g. by noise, trigger comparators and the time base generator. Picture 8 illustrates that there is no visible Jitter with the same signal displayed on a HM2005 as in picture 7.



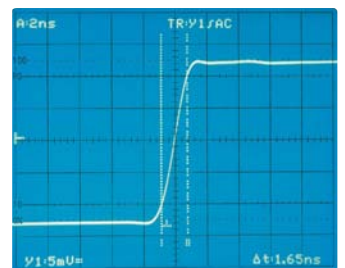
Picture 7: Competitor's oscilloscope display jitter

### Noise

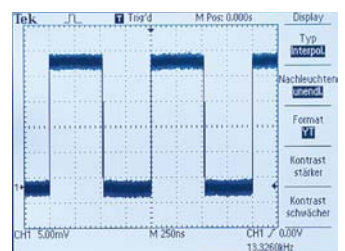
Residual noise of the oscilloscope amplifiers is of great concern, and HAMEG oscilloscopes are known for their very low intrinsic noise. This is of major concern especially with all digital storage oscilloscopes (DSOs).

HAMEG combination analog-/digital-oscilloscopes excel by their extremely low noise. This is achieved by using 8 bit flash A/D converters. Often, it is not discernible from the display whether the HAMEG oscilloscope is operating in the analog or digital mode. Picture 10 shows the display of a HAMEG oscilloscope with no signal displayed; there is practically no noise visible. Simple and low cost DSOs particularly display strong noise as shown in picture 9.

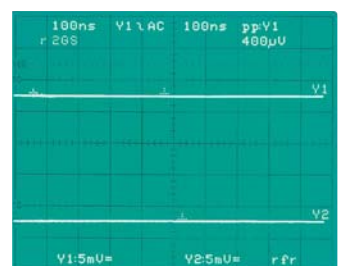
Naturally, one can get rid of noise by averaging. However, one thereby also eliminates the information about the actual noise of the signal source.



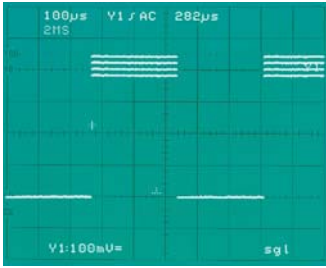
Picture 8: The same signal displayed on a HAMEG oscilloscope shows that there was no jitter in the signal



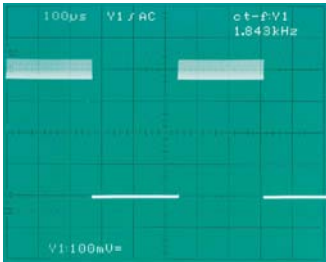
Picture 9: Noise of a competitor's DSO with CCD AD-Converter



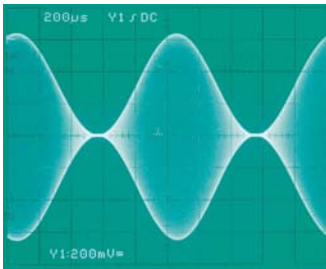
Picture 10: Practically no noise visible on a HAMEG due to flash AD-Converter



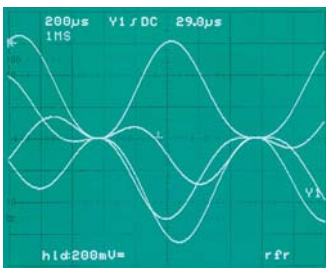
Picture 11: HAMEG oscilloscope operating in the digital mode: seemingly low frequency superposition on a signal



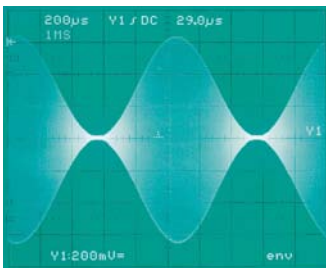
Picture 12: HAMEG oscilloscope in analog mode displays the true nature of the disturbance: the superposed signal is a high frequency signal



Picture 13: HAMEG oscilloscope in analog mode: signal with AM 100 %



Picture 14: HAMEG oscilloscope in the digital mode, the same signal



Picture 15: HAMEG oscilloscope in the digital mode, envelope display

### Signal acquisition

The frequency of signal acquisition is a further criterion of the quality of an oscilloscope.

The higher the signal acquisition and display frequency, the better are the chances of acquiring additional information. The signal frequency and time base settings of the oscilloscope determine the frequency of signal acquisition and display. In the analog mode 500,000 to 2.5 million signal displays are standard. This is only possible by analog signal processing; no graphic display or any LCD can come close to the performance of a cathode ray tube.

In the digital mode the signal must first be acquired and then processed within the instrument.

While the instrument is busy with processing a signal captured previously it can not acquire any other signal. Pictures 11 and 12 show the vital difference in signal display between digital and analog modes.

The next example (picture 13) illustrates a still clearer statement of the facts: an amplitude modulated signal is displayed in analog mode. Without any difficulty one can read from the signal display that the modulation degree is 100% and the modulation frequency is 1kHz. In contrast, in digital mode it is difficult even to recognize that we are dealing with an amplitude-modulated signal (picture 14).

If the digital signal acquisition of the AM signal takes place in envelope mode, the problem of the signal recognition seems to be resolved, as illustrated in picture 15. However, this is valid only when the modulation degree and modulation frequency do not change, because in envelope mode the once acquired maximum value is always displayed. Therefore envelope mode is also no solution for the measurement of modulated signals.

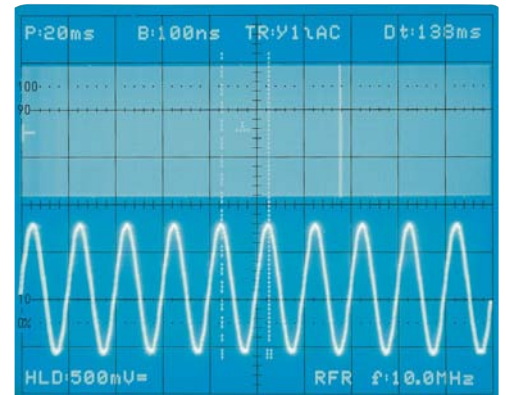
The drawbacks of the digital mode described here apply to competitors whose „only digital“ oscilloscopes do not allow any switch-over to analog operation. HAMEG oscilloscopes excel by the possibility of selecting the analog and digital modes whichever is more useful for the application intended.

### Focus and intensity

The requirements of a good display are focus and intensity, even at 2 kV acceleration voltage reasonable focus and intensity can be obtained, and such a cathode ray tube is used in the HM303-6, HM504 and HM507 oscilloscopes.

The oscilloscopes HM1004-3, HM2005 and HM1507-3 have even superior characteristics, since they are equipped with cathode ray tubes that work with 2,000 volt acceleration voltage and 12,000 volt post-acceleration voltage, providing a very high intensity reserve. This is important for a visible display of signals with a very low repetition frequency and with oscilloscopes with a second time base which allows the display of selected signal portions.

The second time base of a HM1507-3 is also available for digital mode and enables the 200,000-fold X-expansion of a 10 MHz sine wave signal (see picture 16), which is displayed with the A time base at 20ms/cm and with the B time base at 100 ns/cm.



Picture 16: Signal in intensified sector displayed with 200,000 fold magnification.

An expansion to such a degree only makes sense in the digital mode as here the trace intensity will not decrease with increasing expansion. The display of an analog only oscilloscope under such conditions would hardly be visible.

### Resolution

The limits of resolution for analog oscilloscopes are predetermined only by the visual acuity of the viewers, because the electron ray can be deflected in every position of the

screen. Restrictions on the X or Y-resolution consequently do not exist.

In contrast, the resolution for digital oscilloscopes is limited in principle. Most oscilloscopes use 8 bit analog/digital converters. Consequently, there are only 256 possible positions in vertical direction of which 200 positions are visible on the graticule.

This corresponds to 25 possible signal positions per centimeter of raster. The graphic display number one on the right hand side of this page shows the 8 x 10 centimeter graticule and graphic display 2 shows the same graticule, where one raster unit has been enlarged. With the exception of very small sized battery operated digital oscilloscopes, the 25 dot resolution in vertical direction is the standard because of their 8 bit A/D converters.

For horizontal resolution the situation is different, as the physical characteristics of the display determine the resolution.

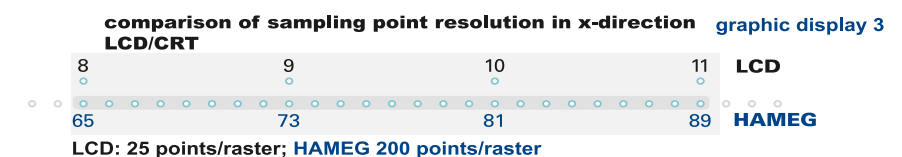
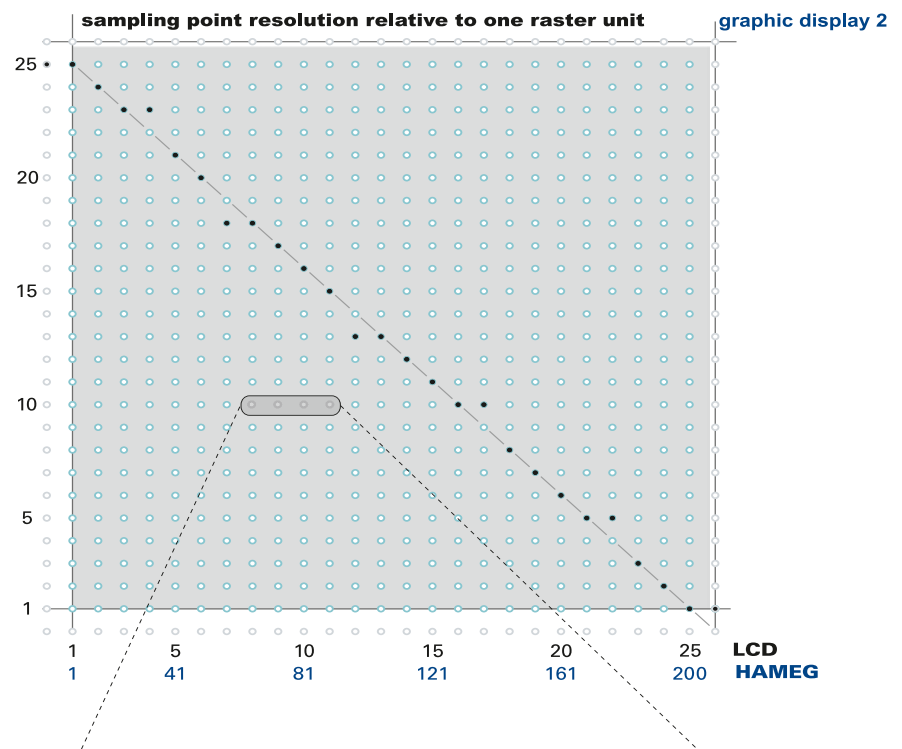
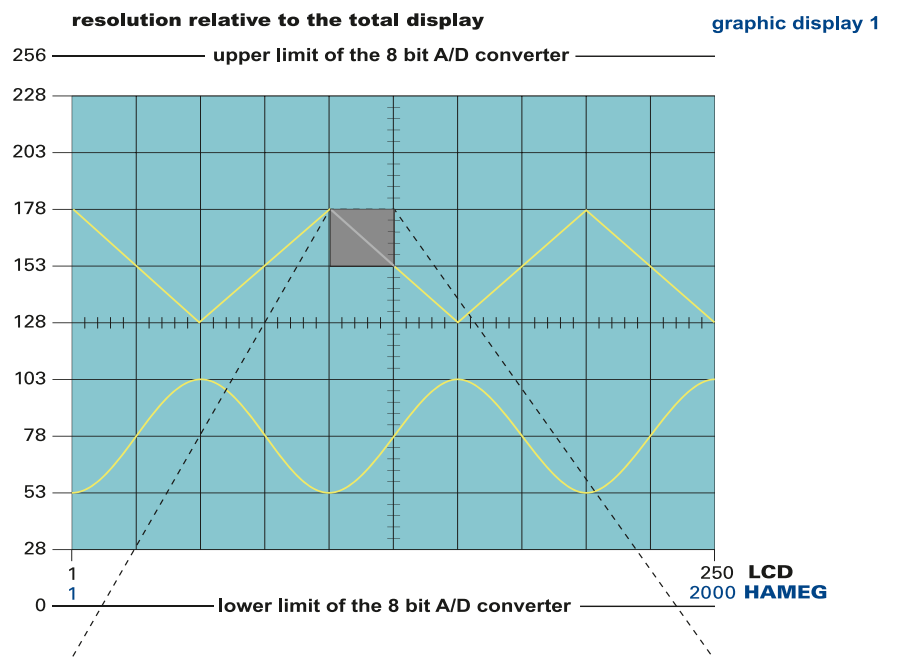
A LCD normally allows for 250 dot resolution for the complete signal display in horizontal direction. This means that only 25 dots (samples) can be displayed in horizontal direction. Graphic display 2 shows this resolution.

Monitor tubes feature a resolution of about 50 points in X-direction and 25 points in Y-direction, however, but they do not reach the resolution which HAMEG oscilloscopes feature in the digital mode.

An oscilloscope CRT allows a complete display of the memory of 2,000 sampling points. The resolution per raster is about 200 points in X and 25 points in the Y direction. As shown in the graphic display 3 on the right hand side the resolution in X-direction is better by a factor of 8 compared to LCDs. Of course, in order to make use of the higher resolution the sampling rate should also be higher by the same factor.

### Memory, resolution and sampling rate

These three parameters stand in direct relationship to each other. As mentioned the memory capacity of HAMEG analog-/



graphic display 1: full display

graphic display 2: one raster unit with 25 points in Y- and 25 points in X-direction (LCD)

graphic display 3: 8 times higher resolution = smaller sampling intervals

digital oscilloscopes is 2,000 sampling points (per channel) which are all displayed. This means that the memory depth and the display resolution are identical. This is very important to note, as there are competitive instruments that can store more than 2,000 samples but they display only every tenth sample. This is equivalent to only one tenth of the sampling rate specified.

With all DSOs the effective sampling rate depends on the memory depth and the time base setting. The user can only select the time base setting. Consequently, as the time base is set to slower sweep speeds this sampling rate must be decreased, and is done automatically, but very few oscilloscopes on the market do display the actual sampling rate on the screen.

If for example the memory depth is 2,000 sampling points and is completely displayed on a CRT, the X resolution is 200 points per raster. If the time base is adjusted, for example, to  $10\ \mu\text{s}/\text{cm}$  (per raster), this means that 200 samples must be acquired within  $10\ \mu\text{s}$ . The sampling interval is then  $10\ \mu\text{s} : 200 = 50\ \text{ns}$ ; this means that the signal is sampled in 50ns intervals. Consequently the sampling rate is  $1/50\ \text{ns} = 20\ \text{MSa/s}$  (20 million samples per second). The duration of one samples is very short compared to the sampling interval. Of course, any signal changes between two samples will be ignored.

In contrast, LCDs can often display only 25 samples per raster. If  $10\ \mu\text{s}/\text{cm}$  as time base setting is also required, then the sampling interval is  $10\ \mu\text{s} : 25 = 400\ \text{ns}$ . This however corresponds to a sampling frequency of only  $2.5\ \text{MSa/s}$ . This will be the case irrespective of the maximum sampling rate specified for the instrument.

A shorter memory as well as a lower resolution will thus lead to a lower sampling rate.

The repercussions in practice are shown by the following example, whereby the following facts are to be considered:

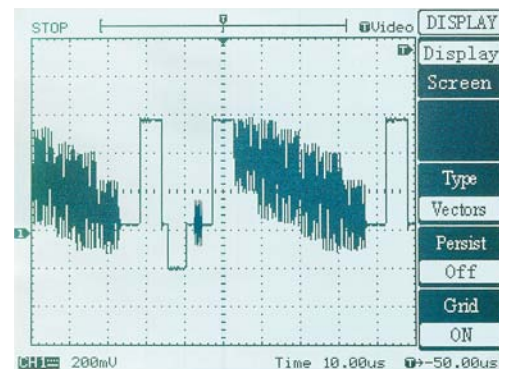
1. The period duration of the measuring signal defines the time base setting.
2. If sine wave signals are acquired, at least 10 samples per signal period will be nec-

essary otherwise it will be impossible to discriminate between sine wave and triangle signals.

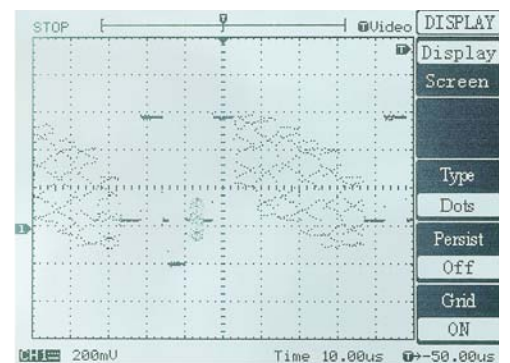
As a result, the sampling rate for the acquisition of a 5 MHz sine signal must at least be 50 MSa/s (sampling frequency 50 MHz). If signals with a low repetition rate, containing signals of very high frequencies, are sampled at a low rate, serious distortions and aliasing will result.

An example of this is a composite video signal which contains signals up to 5 MHz, even though the half frame frequency is only 50 Hz and the line frequency only 15.625 kHz ( $64\ \mu\text{s}$  period). In order to display a complete line, the time base setting must be  $10\ \mu\text{s}/\text{cm}$ . For an „only digital“ oscilloscope with LCD, as shown in picture 17, the sampling rate will then be 2.5 MHz.

Consequently the highest signal frequency may only be 250 kHz. Picture 18 displays the same signal where only the sampling points are displayed. Obviously this display is of no relevance or use whatsoever.

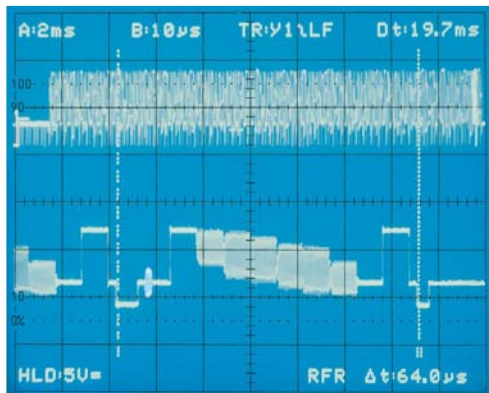


Picture 17: Composite video signal displayed with LCD (competitor's instrument, vector display)



Picture 18: LCD displays composite video signal, only the sampled points are shown (competitive instrument)

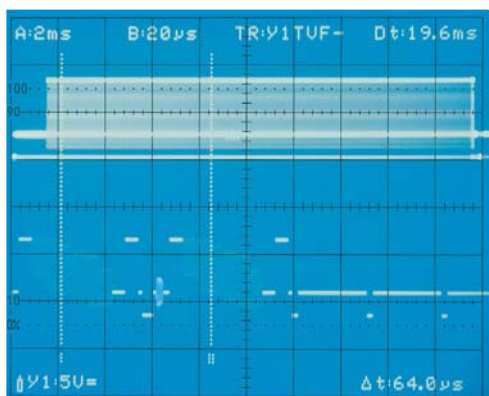
With the HAMEG oscilloscope, however, the resolution of 200 points/cm at 10 μs/cm yields a sampling rate of 20 MSa/s, which



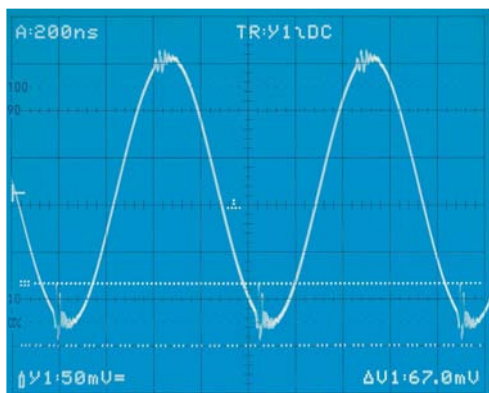
Picture 19: Composite video signal displayed on a CRT with a HAMEG oscilloscope

is still fairly adequate to display 2 MHz with 10 points per signal period. The top display in picture 19 shows half a frame with time base A. The lower display in picture 19 shows one line with time base B.

Please note, that in sharp contrast to these principle shortcomings of any DSO if the



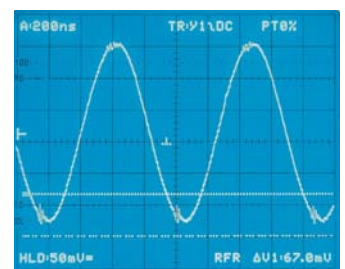
Picture 20: Optimum analog display of a composite video signal on a HAMEG oscilloscope



Picture 21: Analog display of superimposed noise on a HAMEG oscilloscope

HAMEG oscilloscope is operating in the analog mode, the full bandwidth of the instrument will be available at all sweep settings. Analog oscilloscopes always display the true signal itself and not a more or less distorted reconstruction of the signal.

Picture 21 shows a sine wave signal on which high frequency noise is superimposed. The picture was taken in the analog operating mode, and the amplitude of the superimposed noise is about 6.7 mV<sub>pp</sub>. With the same signal displayed in digital operation mode, the noise will be displayed with a much lower amplitude, which is hardly discernible (picture 22).



Picture 22: Same display in digital mode shows distorted and reduced amplitude of noise

## Summary

The characteristics described here are only a small part of the most important quality characteristics of an oscilloscope. It is definitely untrue that analog oscilloscopes are not „up to date“.

Naturally, a digital oscilloscope offers advantages for single-event acquisition, the storage of very slow signals and the documentation of signals. Further advantages are the possibility of pre- and post-trigger and the feature of extremely high signal expansions in x-direction using the 2nd time base without a reduction in trace intensity. The disadvantages, however, are numerous and severe.

This is one reason why analog oscilloscopes in most applications are the technically superior as well as more economical solution. The combination of analog and digital oscilloscopes — as offered by HAMEG — remains the optimum. Pressing a button is all it needs to change from analog to digital operating mode.