The build-up and the operation of the oscilloscope

I. THEORETICAL BACKGROUND

A. The oscilloscope

The oscilloscope is one of the most frequently used device in electronic measurements. It directly visualize the time-dependence of voltage and current signals, which makes the oscilloscope capable to gather much more information than e.g. a multimeter.

The following quantities can be measured with an oscilloscope directly or indirectly:

- DC voltage
- AC voltage
- DC current
- AC current
- time, time difference
- phase, phase difference
- frequency

The deformation, the AC and DC components (separately) of the signal, or higher harmonics can be measured with an oscilloscope. A multichannel oscilloscope is capable to visualize 2 or 4 time-dependent signal at the same time.

B. The build-up and the operation of the oscilloscope

The main parts of the oscilloscope is shown on Fig. 1.

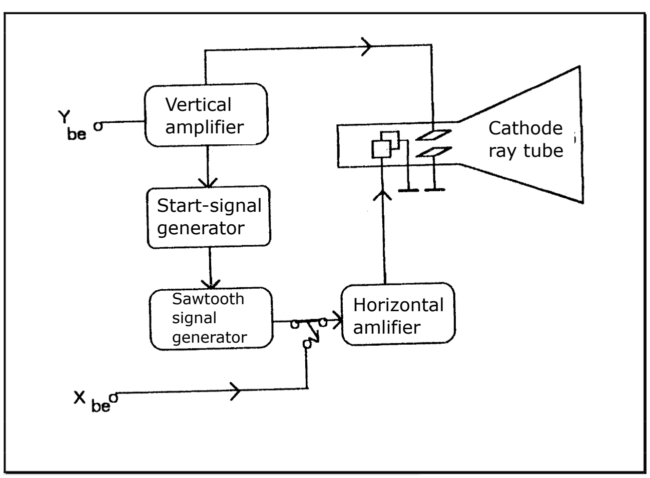

FIG. 1.

1. *Cathode ray tube*

The cathode ray tube (CRT) visualize the measured signals. It is a conical shaped, closed vacuum tube. The narrow end contains the cathode, i.e. the electron gun. Electrons are emitted from the heated cathode and they are accelerated towards to anode by the electric field between the anode and the cathode. If the potential difference between the anode and the cathode is U_a and the distance is b, the electrons with mass m and charge q are accelerated by the $F = qE_l$ electrostatic force, where $E_l = U_a/b$ the "longitudinal" electric field. Using the work-energy principle $Fb = \frac{mv^2}{2}$, the velocity of the electrons at the anode is $v = \sqrt{\frac{2q}{m}}\sqrt{U_a}$ (assuming that the initial velocity of the emitted electrons is negligible.)

The electrons going through the slit on the anode are focused into a beam. The beam is deflected horizontally and vertically by two plane capacitor-like parallel metal plate pairs, which are orthogonal to each other. The wide-end of the CRT is coated by fluorescent layer, this way the high speed incident electrons cause a flash.

In the following the deflection mechanism will be discussed. Lets assume that U_v voltage is applied on the vertical deflector plates, and their distance is d, the electrons will accelerate vertically due to $F = qE_v$ force, where $E_v = U_v/d$ vertical defecting electric field. The acceleration is $a = \frac{qE_v}{m}$. (See Fig. 2.)

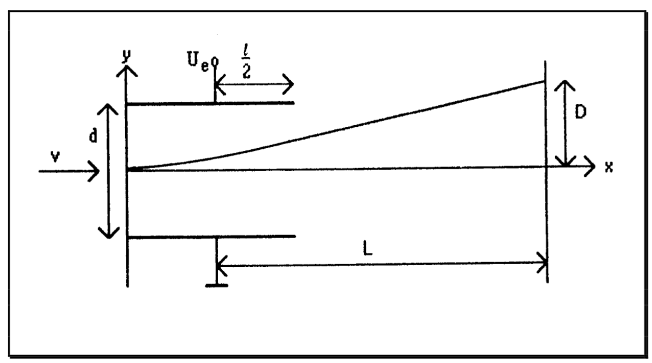

FIG. 2.

Since the electrons preserve their horizontal velocity, but they are accelerating vertically, their path is a parabola (throwing in mechanics):

$$x = vt$$
$$y = \frac{a}{2}t^2$$
$$y = \frac{qE_v}{2mv^2}x^2.$$

The electrons leaving the deflector plates will move along the tangent of the path in $x = l$, where l is the length of the metal plates. At this point the tangent of the path is

$$tan\alpha = \frac{qE_v l}{mv^2},$$

and the equation of the line is $y = \frac{qE_v l}{mv^2}\left(x - \frac{l}{2}\right)$.

The electron reach the display, which is in distance L from the center of the deflector plates, in height D. With the above calculated values, the deflection at $x = (L + l/2)$, i.e. at the display:

$$D = \frac{qE_v}{mv^2} lL.$$

Using the formula for the vertical deflecting electric field:

$$D = \frac{lL}{2dU_a} U_v.$$

The sensitivity of the CRT is defined as the deflection induced by unit deflecting voltage:

$$S = \frac{D}{U_v} = \frac{lL}{2dU_a},$$

which implies that the geometrical and the electronic parameters of the CRT determines the capabilities of the oscilloscope.

2. Sawtooth signal generator

Usually time-dependent signal are examined by the oscilloscope, so the horizontal axis is the time. Generally the measured signal are changing too rapidly to immediately evaluate them, so a continuous, fixed positioned visualization is required. The sawtooth signal generator produces a signal shown on Fig. 3, which is applied on the horizontal deflection plates after amplification. The amplified signal deflects the electron beam from one side of the display to the other.

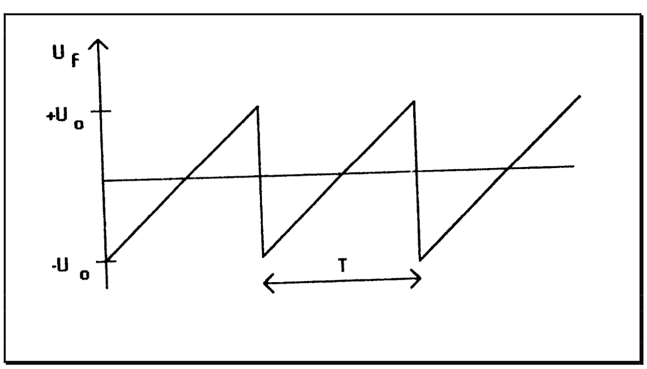

FIG. 3.

The period of the signal is variable, which changes the "length" of the horizontal axis (changes the time while the beam sweeps through the display horizontally). Examining faster changing signals, requires shorter period for the sawtooth signal, since a signal can be well visualized if the speed of the changing of the signal (vertical deflection) is comparable to the speed of the horizontal deflection. (The period of the sawtooth signal is equal to several period of the examined signal).

3. Start signal generator, synchronization, trigger

The synchronizator is responsible for starting the plotting of the rapidly oscillating signals at the same phase. Assume that the sine wave, shown on Fig. 4 is connected to the input of the oscilloscope. At time $t = 0$ the voltage of the sawtooth signal generator is U_a, so the beam is at the life side of the display. During the period of sawtooth signal, T, a bit more than one period of the sine signal is plotted. When the beam runs back to the left side, the incoming signal has a different value, the vertical deflection would be different than in the previous period. So if the plotting would start at this point, the new curve would not be the same, but shifted to the previously plot one. Repeating this argument, it is easy to see that a bright stripe would appear on the display. The synchronizator starts the next period of the sawtooth signal, only when the examined signal reaches a given value. It implies that T length section of the examined signals are plotted onto each other. The shaded section of the signal is not visualized by the oscilloscope, but since the period of the sawtooth signal is larger than the period of the examined signal, it does not cause information loss, all important information is contained within one period.

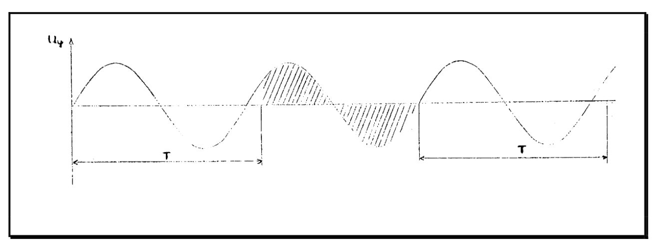

FIG. 4.

4. Horizontal and vertical amplifier

The parameters of the CRT determines the voltage required to deflect the beam to the side of the screen (usually couple of hundred volts). The amplitude of the examined signal can vary in wide range, so changing the gain of the amplifier allows us to plot the signal on the whole screen. The horizontal amplifier amplifies the signal of the sawtooth generator, or the external signal connected to the X input (see Sec. 3b).

5. Dual channel oscilloscope

Usually it is required to visualize more (two) time-dependent signal. It solvable by applying the two signals to the vertical deflecting plates alternately. In case of slow signal a short sections of the two signal is plotted in each period (chopper mode), while in case of fast signals, one of them is visualized in one period, and the other in the next one (alternative mode).

II. MEASUREMENTS WITH AN OSCILLOSCOPE

A. Periodic voltage signal

Connecting the examined signal (voltage-time function) to the Y input and using the internal horizontal deflection the time dependence can be investigated. Measurable quantities: shape of the signal, amplitude, period, frequency.

B. Adding orthogonal harmonic oscillations

1. Measuring the relative phase at equal frequency

In this case the signal connected to the X input is used for the horizontal deflection instead of the sawtooth signal. Assume that the signal connected to the X input is $x = Asin(\omega t)$, while on Y input $y = Bsin(\omega t + \varphi)$. Simply substituting one into the other:

$$y = \frac{Bx}{A}cos\varphi + B\sqrt{1 - \frac{x^2}{A^2}}sin\varphi,$$

which discribes an ellipse. The relative phase, φ can be calculated from y and $x = 0$, assuming that B is known (see Fig. 5): $\varphi = arcsin\frac{y}{B}$.

The ellipse corresponding to several different phase difference is shown on Fig. 6 for $A = B$.

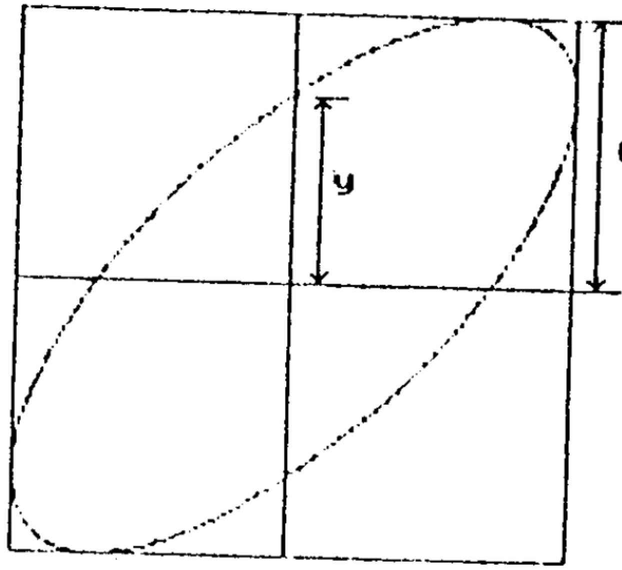

FIG. 5.

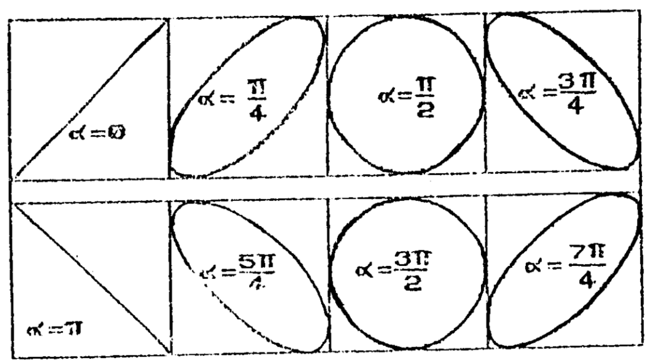

FIG. 6.

2. Adding oscillations with different frequencies

If the frequencies are just slightly different, it will appear as a slow, continuous change of the phase difference. The plotted curve goes through the subgraphs of Fig. 6. This effect is called *beating*.

If the frequencies differ significantly, the measured curves (so called Lissajous-curves) are more complicated. If the ratio of the two frequencies is rational, the curves are closed (see Fig. 7), if not, the beam sweep through the whole screen and the curve is not closing to itself. The ratio of the frequencies can be determined from:

$$\frac{f_x}{f_y} = \frac{N_y}{N_x},$$

where N_x and N_y is number of touching point on the horizontal and vertical sides.

III. THE FRONT PANEL OF THE OSCILLOSCOPE

Here the front panel of the Hameg HM 203 oscilloscope is introduced in detail, but it can be used for the BK PRECISION 2 I 20 as well, which has identical buttons and switches, only in different arrangement. See Fig. 8.

The oscilloscope is dual channel, up to 20 MHz frequency, capable for measuring signal with at least 5 mV amplitude. The screen is meshed to 10 x 8 grid, which

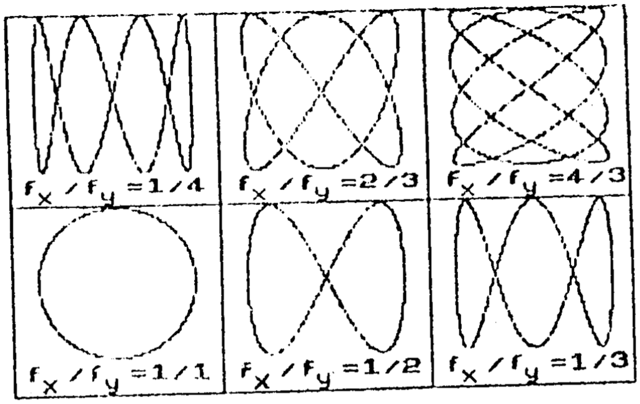

FIG. 7.

help the evaluation of the signals. The size of the grid is unit for the measurement.

Function of the parts of the front panel:

1.: Power button.

2.: Turn knob for changing the intensity of the electron beam (i.e. the brightness).

3.: Turn knob for focusing the electron beam and so the image.

6.: Turn knob for shifting the image horizontally

12.: Switch for changing the period of the sawtooth signal generator. The indicated value corresponds to the unit on the axis, e.g. in 2 ms position the total length of the horizontal axis is 20 ms.

13.: Turn knob for continuously changing the period of the sawtooth signal generator. In CAL position it is turned off, in other position the scale is not accurate.

17.: Turn knob for synchronizing the saw tooth signal to the input signal, it changes the voltage level where the sawtooth signal starts. It allows us to set a "standing" picture.

23.: Input connector for channel I.

24.: Switch for changing the gain of the amplifier of channel I. E.g. in 0.5 V position the total length of the vertical axis is 4 V.

25.: Turn knob for changing the vertical amplification continuously. In CAL position it is turned off.

21.: Turn knob for shifting the image of channel I. vertically.

22.: Pressing the GND button, the input is grounded, and the image can be positioned with knob 21. If the AC/DC button is in, than both the DC and AC components, in out position only the AC component is visualized.

34.: Input connector for channel II.

30.: Like 24. for channel II.

31.: Like 25. for channel II.

36.: Like 21. for channel II.

35.: Like 22. for channel II.

27.: Choosing channel I. and channel II.

28.: Pressing the button, both channels are shown.

5.: Pressing the button, the sawtooth signal generator is turned off, and channel II. drives the beam horizontally.

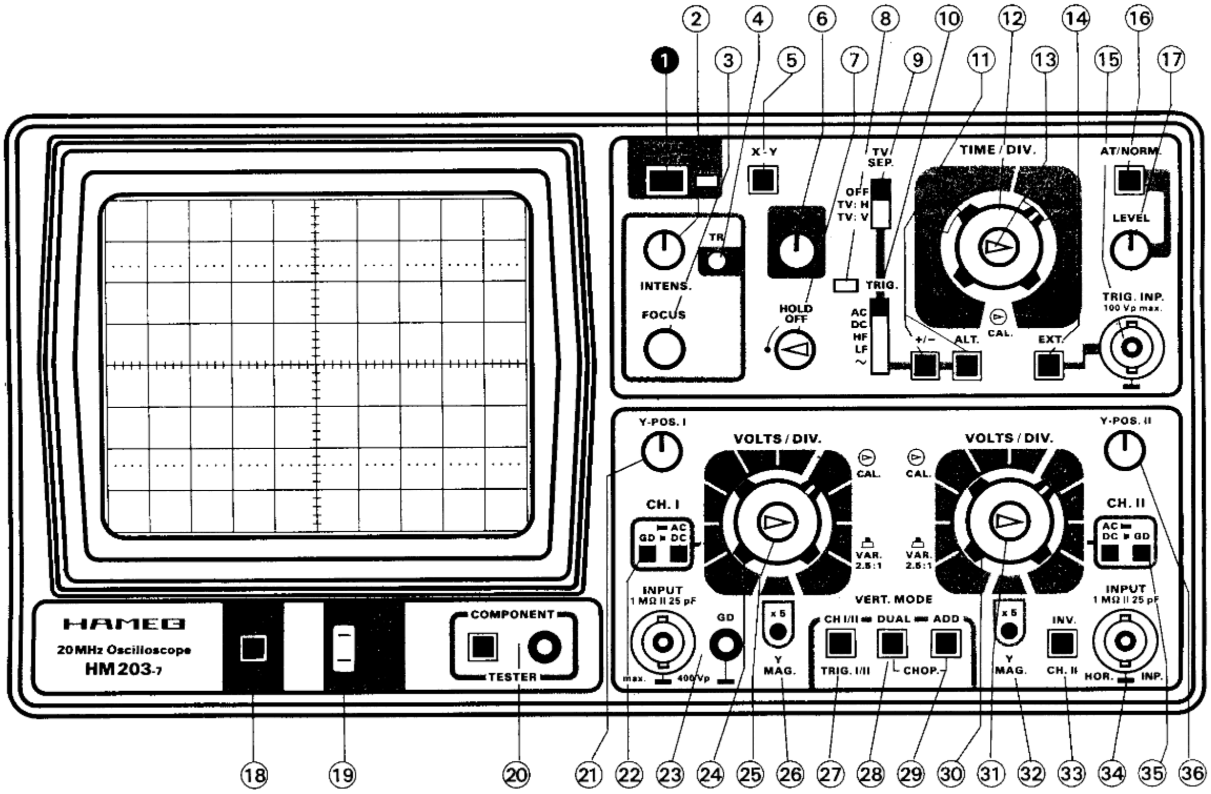
HAMEG
20MHz Oscilloscope
HM 203-7
COMPONENT
TESTER
X - Y
INTENS.
FOCUS
TR
HOLD OFF
TV SEP.
OFF
TV: H
TV: V
TRIG.
AC
DC
HF
LF
TIME / DIV.
CAL.
+/-
ALT.
EXT.
AT/NORM.
LEVEL
TRIG. INP.
100 Vp max.
Y-POS. I
VOLTS / DIV.
CH. I
GD
AC
DC
INPUT
1 MΩ II 25 pF
max.
400 Vp
GD
x 5
Y
MAG.
VAR.
2.5 : 1
VERT. MODE
CH I/II
DUAL
ADD
TRIG. I/II
CHOP.
INV.
CH. II
Y-POS. II
HOR.
INP.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

FIG. 8.