Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

The Project has been realised with the support of the European Union and has been co-financed by the European Social Fund ***

**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

***A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.

ELECTRICAL MEASUREMENTS

(Elektronikai alapmérések)

Measurement of voltage, current, frequency and time. The ELVIS system.

(Feszültség és áram mérése; frekvencia és idő mérése.
Az ELVIS rendszer.)

Dr. Cserey György

Contents

- Deprez instrument, hand instruments
- Measuring alternating current or voltage
- RMS (Root Mean Square)
- Measurement error
- Measuring very high and very low voltage
- Digital voltmeter
- Level measurement
- Waveform measurement
- Measuring time – philosophical considerations
- Measuring frequency
- Measuring time
- The ELVIS system

The principles and basic concepts of electrical measurements

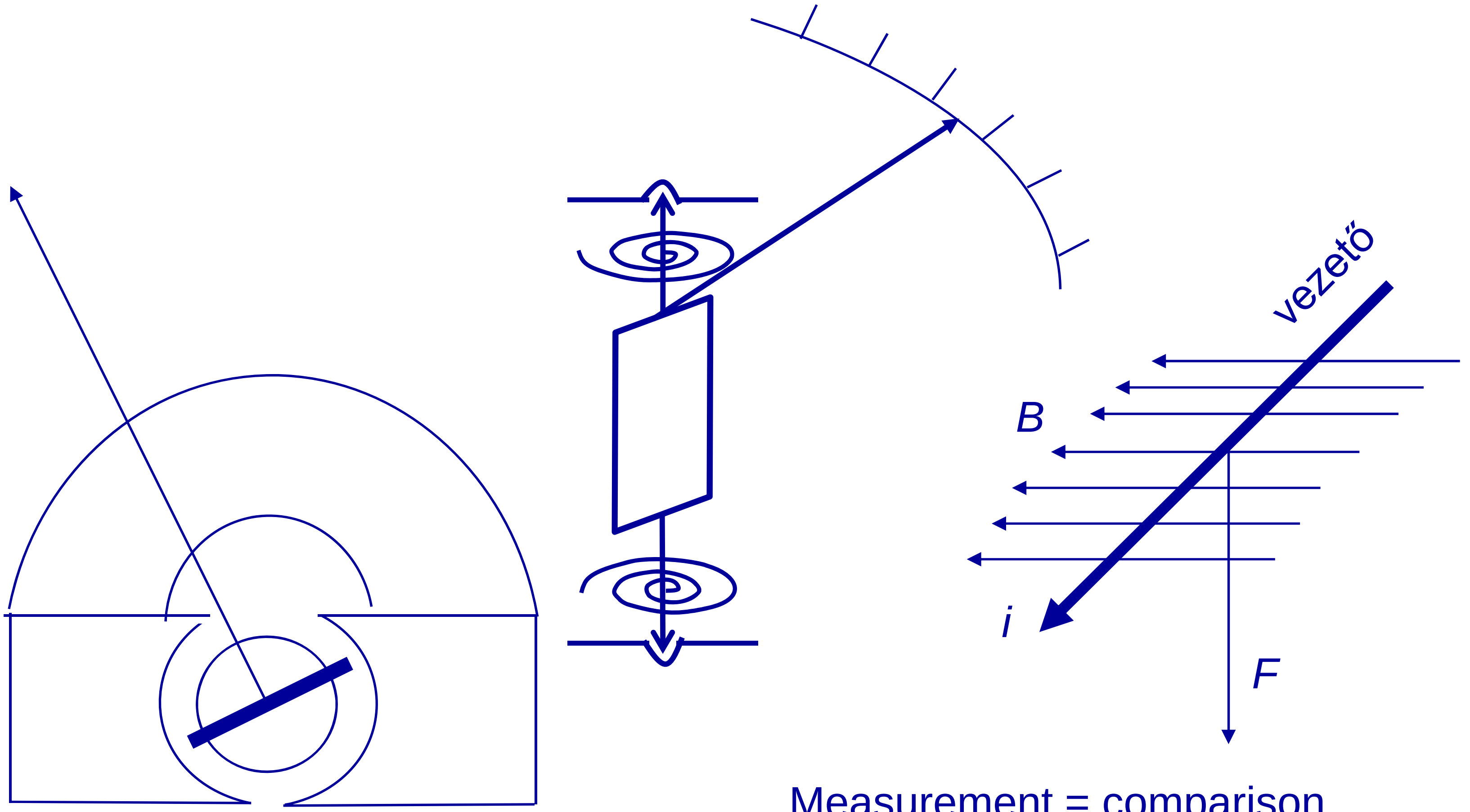
- Measurement = comparison
- All measurements have errors.
- Every measurement disturbs the measured system
  Adapting the measure and the measured
- Authentication

The course is built on four ideas: first, that measurement is a comparison with an etalon. Second, that all measurements have errors. Third, that all measurements, e.g. measuring voltage, disturbs the measured system, so we have to be aware of how big the disturbance is. The fourth is authentication.

The difficulties of measuring current and voltage

- Extremely wide ranges: 1pA-1MA (10^{-12} ….. 10^{6} A), 1nV-1MV (10^{-9} ….. 10^{6} V)
- We are directly interested in bioelectric signals, which ususally stay within the nanovolt range, but there are megavolts flowing through the power lines bringing electricity to our homes.
- Great accuracy is required. Complicated measurement principles are used.
- The Deprez instrument is traditional and easy to understand. The basis of its operation is that in the magnetic field, a force influences the conductor under current. The index displacement against to the spring is proportional to the flowing current. The accuracy of the instruments usually is 1%.

The Deprez system instrument



Measurement = comparison

Electrical Measurements: Measurement of voltage and time

In the Deprez instrument, the spring around the bearing axis initializes the coil. Through this, the flowing current is lead into the coil. There is an index or scale on the axis. If the springs initialize it, and current is flowing through it, and this happens in an appropriate magnetic field, then the pointer moves, and its movement is proportional to the current flowing through it.

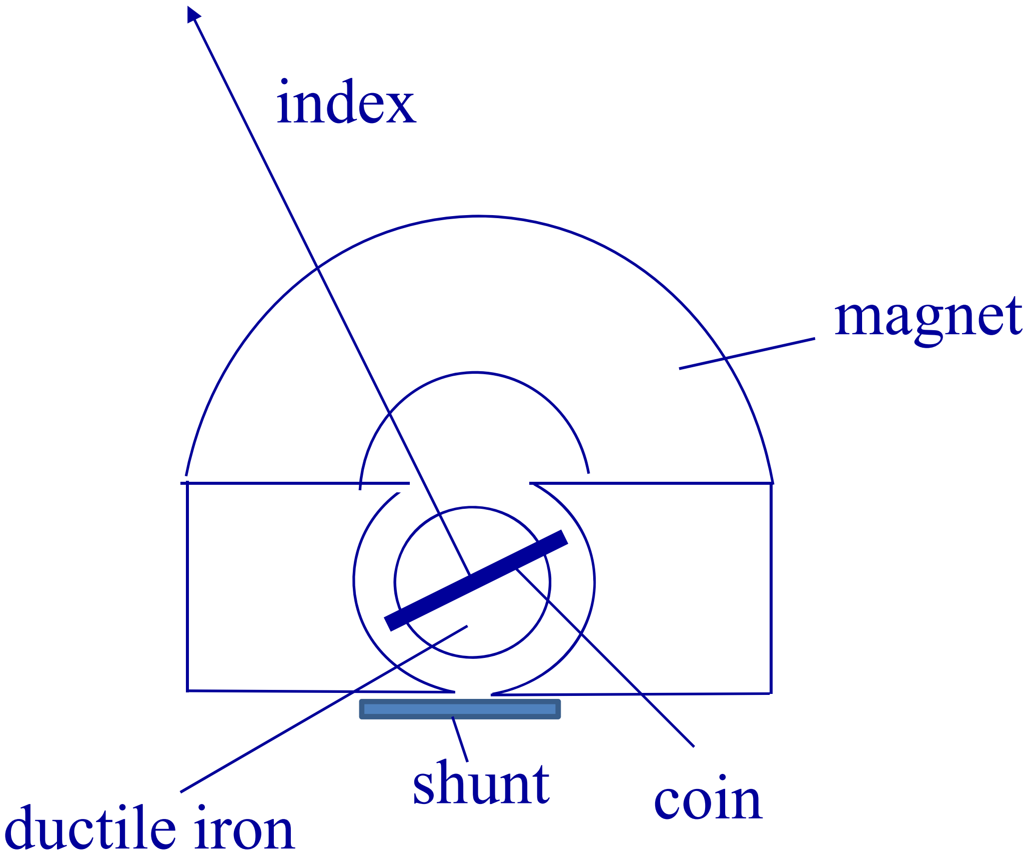
From physics we learnt that there is a magnetic field characterized by an induction, and there is a current flowing through the conductor and this is effected by a force. This shows the direction of the force.

The magnet is horseshoe shaped, forming a permanent field of force.

Measurement is comparison to an etalon. Where is the etalon here? When this instrument is manufactured, the spring is compared to an etalon.

Usually, a magnetic shunt is placed on it, setting the magnitude of the force of the magnetic field. This is authenticated during manufacturing. The spring in the scale preserves this.

Electrical Measurements: Measurement of voltage and time



Giving the error, value dependance I.

Absolute error (*H*): e.g. a voltage source 10V±0,1 V where ***H***≤0,1 V

Relative error (*h*): e.g. a voltage source 10V±1% where ***h***=1%

Connection between the absolute and relative error:

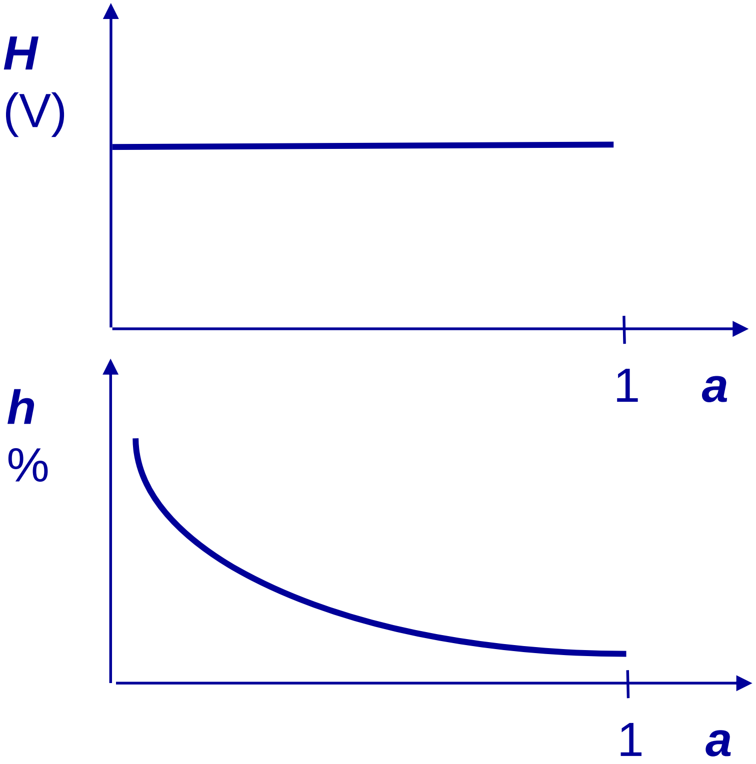
h*=*H*/*a, where *a* is the measured value (displacement)

It is easy to calculate the absolute error from the relative error. Where the searched values' deflexion is found, that means the degree of the pointer deflecting between zero and 1. It is a simple connection to be remembered.

- All measurements have errors.
- How can we calculate the error of measurement in the case of an analog voltage measurement device?
- It can be an absolute error, e.g. 10 Volts +/- 0.1 V if we are speaking about the source of voltage. Denoted by H
- It can also be given relatively: 10 Volt +/- 1%. Denoted by h.
- So absolute error tells us the maximal deflexion from the measured value, so the error is smaller than the given error. Or it can be given as a relative error, which tells how many percents the measured value might deviate from the real value.

Giving the error, value dependance II.

Permanent absolute error: e.g. voltmeter ±0.1 V

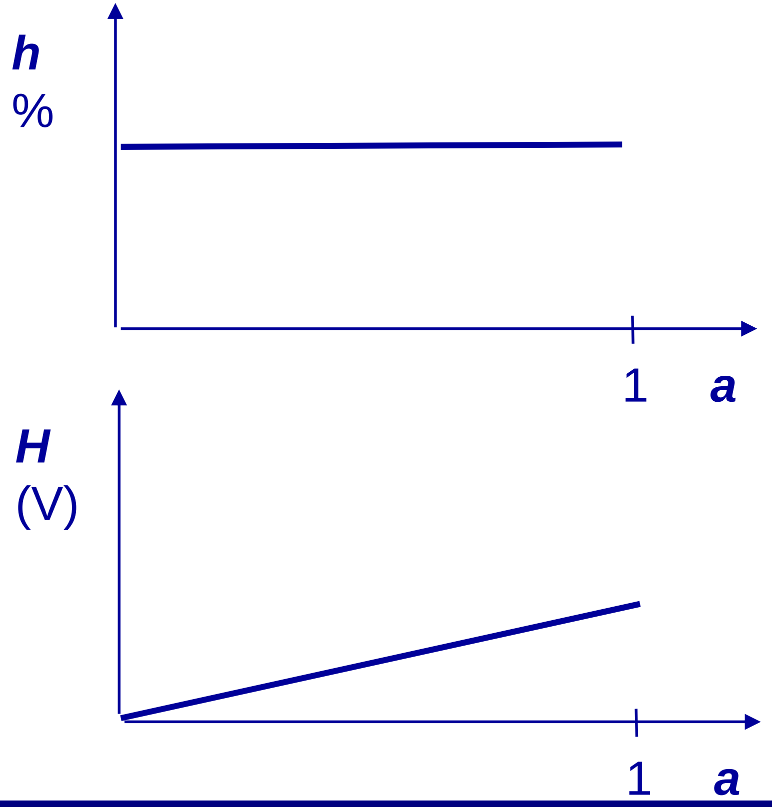


Electrical Measurements: Measurement of voltage and time

If we give the permanent absolute error, e.g. +/-0.1 Volt in the case of a voltmeter, then it does not matter where the pointer is, either at the beginning or at the end of the scale, the error is always 0.1 Volt. Relative error at the same device: e.g. +/- 0.1 Volt: when the pointer is at the beginning of the scale, the relative error grows (hyperbolic function) Therefore, if we measure voltage with a pointer instrument, it has to be switched to a measurement range so that the pointer is at the end of the scale. Then the error of our measure is the smallest.

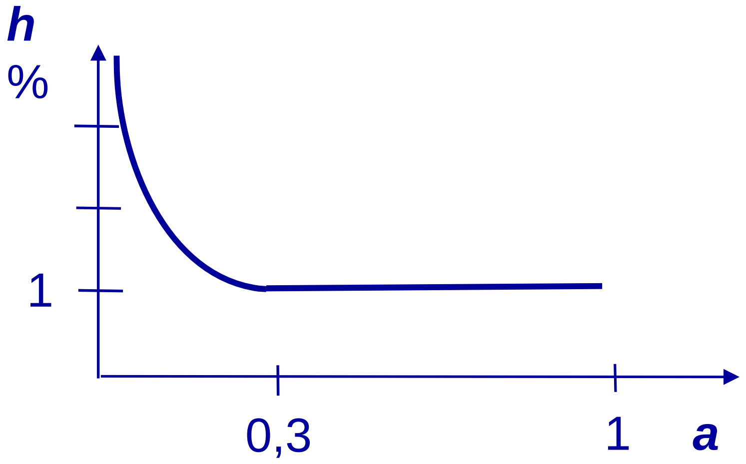
Giving the error, value dependance III.

Permanent relative error: e.g. voltmeter ±5%



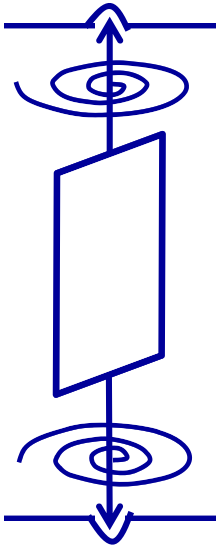
Giving the error, value dependance IV.

Mixed given error: e.g. a voltmeter of 10 V measurement range ***h*=±1%** and ***H*≥±0,03V**



- Usually the error is given as the aggregation of the absolute and the relative error.
- In the case of a 10 Volt measurement range voltmeter, it is possibly 1% or more than 30 mVolt, 0,03 Volt.
- If we depict this in the function of the deflexion, then the 1% section will be horizontal, and the residual section will be hyperbolic.
- We do not use the instrument in this hyperbolic section, if possible, but where the values deviate better.

Errors of a Deprez instrument

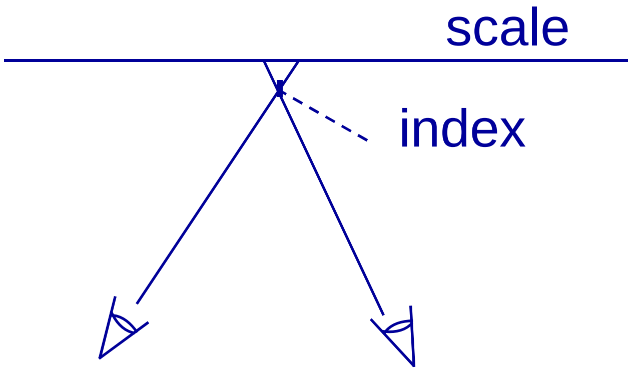


Peak error: the size of the absolute error is permanent

It can only be reduced to the detriment of the load error

Parallax error: the size of the absolute error is permanent

It can be reduced with an anti-parallax mirror



What are the errors of a Deprez instrument?

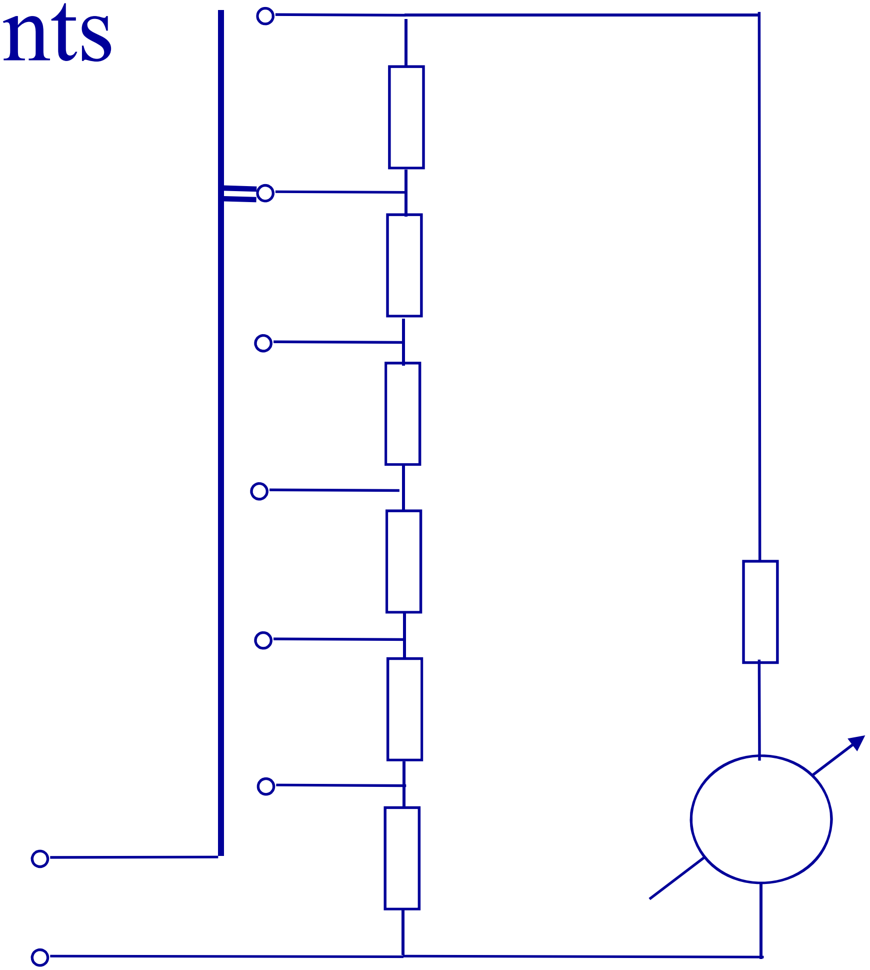
It can be a peak mistake that generally in a good quality Deprez instrument, the bearing at the axis is made by sapphire, so that friction remains small but it should turn easily. The Deprez instrument has a small, but finite friction at the axis. If the instrument does not move, then the adhesive friction is always bigger than the sliding friction, so it is a bit more difficult to move it from its stillness. It is necessary to exert a moment around the axis, so that it moves out of its situation a little bit. So the peak error can be characterized by a permanent absolute error.

How can the peak error be reduced?

At the cost of the load error. If we let a larger amount of current flow with greater torque, then we use a stronger spring. The instrument is used with more current and a greater torque, but in this case, we are interfering more with the measured object. Therefore, only at the cost of the load error can we reduce the peak error, when the instrument is working with greater torque. A good engineering optimum should be reached.

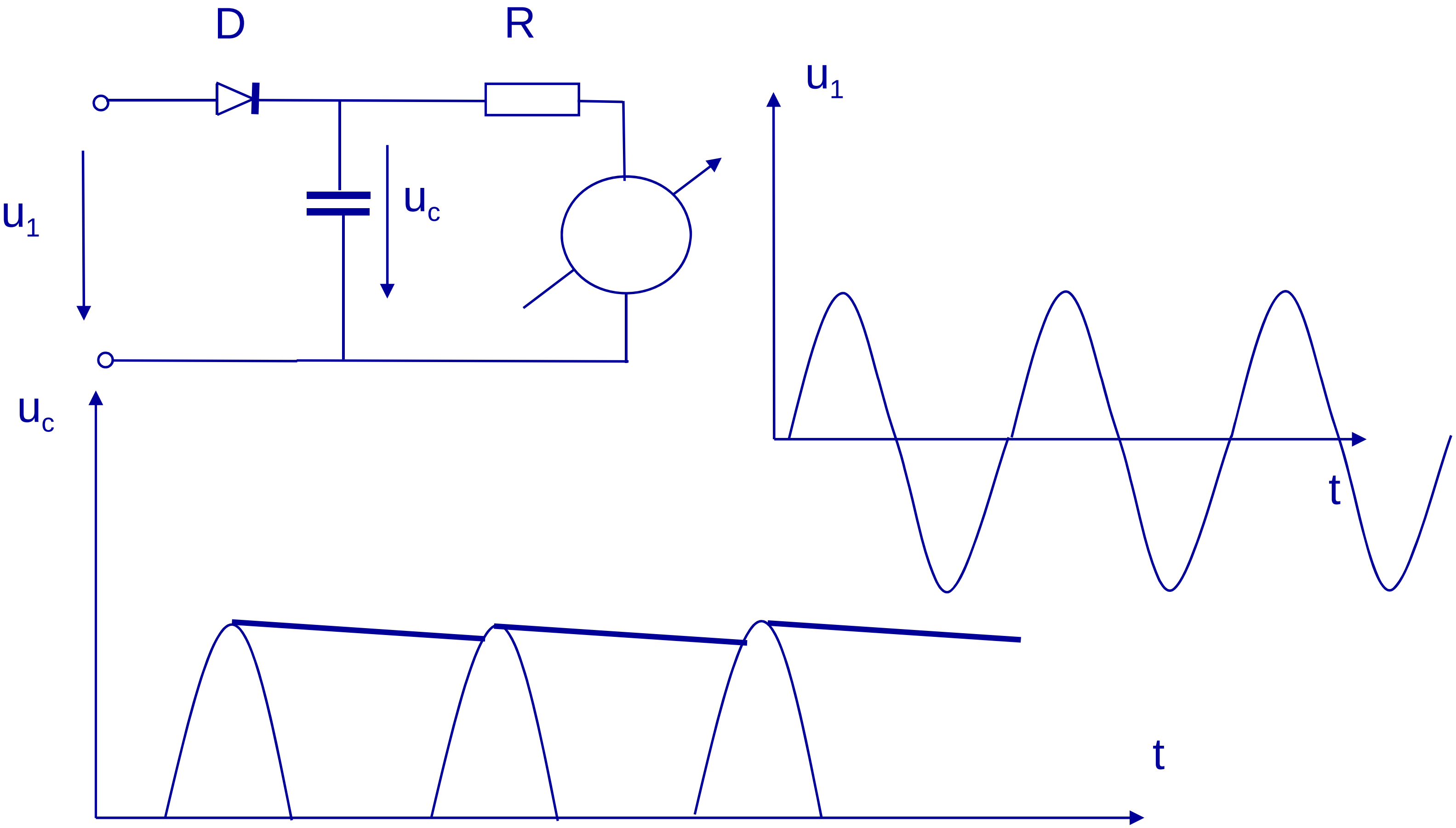
Another possible error is that the instrument can be viewed from different positions, and this way different values can be read. This error can very easily be reduced by placing a mirror behind the pointer, and it should be read from a position where the pointer concurs with its reflection.

Hand instruments



There are hand instruments with many ranges. In the case of the Deprez instrument, this is helped by a ballast resistor or a defender resistance, and then by a resistor divider. Depending on which resistance it its switched to, the instrument can change its ranges. In the previous slide, 2,5 Volt, 10 Volt, 50 Volt, 250 Volt and 500 Volt was the range, so when these resistances are well proportioned, and the switch is set on any of these, then the range of the instrument can be set. There are examples for this in Labview, e.g. The value and breakpoint of these resistances should be calculated in a way that the instrument is set in the appropriate range.

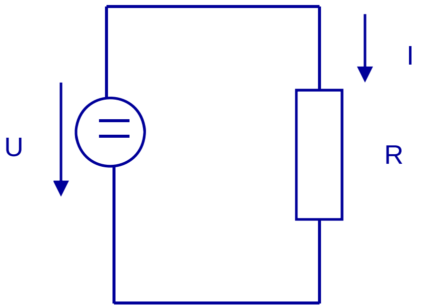
Measuring alternating voltage



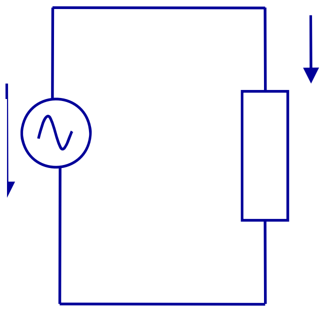
Direct voltage is simple and easy to understand, but we often have to use alternating voltage. For example, in the light network, sine function of the voltage have to be measured. The circuit consists of a diode, a capacitor and a resistance, so a transformer can be made that creates almost direct voltage from the sine wave alternating voltage. When the input voltage is more positive than the other, then the diode opens, or when it is not, it closes the way by polarization. This way, it always fills the capacitor and if the resistance is big enough, it barely discharges in time. It can be seen that the diode charges the capacitor, and the voltage of the capacitor is around direct voltage. It changes a bit around its peak because of discharging.

Calculating RMS (Root mean square)

Basic principle: in a circuit of alternating voltage, the measured value of the power changes.



$u = \hat{U} \sin(2\pi f t)$



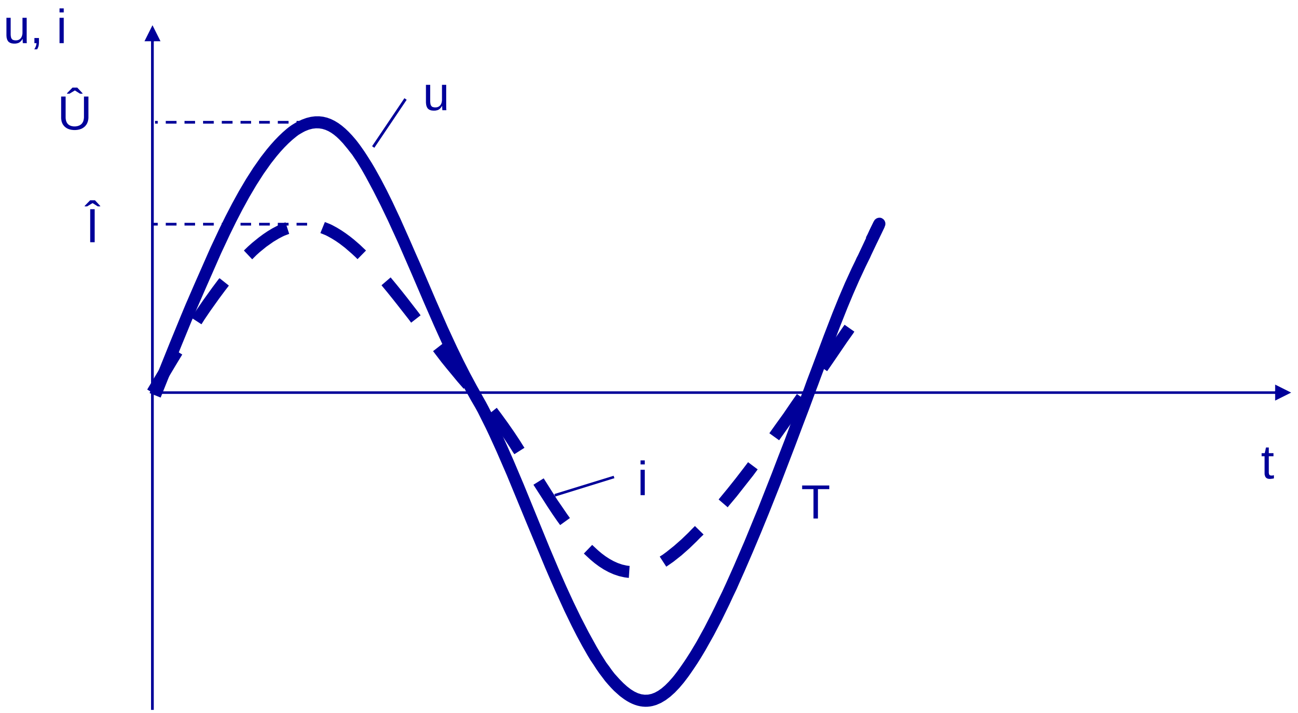
$i = \hat{I} \sin(2\pi f t)$

$P = UI$

$p = ui = \hat{U}\,\hat{I} \sin^2(2\pi f t)$

The basic principle is the following: we have a U voltage source of direct voltage and an R resistance. We connect them and the current is flowing. According to Ohm’s Law, the flowing current can be measured and we can calculate the power that reaches this resistance. If voltage is a sine function in time, that is, the measured value is the sine function of a peak and a frequency, then through this resistance, sine function shaped alternating current will flow, which has a peak, and a measured value. The measured value is always the product of the measured voltage and the measured current. The argument of the two sines is the same in this case.

Electrical Measurements: Measurement of voltage and time



$$p = ui = \hat{U}\,\hat{I}\,\sin^2(2\pi f\,t)$$

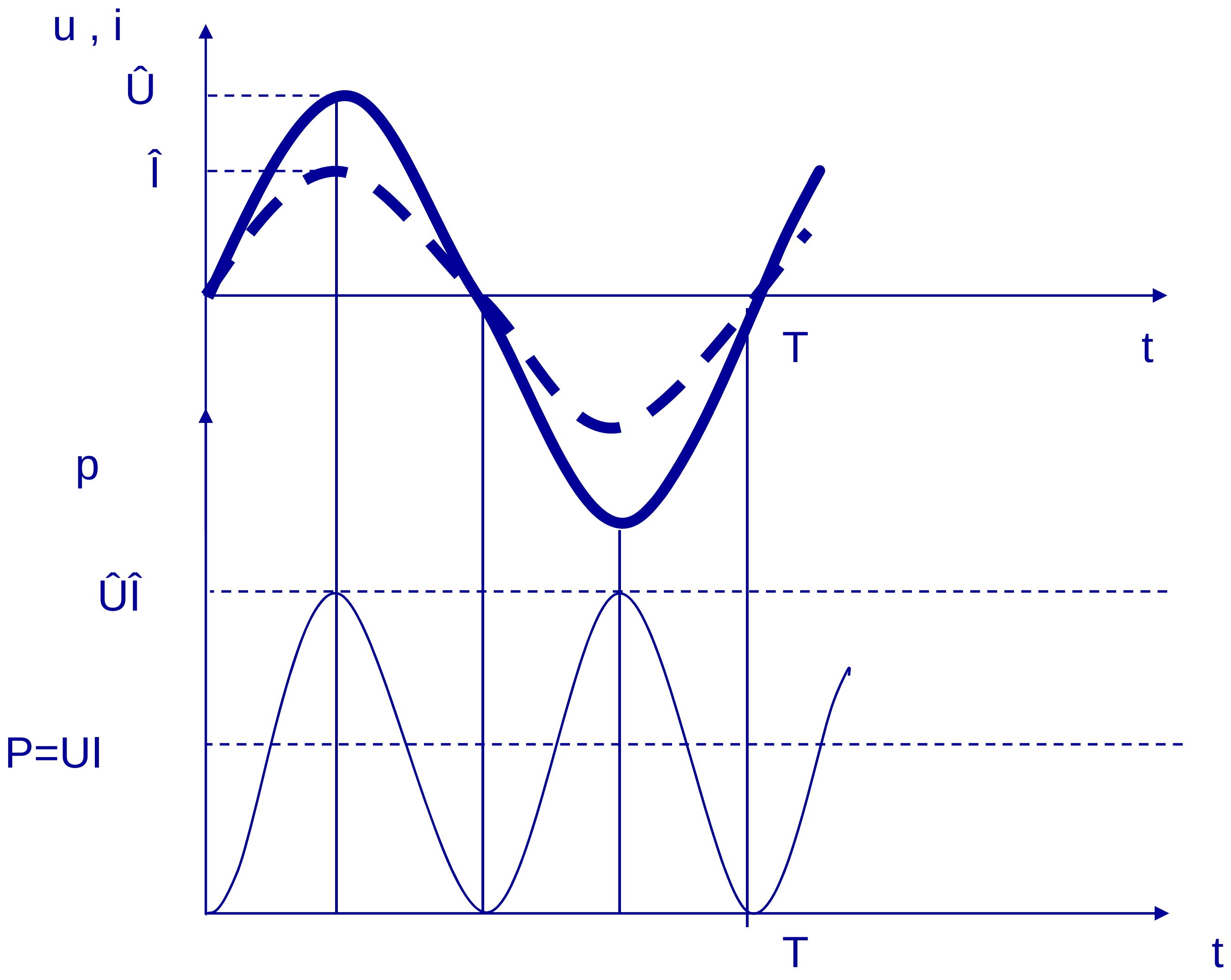
$$\sin^2(2\pi f\,t) = \tfrac{1}{2}[1 - \cos(4\pi f\,t)]$$

$$p = \hat{U}\,\hat{I}\,\sin^2(2\pi f\,t) = \tfrac{1}{2}\,\hat{U}\hat{I} - \tfrac{1}{2}\hat{U}\hat{I}\cos(4\pi\,f\,t)$$

- The measured value is always the product of the measured voltage and the measured current.
- It can be calculated with an easy formula.
- The argument of the two sines is the same in this case.

Sine square x can be easily transformed into cos 2x. The measured power can be calculated this way: half of the peak of the peak voltage minus half of the product of the peak of the peak voltage and a cosine thing. However, in this cosine function, the measured value of the power oscillates around zero with double frequency.

Electrical Measurements: Measurement of voltage and time



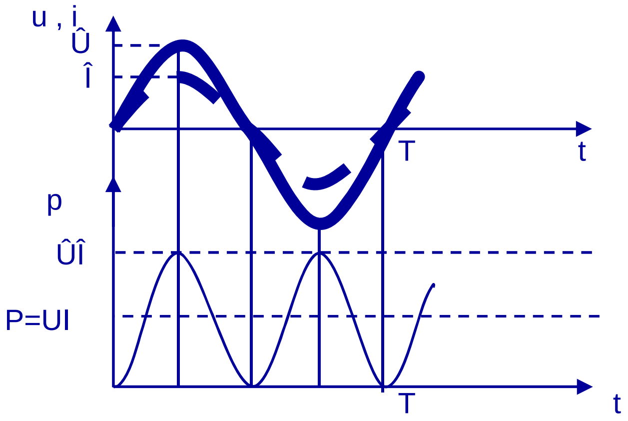
Average of the measured power in a long time

$$P = 1/T \int_0^T p\,dt = \frac{1}{2T}\hat{U}\hat{I} + \int_0^T [1 - \cos(4\pi f t)]\,dt$$

Since the integral of the second part is zero in the whole period,

$$P = \frac{1}{2}\hat{U}\hat{I} = \left(\frac{1}{\sqrt{2}}\hat{U}\right)\left(\frac{1}{\sqrt{2}}\hat{I}\right)$$

$$U_{eff} = \frac{1}{\sqrt{2}}\hat{U} \qquad I_{eff} = \frac{1}{\sqrt{2}}\hat{I}$$

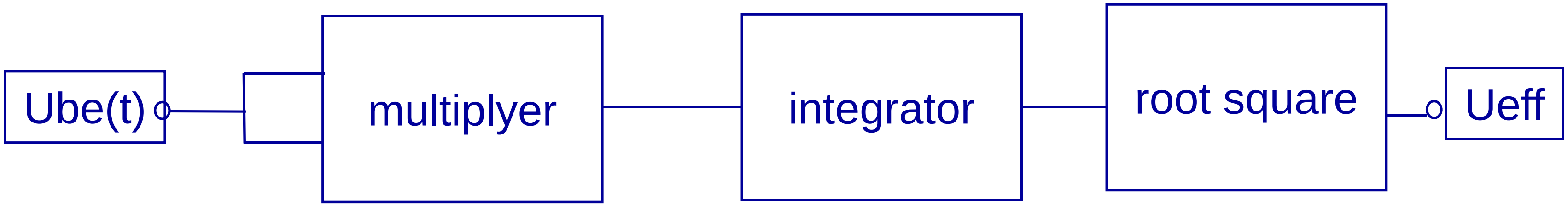


How much is this RMS? We should integral the measured value to the whole period. The formule shows that the integral of the full period is zero. So RMS is the peak value divided by root square two, and the effective current is the peak value of the current divided by root square two. The question is what happens if we deviate from the sine voltage, e.g. take a triangle shaped voltage. The triangle shaped voltage has a peak value as well. How much is its RMS? Can we calculate it the same way? No, it only applies to a sine base. If the integral does not contain a sine sign, then this formula is not valid. Of course we can create an effective value measure, but then we have to put an appliance into the box which carries out this function. The lab has one. How does it function?

Measuring effective RMS

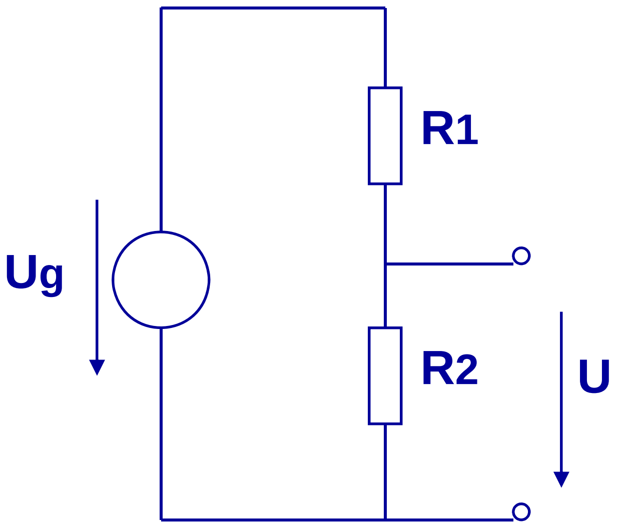
$$T \cdot U_{eff}{}^{2} = \int_{0}^{T} U_{be}^{2}(t)\,dt$$

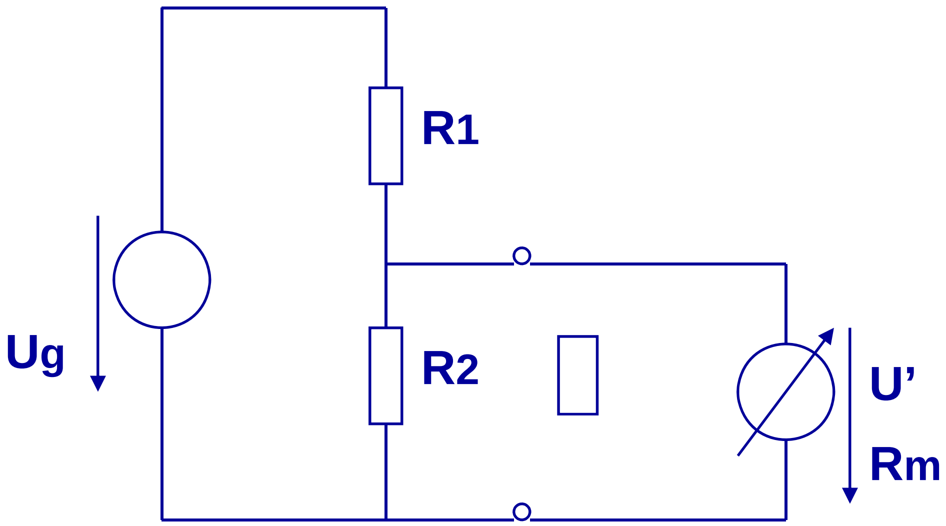
RMS converter



The majority of the cheap instruments work different. The instrument that does the exact same thing is not 999Ft, but 999000 Ft.

Load error





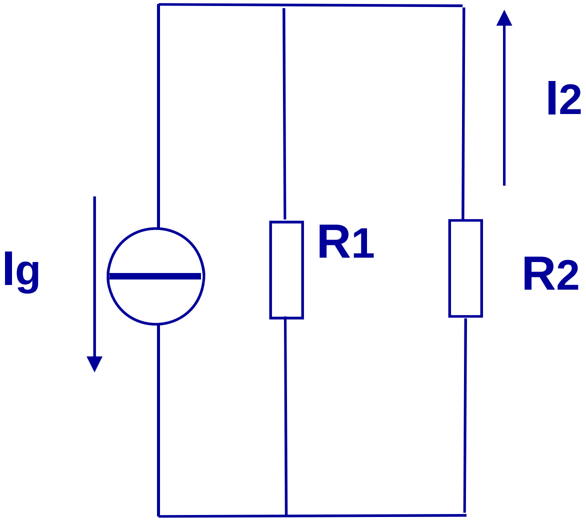
$$U = U_g \frac{R2}{R1+R2}$$

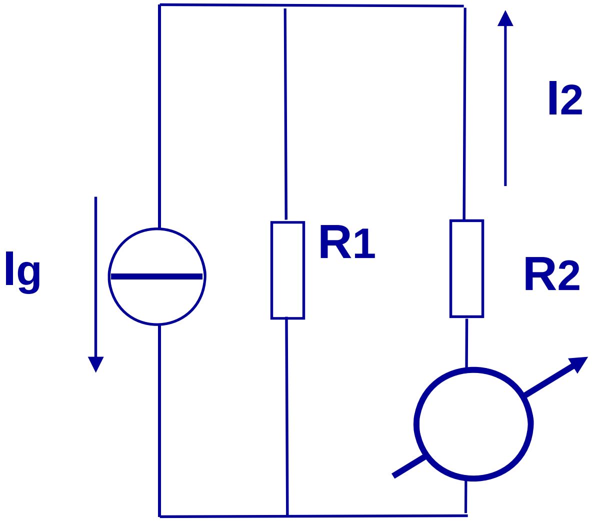
$$U' = U_g \frac{R2}{R1 + R2 + R1\frac{R2}{Rm}}$$

Load error. There is a voltage source, we connect two resistors to it, I want to measure a U voltage with a Deprez Voltmeter. The Voltmeter has an inner resistance, if we do not connect the voltmeter, then we could calculate the voltage exactly. But the inner resistance of the voltmeter is a finite value, and it changes the actual U voltage. It is because the current separates into two, flowing through the R2 resistance and the voltmeter. If it does not flow through, we cannot measure it. How can this error be reduced? We use a voltmeter with a bigger inner resistance.

A Deprez instrument’s resistance is 2kiloohm/volt. This means that when the instrument is switched into a 1 volt position, then its resistance is 2 kiloohm. If we know that its resistance is 2kiloohm, then we can calculate how big the error is. But if that resistance is 5 kiloohm, and then we connect another 5 kiloohm resistance, then what the measures value will be? We should watch out for errors, we should always calculate them. Usually it is a few kiloohm/volt. If we swith it to a 500 volt resistance, then it is 500x2. So its inner resistance will be 1 ohm if we measure in a 500 volt range. Then why not should we measure one or two ohms in a 500 volt range? Because then the relative error, which was 0.3 percent, will rise on the hyperbola.

Load error during current measurement



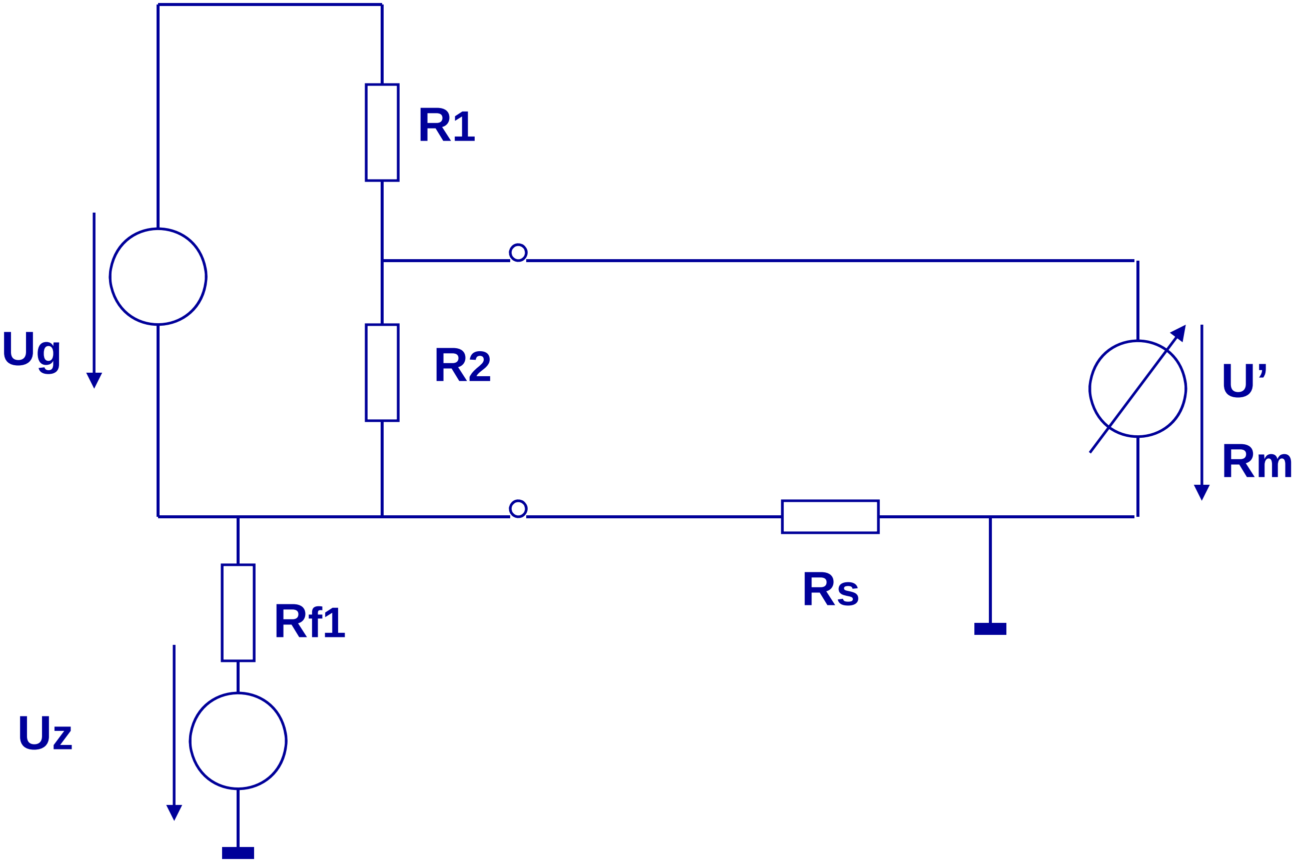


$$I2 = Ig \frac{R1}{R1+R2}$$

$$I2' = Ig \frac{R1}{R1+R2+Rm}$$

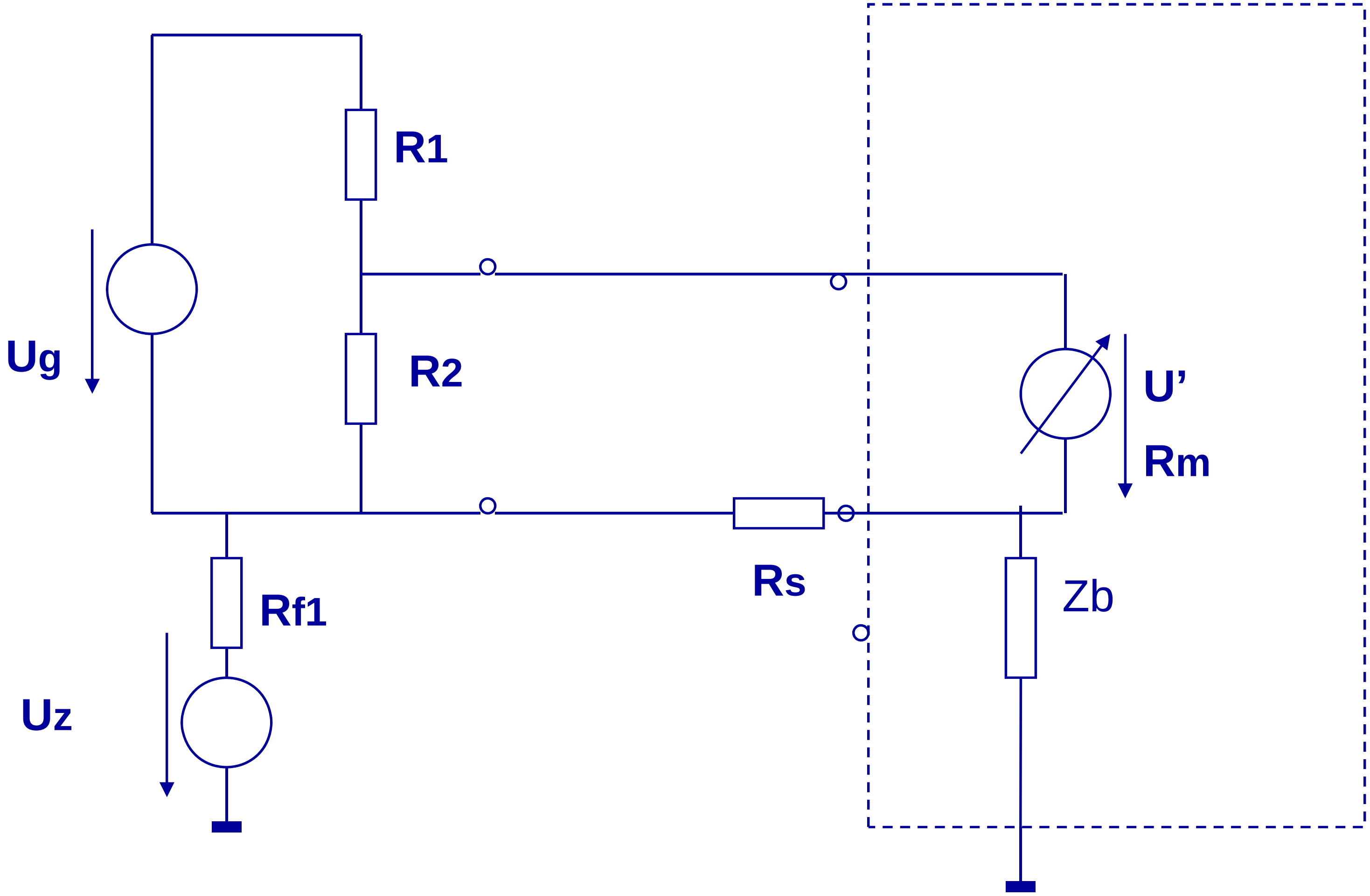
We have a similar problem when measuring current. There is a current generator, to which we connect 2 resistances, R1 and R2, and we measure the I current. Taking into account the current of the generator and the values of the resistances, we can exactly calculate what the measured value should be. If we connect to this the current meter in a row with the resistance, as the figure shows, the value of the current changes. Of course when the current meter's inner resistance is much smaller than the value of the resistance through which the curent flows, then its value is insignificant. All current meters have a finite resistance, it is never zero.

Grounding issues



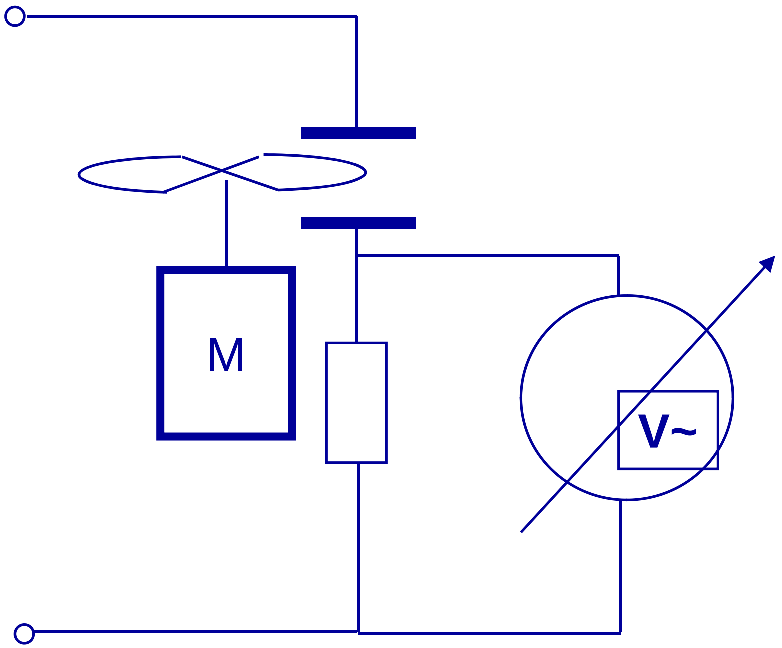
The next thing is grounding. There are instruments working with batteries, and there are others working with network voltage. We are grounding the box of the instrument for safety reasons. The circuit to be measured is grounded, too. Maybe the two points of grounding have a different voltage. It is possible that a Uz noise current occurs, maybe because current is flowing through the ground cable or because it is grounded to a different ground. The measuring cable has a small but finite resistance as well, and if the noise current flows through this, the instrument will measure more than without the noise.

Grounding issues -- GUARD

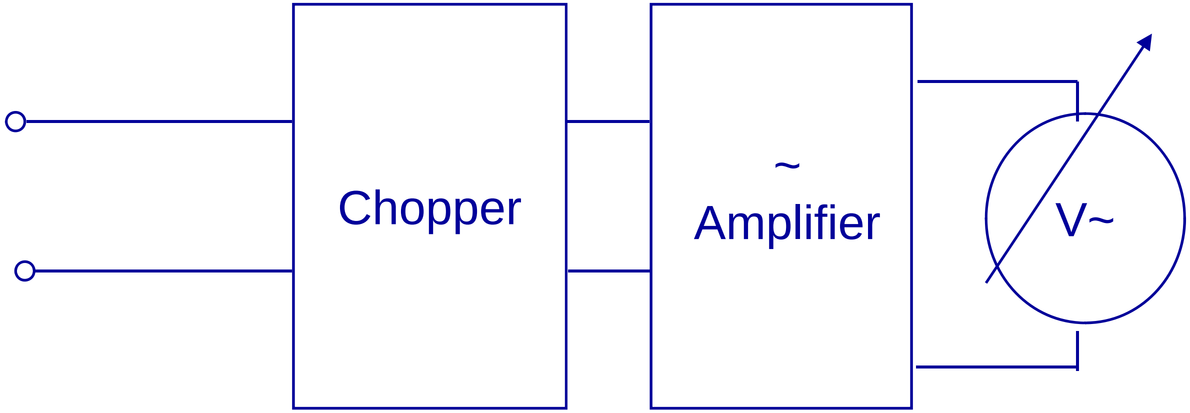


We eliminate this by putting the instrument into a metal box, and none of the instruments’ cables are connected to the metal box. The box is grounded, and between the input point of the instrument and the box, the impedance is very high. Then the value of the noise current will be very small. This way, the grounding error of the measurement will be minimal. This procedure is called GUARD.

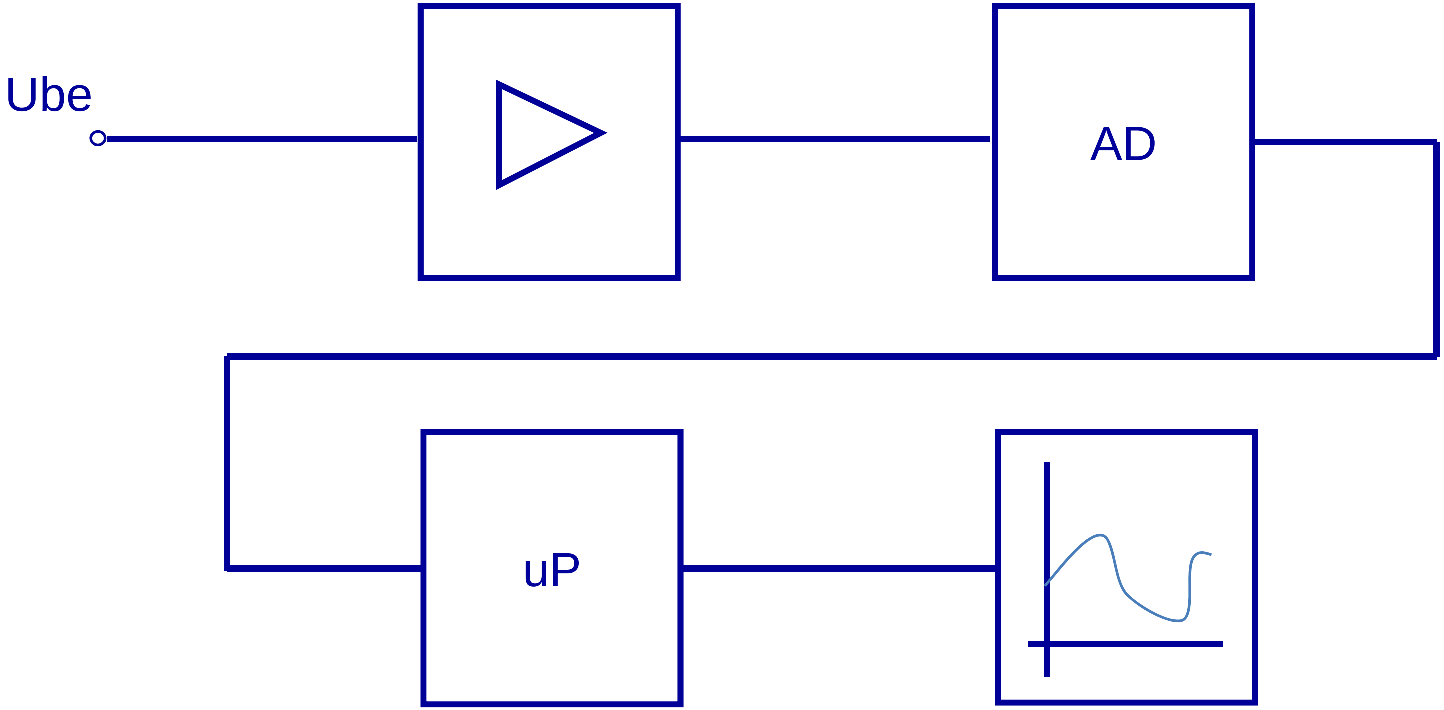
Measuring very big direct voltage



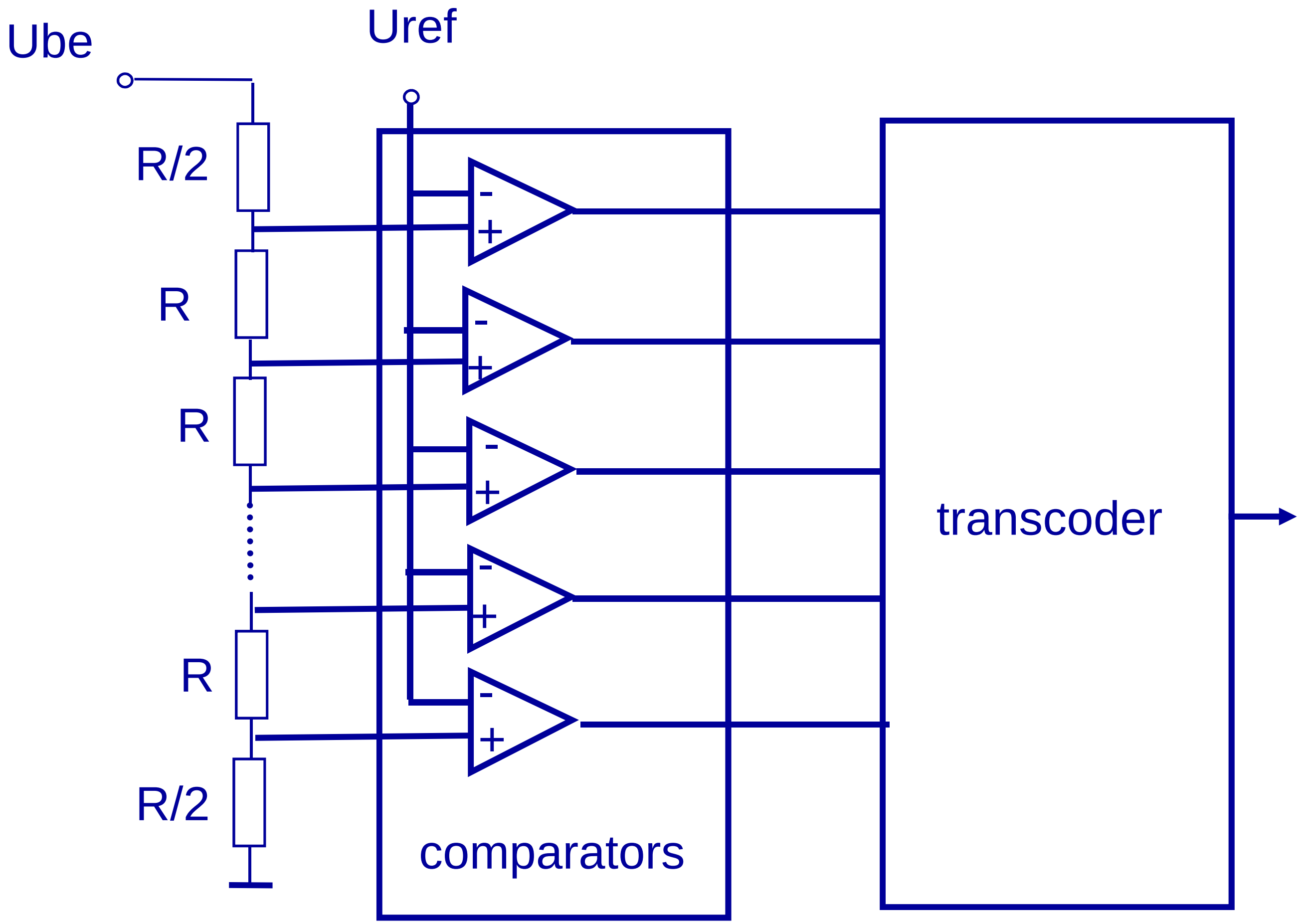
Measuring very small direct voltage



Digital multimeter

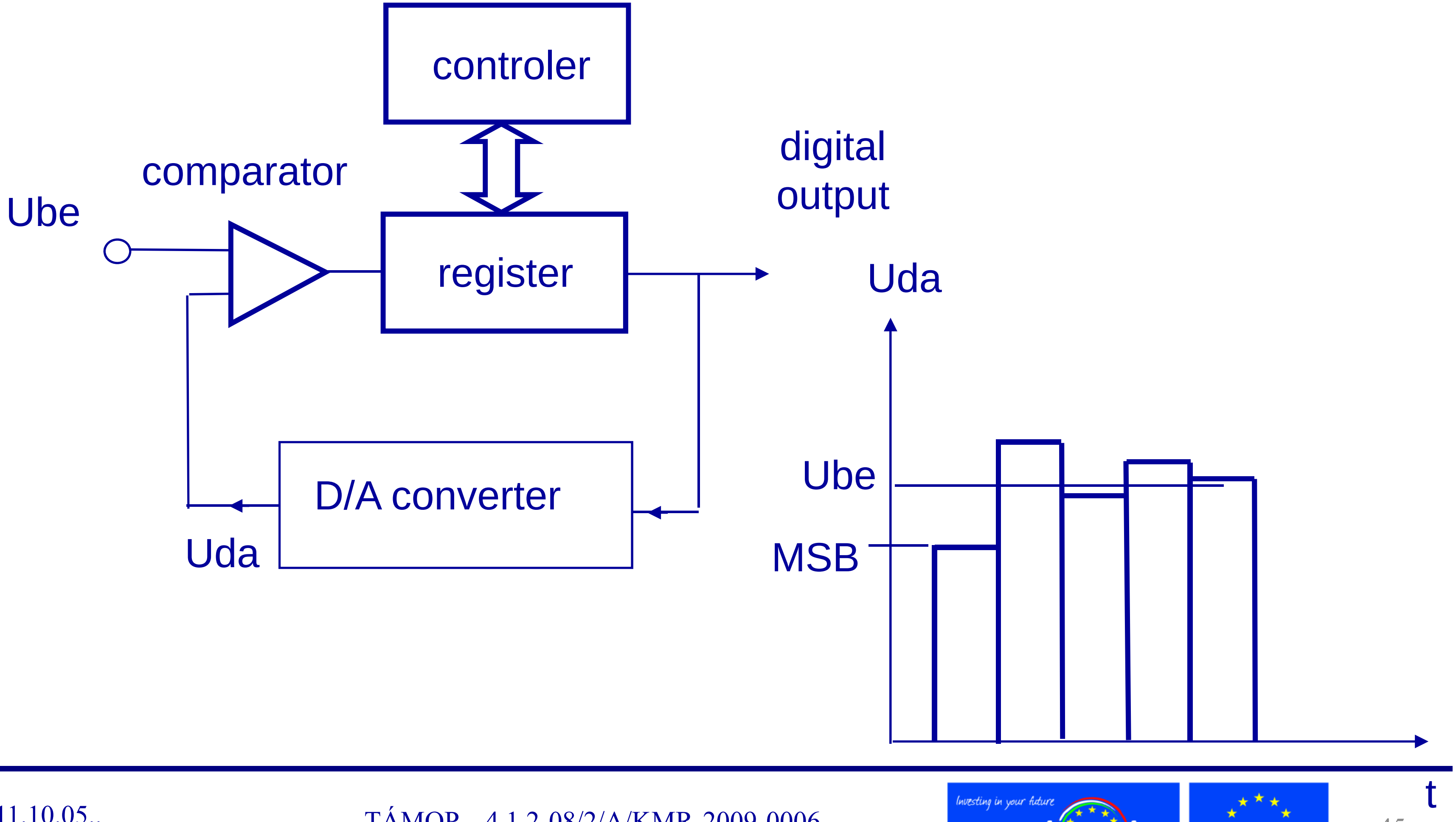


Parallel AD transforming digital voltmeter



Nowadays we usually measure different voltages with digital devices. There are many analog-digital converting principles used in volt meters, one of them is the parallel AD converter. The input voltage goes through a resistance chain, the values of the elements of the chain can be anything, but usually the first and the last resistances are half of the value of the others. After the resistance chain, there is a comparator row. Comparator is a unit that compares the positive and the negative sign that are connected to its input and chooses the bigger one. If the positive is bigger, then its logical output gives 1, but if the negative is bigger, it gives zero. Its input is a row of analog voltages, its output is a binary dataflow with logical outputs, so it is a digital signal. Comparators have a common point which is compared to the reference voltage, so the measuring etalon is the reference voltage, and the comparator compares the input with this.

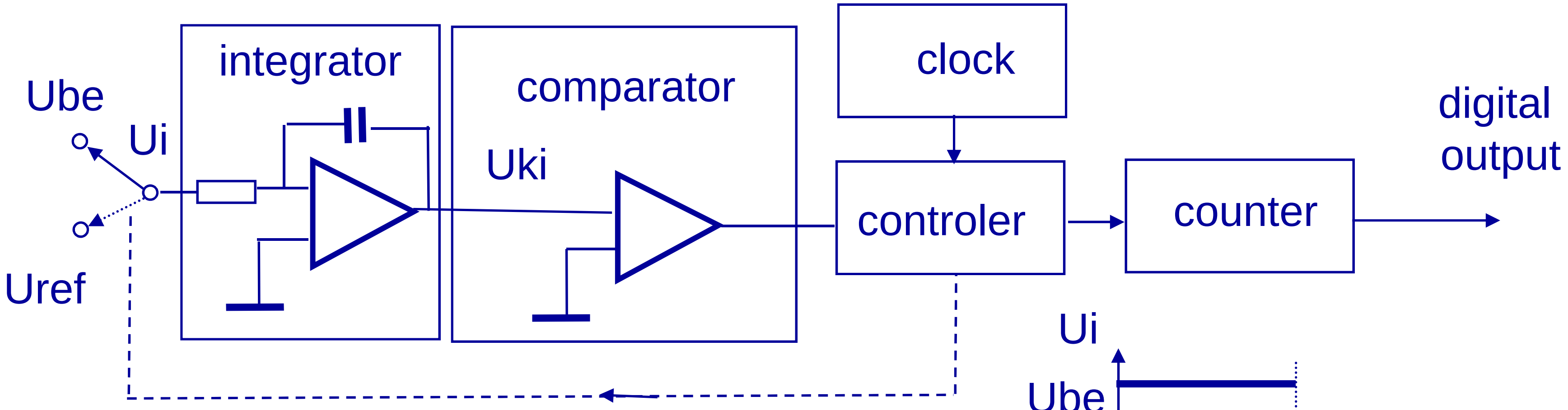
Successive approximation digital voltmeter

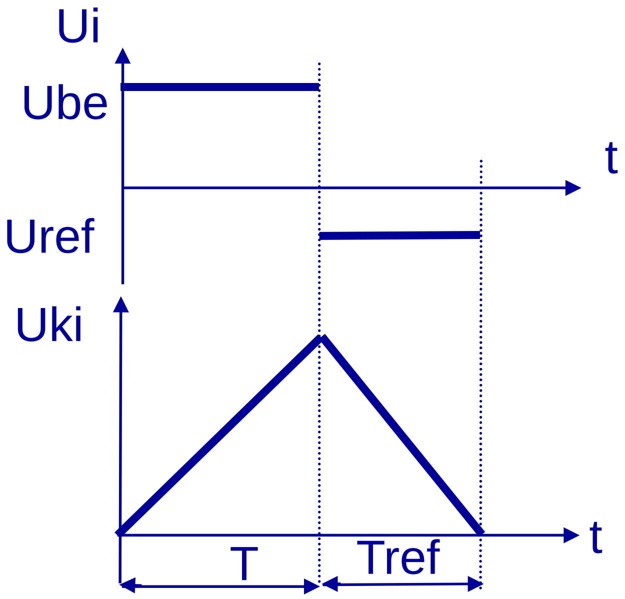


Successive approximation is the principle of iterating closer and closer. We have the input voltage to be measured, a comparator, a digital-analog converter, a register that stores a digital number, and a controller that monitors the measurement procedure. An AD converter is expensive, big and imprecise. A DA is cheap simple and precise. Its mechanism is the following: this controller first sets the msb (most significant bit) to appropriate logic 1 value, then sends the appropriate codes to the register, and the digital converter connects this to the comparator that compares which is the bigger one. If it is smaller, then it adds its half. If it becomes too much, then it takes back the half, and adds a quarter, and so on.

After a few steps, it converges to the input value with high precision, a few bits. It takes only a few comparators, compared to the parallel method, and it does not need a reference directly. The DA converter has its reference in its converter unit and it becomes more and more precise. The circuit is much simpler and precise then in the parallel converter. However, both are used. When do we use the parallel one and when the one with successive approximation? When precision is needed, it is better to use successive approximation. The parallel one is used with video signals, because it is fast. It is used when the video has an analog input and a digital output.

Dual-slope AD converter digital voltmeter





$$\tau\int_0^T U_{be}\,dt = \tau\int_0^{T_{ref}} U_{ref}\,dt$$

$$U_{be} = U_{ref}\frac{T_{ref}}{T}$$

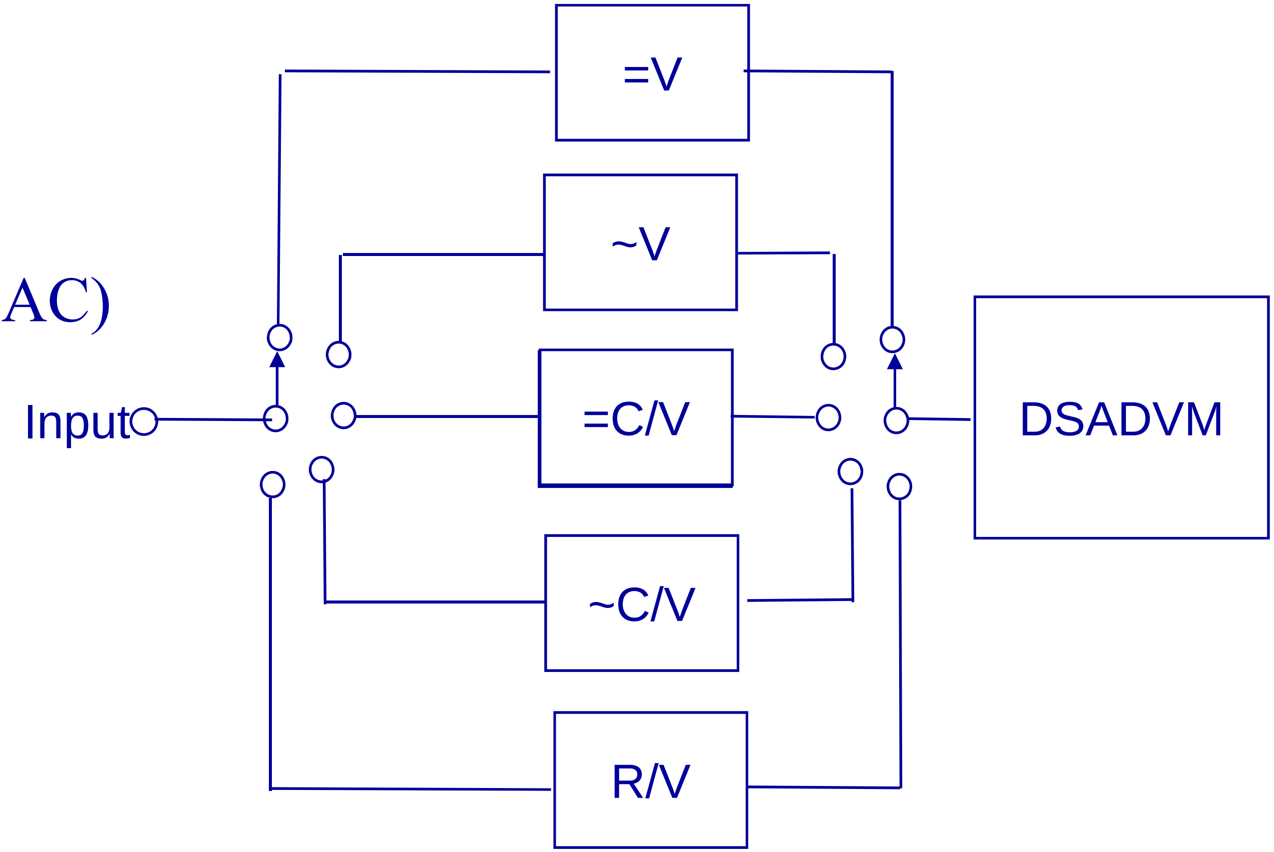
Usually, digital voltmeters contain a dual slot converter. There is an integrator, which consists of a resistance, a capacitor and an operational amplifier; there is a comparator, a counter and a digital number display. It consists of much simpler elements than the methods mentioned above, but its measuring method is more tricky. It has an etalon as well, it measures the input voltage and a reference voltage. First it switches the input switch to the input voltage, and it starts the integrator for a given t time. This output voltage is the integral time of the integrator. Its steepness is constant, reaching a value that is proportional to the voltage and operates the integrator for a t time. Then it switches to the reference voltage, and since it is a negative voltage as compared to the previous one, it operates the integrator until the comparator returns to zero.

- The integral of the input voltage for time t equals to the the integral of the reference voltage for time t. The relationship between the measured input voltage and the reference voltage can be calculated from the ratio of t_{ref} and t.
- Very simple
- Voltage measurement is traced back to the quotient of two times based on a very good etalon and it is very easy to measure.
- It is very accurate becuse it uses time measurement.
- A single chip contains all the needed parts, we do not need to design a circuitry.

Digital multimeters

Regular modes:
Direct voltage
Alternating voltage
Direct current (DC)
Alternating current(AC)
Resistor (R)

Dividers and converters



In digital multimeters there are more modes, it can measure direct voltage, alternating voltage, direct current, alternating current and resistance. There is a switch to choose the needed mode. All measurements trace back to dual slot analog digital converter voltmeter. When it measures alternating voltage, it switches to a direct voltage-alternating voltage converter which consists of a diode, a capacitor and a resistance. We can measure the RMS of sine voltages. When we measure resistance with this instrument, we let a current flow through the resistance and measure its voltage, so this can also be traced back to measuring voltage and to Ohm’s law. Its centre is the dual slope converter unit, it is precise enough and reliable.

Can we throw away the analog devices? It is not that simple. They measure voltage and current without batteries. When particles are speeding at a really high speed (neutron bomb), then notebooks can be thrown out. Pentagon has a lot of analog devices. They cannot be wrecked in space. Another interesting example is a cellar, where solar cells provide the accumulator. The converter system makes a switch of very low frequency, it transforms the voltage of the solar cell to where the accumulator needs to be charged. On digital devices, numbers are racing, but an analog instrument shows what is really happening.

Displaying waveforms

Oscilloscopes – an instrument displaying the time function of the wave form.

Main characteristics: number of channels, sensitivity, knee frequency

Displaying device: cathode ray tube (CRT) or liquid chrystal display (LCD)

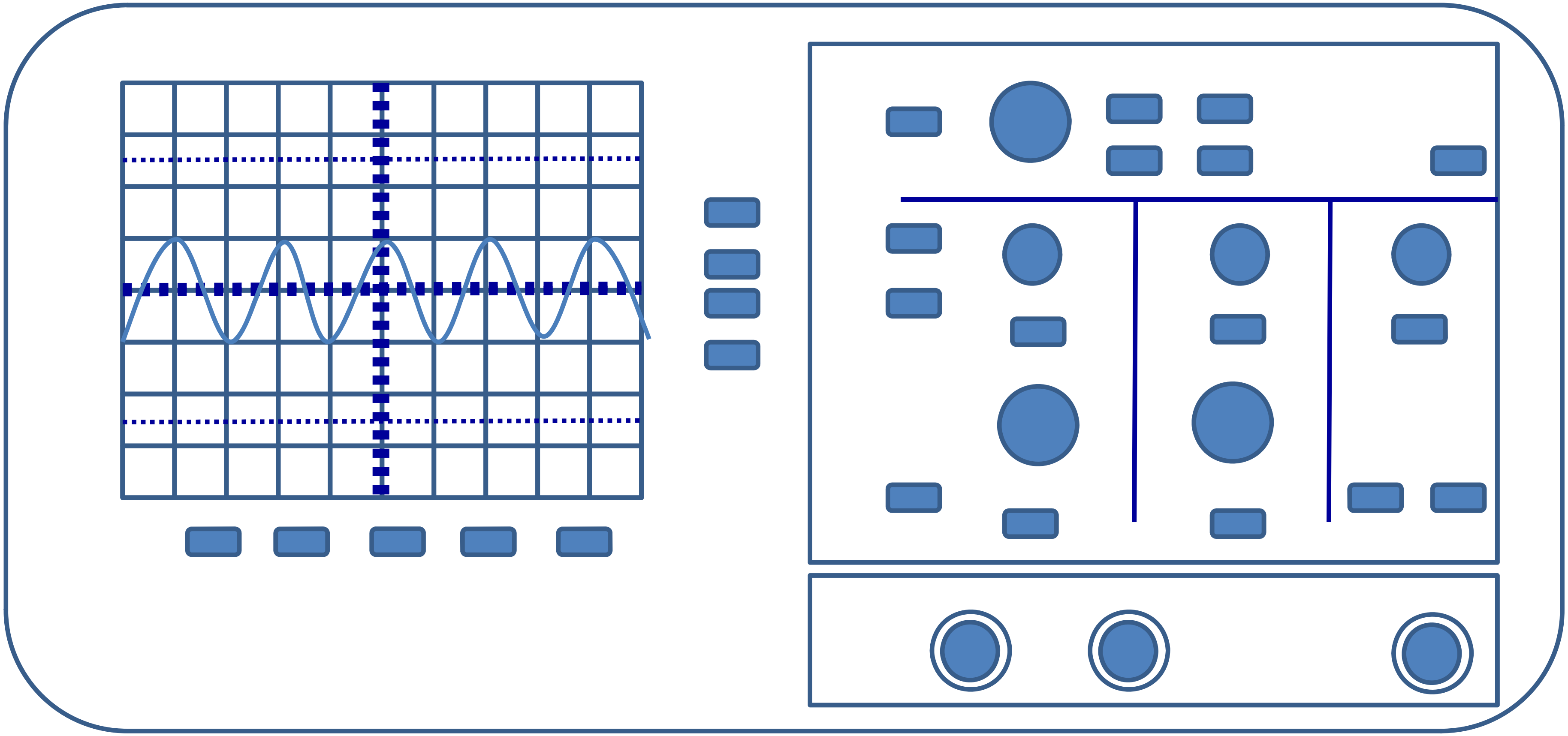
CRT makes the electron ray visible. Its horizontal diversion should be moved at a standard time. (TB – time base)

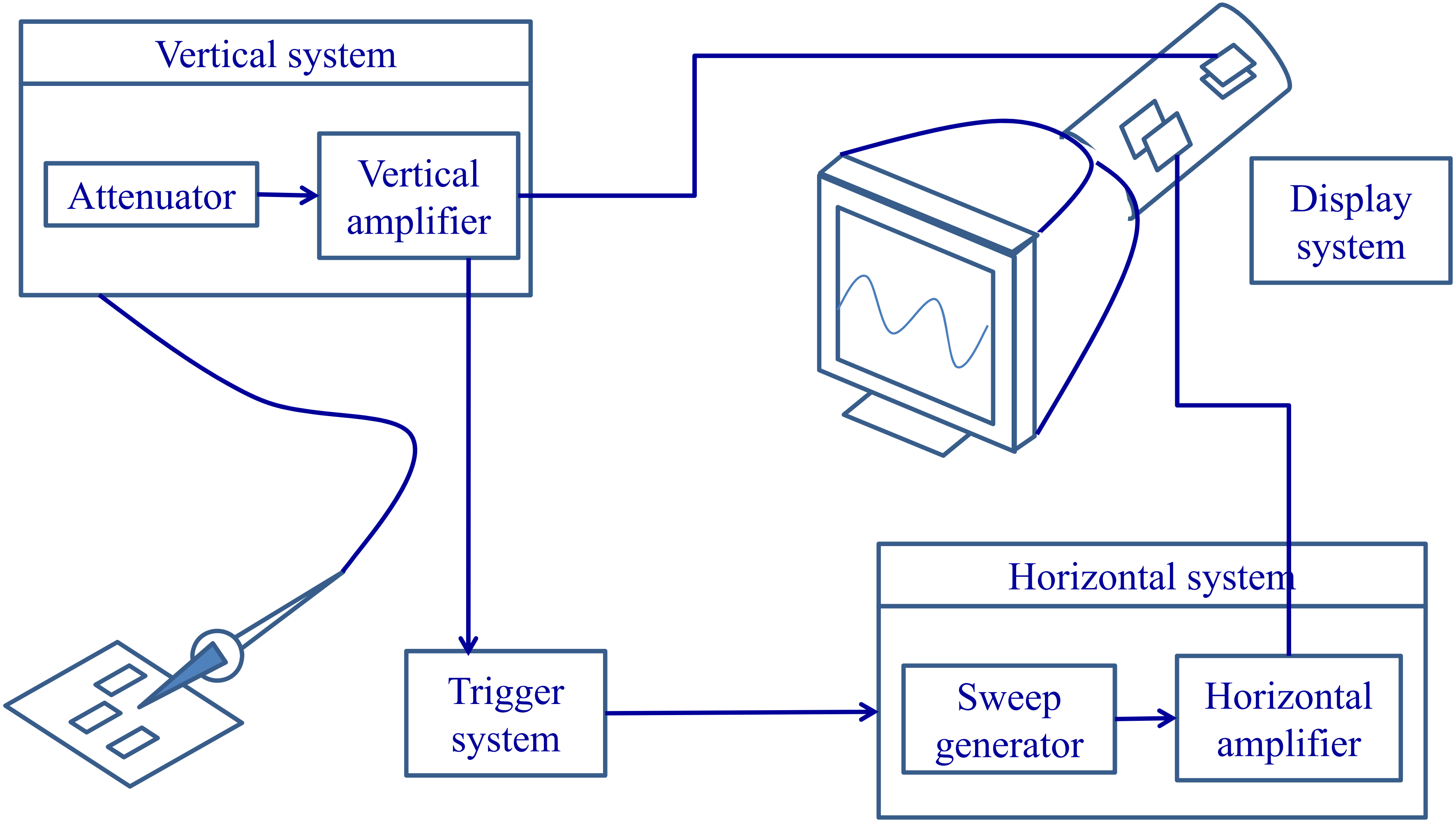
Its perpendicular diversion is controlled by the measured signal.

For the displaying of the wave form, we need an instrument that measures voltage. We look at the time or other process of a signal. Usually we use the oscilloscope for this, either the analog or the digital one. A key characteristic of the oscilloscope is the number of channels, how many time functions or other functions we want to measure. Its sensitivity is also important, so that we know the frequency and voltage range of the measured signals. The number of channels are usually minimum two, sensitivity is usually 4 Volts, counting down from 100. Range depends on what we want to use it for. If we want to measure soind frequency and bioelectric signals only, then a 1 megaherz range would be enough, but that one is no longer available, only 50-100 megaherz instruments.

If we want to measure the radio signals of a cell phone or a GPS receiver, then we would need oscilloscopes ranging up to many gigaherzes. Oscilloscopes differ in the display method as well. It used to be cathod ray tube. It is the same as the tube of the traditional tvs, but it is for measurement. Nowadays there are oscilloscopes with LCD. The cathod ray tube makes the electron rays visible: it makes visible something not perceptible. Usually the horizontal diversion is moved at a standard speed, connecting the input signal to the vertical diversion, the input signal waveform is displayed on the screen.

Oscilloscope




Vertical system
Attenuator
Vertical amplifier
Display system
Trigger system
Horizontal system
Sweep generator
Horizontal amplifier

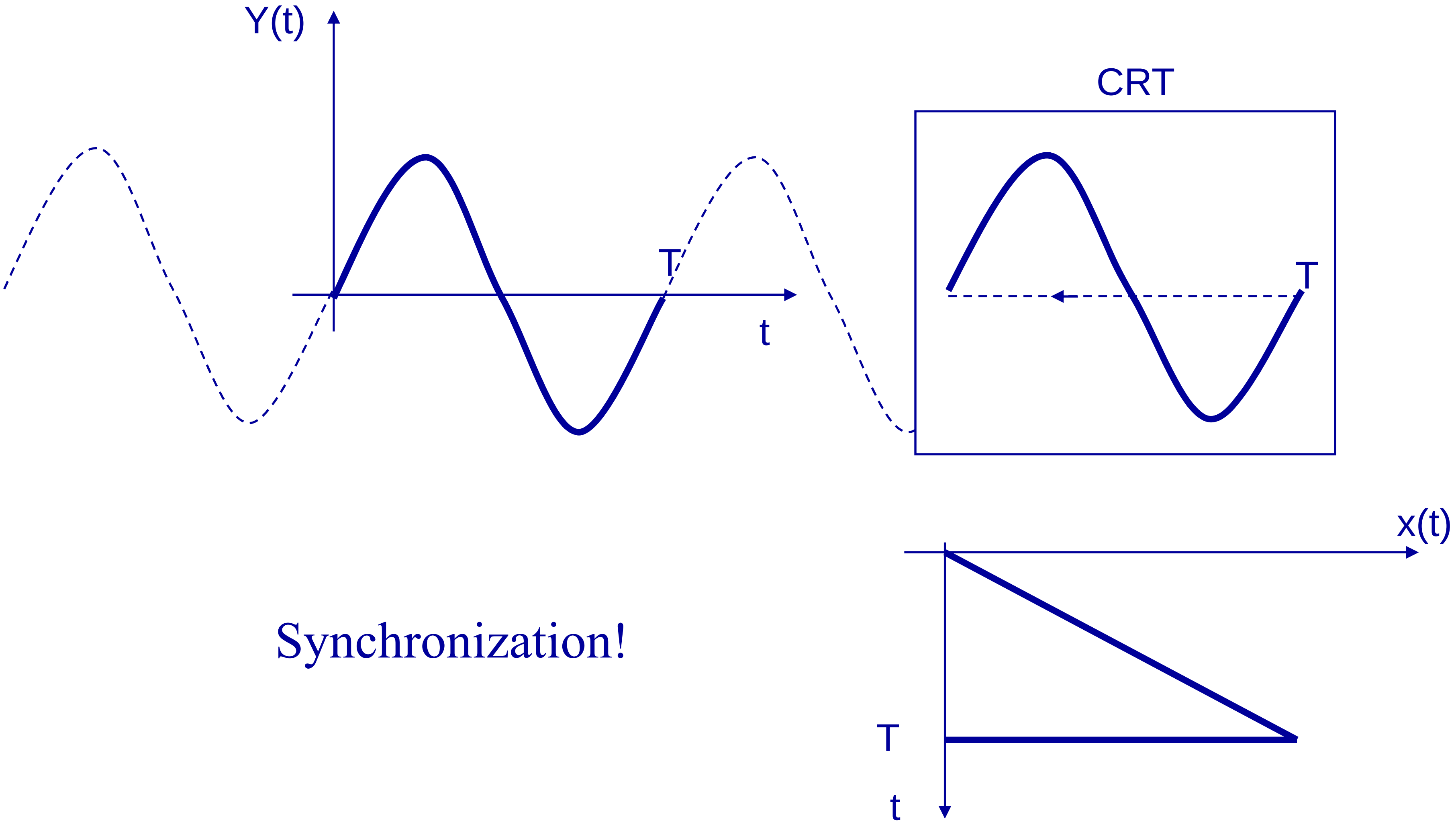
Electrical Measurements: Measurement of voltage and time

How does the inside of an oscillator look like? The display device is a cathod ray tube, it has two deflection plates, which deflect the electron rays horizontally, and there are two perpendicular plates, which deflect perpendicularly. During measurement, usually we touch the measurement point with a probe, this connects to the divider, which includes an amplifier. The perpendicular amplifier amplifies the signal with a few decibels so that it shows a big deflexion. Like with the voltmeter, the oscilloscope is also better when we measure at the upper part of the range. Then its relative error will be small. 0

The horizontal amplifier helps us to amplify a value at any given level. This way we can give the electron ray a diversion, where the perpendicular diversion is big enough to reduce the relative error of the measurement.

The horizontal diversion system shows a time function that rises evenly, then jumps back, so it is a saw tooth wave. The saw tooth wave generator is controlled by a trigger-circuit. The trigger is the part of the gun that starts the bullet. Its function is to start the saw tooth generator in the appropriate phase, so that e.g. a sine wave always gets a still.

Electrical Measurements: Measurement of voltage and time



Synchronization!

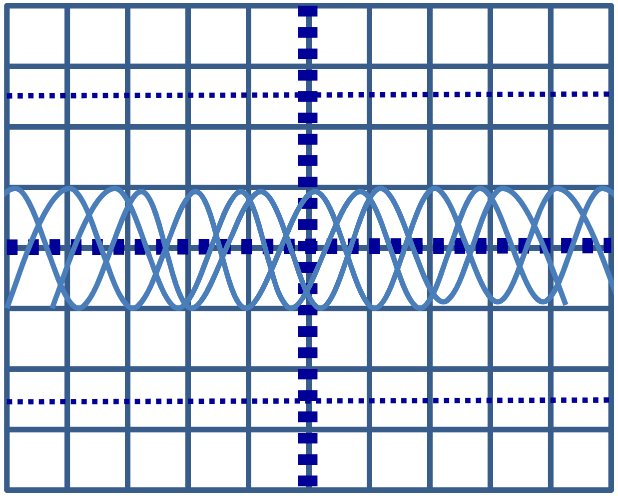
Electrical Measurements: Measurement of voltage and time

So there is a signal to be measured, which, depending on time, is a sine based signal. The sine function is the same from the beginning to the end of time, it never stops. We usually want to display one or two periods of it on a display device. If the x direction diversion is sine shaped, and it is always running back at the end of the period time, then it will always draw a period and then starts the diversion in the x direction. Next time it starts over again, so it should be triggered, and the trigger always starts it in the appropriate time, so a still will be displayed on the device.

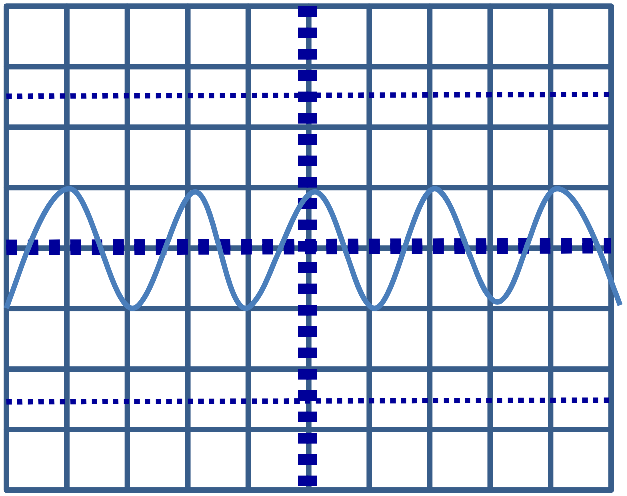
Investing in your future
New Hungary Development Plan

Electrical Measurements: Measurement of voltage and time

Untriggered display:



Triggered display:



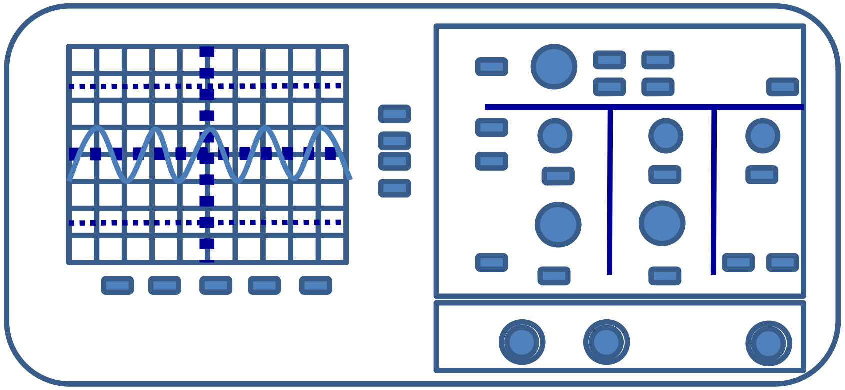
The characteristics of the oscilloscope:

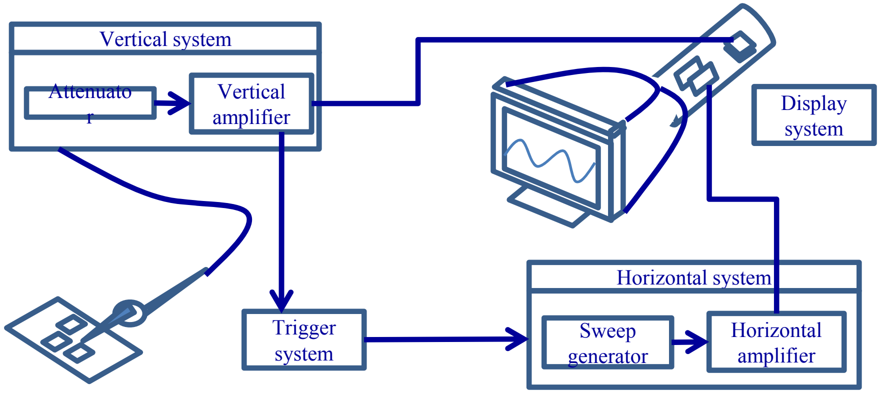
The horizontal and perpendicular diversions can be authenticated, tha values can be seen on the scale display.

The actual wave form can be viewed in the function of time.

Many signals can be viewed simultaneously.

Any part of the wave form can be marked with markers, the values characterizing the signal can be seen.

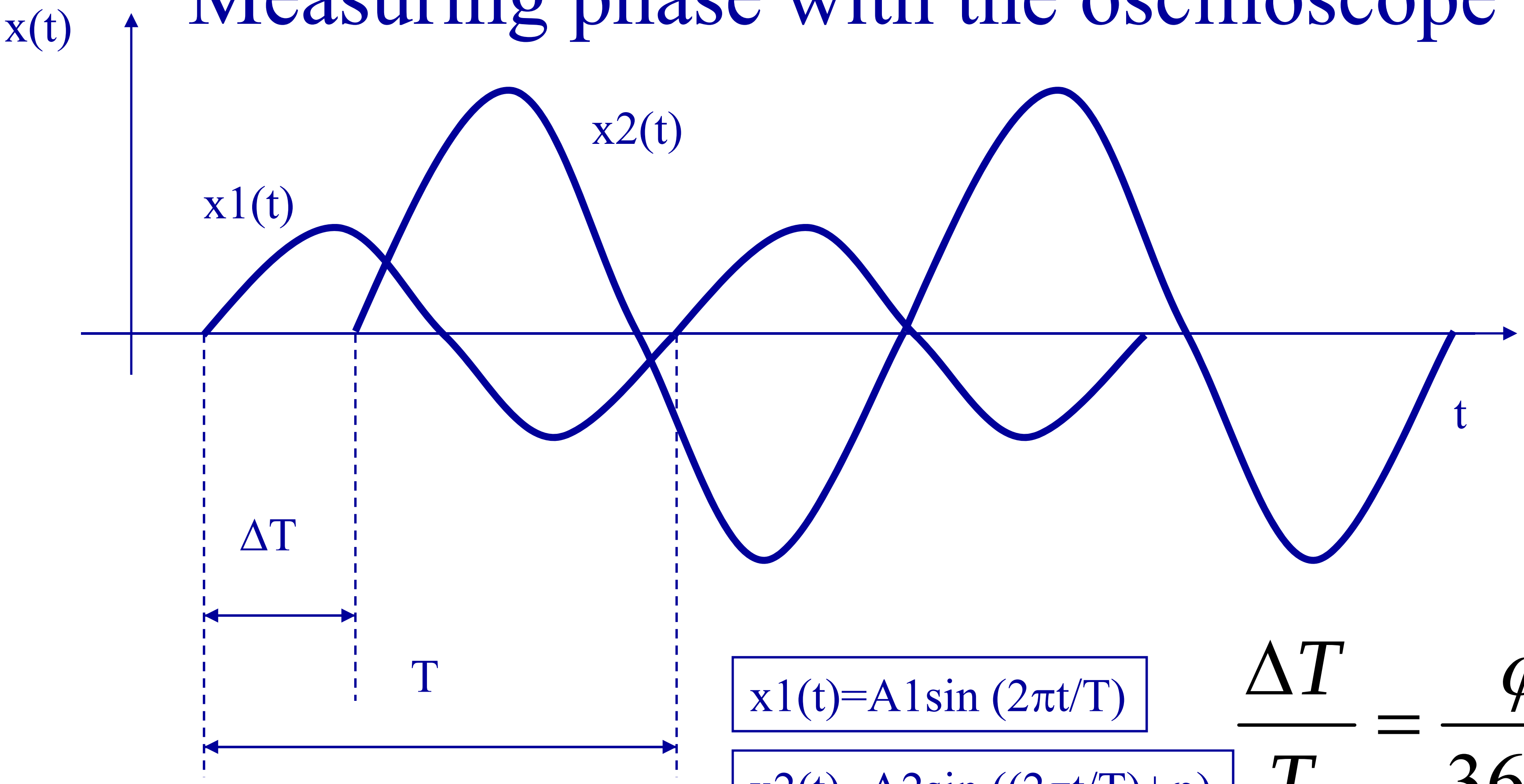




The horizontal and the perpendicular diversions can be authenticated, they can be seen on the scale. Any kind of wave form voltage can be measured with it: direct voltage or sine wave, triangle or quadrilateral signal. It is good for everything, and it can be seen on the authenticated scale. There is a scale on the measurement range of the oscilloscope. Usually the amount of the voltage is given related to one division of the scale, e.g. 2 Volt/div means that one step on the displayed scale is a 2 Volts step. If the scale is authenticated, then the peak value can be read, the RMS can be calculated, the period length of the signal can also be seen, and from its reciprocal, the frequency of the signal can be given.

The wave form, voltage value, frequency value, time value can all be seen. Many signals can be viewed simultaneously, and their relative location can be seen. When we measure the bus of a processor, it can be calculated where a sign’s location is, compared to the clock sign. In case of a modern oscilloscope, like the ones in Labview and ELVIS, we can put markers to any signals. The oscilloscope can measure and display the time difference and voltage difference between two markers placed on the signal.

Measuring phase with the oscilloscope



x1(t)=A1sin (2πt/T)

x2(t)=A2sin ((2πt/T)+φ)

$$\frac{\Delta T}{T} = \frac{\varphi}{360^0}$$

Two signals have the same signal frequency and period length, but they are in different phase. Can the phase be measured by the oscilloscope? Of course it can be and the method is as follows: there is a length in time of a full period, you can see it on a calibrated oscilloscope, if we use the screen in a sufficient precision range. We can also measure the distance between the starting points of two signals. We know that one period is exactly 360 degrees. Based on these two measurements, we can determine the proportion and evaluate the exact phase shift.

What is the basic unit of time?

- What is a day, hour, minute and second?
- Sumers, sexagesimal (base-60) system
- From Noon to Noon.
- Wagon transport (leave at peep of dawn), train (exact timing)
- Sea navigation was also based on time measurement. Especially they need very accurate time measurement.
- What is the etalon of the time? If a shadow of a stick was the shortest, it was noon.
- The Earth's full rotation is a day, it is not a good etalon.

Consequences of the tsunami on 26. December 2004:

- The North Pole has shifted 2.5 cm to the direction of 145th degree east meridian.
- The shape of the Earth has changed.
- After the earthquake, the speed of the rotation of the Earth has changed.
- „theoretical models suggest the earthquake shortened the length of a day by 2.68 microseconds”
- Large or small? Unfortunately it can not be neglected. This measurement error affects very much in some situations.
- The Earth's full rotation is a day, it is not a good etalon.

What then is time? If no one asks me, I know: if I wish to explain it to one that asketh, I know not...

“Who will tell me that there are not three times (as we learned when boys, and taught boys), past, present, and future; but present only, because those two are not? Or are they also; and when from future it becometh present, doth it come out of some secret place; and so, when retiring, from present it becometh past? For where did they, who foretold things to come, see them, if as yet they be not? For that which is not, cannot be seen. And they who relate things past, could not relate them, if in mind they did not discern them, and if they were not, they could no way be discerned. Things then past and to come, are.”...

For if times past and to come be, I would know where they be. Which yet if I cannot, yet I know, wherever they be, they are not there as future, or past, but present. For if there also they be future, they are not yet there; if there also they be past, they are no longer there. Wheresoever then is whatsoever is, it is only as present.

Although when past facts are related, there are drawn out of the memory, not the things themselves which are past, but words which, conceived by the images of the things, they, in passing, have through the senses left as traces in the mind. Thus my childhood, which now is not, is in time past, which now is not: but now when I recall its image, and tell of it, I behold it in the present, because it is still in my memory. Whether there be a like cause of foretelling things to come also; that of things which as yet are not, the images may be perceived before, already existing, I confess, O my God, I know not. This indeed I know, that we generally think before on our future actions, and that that forethinking is present, but the action whereof we forethink is not yet, because it is to come. Which, when we have set upon, and have begun to do what we were forethinking, then shall that action be; because then it is no longer future, but present.

Electrical Measurements: Measurement of voltage and time

Which way soever then this secret fore-perceiving of things to come be; that only can be seen, which is. But what now is, is not future, but present. When then things to come are said to be seen, it is not themselves which as yet are not (that is, which are to be), but their causes perchance or signs are seen, which already are. Therefore they are not future but present to those who now see that, from which the future, being foreconceived in the mind, is foretold. Which fore-conceptions again now are; and those who foretell those things, do behold the conceptions present before them. Let now the numerous variety of things furnish me some example. I behold the day-break, I foreshow, that the sun, is about to rise. What I behold, is present; what I foresignify, to come; not the sun, which already is; but the sun-rising, which is not yet. And yet did I not in my mind imagine the sun-rising itself (as now while I speak of it), I could not foretell it. But neither is that daybreak which I discern in the sky, the sun-rising, although it goes before it; nor that imagination of my mind; which two are seen now present, that the other which is to be may be foretold.

Future things then are not yet: and if they be not yet, they are not: and if they are not, they cannot be seen; yet foretold they may be from things present, which are already, and are seen...

What now is clear and plain is, that neither things to come nor past are. Nor is it properly said, “there be three times, past, present, and to come”: yet perchance it might be properly said, “there be three times; a present of things past, a present of things present, and a present of things future.” For these three do exist in some sort, in the soul, but otherwhere do I not see them; present of things past, memory; present of things present, sight; present of things future, expectation. If thus we be permitted to speak, I see three times, and I confess there are three. Let it be said too, “there be three times, past, present, and to come”: in our incorrect way. See, I object not, nor gainsay, nor find fault, if what is so said be but understood, that neither what is to be, now is, nor what is past. For but few things are there, which we speak properly, most things improperly; still the things intended are understood...

I heard once from a learned man, that the motions of the sun, moon, and stars, constituted time, and I assented not. For why should not the motions of all bodies rather be times? Or, if the lights of heaven should cease, and a potter's wheel run round, should there be no time by which we might measure those whirlings, and say, that either it moved with equal pauses, or if it turned sometimes slower, otherwhiles quicker, that some rounds were longer, other shorter? Or, while we were saying this, should we not also be speaking in time? Or, should there in our words be some syllables short, others long, but because those sounded in a shorter time, these in a longer? ...

I desire to know the force and nature of time, by which we measure the motions of bodies, and say (for example) this motion is twice as long as that. ...

Dost Thou bid me assent, if any define time to be “motion of a body?” Thou dost not bid me. For that no body is moved, but in time, I hear; this Thou sayest; but that the motion of a body is time, I hear not; Thou sayest it not. For when a body is moved, I by time measure, how long it moveth, from the time it began to move until it left off? And if I did not see whence it began; and it continue to move so that I see not when it ends, I cannot measure, save perchance from the time I began, until I cease to see. And if I look long, I can only pronounce it to be a long time, but not how long; because when we say “how long,” we do it by comparison; as, “this is as long as that,” or “twice so long as that,” or the like.

Electrical Measurements: Measurement of voltage and time

But when we can mark the distances of the places, whence and whither goeth the body moved, or his parts, if it moved as in a lathe, then can we say precisely, in how much time the motion of that body or his part, from this place unto that, was finished. Seeing therefore the motion of a body is one thing, that by which we measure how long it is, another; who sees not, which of the two is rather to be called time? For and if a body be sometimes moved, sometimes stands still, then we measure, not his motion only, but his standing still too by time; and we say, “it stood still, as much as it moved”; or “it stood still twice or thrice so long as it moved”; or any other space which our measuring hath either ascertained, or guessed; more or less, as we use to say. Time then is not the motion of a body...

Does not my soul most truly confess unto Thee, that I do measure times? Do I then measure, O my God, and know not what I measure? I measure the motion of a body in time; and the time itself do I not measure? Or could I indeed measure the motion of a body how long it were, and in how long space it could come from this place to that, without measuring the time in which it is moved? This same time then, how do I measure? do we by a shorter time measure a longer, as by the space of a cubit, the space of a rood?...

It is in thee, my mind, that I measure times. Interrupt me not, that is, interrupt not thyself with the tumults of thy impressions. In thee I measure times; the impression, which things as they pass by cause in thee, remains even when they are gone; this it is which still present, I measure, not the things which pass by to make this impression. This I measure, when I measure times. Either then this is time, or I do not measure times. What when we measure silence, and say that this silence hath held as long time as did that voice? do we not stretch out our thought to the measure of a voice, as if it sounded, that so we may be able to report of the intervals of silence in a given space of time?

THE CONFESSIONS

of

SAINT AUGUSTINE

translated by

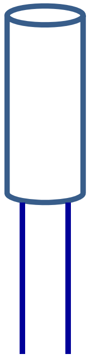
Edward Bouverie Pusey

Why is time / frequency measurement so important today?

- Many practical measurements can be traced back to time measurement. (e.g. GPS positioning , voltage measurement).
- There are very good time/frequency etalons (e.g. 10^{-6} or 10^{-12} quartz crystals)
- Time measurement suits digital technology (calculation, division, gating, display)
- The basic solutions of military technology (radar, missile control)
- Medical technology (e.g. Ultrasound)
- High precision time measurement: experiments in nuclear physics for the measurement of the life span and speed of detected particles. Measuring depth, ultrasound temperature- density- current and thickness measurement, magnetostriction positioning, laser distance measurement.

Characteristics of quartz chrystal

T26W/T38W



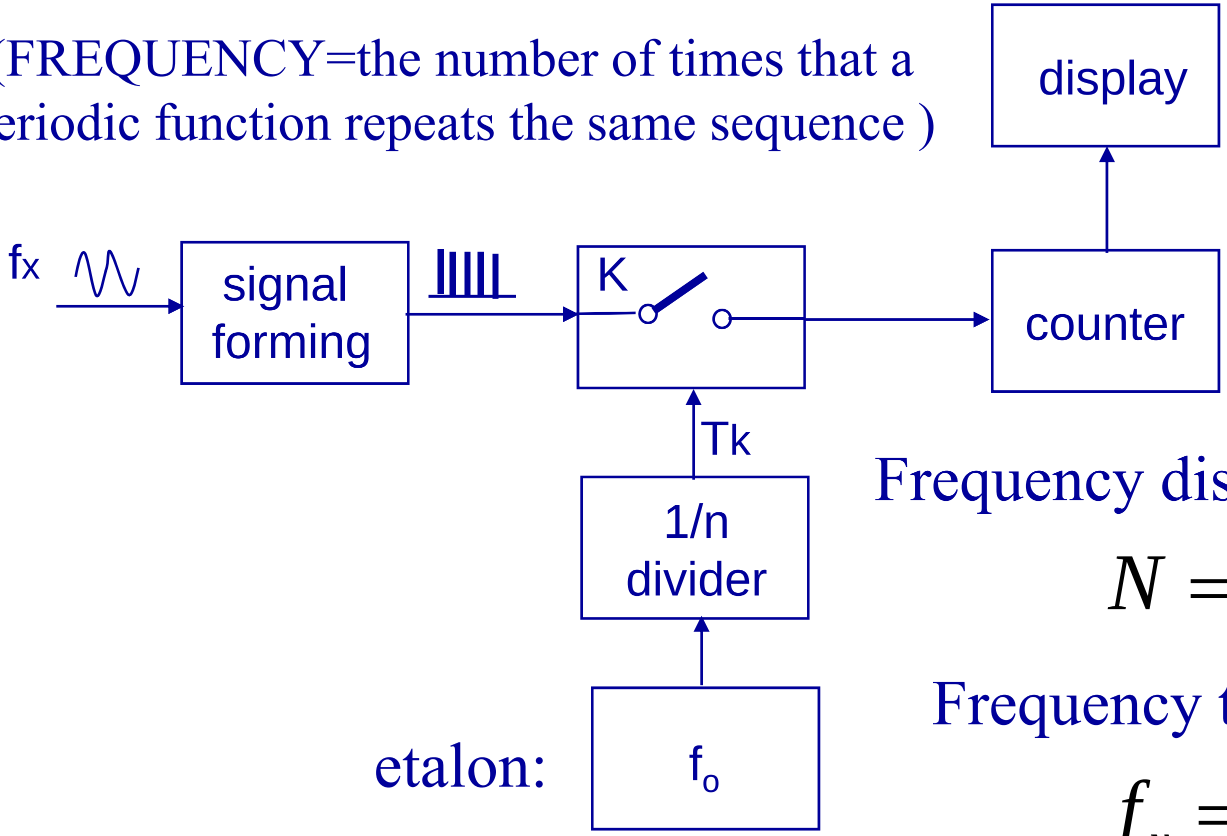
Frequency: 32.768 kHz

Frequency stability ±0.04 PPM / (Δ°C)
Small, cheap
With a binary division, we can create an exactly one second base with it

(The rotational time error of the Earth after the earthquake on 26 December 2004 is -0,00032 PPM)

Digital frequency meter according to the definition of frequency

(FREQUENCY=the number of times that a periodic function repeats the same sequence)



Frequency displayed by the counter :

$$N = f_x T_k = f_x \frac{n}{f_0}$$

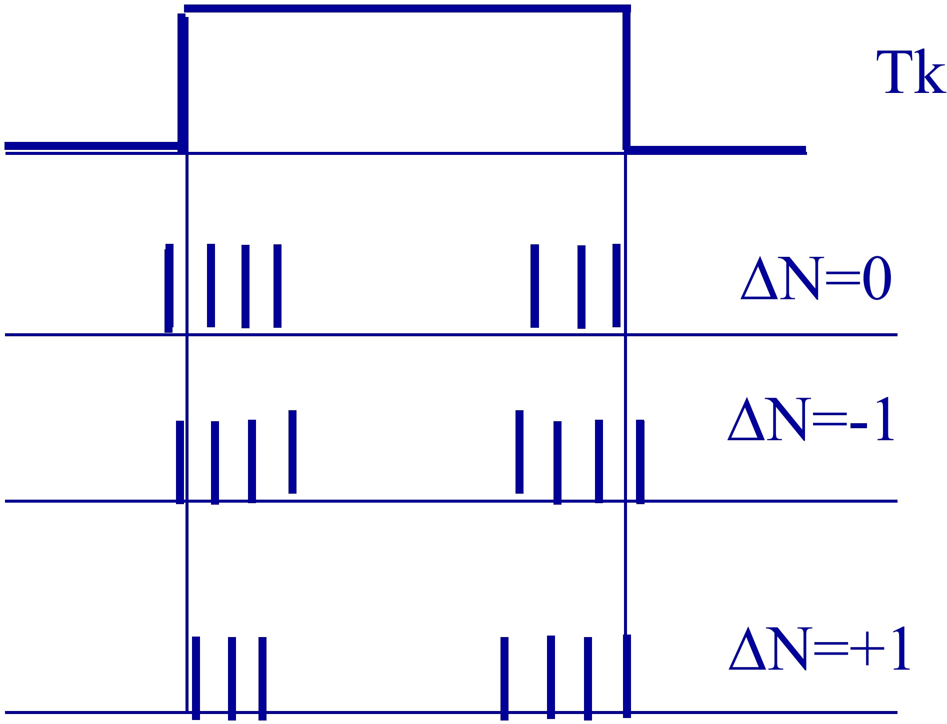
Frequency to be measured:

$$f_x = N \frac{f_0}{n}$$

Relative measurement error of the digital frequency meter

$$\frac{\Delta f_x}{f_x} = \frac{\Delta f_0}{f_0} \pm \frac{1}{N}$$

$Tk = N/f_0$



$\Delta N = 0$

$\Delta N = -1$

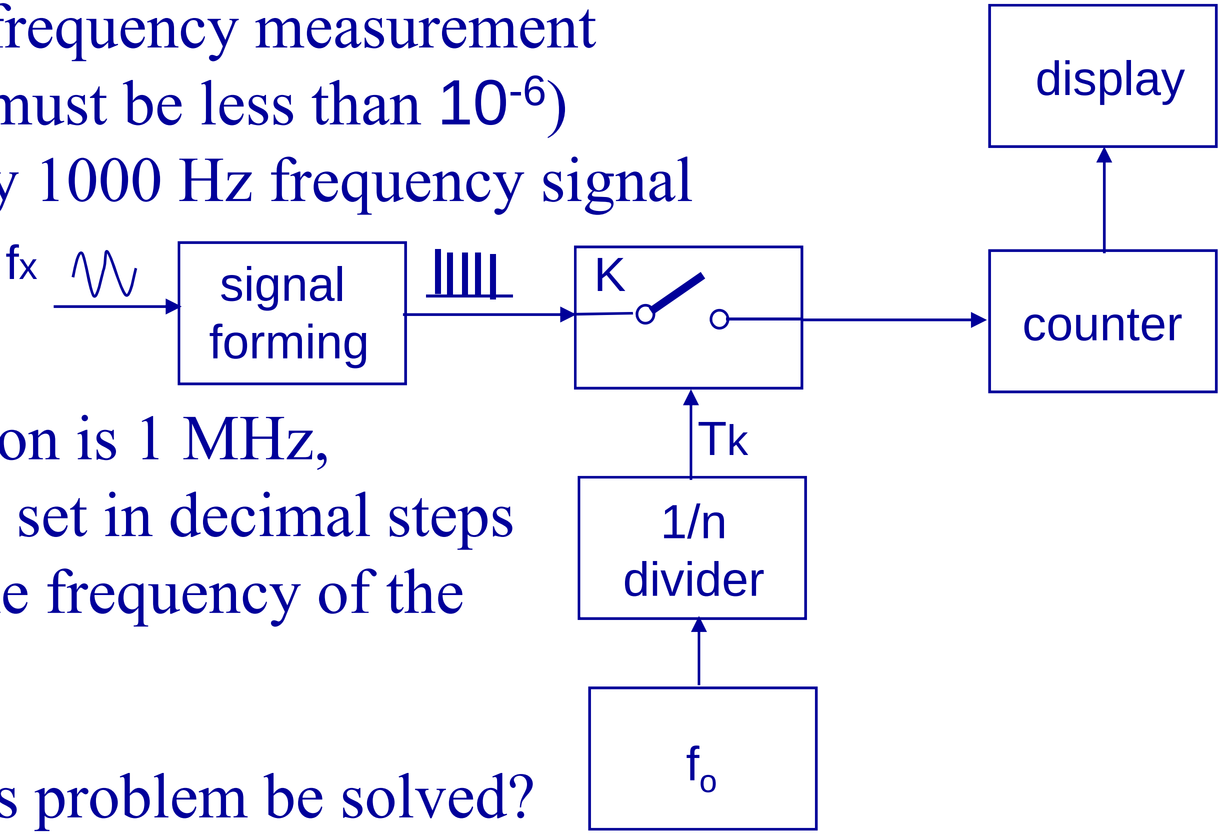
$\Delta N = +1$

Example

Problem: accurate frequency measurement (the relative error must be less than 10^{-6}) of an approximately 1000 Hz frequency signal

Conditions:

- the frequency of the frequency etalon is 1 MHz,
- the divider can be set in decimal steps
- the accuracy of the frequency of the etalon is 10^{-10}



Question 1: Can this problem be solved?
Question 2: How?

Solution:

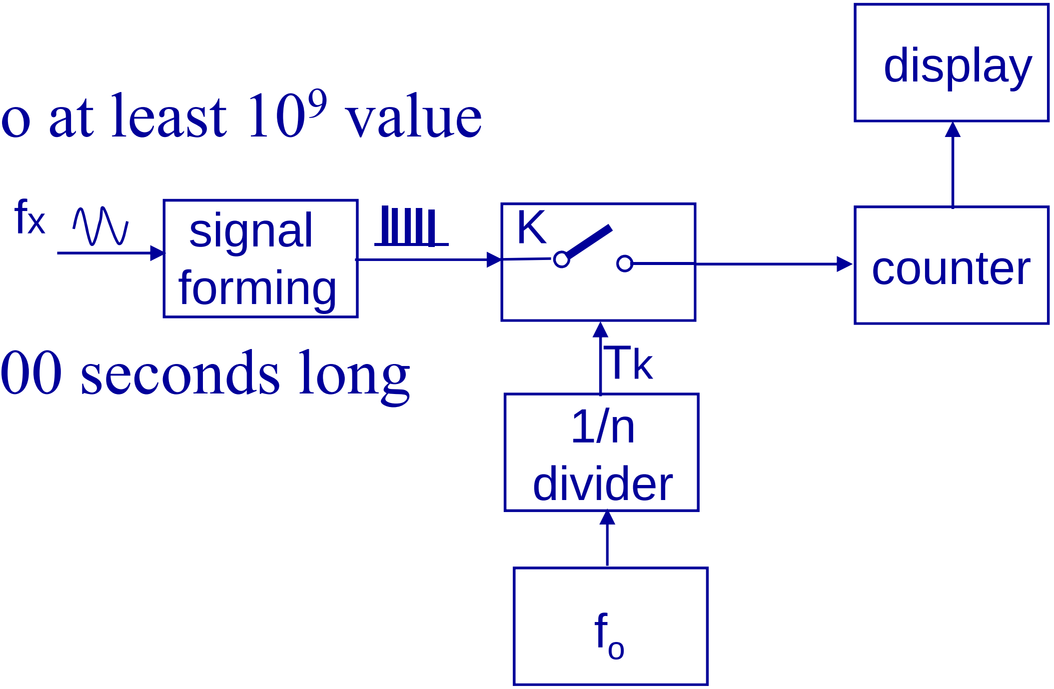
This problem can be solved if we can count more than 1000000

and

If the divider can be set to at least 10^9 value

and

If we measure at least 1000 seconds long



Because

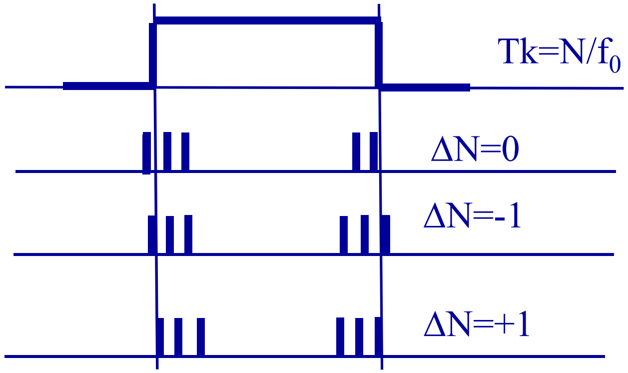
$$\frac{\Delta f_x}{f_x} = \frac{\Delta f_0}{f_0} \pm \frac{1}{N}$$ $10^{-6} = 10^{-10} \pm 1/N$ $10^{-6} \approx 1/N$

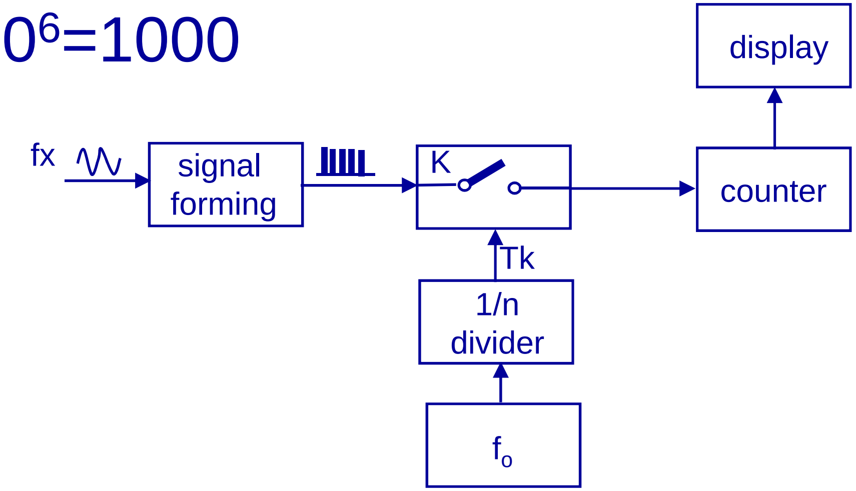
and

$$f_x = N \frac{f_0}{n}$$ $10^3 = 10^6 \times 10^6/n$ $n = 10^9$

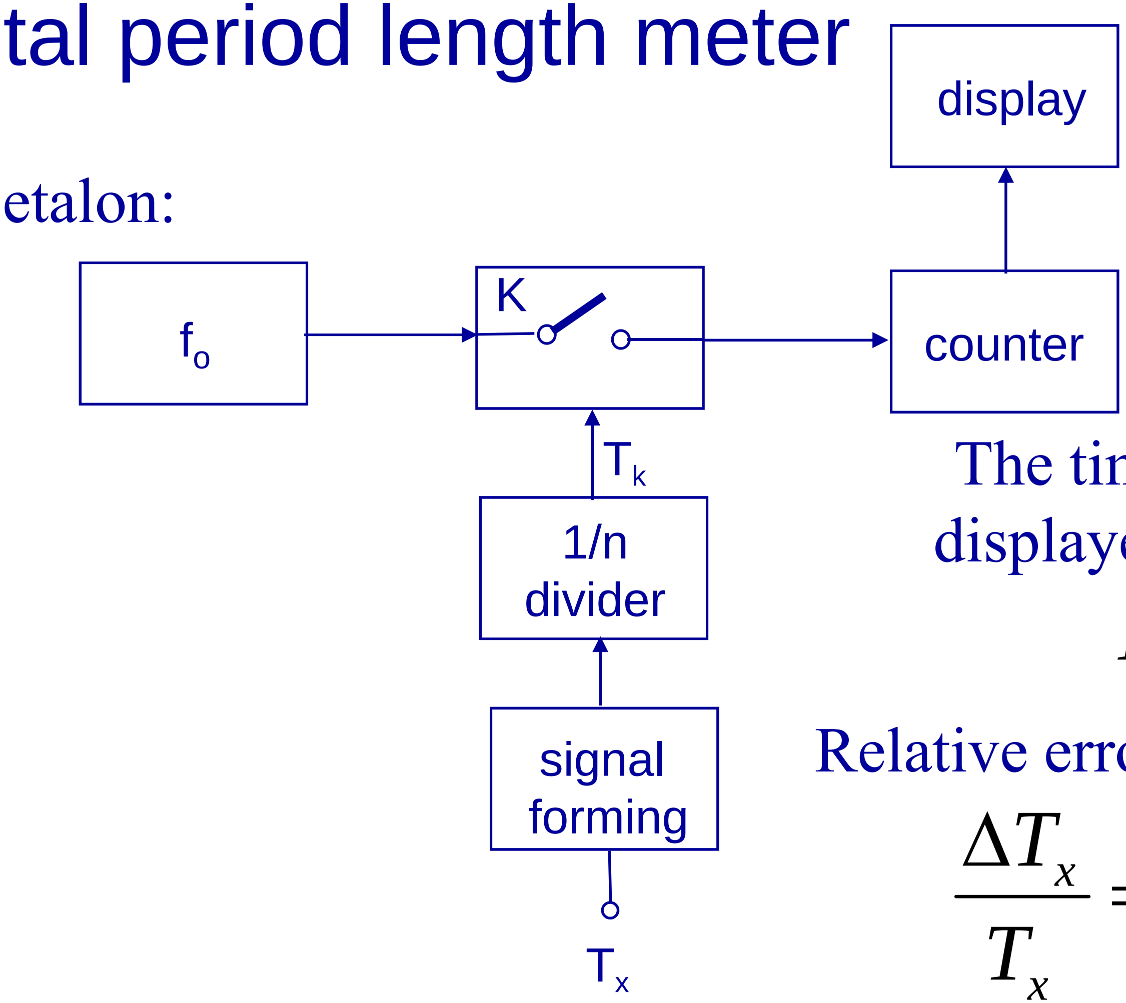
and

$Tk = n/f_0$ $Tk = 10^9/10^6 = 1000$





Digital period length meter



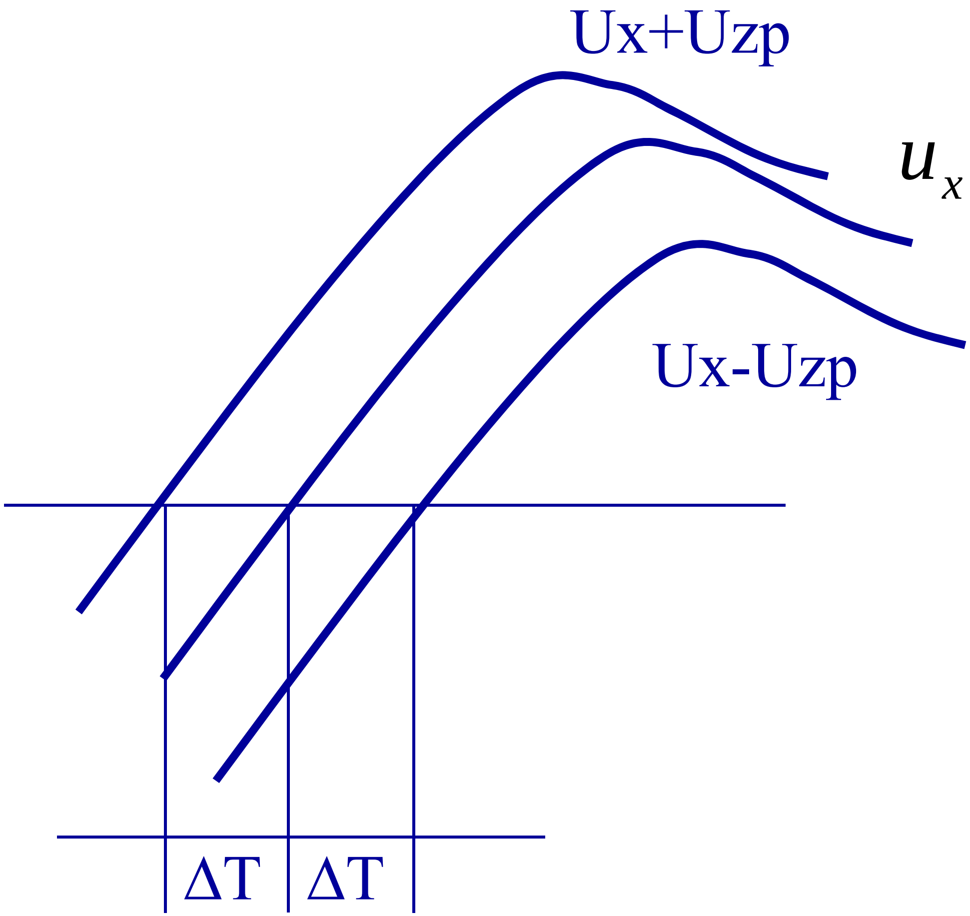
The time of the period, displayed by the counter:

$$N = T_x n f_0$$

Relative error of the measurement:

$$\frac{\Delta T_x}{T_x} = -\frac{\Delta f_0}{f_0} \pm \frac{1}{N}$$

Trigger error of a digital period length meter



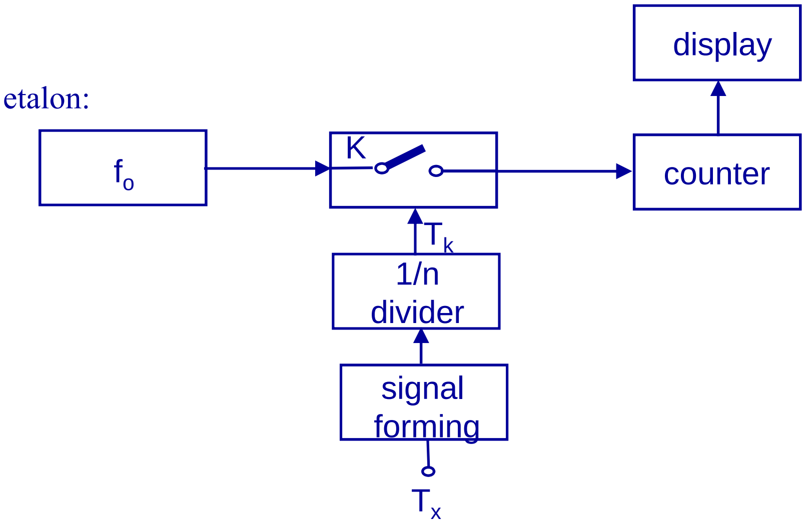
$$u_x = U_{xp} \sin \frac{2\pi}{T_x} t$$

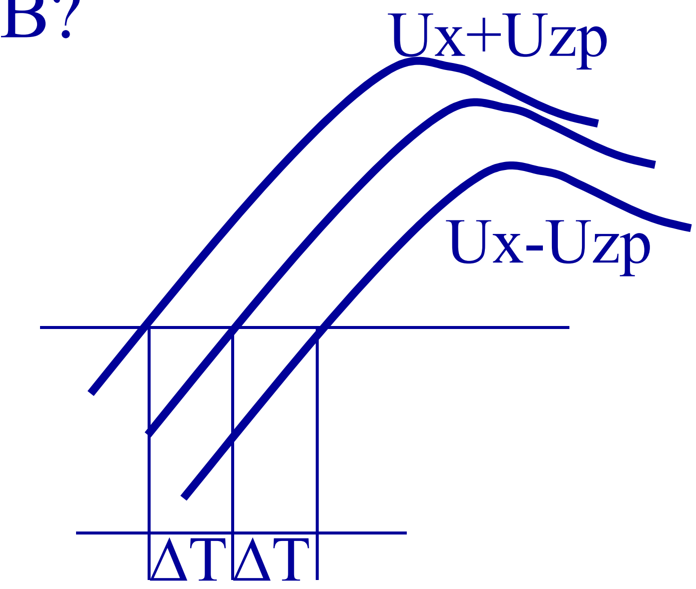
Trigger error of
the time measurement::

$$\Delta T = \frac{T_x}{2\pi} \frac{U_{zp}}{U_{xp}}$$

Example

Problem: What is the trigger error of a digital period length meter, if the frequency of the measured signal is 1kHz and signal to noise ratio is 20 dB?





Solution:

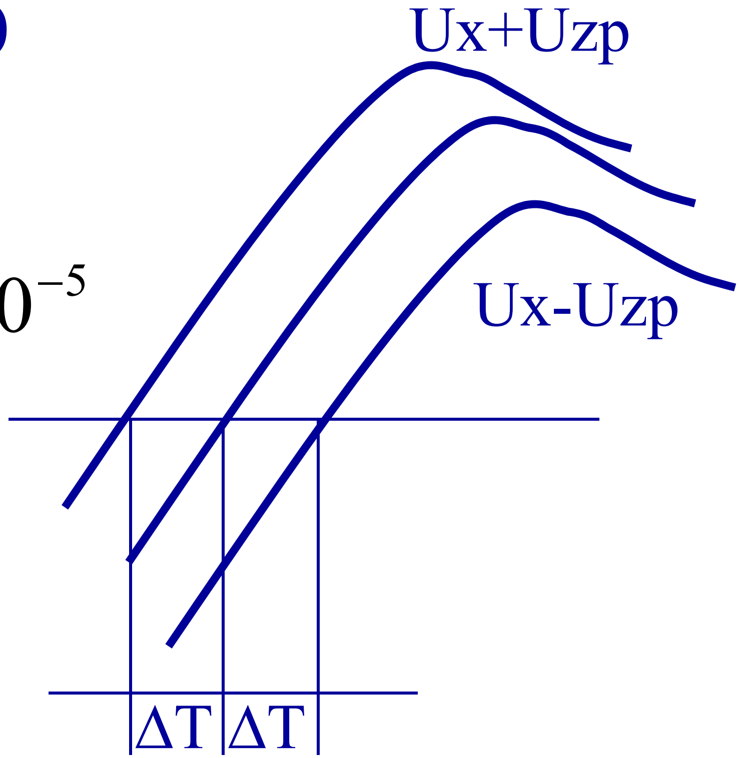
0,016 ms which is equal to1,6%

Justification:

$20\lg(U_{xp}/U_{zp})=20 \quad U_{xp}/U_{zp}=10$

$$\Delta T=\frac{T_x}{2\pi}\frac{U_{zp}}{U_{xp}}=\frac{10^{-3}}{2\pi 10}=1,6*10^{-5}$$

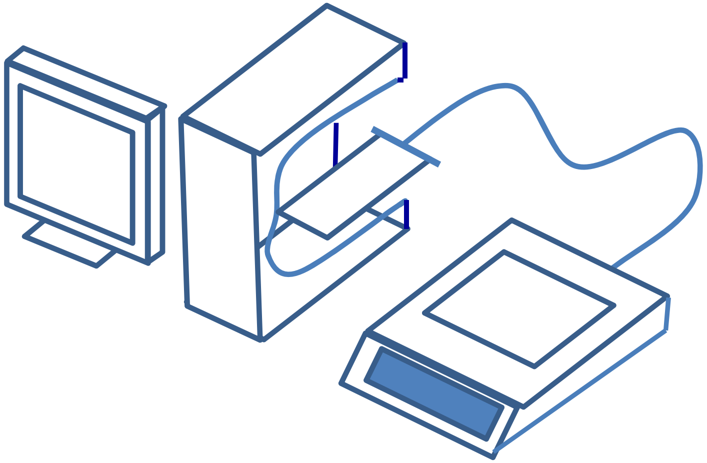
$\Delta T/T=1,6\ 10^{-5}/10^{-3}=1,6\%$



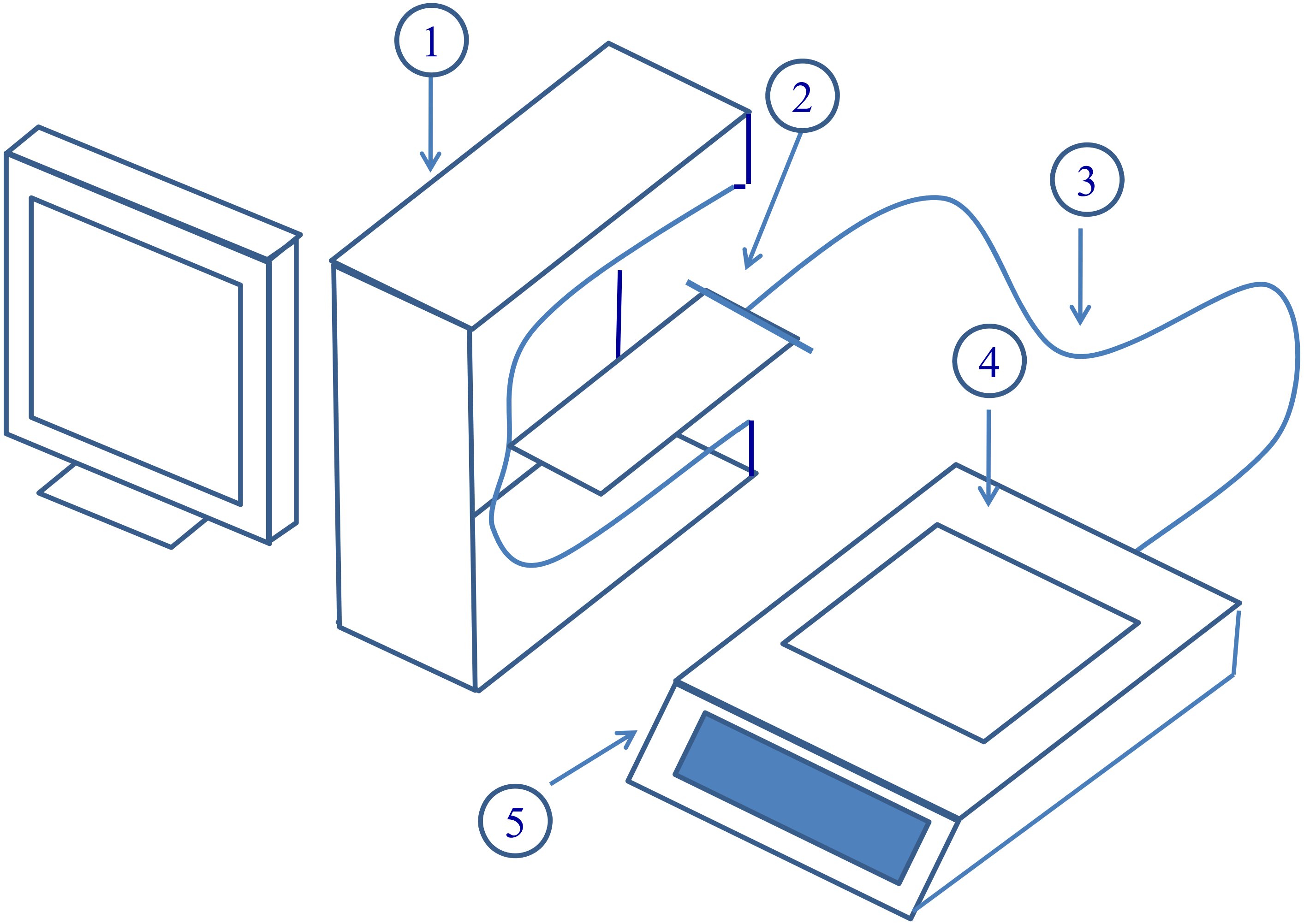
The ELVIS system

The NI ELVIS system has been developed for a special education LabVIEW application. During the introduction of LabVIEW only virtual instruments were created.

The NI ELVIS system also includes real instruments, signals also can be observed by separate real instruments, real signals also can be measured and analyzed by the ELVIS system.



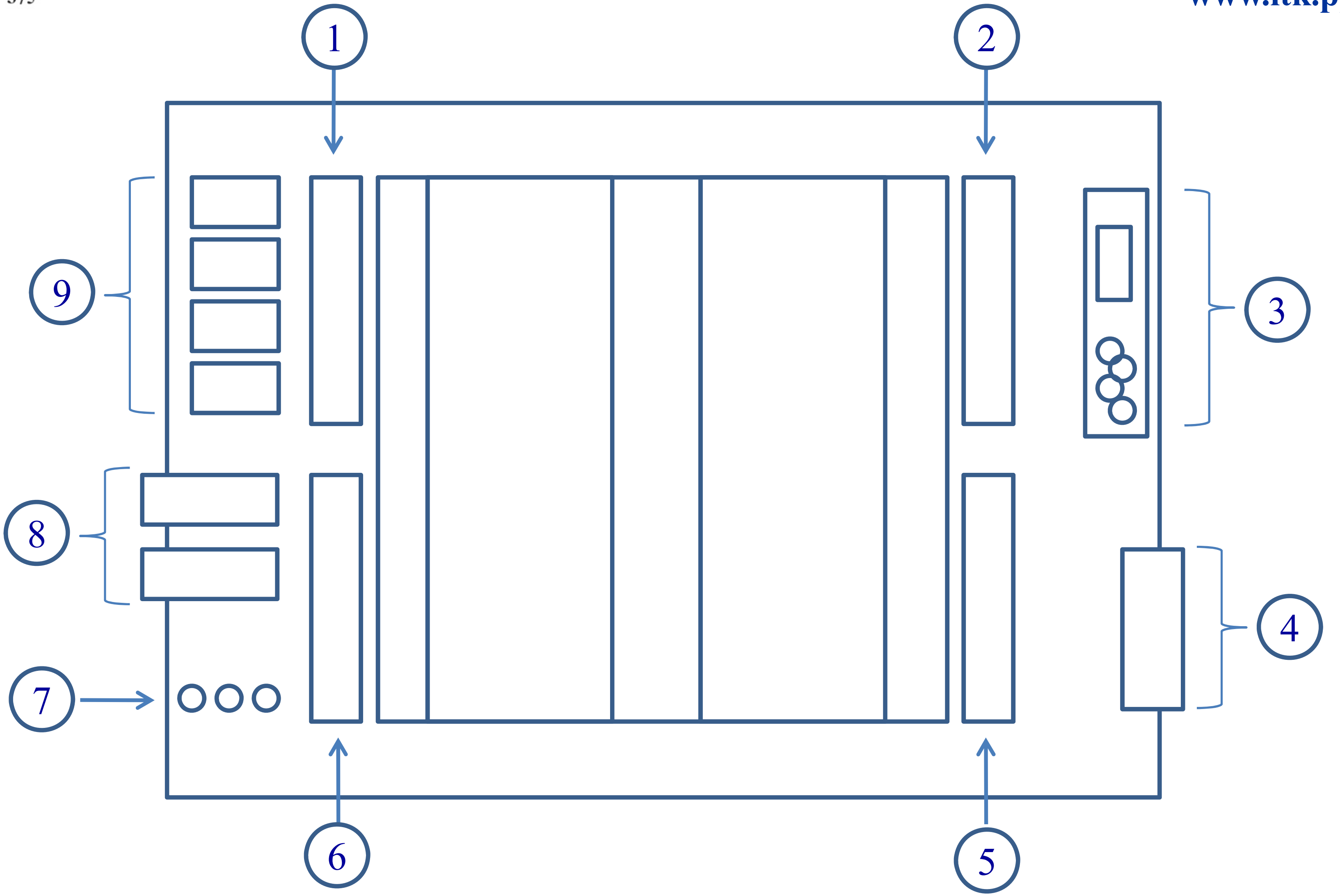
Electrical Measurements: Measurement of voltage and time



Components of the ELVIS system
:

1 – PC, running LabVIEW software
2 – data aquasition card
3 – link cable
4 – ELVIS test board (right-sized electronic components and wires can be assembled to circuits and connected to measuring instruments)
5 – ELVIS workstation (including a variable dual power supply, a function generator, a digital multimeter and an oscilloscope, connected via the data acquisition card to the PC and the LabVIEW software system)

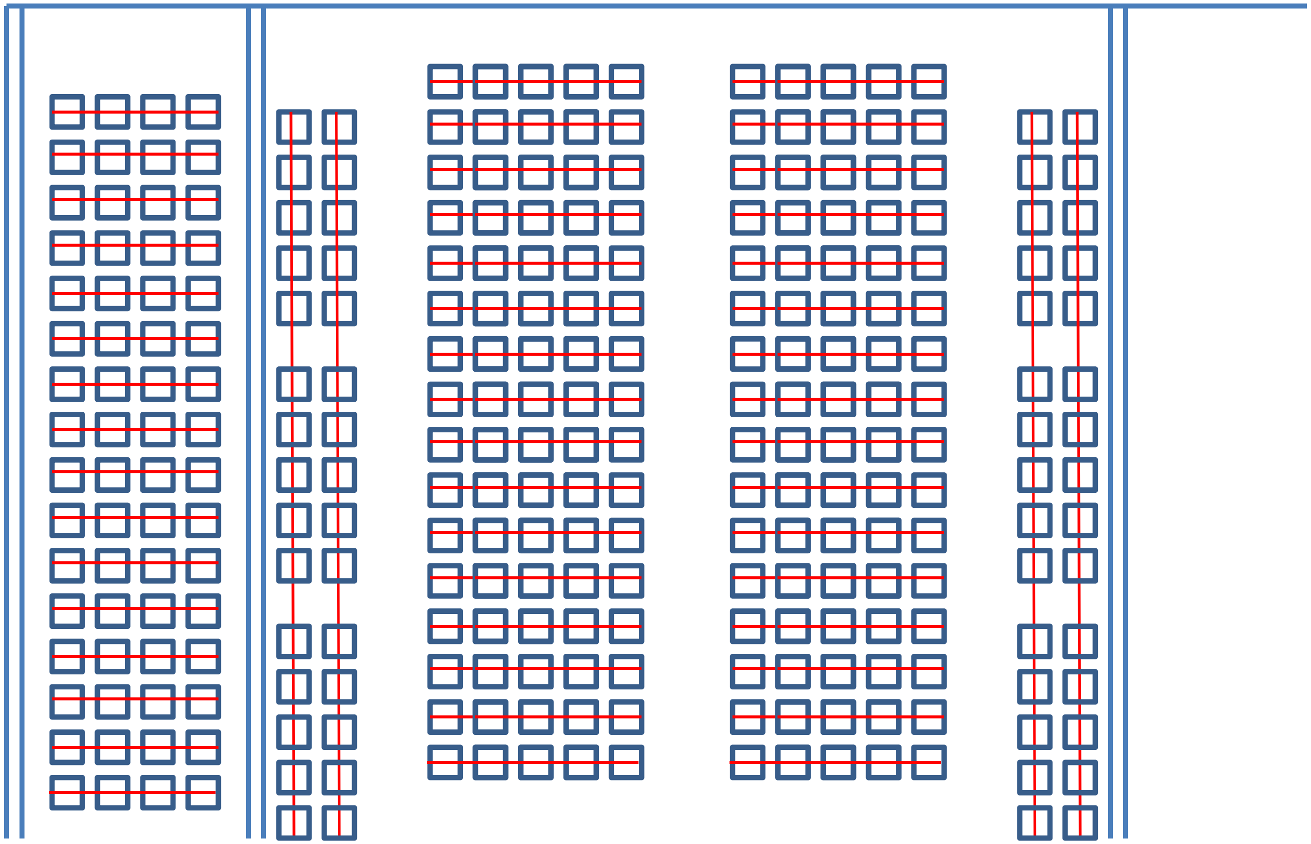
Electrical Measurements: Measurement of voltage and time



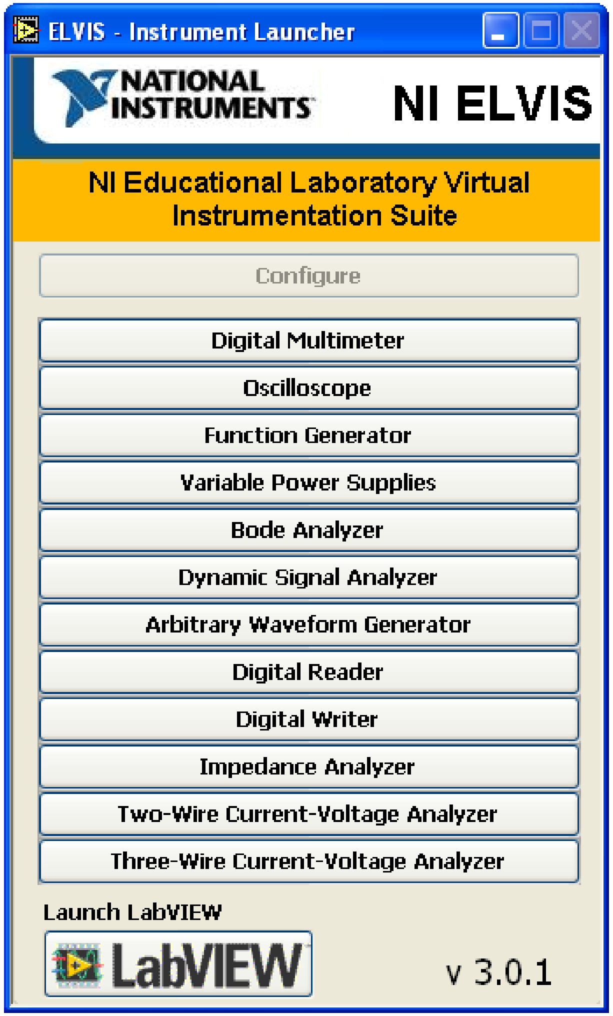
Electrical Measurements: Measurement of voltage and time

1. Analog inputs, oscilloscope inputs
2. Digital inputs, outputs
3. LED – line
4. D connector
5. Counter/Timer signal connectors
6. Digital Multimeter signal inputs ATTENTION: THERE ARE SPECIAL TERMINALS FOR MEASURING THE VOLTAGE. If you connect a battery or AC adapter to the current measurement inputs (it also serves to measure capacity and resistance), the instrument may be damaged !!!! The inputs of the function generator can be also found here.
7. LEDs indicating the state of the power switch
8. BNC terminals
9. Banana jacks

Electrical Measurements: Measurement of voltage and time



Electrical Measurements: Measurement of voltage and time

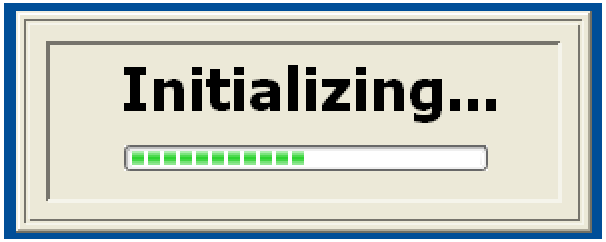


ELVIS - Instrument Launcher

NATIONAL INSTRUMENTS

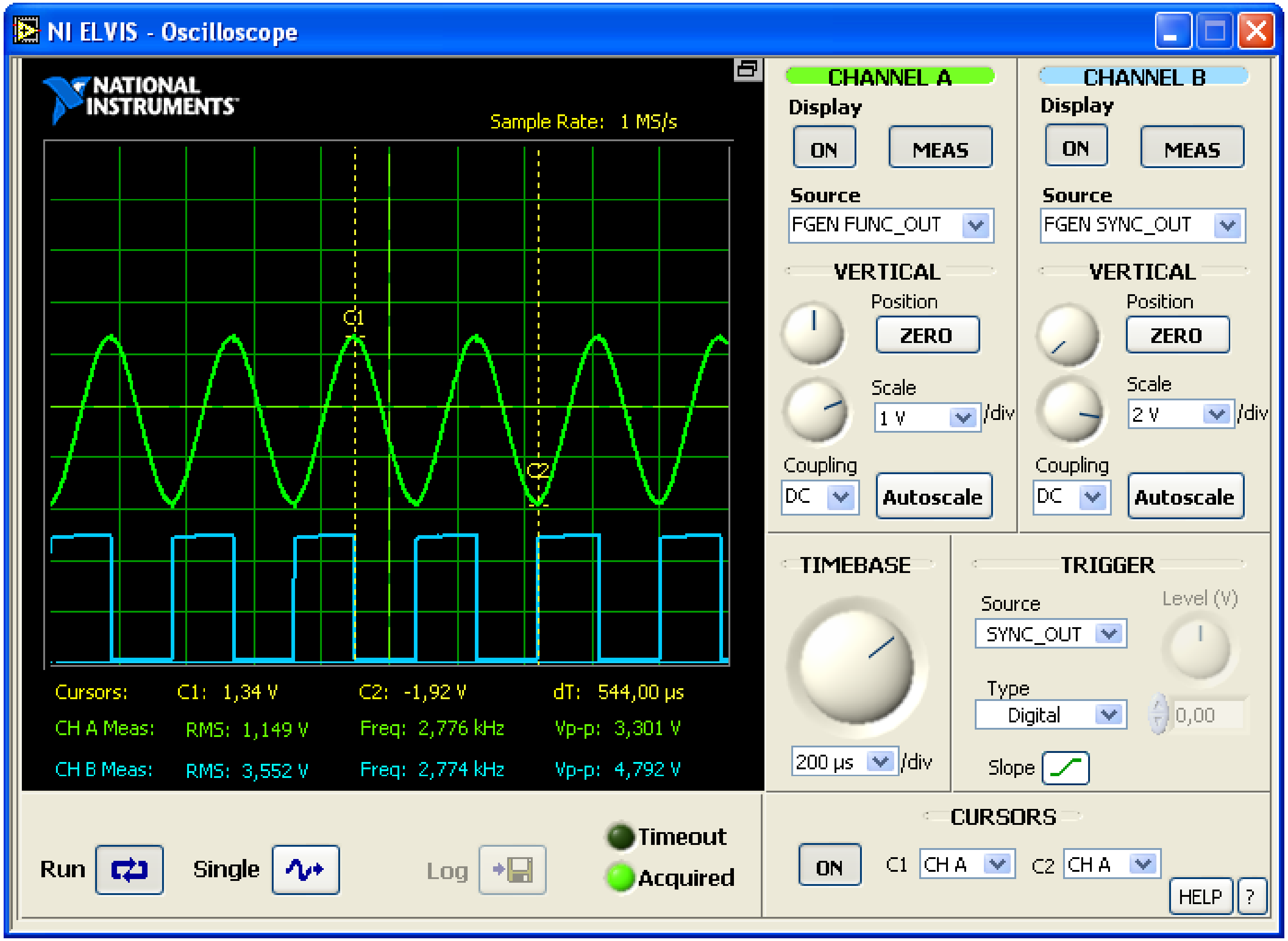
NI ELVIS

NI Educational Laboratory Virtual Instrumentation Suite



Initializing...

Electrical Measurements: Measurement of voltage and time



NI ELVIS - Oscilloscope

Sample Rate: 1 MS/s

Cursors: C1: 1,34 V C2: -1,92 V dT: 544,00 µs

CH A Meas: RMS: 1,149 V Freq: 2,776 kHz Vp-p: 3,301 V

CH B Meas: RMS: 3,552 V Freq: 2,774 kHz Vp-p: 4,792 V

CHANNEL A

Source FGEN FUNC_OUT

Scale 1 V /div

Coupling DC

CHANNEL B

Source FGEN SYNC_OUT

Scale 2 V /div

Coupling DC

TIMEBASE 200 µs /div

TRIGGER

Source SYNC_OUT

Type Digital

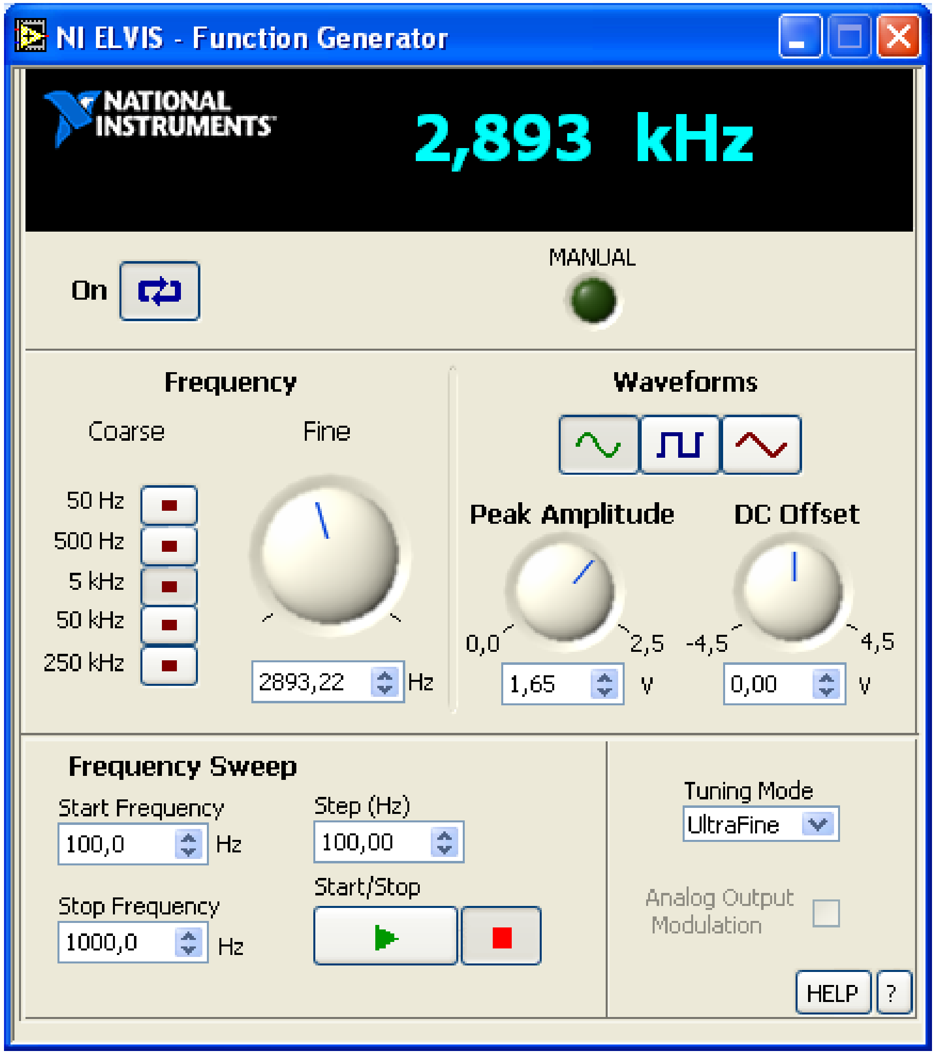
Level (V) 0,00

CURSORS

C1 CH A

C2 CH A

Electrical Measurements: Measurement of voltage and time



2,893 kHz

Fine: 2893,22 Hz

Peak Amplitude: 1,65 V

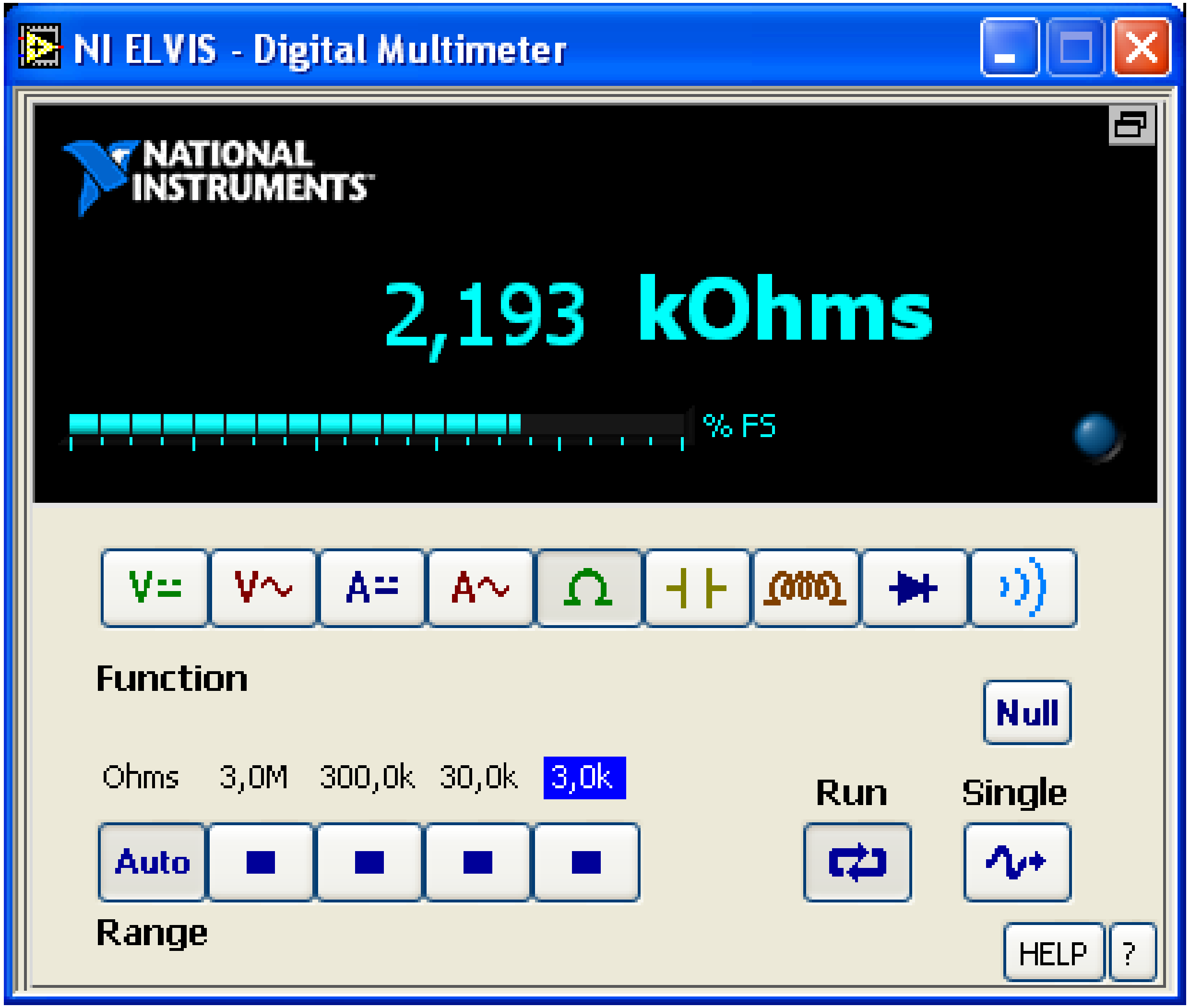
DC Offset: 0,00 V

Start Frequency: 100,0 Hz

Step (Hz): 100,00

Stop Frequency: 1000,0 Hz

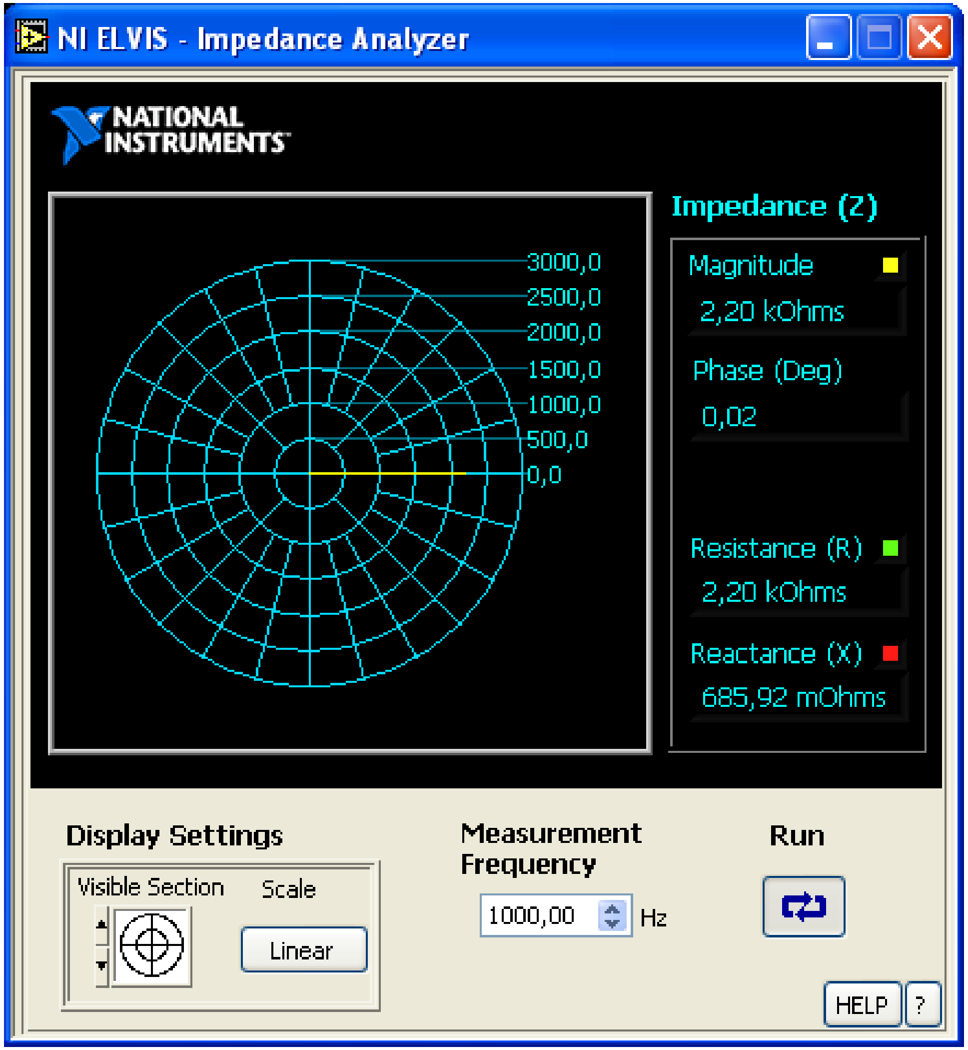
Tuning Mode: UltraFine



NI ELVIS - Digital Multimeter

2,193 kOhms

Electrical Measurements: Measurement of voltage and time



NI ELVIS - Impedance Analyzer

Impedance (Z)

Magnitude 🟨
2,20 kOhms

Phase (Deg)
0,02

Resistance (R) 🟩
2,20 kOhms

Reactance (X) 🟥
685,92 mOhms

Display Settings

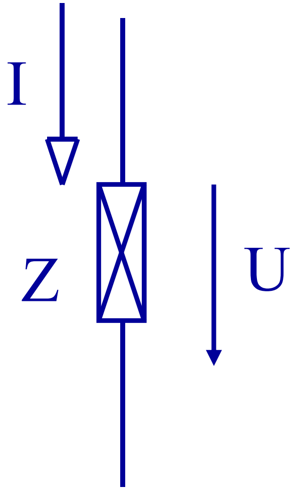
Visible Section

Scale: Linear

Measurement Frequency

1000,00 Hz

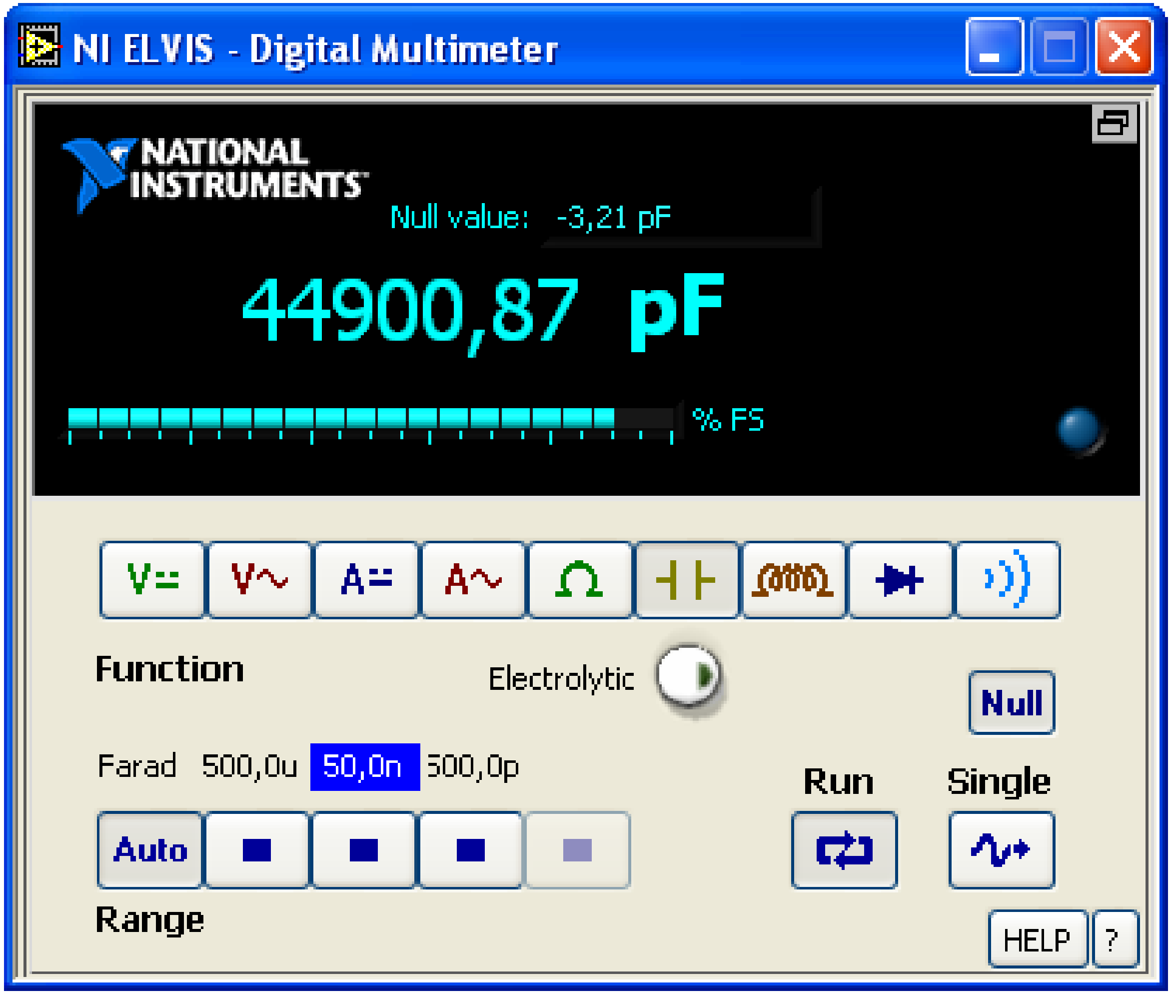
Run



Z=U/I

Z, U, I complex values

Electrical Measurements: Measurement of voltage and time

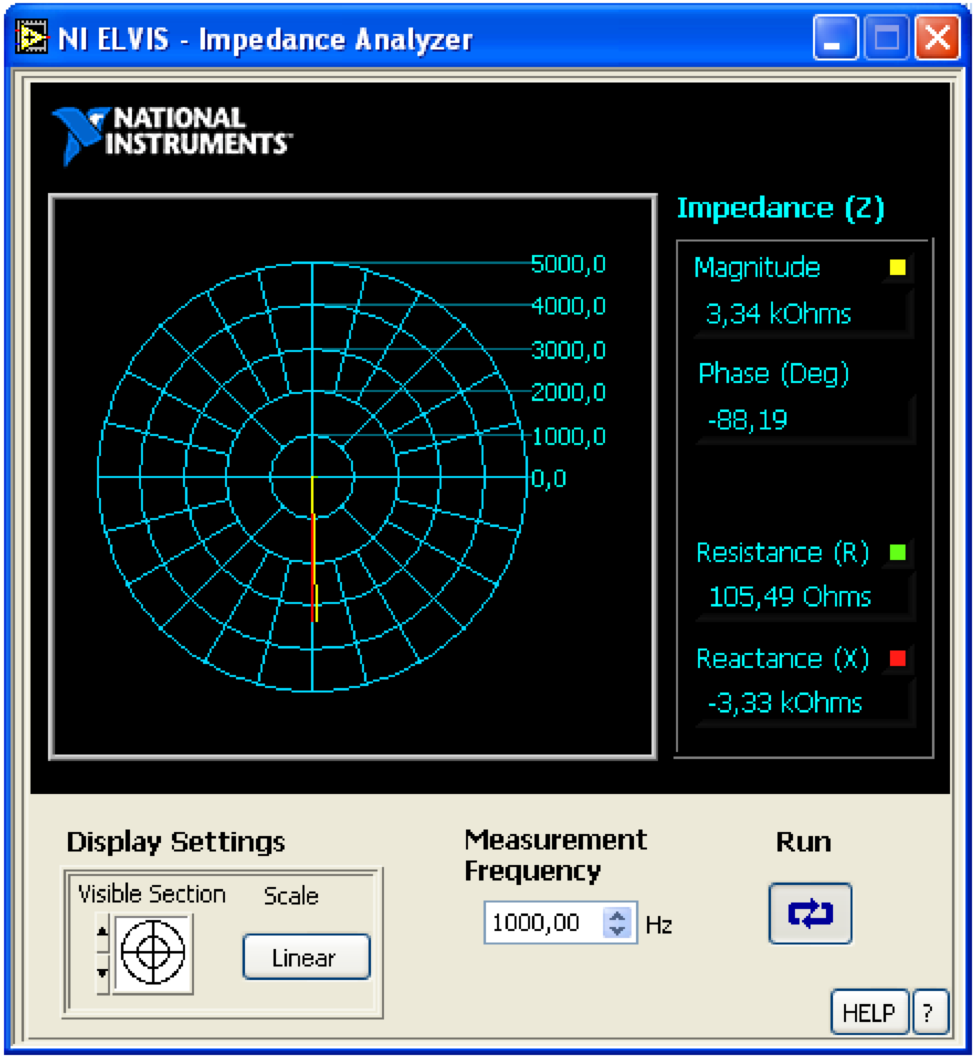


NI ELVIS - Digital Multimeter

Null value: -3,21 pF

44900,87 pF

Electrical Measurements: Measurement of voltage and time



NI ELVIS - Impedance Analyzer

Impedance (Z)

Magnitude 🟨
3,34 kOhms

Phase (Deg)
-88,19

Resistance (R) 🟩
105,49 Ohms

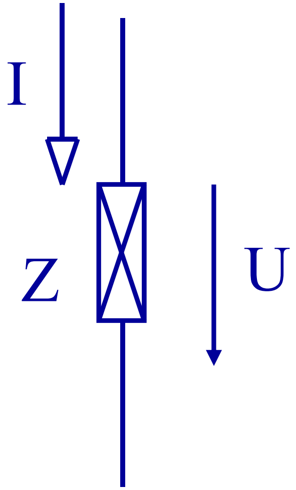
Reactance (X) 🟥
-3,33 kOhms

Display Settings

Visible Section
Scale: Linear

Measurement Frequency
1000,00 Hz

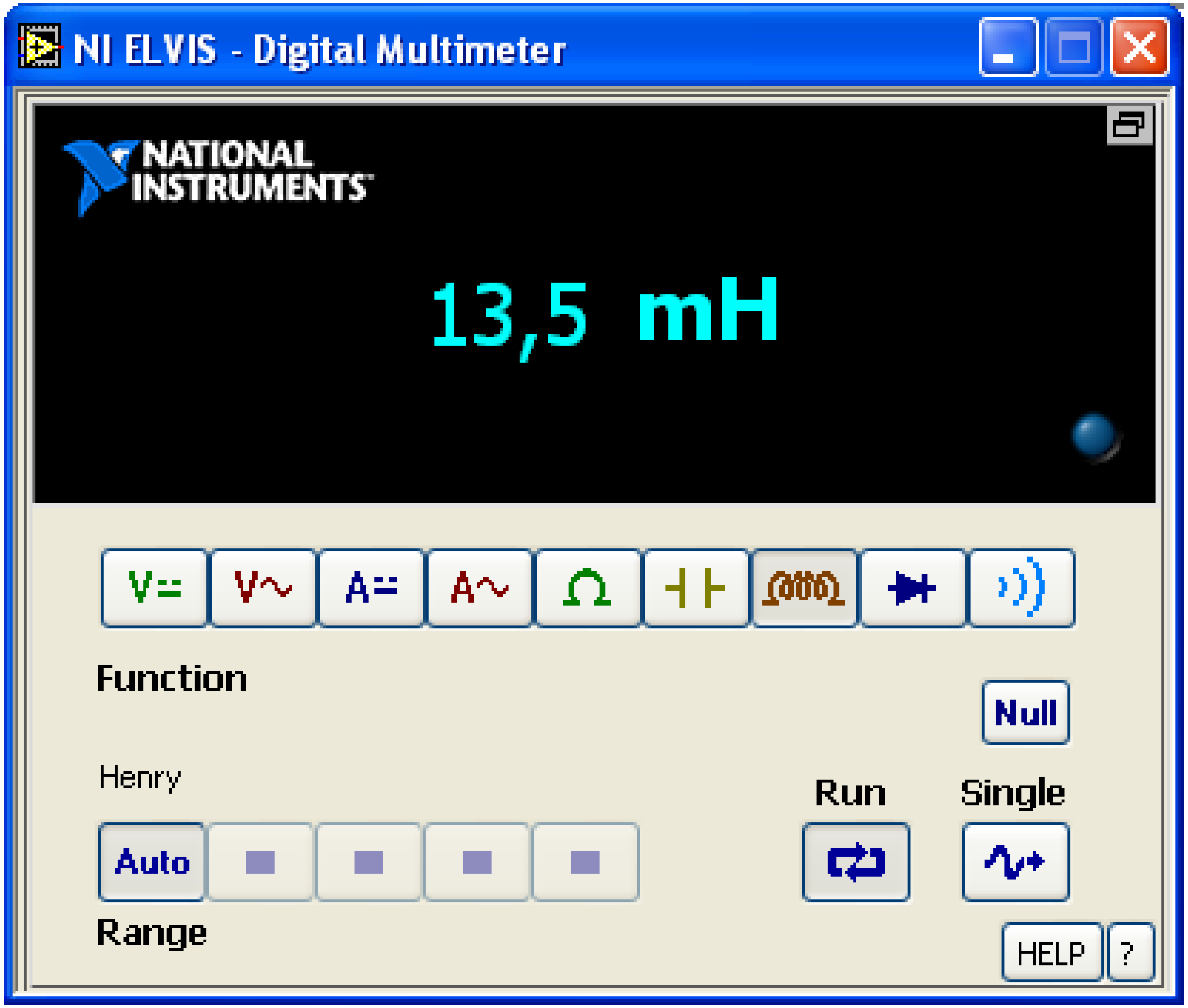
Run



Z=U/I

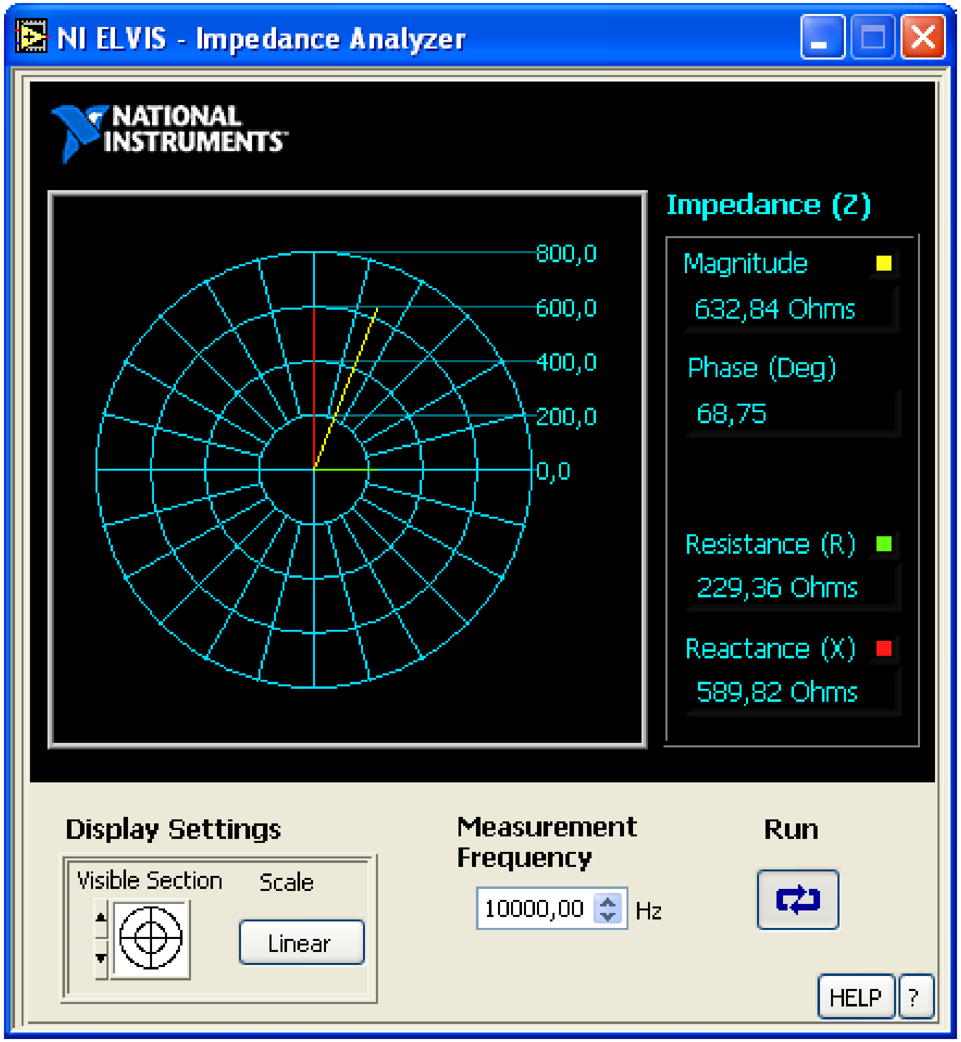
Z, U, I complex values

Electrical Measurements: Measurement of voltage and time


NI ELVIS - Digital Multimeter

13,5 mH

Electrical Measurements: Measurement of voltage and time



Impedance (Z)

Magnitude 🟨
632,84 Ohms

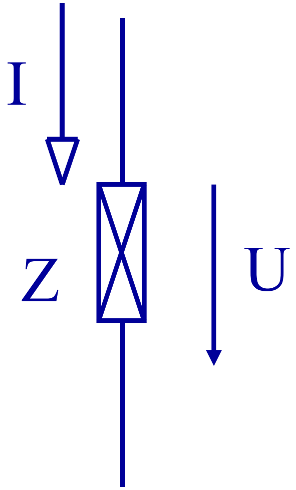
Phase (Deg)
68,75

Resistance (R) 🟩
229,36 Ohms

Reactance (X) 🟥
589,82 Ohms

Display Settings
Visible Section
Scale: Linear

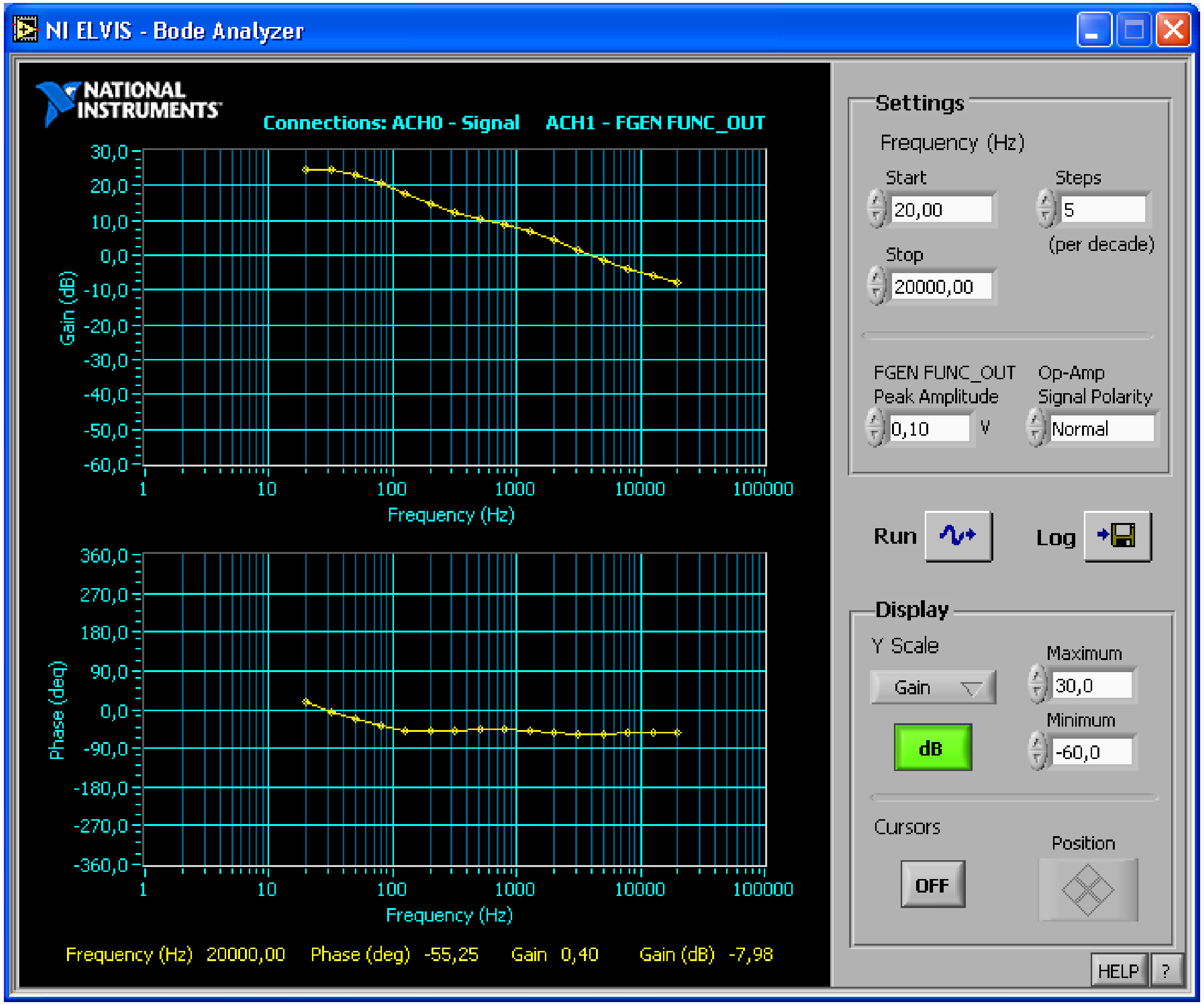
Measurement Frequency: 10000,00 Hz



Z=U/I

Z, U, I complex values

Electrical Measurements: Measurement of voltage and time



Connections: ACH0 - Signal ACH1 - FGEN FUNC_OUT

Frequency (Hz) 20000,00 Phase (deg) -55,25 Gain 0,40 Gain (dB) -7,98

Settings

Frequency (Hz)

Start: 20,00

Steps: 5 (per decade)

Stop: 20000,00

FGEN FUNC_OUT Peak Amplitude: 0,10 V

Op-Amp Signal Polarity: Normal

Display

Y Scale: Gain

dB

Maximum: 30,0

Minimum: -60,0

Cursors: OFF

Position