

CNS Institute for Physics Teachers

Title:	Introduction to the Oscilloscope OR Not All Volts are Created Equal OR I Hear the Beat ... So That's What it Looks Like
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Abstract:	<p>The oscilloscope is one of the most versatile and heavily used measuring instruments in science, engineering, and industry in general. It earns this status, in part, because it neatly provides an instant graph of how the voltage of a signal varies as a function of time or a second signal, and in part because so many different devices result in a signal worthy of such consideration. It also allows easy comparison of separate signals. This lab will provide an introduction to the basic operation of a 'scope'. An examination of AC and DC voltages and of the superposition of sound waves to cause beats will provide a useful means to that end.</p>
Time Required:	
NY Standards Met:	
Special Notes:	Although most of this lab will relate to the use of any oscilloscope, this lab will focus on the Tektronix TDS-1002B oscilloscope used in the Cornell Institute for Physics Teachers.
Credits:	http://www.physics.udel.edu/~watson/phys345/lab/scope.html George Watson, Univ. of Delaware, 1999.

Introduction to the Oscilloscope
OR Not All Volts are Created Equal
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Introduction

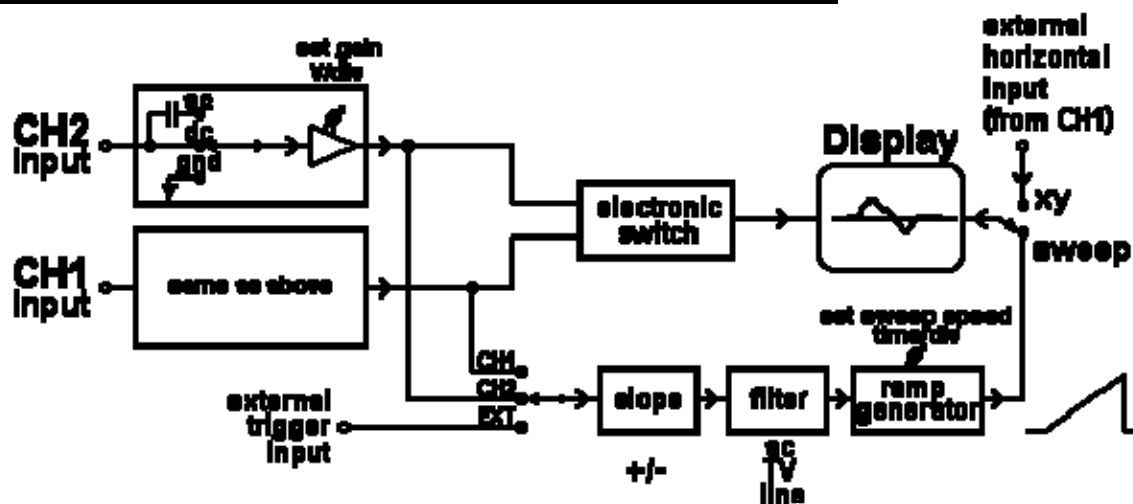
The oscilloscope or 'scope' is among the most versatile and heavily used electronic measuring instruments in science, engineering, and industry. It earns this status, in part, because it neatly provides an instant graph of how the voltage of a signal varies as a function of time, and in part because so many different devices, called transducers, result in signals worthy of such consideration. A microphone, which converts sound waves into an electric voltage which varies with time, is an excellent example. A scope also allows easy comparison of separate signals. This lab will provide an introduction to the basic operation of a 'scope'. This lab will necessarily include fairly detailed descriptions. Please do not skip reading them. The combination of reading and doing will help you master this fairly complex instrument. By the same token, don't be intimidated by the number of controls on the front of the scope. There is a lot of duplication of controls, and a bit of exploration will allow you to really master them.

A function generator will also be used in this lab. It is an electronic device that produces uniform sine, square, and/or triangle wave electric signals over a wide range of selectable frequencies and amplitudes. The function generator in this lab will provide signals both for viewing and comparison.

How A Scope Works – The Basics

An oscilloscope doesn't exactly display the signal itself, but rather displays a processed, scaled display of the voltage signal as a function of time (usually) or as a function of a second signal voltage. When one adjusts the scaling of the x or y axis on the scope, the input signal is not changing at all. Think of such adjustments as zooming in or out on the view of the signal, instead. Older CRT (Cathode Ray Tube) scopes accomplished the display of a signal by using parallel electrically charged plates above, below, right, and left of the 'picture tube' to force the electron beam to sweep across a fluorescent phosphor screen in accord with the input signal's behavior, much like CRT television displays do with the incoming program signal. Newer scopes, like the ones used here, use digital processing and liquid crystal displays like those found in flat panel televisions or computer displays, and some scopes even work by bringing the signal into a computer and processing and displaying the information right on the computer monitor.

Figure I: General Block Diagram of a 2 Channel Oscilloscope



(Diagram reprinted by permission from Dr. George Watson, University of Delaware)

The x-axis ... Sweeping the electron beam across the screen: The ‘Ramp Generator’ in Figure I is a signal generator which creates a voltage signal like the ‘sawtooth’ shown at the bottom right of the diagram above. A triggering (initiating) signal causes the sawtooth signal to begin. As the voltage of the sawtooth climbs (the sloped portion) the electron beam of the scope sweeps across the screen. When it gets to the maximum voltage (right hand side of the screen), the voltage drops quickly back to the maximum negative voltage (left hand side of the screen), and repeats the cycle. Both the method of initiating the sweep (triggering), and the rate of the sweep are adjustable with controls on the front panel of the scope. The steeper the slope of the sawtooth, the faster the electron beam sweeps across the screen.

The y-axis ... displaying a voltage: An external signal voltage is connected to one of the oscilloscope inputs. A second signal can be connected to the second input if desired. The signal is amplified to the extent set with the vertical gain controls on the front panel of the scope and applied to the y-deflection plates. The more positive the input signal, the higher the electron beam hits the screen, and the more negative the input signal, the lower it hits.

The graph: Since the x-axis and y-axis motions described above occur at the same time on the same beam, they result in the plotting of a graph of the input voltage vs. time!

The scopes you will be using here are rather fancy digital units. They don’t use electron beams in the same way as CRT scopes do, but the displayed signals are interpreted in pretty much the same way. The basic concepts provided here apply to most scopes.

Display Controls:

Appendix A shows the front panels of the function generator and the oscilloscope used in this lab’s activities. Feel free to ‘try out’ any or all of the controls on both devices, as much of your learning here will come from exploring the instruments. The labels and numbers on the drawings and in the text of the lab should help with the settings. The buttons are numbered

in a roughly clockwise order starting at the upper left of each diagram. The number labels appear in square brackets in both the drawings and the text.

Using a function generator

- Connect the OUTPUT terminal [5] of the function generator to a speaker. The connectors on both the scope and the function generator are called ‘BNC’ connectors. To attach wires, push the BNC connector straight on, then turn it about a quarter turn clockwise to lock it in place. To remove it, turn counterclockwise until it stops, and then pull the connector straight off. It doesn’t matter which wire goes to which terminal on the speaker.
- Turn the power [1] on. The function generator might or might not be set to an audible frequency (roughly 20 Hz – 20 KHz for good human hearing), and it might or might not be set to an audible amplitude.
- The three buttons [3] in the upper right-hand corner of the function generator show little pictures of the three waveforms the function generator can produce. Push the button with the sine wave.
- Set the frequency [7] to a convenient frequency in the audio range between 200 and 400 Hz. How? Figure it out!
- (OK ... here’s a hint: Select an appropriate ‘range’ or ‘decade’ setting to get to the right order-of-magnitude (power of ten) with a button [2] in the row just to the left of the waveform buttons. Then adjust the course frequency to get a value in the range.)

What do you hear?

- Leave the frequency knob alone and adjust the AMPL (‘amplitude’) knob [4].

What do you hear as the adjustment is made?

- Leave the amplitude knob alone and adjust the larger (COARSE) [7a] or the smaller (FINE) [7b] frequency knob.

What do you hear as the adjustment is made?

- Push the other waveform buttons [3] to sample their effect.

The triangle wave sounds like:

The square wave sounds like:

- Disconnect the speakers. The sci-fi movie sounds get pretty annoying pretty quickly!

Setting up the scope

- Plug in the oscilloscope and turn it on. The switch is on top. The scope will go through a warm up cycle, and ask for your language preference. Don't do anything but wait impatiently a bit longer and the scope will display a graph grid surrounded by words and numbers ... useful info, no doubt.
- Some scopes have an adjustable stand so they can be set to a comfortable viewing angle. Do so.

(Side note: CRT scopes have a FOCUS and an INTENSITY knob to adjust the sharpness and brightness of the trace (the line on the screen). Digital scopes like ours have neither, and do not give such nice sharp displays. They do, however, have many very redeeming qualities! When using an analog CRT scope, set the trace to be sharp and bright enough to be easily viewed, but no more intense than necessary. An overly bright display will cause the phosphor of the display to quickly and irreparably deteriorate.)

- Digital scopes like these remember their previous settings, but let's start fresh with the factory default settings. Push the DEFAULT SETUP button [7] for generically useful settings.

Observe a rectangular field with a heavy black horizontal line in the middle of the display. It says 'DEFAULT' at the top and 'Undo Default Setup' at the bottom. What is the input voltage at the moment? What are two indicators that this is true?

Input voltage = _____ volts

a)

b)

- Push the button labeled CH 1 MENU [4]. The right-hand side of the display should now display a column of labels beneath the header CH 1.
 - The first label is 'Coupling'. If 'AC' appears just beneath it in reverse video (white letters on a black background), that is the desired setting at the moment. If 'DC' appears, push the function button [14a] which is to the right of that label and the coupling will change to 'AC'. As soon as any non-zero voltage is displayed, this setting will cause it to be centered vertically on the screen.
 - FYI: The centering in AC coupling is accomplished by stripping out any underlying DC potential. DC coupling feeds the input signal directly into the scope w/o such processing, and the ground coupling shorts the input, providing an accurate zero reference.
- Plug the BNC connector of the oscilloscope probe into CH 1 [13] on the oscilloscope and make sure its switch is in the 1X position.
- Clip the probe's spring-loaded hook onto the positive (red) terminal wire from the function generator output connector, and the alligator clip coming from the side of the probe to the negative (black) terminal wire from the function generator.
- The function generator should be set as it was before with sine wave output in the audio range of human hearing.

One down side of digital scopes is that they don't give nice sharp displays of graphs like analog scopes do, **but** they have lots of other features that more than make up for that! Digital scopes can freeze displays, save displays to USB flash drives, perform mathematical manipulation of displays, and best of all, they can autoset. Autoset is like a 'point-and-shoot' automatic camera. It does all the set-up for you.

- Push the AUTOSET button [8] which is in the upper right corner of the oscilloscope front panel, and a nice, neat sine wave with a few cycles shown should appear on the oscilloscope display. A series of values appear along the bottom of the screen.
 - The number immediately after the label CH1 is the vertical scale on the graph (the voltage corresponding to one large vertical division on the screen).
 - The number in the middle is the horizontal scale on the graph (the time corresponding to one large horizontal division on the screen). The 'large divisions are ~1 cm apart.
- Move the display around on the screen with the CH 1 POSITION knobs [3 and 6].
 - The CH 2 POSITION knob [3] will not have any effect on the vertical display because there is no signal going into the CH 2 input.
- Tweak both vertical position knobs.

What happens?

- Tweak the HORIZONTAL POSITION knob [9].

What happens?

- Turn the horizontal scale knob (SEC/DIV [10] just above the BNC input jacks) one click clockwise.

What happens to the graph displayed?

Which numbers at the bottom of the display change? In what way?

- Turn the vertical scale knob (VOLTS/DIV [12] just above the BNC input jacks) one click clockwise.

What happens to the graph displayed?

- Which numbers at the bottom of the display change? In what way?

If the display becomes completely messed up or lost, simply push the AUTOSET button to get back to the original display. (One of the joys of digital scopes!)

Changes to the input:

This lab began with a sampling of sounds from a function generator. What do those signals look like when graphed? It's time to find out!

What happens to the wave on the screen when the function generator AMPL knob is turned clockwise?

What happens to the wave on the screen when the function generator fine frequency knob is turned clockwise?

What happens to the wave on the screen when the function generator *triangle* waveform button is pushed?

What happens to the wave on the screen when the function generator *square* waveform button is pushed?

- Write down the numbers which appear across the bottom of the display and then change the range button on the function generator. You will probably have to use the AUTOSET button as a result of the change.

What happens to the display (waveform and numbers across the bottom) comparing before with after the AUTOSET button is used?

Making measurements.

In the 'Old Days', a measurement with a scope required the counting of divisions, and application of scales to every reading. Digital oscilloscopes will make such measurements automatically!

- Set the function generator for some frequency in the audio range and push the AUTOSET button to get a nice display, with three to five cycles of the signal. The frequency displayed in the lower right of the display should agree with the frequency displayed on the function generator reasonably well.
 - The frequency is also displayed at the bottom of the graphing area of the display just to the right of center.

- The period of the wave appears in the lower left. Remember that the period is simply the reciprocal of the frequency.

How would a person read the period right from the graph?

- The 'peak-to-peak' voltage (the potential difference taken from the positive peak to the negative peak, or from the maximum voltage to the minimum voltage) is displayed just above the period. The amplitude of waves is generally used in the study of acoustics instead of the peak-to-peak amplitude. Amplitude is measured *from equilibrium* to the positive *or* negative peak. That means that the amplitude for a sine wave is half the peak-to-peak amplitude.

Looking at Beat Frequency

Lets try to use the scope to look at something much more complex, and use some more features of the digital scope.

- Connect the function generator to CH 1
 - set the function generator to the tuning fork frequency + ~30 Hz
 - set the function generator amplitude to its minimum setting (ccw)
 - pull the function generator amplitude knob outwards if it isn't already there to reduce the amplitude range by 20 dB
- Set the oscilloscope CH 1 vertical scale to 1.00 V/div
- Use the vertical position control to move the CH 1 trace to the bottom of the screen
- Connect the microphone to CH 2
- Press the CH 2 button to temporarily switch the display controls from CH 1 to CH 2
- Set the CH 2 vertical scale to 1.00 V/div
- Strike the tuning fork on a soft object like the sole of a sneaker.
- Being very VERY careful not to bump the microphone with the tuning fork, bring the tuning fork close to the microphone. Don't Let It Hit!!!!

Is the microphone signal (CH 2) greater than, less than, or roughly equal to the function generator signal (CH 1)?

- Adjust the CH 2 Attenuation, one step at a time, resetting the CH 2 vertical scale to 1.00 V/div each time, until the amplitudes of CH 1 and CH 2 are approximately equal on the graphic display.
- Press the 'Math Menu' button, and then explore the various options contained in it. After exploring, leave it set to [CH 1 + CH 2].
- Have one lab partner strike the tuning fork and hold it close to the microphone. Don't let them touch!
- Another lab partner will watch for a good strong clean signal display, and press the Run/Stop button to freeze the display in time.
 - If there is not more than one cycle of the sound going from soft to loud to soft again (one 'beat') clearly seen in the sum, reset the horizontal scale to a higher value of sec/div, press Run/Stop to restart the display and repeat this experiment.
- Press the 'measure' button.
 - Record the frequency for CH 1
 - Record the frequency for CH 2
 - Calculate the difference $|f_1 - f_2|$ to get the beat frequency
- Estimate the number of horizontal divisions to go from 'soft' to 'soft'.
 - Hint: adjust the horizontal position to get a convenient start point
 - Multiply (divisions)x(seconds/division) to get the period of the beats
 - Take the reciprocal to get the beat frequency from this second method.
 - Compare.

[The oscilloscope can also facilitate measurements between two points on the screen. In a complex wave, for example, one might want to measure the time between two small features on the screen. Measurements like this use the CURSOR function of the scope. The cursor function will appear in a future version of this lab, but here is the basic idea for the previous model of our scopes: (On the previous model of these scopes, one would push button [5] near the top of the instrument panel. The menu at the right of the display would give two functions, "Type" (currently set to "Off") and "Source" (currently set to "CH 1"). Push the first function button [14a] (opposite the label "Type"), which will change it from "Off" to "Voltage." Push it a second time to get "Time," which is the measurement you're about to make. You should now see two dotted vertical lines on the display and some new items on the menu. You will be especially interested in the third menu item, "Delta," which is the time interval between the two vertical lines. Also notice that the green indicator lights underneath the two position knobs are lit up. These lights indicate that now you use the POSITION knobs to control the locations of the vertical lines (the cursors), and you'll be using both CH 1 and CH 2. Adjust the first position knob [3] to move CURSOR 1 until it is well-centered on one of the peaks of the wave. (CURSOR 1 will probably but not necessarily be the left-hand cursor.) Do the same with the second position knob [6] to move the second cursor over to the next peak. The Delta menu item now reads out the time between the cursors, and since you've set them to two corresponding points on two cycles of the wave, you've just measured the wave period. It should be in good but probably not perfect agreement with the period measurement you got with the oscilloscope in AUTOSSET mode.)]

Looking at an acoustic (but electronically-generated) signal.

Now let's look at an acoustic signal, a waveform generated by a tuning fork. Hook up your *microphone* to Channel 1. Make sure you've switched the on/off switch on the mike to 'on' if it has one. Hit the tuning fork against your knee to make a sustained sound rather than a percussive one. You may find that you have to adjust the VOLTS/DIV knob [12] to get a waveform that really shows detail. The oscilloscope has difficulty with complex waves because it's primarily designed to be used in electrical engineering, where the signals are typically fairly standard waveforms such as sine waves or square waves. Keep in mind that while the oscilloscope may be faster than you are with frequency measurements, you're much smarter than it is about recognizing complex waveforms.

For starters, see if the oscilloscope can measure the frequency of your waveform. If you get a frequency measurement, compare it to the frequency corresponding to that pitch on the tuning fork. (These frequencies are stamped on the tuning forks.) Do they agree? If not, do they differ by some integer factor such as 2 or 3? (We'll find out later in the semester why an integer factor might be reasonable.) Or does the frequency measured by the oscilloscope jump around? That's also likely with a complex wave.

Even if the oscilloscope is having trouble finding the frequency of your complex wave, you can still measure the period using the cursors the way you did above. Measure the frequency that way and check it against the frequency you'd expect from the pitch.

Storing waveforms.

Next, compare two tones you can make by whistling or humming. Use the same pitch. Comparing them is awkward because you can't play both sounds simultaneously, and you lose the display once you stop the sound. Or do you? If you look really closely at the information on the case just over the screen, you'll find that your oscilloscope is a "digital storage oscilloscope." That is, you can save waveforms. Our oscilloscopes are two-channel oscilloscopes, and you can save either or both waveforms.

Once you have your oscilloscope set to give a good display of some waveform from the keyboard, push the SAVE/RECALL button [2]. You will get the usual menu on the right-hand side of the display, and the first menu item is "Action," with "Save All" right underneath it in reverse video. Push the first function button [14a] to select "Save Waveform." Now you get some more menu options underneath. The next option, "Save To," should be changed to File with the second function button [14b]. The next choice, "Source," is the channel connected to your microphone, and it will probably be "CH1." (You've probably figured out that you would change it to "Ch2" if you pushed the third function button [14c].) The last choice gives a file name which will

be something like "TEK0000.CSV." When you push the fifth button, you will see that menu item replaced with a clock face. Keep making the sound until the clock face disappears and you get the "Save TEK0001.CSV" command again. This will take a couple of seconds, so keep the sound going until the clock face vanishes. Notice that the new file name is greater by 1 than the previous file name, so you won't overwrite the file with the sound you just made if you generate a second sound and save it. Make a note of which file name goes with which sound, because the oscilloscope can't do that for you. (You can actually give each file a name that describes the sound by going through the UTILITY menu, but I'll leave it up to you for right now to figure out how to do that.)

To look at the sound(s) you just saved, go to the first function button and push it until you get "Recall Waveform." The fifth choice lets you recall immediately the last sound you saved (in the file you last generated). When you push the fifth function button, you again get the clock face until the waveform gets loaded from the memory and plotted on the screen, which (like saving the file) takes a couple of seconds. (It seems like forever, I know.) To load a different file push the fourth function button ("Select File") and use the horizontal position knob to choose the desired file. You should also push the second function button to change the trace the file is being sent to from "RefA" to "RefB" (or *vice versa*) so that you can look at both traces at the same time. After you've chosen the file and the destination, push the "Recall" button [14e] to see both traces.

(You will probably find that the microphone input, which right now should be around zero because you aren't making any sound into it, is still hanging around at the center of the screen and being generally annoying. You can move it with the POSITION knob to a part of the screen where it isn't in the way, and you can make it much thinner by adjusting the VOLTS/DIV knob. There's probably also some really clever way to get it to vanish entirely, but I haven't figured that out yet.)

Looking at an acoustically-generated signal.

First, try singing a steady note. What happens to the waveform if you keep the frequency (pitch) of the note fairly constant but change its timbre? An easy way to change the timbre is to sing a different vowel. To get a chance to practice measuring with the scope, measure the frequency of both the highest note and the lowest note you can sing. Use the SAVE/RECALL feature and the cursors to make this measurement. Check your results by using the function generator to determine directly the lowest and highest notes you can sing, and look up their frequencies. Each person in your lab group should make these measurements for his/her own voice. Use headphones in conjunction with the function generator and do a similar experiment to find out the range of your hearing. Compare results with your lab partners.

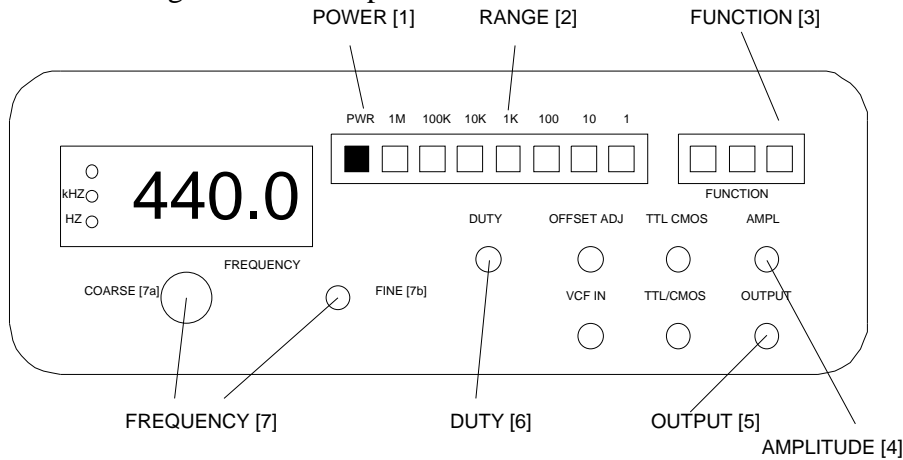
Finally, look at the difference between vowels and consonants. This will give you an excuse to explore another cool feature of these oscilloscopes, their ability to "trigger" and catch a short-lived or "single-shot" signal. This will let you look at the beginnings of sounds that aren't sustained. Start by singing into the microphone and push AUTOSET to set the oscilloscope to VOLTS/DIV and SEC/DIV settings that are appropriate for a signal from the microphone. Then push the ACQUIRE button, which will bring up the Acquire menu on the screen. Select the Peak Detect option with the second function button. Then push the TRIG MENU button to get the "Trigger" menu. (Basically, the "trigger" tells the oscilloscope when to start displaying the signal.) Make sure that the Source (second menu item) is set to the channel that has the microphone input, and also check that the Mode (fourth menu item) is set to Auto. Now look for the trigger level, which is shown with a solid left-pointing arrow somewhere on the right-hand edge of the screen. Adjust its positive with the Trigger Level knob to some positive voltage that isn't more than about one large division on the screen. You can check if your settings are reasonable by tapping the microphone. The display won't last for long, but if it goes off the screen you should change the VOLTS/DIV setting to something less sensitive. If instead the display has a really small amplitude, change the VOLTS/DIV setting to something more sensitive. Finally, push the SINGLE SEQ button. The next sound that goes into the microphone will trigger the display and get saved on the screen.

You may find that you don't see as much of your short-lived signal as you would like. For example, you may find that the sound you make is significantly louder or softer than the effect of tapping the microphone, which

means that you should adjust the VOLTS/DIV setting. Alternatively, you may get only a few oscillations on the screen and you'd like to see more of the signal, which you can do by changing the TIME/DIV setting. You can also get more of the signal after it starts by changing the position on the screen where the signal reaches the trigger voltage with the horizontal position knob. But remember to push the SINGLE SEQ button each time you want to make a new sound.

Compare the waveforms for vowels and consonants. Which sounds require looking at a single-shot signal? Do any sounds seem to have a definite pitch? What (if anything) do the waveforms of vowels have in common? Consonants? Do some groups of consonants have similar waveforms?

BK function generator front panel



Tektronix TDS 1002 oscilloscope front panel

