Reference materials for Lab instructors on the new Agilent equipment

How to use the new Agilent oscilloscope (3000-series) and function generator 33220A

This document is intended to help EECS Lab instructors start using the new core equipment just purchased for all Instructional Laboratories. It is based on the AC Lab written for EECS 215 (*Circuits make sense,* 5th edition, Wiley, 2006).

For more detailed information on the new instruments, see the web sites
http://cp.literature.agilent.com/litweb/pdf/D3000-97000.pdf for the oscilloscope
http://cp.literature.agilent.com/litweb/pdf/33220-90002.pdf for the function generator

Ask questions by email
labsupport@eecs.umich.edu

September 7, 2006

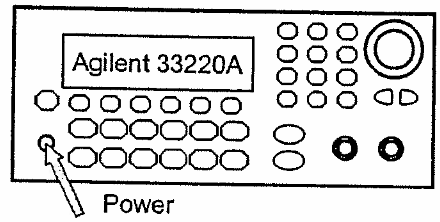
Learning in the Lab: Part One
Basic measurements in the time domain

Today you will start using two instruments of your workstation that you did not use before – Agilent 33220A function generator and Agilent 3000-series oscilloscope such as DSO3102A (using the professional jargon, sometimes we simply call it a "scope"). These instruments may look awesome when you begin but indeed they are a lot of fun as soon as you learn how to use them. **Hope you'll have some fun today!**

Remember that both the function generator and the oscilloscope have built-in computers with memory, and you have to reset that memory when you turn on the instruments.

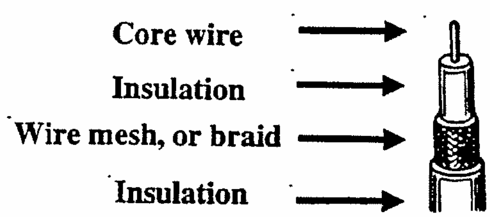
Turn on Agilent 33220A function generator and reset it

□ Turn on your Agilent 33220A function generator (arbitrary waveform generator) by pressing the **Power** button. Make sure its display reads 1.000 kHz (with a few extra zeros) and shows the symbol of a sine wave. These factory defaults are reset every time when you turn on the function generator.

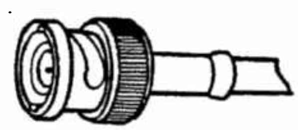


Coaxial cables

Signals are transferred from the function generator to the oscilloscope via coaxial cables. A coaxial cable has the inner core conductor that carries the signal itself, and the outer wire mesh, or braid that is connected to the ground, which protects signals from noise.



The coaxial cables we use in the lab are connected to the instruments (function generator and oscilloscope) with BNC connectors. The abbreviation BNC stands for "bayonet Neil-Conselman" and probably commemorates the inventors.



Notice that, **when a BNC connector is locked** on a terminal of the instrument (such as function generator or oscilloscope), **both its conductors** – for the signal (core wire) and the ground wire – **are connected** to the corresponding conductors in the instrument.

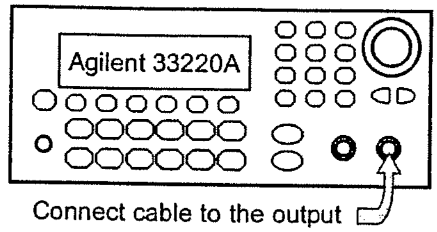
For this Lab, you need 3 coaxial cables:

- 2 cables with BNC connectors on both ends
- 1 cable with a BNC connector on one end and alligator clips on the other end

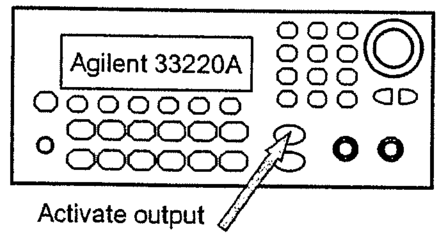
□ Get the coaxial cables.

Connect the coaxial cable to Agilent 33220A generator

- Use one of the cables with BNC connectors on both ends: connect it to the **Output** terminal of the function generator.
- Make sure that you push and turn the head of the BNC connector to lock its bayonet on the function generator.



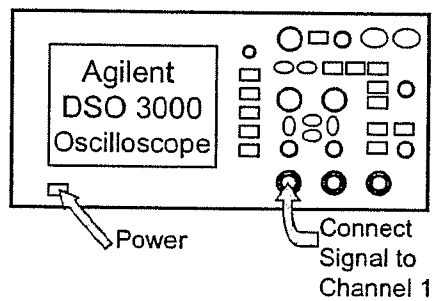
- The output signal can be connected to the **Output** terminal – or disconnected from it inside the generator. To ensure connection, or activate the output, push the **Output** button on the front panel. When activated, the **Output** button lights up.



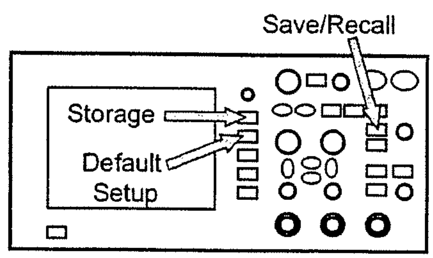
Turn on Agilent 3000-series oscilloscope and reset it

- Turn on your oscilloscope by pushing the **Power** button.

  Connect the coaxial cable from the **Output signal** of your function generator to **Channel 1** terminal of your oscilloscope. Push and turn the head of a BNC connector: make sure that you lock the bayonet.



- Locate the **Save/Recall** button on the front panel of the oscilloscope and push it. The **Save/Recall** menu appears in the right part of the oscilloscope screen. The top line of this menu should read "**Storage**"; under it "**Setups**" should be highlighted. If you do not see "**Setups**", press the button. Then press the "**Default setup**" button, which resets the oscilloscope to its factory defaults.



- At the bottom of the oscilloscope screen, the following parameters should be displayed:

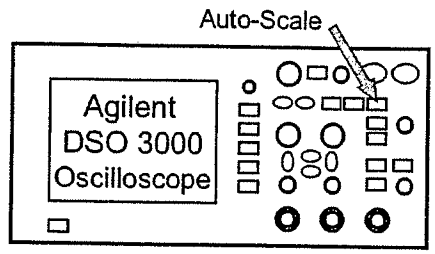
CH1 100mV/	(means 100 mV/div for the vertical scale)
1.000us/	(means 1.000 μsec/div for the horizontal scale)
50.0MSa/s	(means 50.00 megasamples [$5\cdot10^7$ samples] acquired per second)

Many instruments do not display the Greek μ (for 10^{-6}): instead of it they display Latin u thus you see **100 us/div instead of 100 μsec/div**, etc.

Reference materials for Lab instructors on the new Agilent equipment

□ The image on your oscilloscope screen should look nearly like a flat line because the factory default settings are not optimal for the signal fed from the function generator.

□ On the oscilloscope press the **Auto-Scale** button. After a brief delay, the screen will display a clear image of the sine wave, usually, 6 periods.



If you do not see the sine waveform, check all connections and make sure that the **Output** button on your function generator is highlighted. Then run the **Default Setup/Auto-Scale** sequence again.

If it does not solve the problem, ask your Lab instructor for help.

□ At the bottom of the oscilloscope screen, the following parameters should be displayed:

CH1 50mV/	(means 50 mV/div for the vertical scale)
500.0us/	(means 500.0 μsec/div for the horizontal scale)
200.0kSa/s	(means 200.0 kilosamples [$2 \cdot 10^5$ samples] acquired per second)

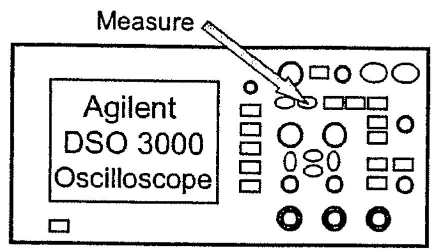
Note that the vertical zoom was automatically changed 2-fold;
the horizontal zoom was changed 500-fold, and
the sampling rate was changed 250-fold.

□ Remember that your oscilloscope has its own memory, which can store previous settings, which you do not need (they can even confuse you!). Thus running the **Default Setup** or **Default Setup/Auto-Scale** sequence is a good professional habit. <u>Do so every time you turn on your oscilloscope – or when you get lost during the measurements.</u>

The first measurement with your oscilloscope

Your Agilent 3000-series oscilloscope can measure many parameters of signals. Let us begin with the measurement of signal amplitude.

□ On the front panel of your scope press the **Measure** button.
At the right edge of the screen, the **Measure** menu appears, with the default settings highlighted:
Source CH 1 (means that the signal connected to **Channel 1** is measured)
Voltage (pressing this button activates the **Voltage** menu)
Time (pressing this button activates the **Time** menu)

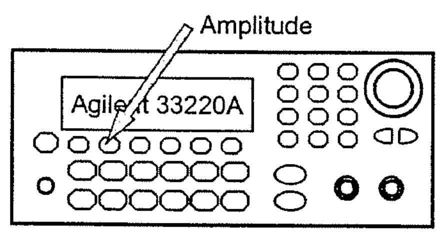


□ Select **Voltage** by pressing the menu-defined button and observe the **Voltage** menu: the top entry reads **Voltage 1/3**, which means page 1 of 3 (this menu has 3 pages).

□ Select **Vpp,** which measures the peak-to-peak amplitude. At the bottom of the screen, the **Vpp** amplitude is displayed in mV. Record the reading: **Vpp** = ________ **mV.**
(You should obtain a reading of 200 mV ppk within less than ±5%)

The first mystery

□ On the function generator press the **Ampl** (**Amplitude**) button and record the the peak-to-peak amplitude displayed by the function generator:



V_{pp} =	(remember the units!)

(I expect that you read 100 mVpp value.)

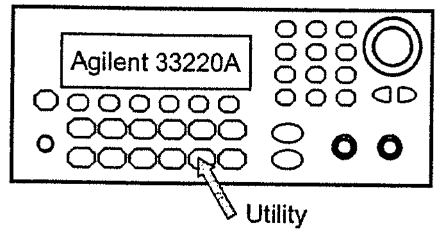
This is a real mystery: the readings of the same signal amplitude displayed by two instruments differ by a factor of 2. Why?

How to make the readings of two instruments agree, or How to begin measurements with your function generator

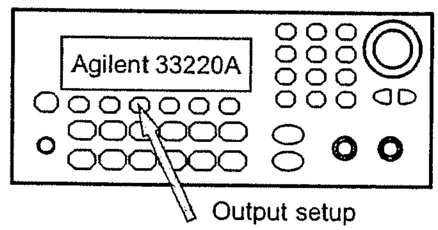
First of all, we have to know which instrument is in the wrong. The question is not trivial. Let me give away the answer: **in this particular case, the function generator displays a wrong value.** To bring the two readings in agreement, we have to **switch the function generator into the HIGH Z mode.**

If needed, review the section *What exactly is the High Z mode?* (Introduction page 2).

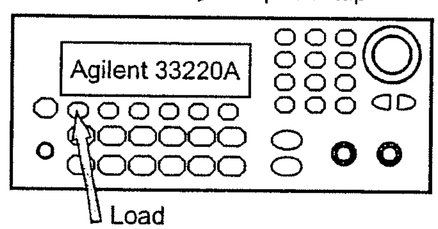
□ On the function generator, press the **Utility** button.



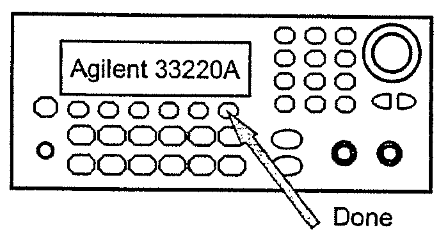
□ In the **Utility** menu, chose **Output setup.**



□ In the **Output setup** menu, the leftmost button is **Load**; it shows up with **50 Ω** displayed. Press the **Load** button to ensure that **High Z** is highlighted; then press **Done.**



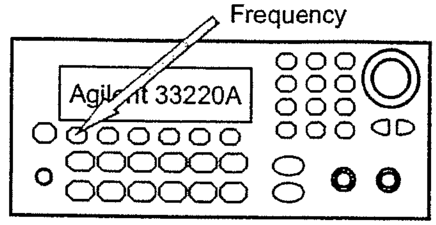
□ Notice that the display of the function generator now reads **200.0 mVpp**, in agreement with the amplitude reading of the oscilloscope (there was no change on the oscilloscope display: both the waveform and its automatically measured amplitude remain the same).
Also, **High Z Load** is shown in the upper right corner of the function generator's display.



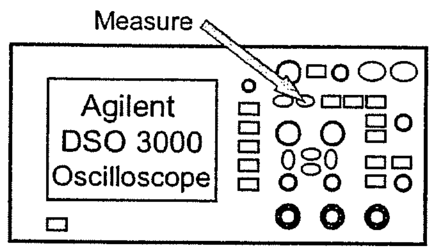
> We will call the procedure above **"Go to the HIGH Z mode"** and shall **use it every time we turn on the Agilent 33220A function generator,** ***before*** we begin the measurements using its signals.

□ Note that, as you switched the function generator from **50 Ω** mode to the **High Z** mode, the voltage displayed on the function generator changed by a factor of 2 but there was no change of the amplitude displayed on the oscilloscope.

Frequency measurements and a *very* important lesson



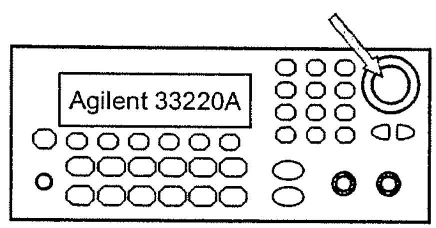
□ On the front panel of the function generator press the **Frequency** button. Notice that the display reads frequency of the default signal, namely **1.000 kHz** (with a few extra zeros).



On the oscilloscope front panel, press the **Measure** button; note the highlighted **CH1**, **Voltage**, and **Time**; activate **Time**, then activate **Freq** (frequency).

□ At the bottom of the oscilloscope screen, note **Freq** (frequency) displayed practically equal to 1 kHz, as set on the function generator.

□ On the function generator, **1.0̲00 kHz** is displayed with the first decimal place highlighted (here, it is underscored): it means that, when you rotate the wheel, the frequency will change in **0.1̲00 kHz** steps.



□ Rotate the function generator's wheel **clockwise** and observe how the sine wave is compressed on the oscilloscope screen, its frequency increasing. Note the agreement between the reading on the function generator and at the bottom of the oscilloscope screen.

□ Then rotate the function generator's wheel **counterclockwise** and observe the effects of decreasing frequency.

□ Note that at 200 Hz the oscilloscope can measure the frequency, but at 100 Hz it fails: instead of the frequency reading, ***** is shown.

The displayed portion of the waveform is too short for the frequency measurements. Indeed, from the display as you see it (with the setting of 100 Hz on the function generator and 500 µs/div on the oscilloscope), one cannot even tell whether the signal is periodic!

The lesson:

Your oscilloscope screen must display more than one period of the waveform in order to confirm that the signal is periodic, and to measure its frequency.

As the user, you are responsible for setting the appropriate **Time/div** (normally, 2 to 5 periods displayed on the screen is OK).

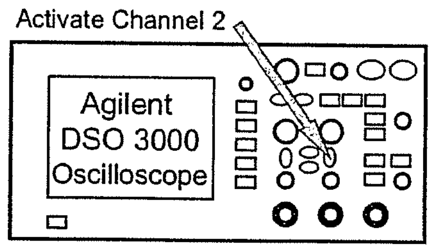
Amplitude measurements and the other important lesson

□ Make sure that your

- function generator is set at 1 kHz sine wave at 200 mVpp in the **High Z** mode
- oscilloscope is set at 1 ms/div and 50 mV/div in Channel 1, and both the **Vpp** amplitude and the frequency are displayed on the oscilloscope screen.

□ Press button **2** on your oscilloscope to activate Channel 2. You should see a green trace – nearly a horizontal straight line – in the middle of the screen.

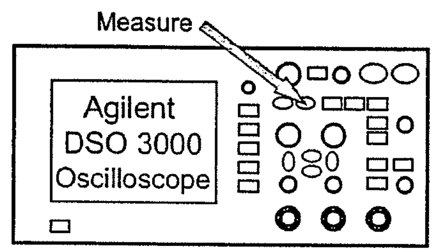
Since you have not connected any signal to channel 2, what you observe is noise (which is present everywhere).



□ Press the **Measure** button, measure and record the peak-to-peak amplitude of noise in Channel 2:

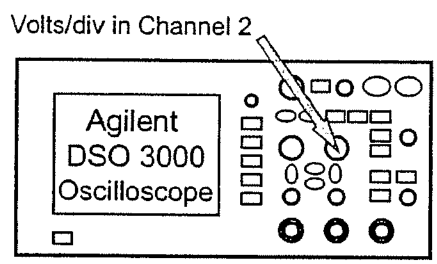
Vpp = ____________ mV

You probably read between 4 and 8 mVpp.



Note that the displayed readings are color-coded: yellow corresponds to Channel 1, and green belongs to Channel 2.

□ Rotate the **Volts/div** knob for **Channel 2** clockwise to zoom in until **Volts/div at limit** is displayed.

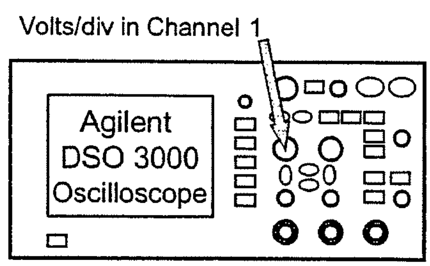


□ Observe that the readings of **Vpp** in **Channel 2** changed to about 1 mVpp (at 2 mV/div).

□ Rotate the **Volts/div** knob for **Channel 2** counterclockwise to zoom out until **Volts/div at limit** is displayed.

□ Note that **Vpp** in **Channel 2** is displayed as 200 to 400 mVpp (at 5 V/div).

Why does the scope **measure the same** noise signal **as either 1 mV or 400 mVpp?** Maybe because it's noise and has a random amplitude?



□ Make sure your signal in **Channel 1** is measured as 200 mVpp (at 50 mV/div).

□ Rotate the **Volts/div** knob for **Channel 1** counterclockwise to zoom out until **Volts/div at limit** is displayed.

Observe that the same 200-mV signal is now measured as 400 mVpp (at 5 V/div). Why?

The readings of the noise and the sine wave amplitude differ so dramatically at various settings of **Volts/div** because, when you zoom out, the resolution becomes insufficient (as if you tried to measure the thickness of this page with a yardstick) and the instrument *estimates* the amplitudes instead of measuring them accurately.

Since the waveform information is also lost (the trace looks like a horizontal line, and the frequency is reported as *****), you may think of a loss of the pixel-to-pixel resolution.

□ Rotate the **Volts/div** knob for **Channel 1** clockwise to zoom in and restore **50 mV/div** setting. You should read 200 mVpp.

□ Rotate the **Volts/div** knob for **Channel 1** clockwise to zoom in further – and note that even at 20 mV/div your waveform goes off the screen, gets clipped at the edges of the window, and its amplitude cannot be measured: the display reads Vpp = *****.

□ Press Auto-Scale button and observe that the trace in Channel 2 is gone, and the readings of frequency and amplitudes are erased from the oscilloscope screen.

The lesson:

For accurate automatic measurements of the signal amplitude, your oscilloscope screen must display the waveform so that it neither looks like a flat horizontal line nor is clipped at the edges of the screen.

As the user, you are responsible for setting the appropriate **Volts/div** in each channel (normally, the amplitude from ¼ to ¾ of the vertical size of the screen is OK).

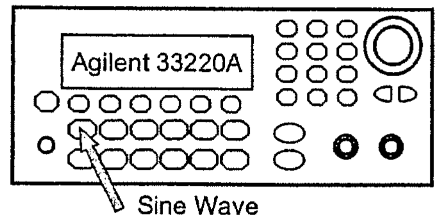
Combine the two lessons into a simple rule worthy to remember:

In waveform measurements,
adjust **Time/div**
to display **2 to 5 periods** on the oscilloscope screen;
adjust **Volts/div** so that
the signal occupies **from ¼ to ¾** of the screen height.
Do **not** rely on **Auto-Scale,**
because it may erase your carefully chosen settings.

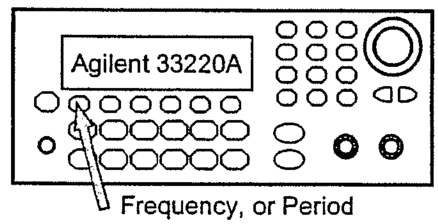
As a summary, you may think that your oscilloscope **does *not* operate on the true signal: instead, it operates on the content of its screen.** For example, when Volts/div is too high (zooming out), the signal itself does *not* change, but its image on the screen looks like a flat line so the scope cannot measure the true amplitude as if it is limited with its pixel-to-pixel resolution.

Observe a variety of waveforms

Your function generator can produce many waveforms and control their parameters. Let us explore some of its standard menu choices.



- □ Make sure that your function generator is set to produce a sine wave at **1 kHz** and **200 mVpp** in **High Z** mode.
- □ Make sure that your oscilloscope is set at **500 μsec/div** and **50 mV/div.**
- □ Note that on your function generator, the button for **Sine wave** is highlighted.
- □ The menu operation softkeys allows you to vary the parameters of the sine waveform.



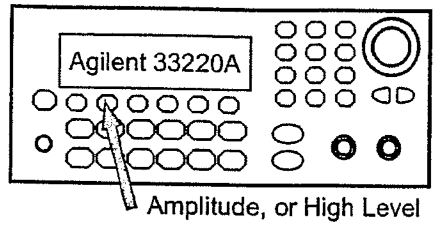
- □ Press the **Frequency, or Period** softkey and look at the display.

  Freq should be highlighted thus you can adjust the frequency either by turning the wheel (the highlighted digit will vary) or by using the keypad, which is located between the display and the wheel.
- □ Turn the wheel clockwise: observe that the frequency is increased in **0.1-kHz** increments, and the waveform on the screen of your oscilloscope is compressed horizontally, while its amplitude (vertical size) remains unchanged.

  Stop at **2.0 kHz.**
- □ Press the the **Frequency, or Period** softkey again: notice that **Period** is highlighted and **500.000 μs** displayed (with extra zeros); the highlighted digit is underscored here: it corresponds to tens of microseconds. Turn the wheel clockwise and observe that the period is increased in **10-μs** increments; the waveform image on your oscilloscope is expanded horizontally, while its amplitude remains unchanged.

  Stop at **800 μs.**
- □ Press the **Frequency, orPeriod** softkey again: notice that **Freq** is highlighted and **1.250 kHz** displayed (with extra zeros); the waveform on your oscilloscope screen remains the same.
- □ On the keypad, press **1**; then press the softkey under **kHz.** The frequency should be set at **1 kHz** and displayed with many zeros.

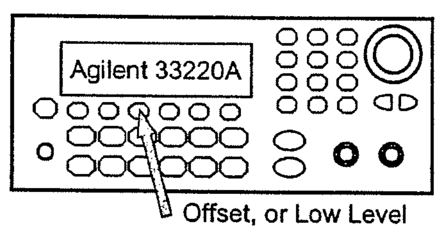
You have just learned several ways to adjust the frequency and period of waveforms.



- Press the **Amplitude, or High Level** softkey. Note that **Ampl** is highlighted, which allows you to vary the peak-to-peak amplitude by turning the wheel or using the keypad.
- Observe that, on your oscilloscope screen, the sine waveform of **200 mVpp** is symmetric: displayed 4 divisions high, with its minima at –100 mV, or 2 divisions below the zero line (the middle of your oscilloscope screen) and its maxima at 2 divisions above the zero line, at +100 mV.
- With the **Ampl** highlighted on your function generator display, turn the wheel clockwise and observe that the waveform on the screen of your oscilloscope is expanded vertically (horizontally, it remains the same); its expansion is symmetric: both the maxima and minima move away from the zero level.

  Stop at **300 mVpp.** Displayed on the oscilloscope at **50 mV/div,** your sine wave screen should be 6 divisions high = 3 divisions above zero and 3 below zero.
- Press the **Amplitude, or High Level** softkey again: note that **HiLevel** is highlighted and **+150.0 mV** displayed (the highlighted digit corresponds to tens of mV).
- Rotate the function generator wheel counterclockwise and observe that, on your oscilloscope screen, the waveform is shrunk vertically but only its maxima move closer to the zero line, while the minima remain where they were.

  Stop at **+100 mVpp.**
- Note that, on your oscilloscope screen, the sine wave is 5 divisions high; its amplitude displayed as **250 mVpp.** The vertical symmetry is lost: measure the average voltage and observe that it is about **–25 mV** (press **Measure, Voltage, Vavg**).



- On your function generator, press the **Offset, or Low Level** button and observe that **LoLevel** is highlighted and **–150 mV** displayed.
- Rotate the function generator's wheel clockwise and observe the changes on the oscilloscope screen.

  Stop at **–100 mV.**
- On your oscilloscope screen, you should read **Vpp = 200 mV** and **Vavg = 0 mV** (within a few mV).
- On your function generator, press the **Offset, or Low Level** button again: observe that **Offset** is highlighted and **0.000** $\mathbf{V_{DC}}$ displayed.
- Turn the wheel clockwise (one click) to get **1.000** $\mathbf{V_{DC}}$ displayed. Note that the highlighted digit corresponds to volts thus you added a **+1 V DC** offset to your waveform.

- □ Mathematically, your sine wave used to be **(100 mV)· sin(2 π · 1 kHz)**; now it becomes **1000 mV+ (100 mV)· sin(2 π · 1 kHz)** and disappears from the oscilloscope screen.
- □ On your oscilloscope, set **Volts/div** for Channel 1 at **500 mV/div** and observe the sine wave centered 2 divisions above the zero line (the image can be unstable, the frequency could be not read out, but do not pay attention to it for the time being).

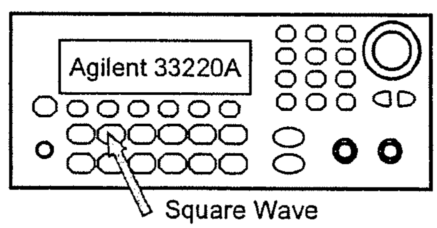
  The readings should be **Vpp = 200 mV** and **Vavg = 1.000 V** (within a few mV).
- □ On the function generator, turn the wheel counterclockwise (one click) to get **0.000 V_{DC}** displayed.

  On the oscilloscope, observe the sine wave centered at zero (in the middle of the screen).

  The readings should be **Vpp = 200 mV** and **Vavg = 0 mV** (within a few mV).
- □ On the function generator, turn the wheel counterclockwise (one click) to get **-1.000** V_{DC} displayed. On the oscilloscope, observe the sine wave centered at 2 divisions below zero.

  The readings should be **Vpp = 200 mV** and **Vavg = -1.000 V** (within a few mV).
- □ On the function generator, turn the wheel clockwise (one click) to get **0.000 V_{DC}** displayed. On the oscilloscope, observe the sine wave centered at zero; set **Volts/div** at **50 mV/div** in Channel 1; make sure that the sine wave is stable and the readings are **Vpp = 200 mV, Freq = 1.000 kHz,** and **Vavg = 0 mV** (within a few mV and a few Hz).

You have learned several ways to vary the signal voltage (AC amplitude and DC offset).



- □ On the function generator, press the **Square wave** button; observe the change of waveform on the oscilloscope screen.
- □ Note that, in addition to the familiar softkeys

  Frequency, or Period
  Amplitude, or High Level
  Offset, or Low Level

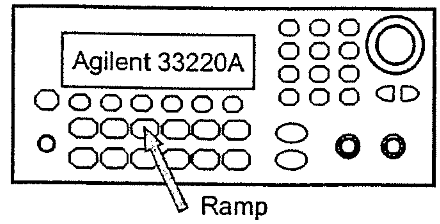
  an additional softkey **Duty cycle** is also available.

  Activate **Duty cycle** and observe **50%** displayed. It means that 50% of the time the voltage remains at its high level.
- □ Rotate the function generator's wheel: observe the changes of the **Duty cycle** readings on the function generator's display, and the changes of the waveform on your oscilloscope screen. Note that the limits of the **Duty cycle** are **20%** and **80%.**

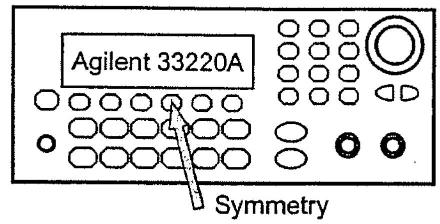
  Restore the **50% Duty cycle.**

□ On the function generator, press the **Ramp** button; observe the waveform on your oscilloscope screen.

It should be the saw-tooth wave (see *Introduction* page 16)



□ Note that, in addition to the familiar softkeys
Frequency, or Period
Amplitude, or High Level
Offset, or Low Level
an additional softkey **Symmetry** is also available.



□ Press the **Symmetry** softkey: **100%** should be displayed, with the highlighted digit corresponding to tens percent.

□ Rotate the function generator's wheel and observe the changes in the waveform displayed on the oscilloscope screen.

Observe that **Symmetry = X%** simply states that the voltage linearly increases during **X%** of each period; during the rest **(100 – X)%** the voltage linearly decreases.

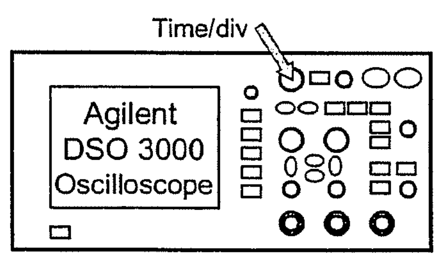
In particular, at **Symmetry = 50%** you should observe the triangular waveform (see *Introduction* page 14).

□ On the oscilloscope, press the **Measure** button, then activate **Period, Rise Time,** and **Fall Time** (the previously set readings will be erased from the screen).

□ Observe how the readings of **Rise Time** and **Fall Time** change as you vary the **Symmetry** setting.

□ Set **Symmetry = 0%** (this waveform is called "negative ramp") and observe that your oscilloscope displays **Rise Time < 50 μs** because Rise Time is so short that it cannot be measured the at your present setting of **500 μsec/div.**

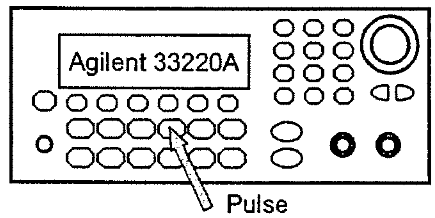
□ Rotate the **Time/div** knob on your oscilloscope to zoom in; set **50 ns/div** (zoom in by a factor of 10,000).



□ Observe that, at **50 ns/div,** your oscilloscope displays **Rise Time = 80 ns** (within 5%) but cannot measure the **Period** and **Fall Time:** as already mentioned, it operates on the content of the screen rather than on the entire waveform.

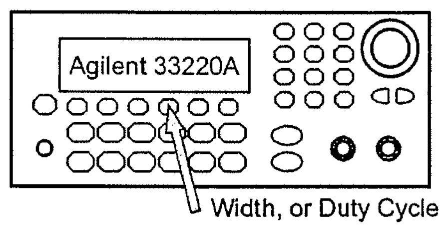
□ On the function generator, press the Square wave button: observe that the rising edge displayed on the oscilloscope screen becomes much steeper, and the oscilloscope cannot measure the new **Rise Time < 10 ns.**

- □ Rotate the **Time/div** knob on your oscilloscope to zoom in; set **2 ns/div,** which is the limit setting: this model of oscilloscope cannot measure faster signals. Note that a period of 2 ns corresponds to 0.5 GHz, which is probably below the frequency at which your computer runs. It means that for digital signals such as in your computer, one would need a faster oscilloscope.
- □ Observe that, at **2 ns/div,** your oscilloscope measures the **Rise Time** and displays it with 3 significant digits.
- □ On the function generator, set the **Ramp** waveform: note that on the oscilloscope screen the fraction of its rising edge is so small that you cannot see its shape.
- □ Rotate the **Time/div** knob on your oscilloscope to zoom out; set **500 μs/div** to observe 6 periods of the negative ramp waveform.
- □ On the function generator, press the **Pulse** button; observe the waveform on your oscilloscope screen.



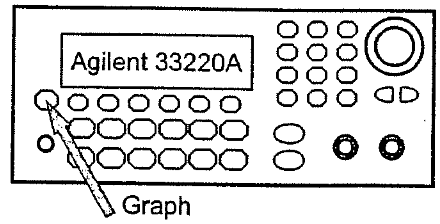
- □ Note that, in addition to the familiar softkeys
  - **Frequency, or Period**
  - **Amplitude, or High Level**
  - **Offset, or Low Level**

  two additional softkeys are available:
  - **Width, or Duty cycle** and
  - **Edge Time.**



- □ Press the **Width, or Duty cycle** softkey:

  Width should be highlighted and **1<u>0</u>0 μs** displayed, with the highlighted digit corresponding to tens of microseconds.
- □ Press the **Width, or Duty cycle** softkey again: **Duty cycle** should be highlighted and 1<u>0</u>% displayed, with the highlighted digit corresponding to single percent.
- □ The adjustment of pulse width is similar to that for the square wave; the only difference is that here you can also set the pulse duration in microseconds without calculating it as a fraction of the period.
- □ If you wish, experiment with the settings of **Width, or Duty cycle**; then restore the original settings listed above.
- □ Press the **Edge Time** softkey: **5.<u>0</u> ns** should be displayed, with the highlighted digit corresponding to 0.1 nsec.
- □ If you rotate the wheel to vary the **Edge Time** in the nanosecond range, no effect will be seen on the oscilloscope screen at its present setting of 500 μsec/div. An alternative way to adjust the waveform parameters is the following.



- On the function generator, press the **Graph** button. The display changes to show you the details of your waveform.

  Edge is highlighted, reading **5.0 ns,** with the highlighted decimal place for one tenth of a nanosecond.

  You can vary **Edge Time** by turning the wheel.

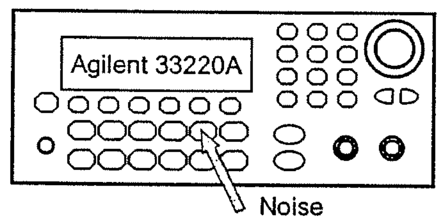
  If you push an arrow button below the wheel, the highlighted decimal place changes, to allow you more coarse changes of the **Edge Time.**

- Explore what happens when you press other softkeys.

  Observe that all familiar adjustments are available: on the **Graph** display you can vary

  Frequency, or Period
  Amplitude, or High Level
  Offset, or Low Level
  Width, or Duty cycle
  Edge Time.

  As usual, you can vary each parameter either by turning the wheel or by entering the desired value on the keypad.



- Keep your function generator in the **Graph** display and press the **Noise** button.

  On the **Graph** display as well as on your oscilloscope screen you should see noise with adjustable **Low Level** and **High Level.**

- Press the **Graph** button again. Observe that, on the normal display of your function generator, you can also adjust the **Amplitude** and **Offset** of the noise signal.

You have just learned a few standard features of your function generator.

Let us apply this new learning to simple measurements, for which you will earn points.

Learning in the Lab: Part Two
Spectra of signals

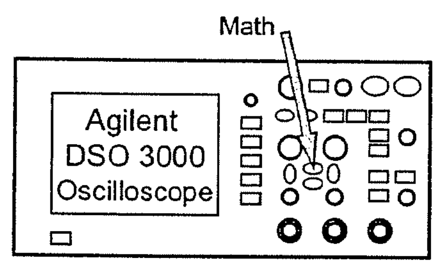
The same signal can be represented as a waveform (voltage vs. time) in the time domain and as a spectrum (intensity vs. frequency) in the frequency domain.

Your oscilloscope has a built-in computer that runs a Fast Fourier Transform (FFT) algorithm thus you can observe and measure spectra in real time.

How to display the FFT spectrum along with the waveform on your oscilloscope screen

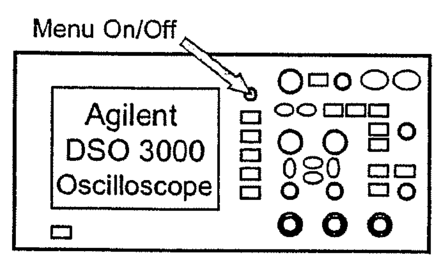
□ Make sure that both your function generator and your oscilloscope are reset to their factory defaults.

□ On the oscilloscope, press the **Auto-Scale** button, then activate channel 2 (but do not connect any cable to channel 1 input). You should see 6 periods of a sine wave (yellow trace for channel 1) and a flat horizontal line (green trace for channel 2).



□ Press the **Math** button. Note that a purple trace appears on the screen, overlaid with the other two traces, and the **Math** menu is displayed.

□ On the **Math** menu, the top entry is **Operate,** with **1 + 2** highlighted, which means that your oscilloscope's computer adds the voltages in two channels. The result (purple trace) is seen as a sine wave of a very small amplitude, because its scale is automatically set at 1 V/div (see the purple display in the lower left corner of the oscilloscope screen).



□ Press the **Operate** softkey several times to scroll through all menu choices; stop when **FFT** is displayed. In order to activate or hide menu, you can press the **Menu On/Off** button at any time.

□ By default, the oscilloscope screen is split: in its top part, you can see the waveforms; in the bottom part, the FFT spectrum. Note the scale for the spectrum displayed (in purple): it reads **20 mVrms/div** for the vertical scale and **5 kHz/div** for the horizontal scale, along with the sampling rate of **200 kHz.**

□ The spectrum contains only one peak (near the left edge of the screen), as expected of the sine wave.

□ The next menu entry is **Source,** with **CH1** highlighted, which means that the spectrum belongs to the signal connected to channel 1. Of course, the other choice is **CH2.**

□ The following menu entry **Window** is discussed below. By default, **Rectangle** is highlighted. You may scroll the choices; stop at **Rectangle.**

□ The next menu entry is **Display,** with **Split** highlighted. When you press this softkey, it toggles to **Full Screen,** which overlays the spectrum with waveforms.

□ The last entry is **1 / 3** with the arrow pointing down: it means that the FFT menu has 3 pages, out of which page 1 is displayed. Press this softkey and look at page 2.

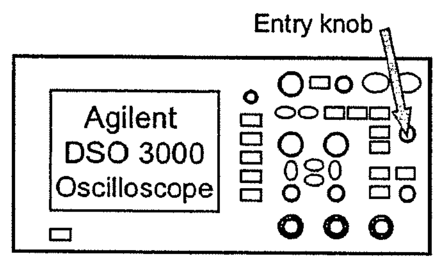
□ **Scale** has V_{RMS} highlighted; the other choice is **dBV**$_{RMS}$ which displays the spectrum on a logarithmic vertical scale.

□ Press the **Scale** softkey; activate **dBV**$_{RMS}$. Note that the spectrum changed: instead of a sharp peak on a flat background you should observe a smaller peak with pronounced "wings."

□ Use the following two menu entries to zoom in and shift the spectrum.

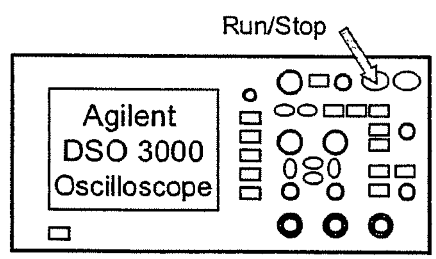
Read the displayed **dBV/div** and set it at **20.**

When you activate the softkey for the vertical zoom or vertical displacement (both are labeled with a curved arrow), rotate the **Entry knob** (also labeled with a curved arrow) to make the adjustment of the screen image.



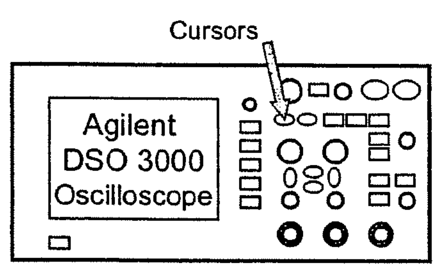
□ You should see the entire spectrum with the peak on the left and the nearly flat line (with noise) on the right. At **20 dBV/div,** each division on the vertical scale corresponds to a factor of 10 thus the 3-division difference between the peak and the background actually means that their voltages differ by a factor of 1,000.

□ Note that the noise seen in the spectrum in the right part of the screen is changing all the time because you observe the FFT spectrum in real time.



□ Press the **Run/Stop** button to "freeze" the signals displayed: the button itself should glow red; the STOP annunciator should be displayed in the upper left corner of the screen, and you should see that all traces on the screen "froze."

□ Press the **Cursors** button and set the following menu choices:



Mode = Manual (you will move the cursor by rotating the **Entry knob**)

Type = Time (it will be a vertical dash line to measure the horizontal position on the screen)

Source = FFT (the readout belongs to the FFT spectrum).

□ Activate **Cursor A.**

□ Rotate the **Entry knob** to align the cursor (vertical blue line) with the peak in the FFT spectrum. Read the cursor position; make sure you get 1.000 kHz = the frequency of the sine wave set on your function generator.

□ Press the **Cursors** button and set

Type = Voltage (it will be a horizontal dash line to measure the vertical position on the screen)

Keep the other choices unchanged:

Mode = Manual

Source = FFT

□ Align active **cursor A** with the peak in the FFT spectrum; read out its amplitude in dBV.

□ Press the **Cursors** button and activate **cursor B.** Align **cursor B** with the noise in the right part of the screen; read out its amplitude in dBV.

Read **ΔY** to see the difference between the peak amplitude and the noise, measured in dBV. Typically, you will read 50 dB or more, which means that the RMS amplitude of noise is smaller than the RMS amplitude of the peak by a factor of 300 or more.

□ Press the **Math** button to activate the **Math** menu; go to its page 1.

□ Scroll through the **Window** types and observe how the spectrum is affected. Each type of window has its own strengths and weaknesses: **Rectangle** provides the best frequency resolution but the worst magnitude resolution; **Hanning** and **Hamming** are similar: they provide better frequency resolution and poorer magnitude resolution; **Blackman** has the best magnitude resolution and the worst frequency resolution. If you wish to understand the theory, take a course in signal processing, especially DSP.

In practice, a compromise is needed for every application.

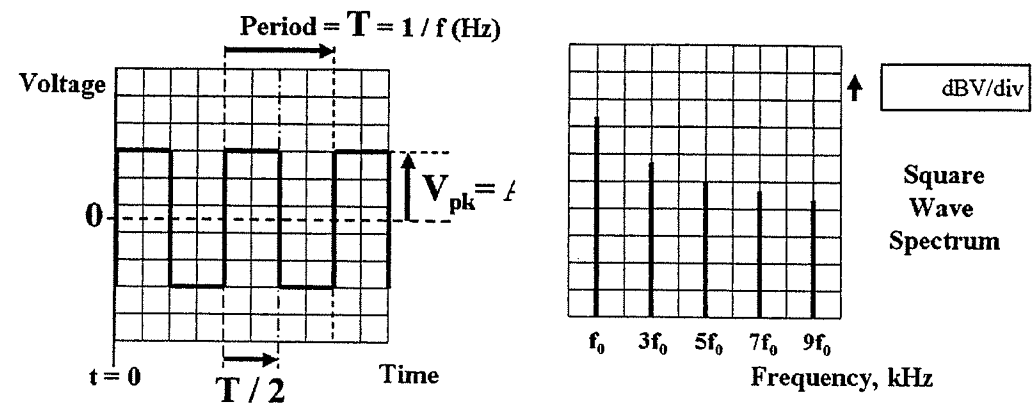
□ Rotate the **Time/div** knob to set **10 ms/div:** the sine wave will be compressed but its spectrum spread out, with the peak near the middle of the screen (note that 250 Hz/div is displayed).

□ If you are curious about the subtle changes of the spectrum calculated with various window types, scroll all the **Window** types as explained above.

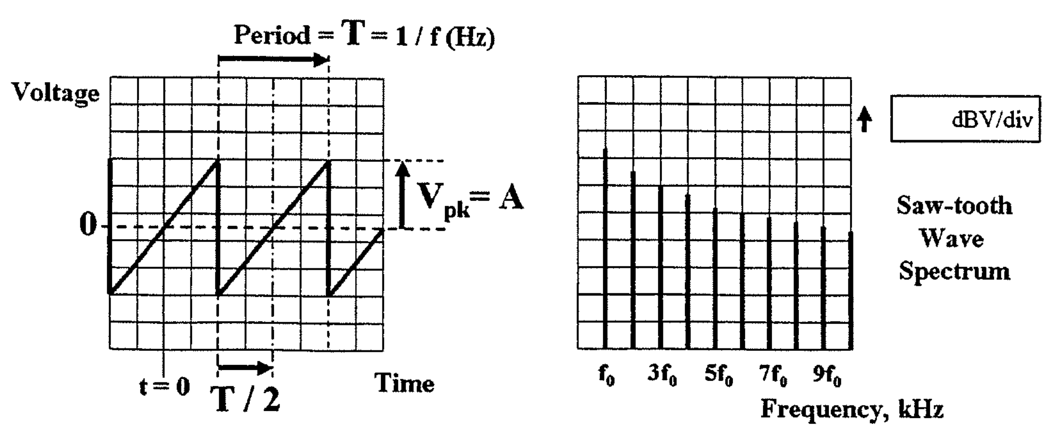
□ Set the **Hanning** window.

□ Rotate the **Time/div** knob to set **2 ms/div:** you should see 20 periods of the sine wave, with the peak near first division in the left part of the screen (note that **1.250 kHz/div** is displayed). The spectrum extends from 0 to 15 kHz (12 divisions on the horizontal scale) but, for the sine wave, it has only one peak, at the fundamental frequency f_0.

- □ On the function generator, press the **Square wave** button. Note the change of the spectrum: in addition to the peak at the fundamental frequency f_0 , 6 additional peaks are displayed!
- □ In order to see the spectrum more clearly, you can activate **Full screen** display, and press the **1** button to hide the waveform (when the waveform is not displayed, the **1** button does not glow).
- □ Use the cursor to verify that the 6 new peaks belong to the odd-numbered harmonics, located at $3 \cdot f_0$, $5 \cdot f_0$, $7 \cdot f_0$, $9 \cdot f_0$, $11 \cdot f_0$, and $13 \cdot f_0$ (see *Introduction* page 12).

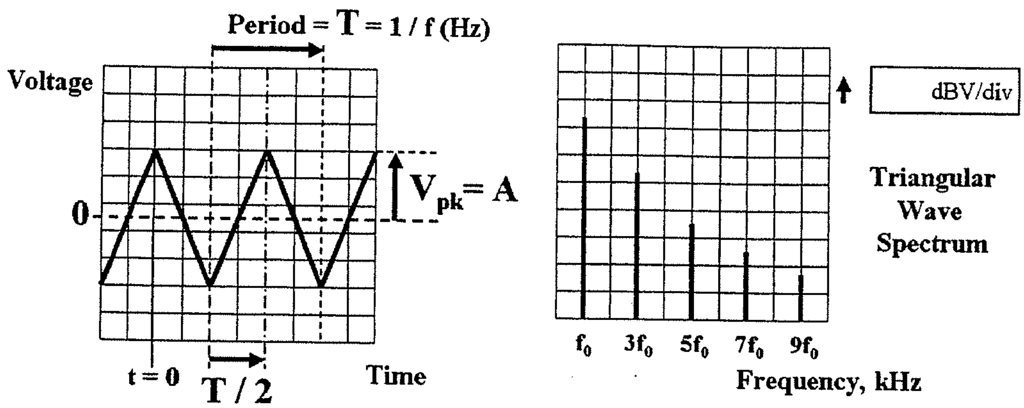


- □ On the function generator, press the **Ramp** button. Observe that the FFT spectrum changed: now, it contains 14 peaks = the fundamental and all harmonics, both odd-numbered and even-numbered (see *Introduction* pages 15 – 16).



□ Activate **Symmetry** and change it from **100%** to **50%.** Observe the dramatic change in the spectrum: all even-numbered harmonics disappear!

Of course, you changed the waveform from **Saw-tooth** to **Triangular** (see *Introduction* Pages 13 – 16).



□ On the function generator, press the **Pulse** button. Observe that the FFT spectrum contains fewer peaks: the fundamental is present but some of the harmonics disappear. Vary the **Width, or Duty cycle** and explore its effect on the spectrum.

□ On the function generator, press the **Sine wave** button. Observe that the simplest spectrum with only one peak is displayed on the oscilloscope screen.

You have learned how to observe the FFT spectra along with the waveforms, and how to measure the frequency and amplitude of these spectra.

Apply your new knowledge to the following Lab experiment.

