Experiment 0 - Exploring the Instruments and ORIGIN

Introduction

The goal of this laboratory is to become familiar with some of the tools and techniques you will be using throughout the quarter. Many of these tools will be used for the next several labs (e.g. the oscilloscope), and others you will use during every lab (e.g. ORIGIN software). If you pay close attention to the functions of the various devices you will be examining this week, your future experiments may proceed more smoothly.

1 Data Analysis

1.1 Significant Figures / Rounding

Proper analysis of data requires that you are familiar with and use significant figures. Here is a brief review of the rules of significant figures.

First, let us define significant digits. Non-zero digits are always significant. Zeros are significant if they occur between non-zero digits (e.g. 504) or if they occur to the right of the decimal point as trailing zeros (e.g. $4.50 \cdot 10^3$). Leading zeroes as in 0.00045 are not significant, as they function only as placeholders for the two significant digits.

Here are two simple rules for rounding the reported uncertainty:
1. Round your error to one (the first) significant figure unless the first digit is '1'. If it is '1', keep the next digit too. Taylor also argues that this can be done if the first digit is '2'.
2. Round your value so that its last significant digit is in the same position (or place value) as the last significant digit of the uncertainty.

Example Question

Question: The unrounded value of length, x, is 2,346.67cm. The unrounded uncertainty, Δx is 23cm. What is the rounded value of x with rounded uncertainty?

Answer: Since the most significant (leftmost) digit of Δx is not a '1' the first digit is rounded. Thus, the rounded uncertainty is 20cm. Since the last significant digit of the uncertainty is the tens place then the value of x must be rounded to this place as well. So $x = 2,350 \pm 20$ cm.

You could also use Taylor's standard for rounding to the second digit when the most significant digit is '2'. The answer would then be $x = 2,347 \pm 23$ cm.

1.2 Estimating Uncertainty

Each time you wish to determine the value of a measurable quantity there will be an associated uncertainty in that measurement. Even the most precise instrument has limitations. If your measured quantity is consistent over time and the smallest increment of measured precision is greater than random fluctuation, then your rough estimate of error will be the smallest single increment of the used scale. For example, if you measure length with a ruler with hashmarks every 1/16 of an inch, then you would decide which hashmark is closest for your measurement and your uncertainty would be 1/16 of an inch.

For a digital readout, a single unit of the lowest place value is the uncertainty when the readout is steady. However, if the value fluctuates, then the uncertainty is roughly the range of the fluctuation. For example, if the multimeter displays "8.7" (say Volts), you would record "8.7 ± 0.1 Volts". If it instead fluctuated between 8.6 and 8.8, you would record "8.7 ± 0.2 Volts".

Question 0.1

You are measuring the mass of a paperclip on a digital scale. The measured value fluctuates between 1.01 and 0.90 grams. What value will you record for the mass and its uncertainty?

1.3 Random Errors

When the uncertainty of a measurement cannot be determined because of high fluctuation in relative value, it is best to measure the system numerous times and use the mean, or arithmetic average, as the estimated value and the standard deviation of the mean as the uncertainty.

The mean value is defined as the sum of measurements from all trials divided by the number of trials.

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

The **standard deviation** of a data set is a measure of the width of a Gaussian distribution. It is defined as:

$$\sigma_X = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2}$$

Although n is listed in this equation, performing additional trials should not change the standard deviation in a substantial way. This fact may seem puzzling but recall that σ_X refers to the width of the Gaussian distribution. The distribution of data does not depend on the number of trials and so σ_X should not increase with trials.

However, the uncertainty should decrease with increased trials since with each trial the mean value is more precisely known. The **standard deviation of the mean** is the value we will use as the uncertainty when we take numerous trials. It is defined as:

$$SDOM = \frac{\sigma_X}{\sqrt{n}}$$

Thus, the statement of your result should be:

$$X = \bar{X} \pm \frac{\sigma_X}{\sqrt{n}}$$

Note that the uncertainty decreases as the square root of the number of independent measurements. This means, for example, that to reduce the uncertainty by a factor of 2, you are required to perform 4 times the current number of measurements in total.

1.4 Error Propagation

Typically the value that you would like to know cannot be measured directly—rather, it must be computed from several other measurements, and each measurement has uncertainty. The new value you have determined has an error associated with it, but how do you find it? Assuming we know how our desired value depends on the quantities measured we proceed in the following manner.

Let's say that Z is a function of measurable variables X and Y, $Z = Z(X,Y)$, and we want to find the value of Z and its uncertainty ΔZ. You measure $X = X_0 \pm \Delta X$ and $Y = Y_0 \pm \Delta Y$. Use the following formula:

$$\Delta Z = \sqrt{\left(\frac{\partial Z}{\partial X} \Delta X\right)^2 + \left(\frac{\partial Z}{\partial Y} \Delta Y\right)^2}$$

Here $\frac{\partial Z}{\partial X}$ is the partial derivative of Z with respect to X (while keeping Y constant). There are special cases, which look simpler, but this is the most general form, from which others are derived.

If f is a function of N variables (x_1, x_2, ... x_N), then the general formula is:

$$\Delta f = \sqrt{\left(\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i} \Delta x_i\right)^2\right)}$$

Question 0.2

You are moving at a constant velocity, $v = 2.5 \pm 0.3\,m/s$, for a finite amount of time, $t = 30 \pm 4s$. What is the distance traveled in this time with uncertainty given that $d = v * t$?

1.5 Quantitative Comparisons

There are numerous ways to compare to the expected value of a measurement to the measured value. The test that you will most often employ is the t-value test, which is the number of standard deviations that separates the two values. If you wish to compare theoretical and experimental values, the t-value is defined as:

$$t-value = \frac{|X_{Experimental} - X_{Theoretical}|}{\sqrt{\left[\left(\Delta X_{Experimental}\right)^2 + \left(\Delta X_{Theoretical}\right)^2\right]}}$$

When the t-value is less than one, it means there a very high agreement between the expected value and the measured value.

2 The Experiment

2.1 Using the Multimeter

The multimeter can measure several different quantities. Today, you will measure voltage (Volts) and resistance (Ohms). Next week you will also measure capacitance (Farads). In parentheses the SI units of each quantity is given.

When recording a measurement ALWAYS include units and uncertainty.

1. Record the voltage of the "9 Volt" battery with the multimeter (include units and an uncertainty) by connecting the leads of the battery to the ground and voltage source of the multimeter with banana cables.

    - Use each different voltage scale to determine how the readout changes. The multimeter will automatically choose a scale setting when you first activate it, so you must manually change the scale using the range button. As a general rule, use the scale that produces the highest resolution or a readout up to the lowest place-value. Record the scale setting of the multimeter as measurements are made.

    - Make sure to write briefly in your notebook what you are recording. You may forget what the numbers represent later if you do not.

2. Measure the resistance of the "510 Ohm" resistor with the multimeter.

3. Measure the resistance of the "100 Ohm" resistor with the multimeter.

4. Measure the series resistance of the "510 Ohm" and "100 Ohm" resistors with the multimeter (include units and an uncertainty), where you expect $R_{Series} = R_1 + R_2$.

5. Measure the parallel resistance of the "510 Ohm" and "100 Ohm" resistors with the multimeter, where you expect $R_{Parallel} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$

Cautions:

- Always use resistors of sufficiently large size to limit the battery current to about 1mA (10^{-3} A). This will assure that the battery will not be discharged and will provide a stable voltage.

- Be careful not to "short" the battery by connecting wires from both terminals of the battery to the same node. The long wire running down one side of the block on which you will connect to the resistors is a node.

- Do not measure resistance with the multimeter while it is connected to a voltage source. The multimeter uses its own internal voltage source to produce a current through the resistor to be measured. The multimeter detects current in order to produce a measure of the resistance. That current will be changed if an external voltage source is also connected.

- When you are not using the multimeter please turn it off. The batteries will die otherwise.

Question 0.3

Observe the picture to the right. The display voltage is constant in time. What should your recorded measurement be?

2.2 Calibrating the Oscilloscope

The oscilloscope displays voltage versus time. Factory settings may not necessarily be correct and therefore the user needs the ability to adjust the scaling of both voltage and time so that measurements are accurate. In other words, how can you be sure that a voltage measurement of 1.4V is actually correct? The answer is that you must calibrate your oscilloscope with a known signal (from the PROBE ADJUST) before you make this measurement. You must calibrate your oscilloscope prior to EACH EXPERIMENT.

To exemplify the necessity of calibration think of a bathroom scale. Let's say that when your scale is empty it reads 5 pounds. When you stand on it, the scale reads 150 pounds. Your actual weight is likely closer to 145 pounds. For your friend the scale reads 120 pounds. His/her weight is likely 115 pounds. For the device to register your weight accurately you must use some weight as a standard to calibrate it. In the case of the scale you must make sure that it is zeroed without any weight on it. For the oscilloscope you will use a square wave with a peak-to-peak voltage of 500 mV and a period of 1 ms from the Probe Adjust to calibrate your oscilloscope.

There are two knobs used for scaling. The larger is for changing the number of volts and seconds in a single division on the display of the oscilloscope. The smaller, inner knob protrudes from the other, larger knob, and it is for calibration.

A picture of an oscilloscope with a legend is in Appendix A. All the words in capital letters are on the face of the oscilloscope and its picture in Appendix A.

2.2.1 Check Calibration

1. Use an "alligator clip" and a BNC (Bayonet Neill-Concelman) cable to connect the PROBE ADJUST signal to Channel 1 on your oscilloscope. The PROBE ADJUST is a small metal cylinder protruding from the bottom right of the oscilloscope.

Figure 1 *The top right image is the "alligator clip" end of the cable pictured above. The lower right image is the BNC cable end of the female type.*

2. Adjust the horizontal scale (time scale) and the vertical scale (voltage scale) with the large knobs until you see a square wave on the oscilloscope screen. Be patient, as it takes time to get a feel for the oscilloscope controls.

   - Be sure the trace (the glowing line of the oscilloscope display) is well focused. Use the knob marked FOCUS on the far left of the control panel to adjust if necessary.

   - Also, be sure the trace is not too bright. Use the knob marked INTENSITY on the far left of the control panel to adjust it to a reasonable brightness;

3. Vary the scales and get an intuitive feel for how the view of the signal (the square wave coming from the PROBE ADJUST) changes as you change the scales. Try the SLOPE switch in the upper right section of the oscilloscope control panel.

4. Measure the Peak to Peak voltage of the square wave (include uncertainty and units) before you calibrate.

   - Be very clear about what it is you are measuring. Sketches with labels are very good for doing this quickly and efficiently while using the smallest number of words.

- A division is a square on the oscilloscope screen.

- For oscilloscope readings, the uncertainty is approximately the width of the trace. This uncertainty is typically between 0.1 and 0.2 divisions.

- Measure the height in divisions (with an uncertainty) first, and then multiply by the number of volts per division.

- Use a vertical scale (large knob) such that the square wave fills a reasonable portion of your oscilloscope screen.

5. Measure the period of the square wave (include uncertainty and units).

- Use the horizontal scale (large knob) such that one cycle fills a reasonable space on the oscilloscope screen.

2.2.2 Instructions for Calibration

1. Look at the text underneath the PROBE ADJUST peg. This text states the actual Peak to Peak voltage and the frequency of the signal.

- Compare your measurements to the labeled values for both the period and the Peak to Peak voltage from the PROBE ADJUST, i.e. calculate a *t*-value and state whether the two values agree.

2. Using the calibration knobs (the smaller knobs at the front) adjust the time scaling and voltage scaling so that the oscilloscope displays the proper Peak to Peak voltage and period which are inputted from the PROBE ADJUST.

- After calibrating the oscilloscope, do NOT move the small scaling knobs. If you do, you may need to recalibrate.

Hint: A good large knob scale to use 0.2ms for time and 100mV for voltage.

Question 0.4
What is the function of the multimeter?

Question 0.5
What is the PROBE ADJUST? See Appendix A to find where it is on the oscilloscope.

Question 0.6
Why should the oscilloscope be calibrated?

2.3 Viewing a Function Generator Signal on the Oscilloscope

1. Set the signal generator to a sine wave with a frequency of about 10.0 kHz.

   - Record the actual frequency you use with an uncertainty.

   - You can use a 1-digit error in the last digit of the readout if the frequency is steady.

2. Connect the signal generator to Channel 1 of the oscilloscope using a BNC cable.

3. Adjust the horizontal and vertical scales until you have one full cycle of the sine wave on the oscilloscope screen. In general, the larger your image is on the screen, the lower your relative uncertainty will be.

4. Use the position knobs to slide the wave over to the right until you can see where the wave begins. Keep as much of the signal on the screen as possible.

   - Now, try turning the "level" knob in the TRIGGER section in the upper right-hand section of the oscilloscope control panel. Try flipping the SLOPE switch again.

   - Now re-adjust the knobs and switches until you have one full cycle of the sine wave, as you had in step 3 above.

5. Use the vertical and horizontal position knobs to make the wave appear as a sine wave (i.e. $V = 0$ at $t = 0$, and let $t = 0$ be the leftmost vertical line on the screen).

   - You can always locate the ground (i.e. $V = 0$) on the oscilloscope screen by setting the switch under Channel 1 (or Channel 2, if that is what you are using) to ground (the center setting). You can then move this flat line to whatever height you like, and then set the switch back to AC.

6. Now, use the vertical position knob to raise the wave so that its center is about 0.5 divisions above the central horizontal line on the oscilloscope screen. This height will correspond to your parameter B in the fitting equation discussed in the next section.

7. Be sure to record the current setup in your notebook.

- You will be taking data in Step 8 below. Your lab notebook needs to state clearly what the numbers (your data) stand for, and you must make it clear as how this data can be reproduced. Be sure to record important settings (like the frequency reading on the signal generator).

8. Make a data table of time and voltage for this sine wave

   - Be sure your column labels make sense.

   - Include units and uncertainties in the table.

   - You should have a least 15-20 data points.

2.4 Plotting the Sinusoidal Curve Using ORIGIN

1. Start ORIGIN from the list of programs under the start menu.

   - If ORIGIN is already running, you have no idea what settings the previous user may have changed. It is best to exit the program in this case and start over.

2. You need to input four different columns of data and so you must add two empty columns.

   - Go to "Column" menu and "Add New Column"

   - Add two columns for a total of four columns.

3. Enter the time-data, the voltage-data, and the error for each into the four columns.

4. You will now fit the data (and uncertainties) with a function you will define.

   - First be sure that nothing *is shaded with black!* (If anything is shaded, click on any empty block in the spreadsheet.)

   - In the "Plot" menu, go to "Scatter". A window should appear.

   - Place the dependent variable (Y), the independent variable (X) and the errors for each (err-X and err-Y) in the appropriate data boxes on the right side of this window.

   - Now, click the "OK" button. (This should cause a graph to appear.)

   - In the "Analysis" menu, select "Non-Linear Curve Fit…" and then click "Advanced Fitting Tool".

   - In the "Function" menu, select "New" (which will cause the window to change)

- In the second line, check the box next to "User Defined Parameter Names". (This will cause the window to change again.)

- Make sure to UNCHECK the box labeled "Use Origin C" at the lower left side of the window.

- Erase everything in the "Parameter Names" space. Now, type in your own set of parameters. For example, "w, A, p, B", which could represent the angular frequency, the amplitude, a phase shift, and a constant offset respectively, if you were to use the function y = A*sin(w*t+p) + B. Note that the offset "B" allows for an error in locating $V = 0$ (which is pretty common). The phase "p" offset similarly allows for an error in locating $t = 0$, which is also pretty common;

- Next, click on the large white space for the formula/expression. Enter only the right-hand side of the desired equation. In this case, type "y = A*sin(w*t+p) + B". Note that multiplication must be indicated explicitly by an asterisk. Also, make sure that your independent variable matches what you type in your equation (the independent variable in the equation above is 't').

- Now, go to the "Action" menu and select "Fit". Note: If ORIGIN asks you which data set to use, be sure to click the button labeled "Active Data Set";

- In the new window, enter rough values for each of your four parameters. Note that ORIGIN needs some reasonable starting values to begin the fit. It will then iteratively adjust these values to minimize the error of the fit.

- Click the "100 Iter." Button at the bottom of the window (the values you entered should change). Click again as needed.

5. You will now get ORIGIN to output your fit results.

- Click "Done" in the lower right and the fit should appear along with a box with fitted parameters' information (including the uncertainty of each parameter).

6. Format your graph.

- Include title. Click on "T" in "Tools" toolbar to add a textbox.

- Label axes with title and units. Double-click on generic title to edit.

- Add units to fitted parameters.

Analysis
State or explain the following in your analysis:

- The fitting equation and the qualifications of A, ω, θ and B (i.e. what do these parameters represent?).

Compute the following in your analysis:
- Comparison[1] of battery voltage to the expected voltage;
- Comparison of resistors to nominal (given) values;
- Expected value of resistors in series and in parallel[2];
- Comparison of measured resistance in series and in parallel to expected values;
- Comparison of pre-calibration Measurement of Peak-to-Peak Voltage and period from probe adjust;
- Comparison of the fitted frequency to the frequency from the signal generator.

Conclusions

Highlight the themes of the lab and the physics the experiment verifies. You should discuss the errors you encounter in the lab and how you could improve the lab if you had to repeat it. If your results are unexpected or your t-values are high, you should identify possible explanations.

Hints on reports
- Write neatly—if your TA cannot read it, you could lose points.
- Be organized—if your TA cannot find it, you could lose points.
- Report your data, including plots—if your data is not in your report, your TA does know you did it.
- Record uncertainty.
- Propagate uncertainty.
- Write your final answers with proper significant figures.

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[1] Comparisons will generally be t-values, but in this lab you may simply state whether or not the measured value is in the range of expected values.

[2] Estimate expected values (with propagated uncertainty) of R_{Series} and $R_{Parallel}$ using relevant formulas and MEASURED values of R_1 and R_2. Do NOT use nominal values (e.g $400 \pm 5\%\Omega$ is a nominal value, but $403.3 \pm 0.1\Omega$ could be your measured value).

Appendix A: The Oscilloscope and Its Controls
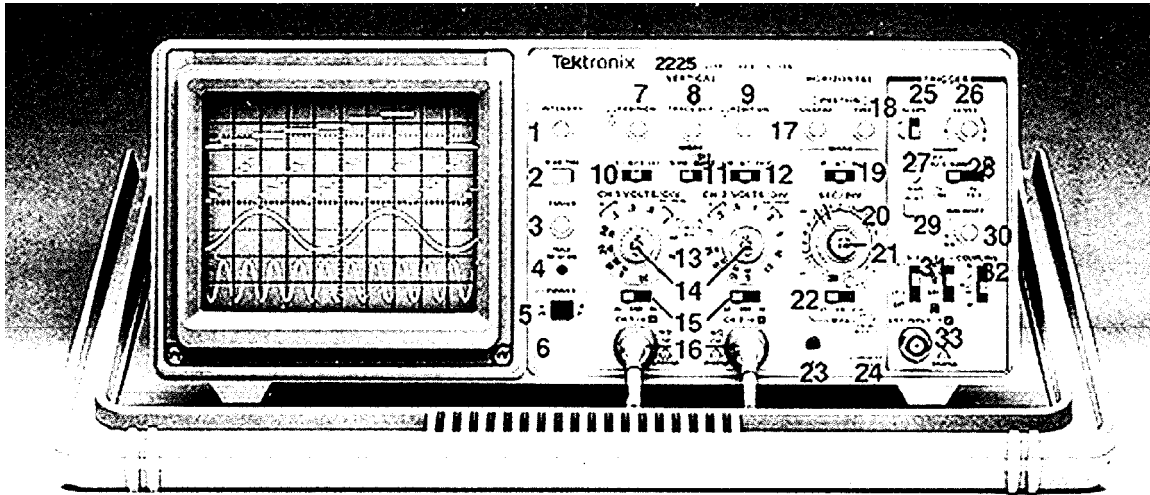
Summary of Controls, Connectors, and Indicators

No.	Title	Function	Recommended Use
1	**INTENSITY**	**Adjusts trace brightness.**	**Compensate for ambient lighting, trace speed, trigger frequency.**
2	BEAM FIND	Compresses display to within CRT limits.	Locate off-screen phenomena.
3	**FOCUS**	**Adjusts for finest trace thickness.**	**Optimize display definition.**
4	TRACE ROTATION	Adjusts trace parallel to centerline.	Compensate for earth's field.
5	POWER	Turns power on and off.	Control power to the instrument.
6	Power Indicator	Illuminates when power is turned on.	Know power condition.
7, 9	POSITION	Moves trace up or down screen.	Position trace vertically and compensate for dc component of signal.
8	TRACE SEP	Moves the magnified trace vertically with respect to the unmagnified trace when HORIZONTAL MODE is set to ALT.	Position unmagnified and horizontally magnified traces for convenient viewing and measurement.
10	CH 1- BOTH - CH 2	Selects signal inputs for display.	View either channel independently or both channels simultaneously

No.	Title	Function		Recommended Use	
11	NORM-INVERT	Inverts the Channel 2 signal display.		Provide for differential (CH 1 - CH 2) or summed (CH 1 + CH 2) signals when ADD is selected.	
12	ADD-ALT-CHOP	ADD shows algebraic sum of CH 1 and CH 2 signals. ALT displays each channel alternately. CHOP switches between CH 1 and CH 2 signals during the sweep at 500 kHz rate.		Display summed or individual signals.	
13	**VOLTS/DIV**	**Selects vertical sensitivity.**		**Adjust vertical signal to suitable size.**	
14	Variable (CAL)	Provides continuously variable deflection factors between calibrated positions of the VOLTS/DIV switch. Reduces gain by at least 25:1.	The CAL control can be pulled out to vertically magnify the trace by a factor of 10. Limits bandwidth to 5 MHz.	Match signals for common mode readings. Adjust height of pulse for rise-time calculations.	Inspecting small signals.
15	AC-GND-DC	In AC, isolates dc component of signal. In GND, gives reference point and allows precharging of input coupling capacitor. In DC, couples all components of signal.		Selects method of coupling input signals to the vertical deflection system.	
16	CH 1 OR X CH 2 OR Y	Provides for input signal connections. CH 1 gives horizontal deflection when SEC/DIV is in X-Y.		Apply signals to the vertical deflection system.	
17	POSITION COARSE	COARSE is convenient for moving unmagnified traces		Control trace positioning in horizontal direction.	
18	POSITION FINE	FINE is convenient for moving magnified traces when either ALT or MAG is selected.		Control trace positioning in horizontal direction.	

No.	Title	Function	Recommended Use

No.	Title	Function	Recommended Use
19	X1 -ALT- MAG	X1 displays only normal (horizontally unmagnified) waveform. ALT displays normal and magnified waveforms alternately. MAG displays only the magnified waveform.	Select normal, comparative or expanded waveforms.
20	**SEC/DIV**	**Selects time-base speed.**	**Set horizontal speed most suited to requirements.**
21	Variable (CAL)	Provides continuously variable uncalibrated sweep speeds to at least 2.5 times the calibrated setting.	Extend the slowest speed to at least 1.25 s/div
22	MAG(X5 - X10 - X50)	Selects degree of horizontal magnification.	Examine small phenomena in detail.
23		Provides safety earth and direct connection to signal source.	Chassis ground connection.
24	**PROBE ADJUST**	**Provides approximately 0.5- V,1-kHz square wave.**	**Match probe capacitance to individual circuit. This source may be used to check the basic functioning of vertical and horizontal circuits but is not intended to check their accuracy.**
25	**SLOPE**	**Selects the slope of the signal that triggers the sweep.**	**Provide ability to trigger from positive-going or negative-going signals.**
26	LEVEL	Selects trigger-signal amplitude point.	Select actual point of trigger.
27	TRIG'D	Indicator lights when sweep is triggered in P-P AUTO, NORM, or TV FIELD.	Indicate trigger state.
29	RESET	Arms trigger circuit for SGL SWP.	
30	HOLDOFF	Varies sweep holdoff time 10:1.	Improve ability to trigger from aperiodic signals.

No.	Title	Function	Recommended Use

31	SOURCE	CH 1, CH 2, and EXT trigger signals are selected directly. In VERT MODE, trigger source is determined by the VERTICAL MODE switches as follows: CH 1: trigger comes from Channel 1 signal. CH 2: trigger comes from Channel 2 signal. BOTH-ADD and BOTH CHOP: trigger is algebraic sum of Channel 1 and Channel 2 signals. BOTH-ALT: trigger comes from Channel 1 and Channel 2 on alternate sweeps.	Select source of signal that is coupled to the trigger circuit.		
32	COUPLING	AC blocks dc components and attenuates signals below 15 Hz. LF REJ blocks dc components and attenuates signals below about 30 kHz. HF REJ blocks dc components and attenuates signals above about 30 kHz. DC couples all signal components.	Select how the triggering signal is coupled to the trigger circuit.		
33	EXT INPUT	Connection for applying external signal that can be used as a trigger.	Connection for applying external signal that can be used for intensity modulation.	Trigger from a source other than vertical signal. Also used for single-shot application.	Provide reference blips by intensity modulation from independent source.