# Chapter 2: DC Measurements

2

ABOUT SUPPLY AND OTHER DC VOLTAGES

Voltage is like a pressure that propels electrons through a circuit, and the resulting electron flow is called electric current. Electric current is often compared to water flow through a pipe or hose. If electric current is like the flow of water, then DC voltage is like the pressure that causes the water to flow through the pipe. The terms DC and AC describe current flow, and stand for direct current and alternating current. DC current flows 'directly' through a circuit, propelled by a voltage that more or less remains constant. In contrast, AC voltage alternates back and forth, causing the AC current to flow back and forth in the circuit.

DC voltage is a fairly easy concept to grasp because it's the measurement for typical supplies like batteries and solar panels. A common assumption about batteries is that they maintain a constant voltage. In contrast to an AC power source like a wall outlet, the voltage a battery supplies is constant –it's a "DC voltage" because it does not oscillate back and forth. However, the DC voltage is not necessarily a fixed value; it can vary. For example, if you measure the voltage across a battery with no current draw, it will be close to its rated voltage, like 9 V_{DC} (volts-DC) for an alkaline battery you can connect to the Board of Education or BASIC Stamp HomeWork Board. When a circuit that draws current is connected to the battery, its voltage may drop a little or a lot, depending on the electrical properties of the circuit and its current draw. The voltage of the battery also decays slowly as it loses its charge. A battery in constant use might start at over 9 V_{DC}, but later, it will measure only 8.5 V_{DC}. The voltage will continue to decline as it loses its charge. At some point, it can no longer power the device, and we call it a 'dead' battery.

Most digital circuits need a steady DC supply voltage to work properly. So, battery supplies get connected to circuit subsystems called voltage regulators. Figure 2-1 shows an example of a voltage regulator on the Board of Education and another on the BASIC Stamp Homework board. The job of a voltage regulator is to maintain a certain voltage level for the circuits it supplies current to, regardless of whether they draw a little or a lot. The voltage of the battery or other source that supplies power to the system is called the unregulated input. The voltage regulator's output, which stays at a fixed value, is called the regulated output. The Board of Education and BASIC Stamp HomeWork board regulators have 5 V_{DC} regulated outputs, meaning they supply the circuits on the boards with a steady 5 V_{DC}, regardless of whether those circuits draw a little or a lot of current.
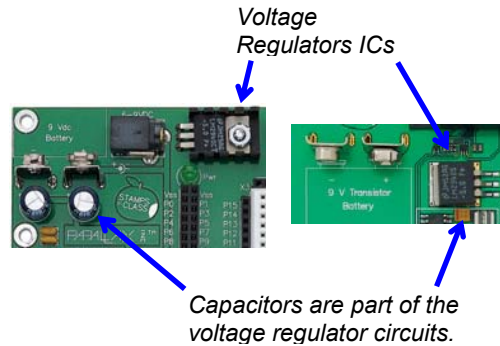
Voltage Regulators ICs

Capacitors are part of the voltage regulator circuits.

Figure 2-1
Voltage Regulators

Board of Education and BASIC Stamp HomeWork Board voltage regulators each have a regulator integrated circuit (IC) and a capacitor.

Since DC supply voltages may vary, they sometimes have to be measured before they get connected to certain types of loads. Also, if a system has a short circuit in it, it can sometimes be detected as an unusually low supply voltage. Likewise, with faulty supply sources and dead batteries. Some systems even require supplies that have certain characteristics that are quantified as output resistance, which can be determined by supply voltage and current tests.

Other devices rely on DC voltages to adjust how they operate. One example is a voltage controlled oscillator. A voltage supplied by a device like the BASIC Stamp or a circuit causes the oscillator to transmit a signal at a certain frequency. Another example, some amplifiers have to be fine tuned with DC voltages, which are called trim voltages. These voltages do not have to supply any power to the devices; they are just there to set some level. Because of this, they can be simpler circuits involving resistors or a digital to analog converter (D/A converter or DAC).

Both supply and other DC voltages are typically measured with a device called a voltmeter. Some voltmeters stand alone, and others are built into devices called multimeters. A multimeters can also measure resistance, current, and sometimes other electrical properties like capacitance and transistor gain.

In this chapter, you will use the PropScope in place of a voltmeter to measure your board's supply voltages. You will also build and test circuits that can generate DC voltages that could be used to adjust how other devices operate, (trim voltages). Additionally, you will use voltage measurements at different points in circuits to

determine the current passing through them, and also to determine whether a BASIC Stamp I/O pin can safely supply the current the given circuit.

ACTIVITY #1: GROUND TEST

The supply voltage sockets above your board's breadboard in Figure 2-2 are labeled Vdd, Vin, and Vss. Vdd is regulated 5 V_{DC}, and Vin is the unregulated voltage of your board's power supply source, which should be in the 6 to 9 V_{DC} range. The sockets labeled Vss are considered 0 V. If you are using a battery, Vss is the voltage at the battery's negative terminal. Vss is commonly referred to as "ground" and also as a "ground reference" because the other voltages on your board are measured with reference to Vss. Vdd is 5 V_{DC} because it's 5 V above Vss. Likewise, Vin should be somewhere in the 6 to 9 V_{DC} range above Vss.
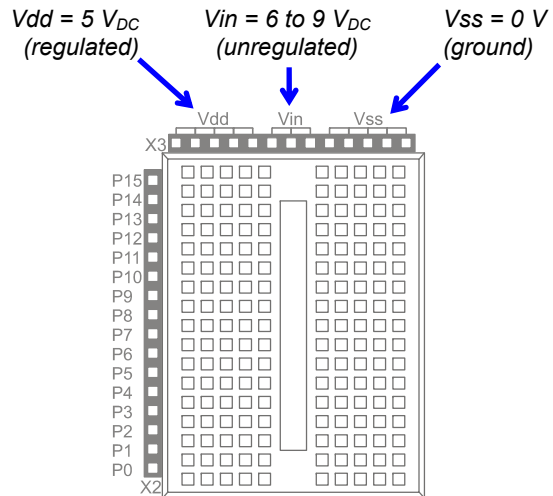

Figure 2-2
Your Board's Supply Voltages

What do the Vdd and Vss supply voltage labels stand for?

The labeling convention came from the names of the BASIC Stamp Interpreter Chip's power supply pins, which in turn came from a convention for names of voltage supplies to groups of a particular type of transistor. The transistors in the BASIC Stamp module's interpreter chip are called field effect transistors or FETs. A typical FET transistor has three terminals, named drain (d) gate (g) and source (s). When measuring a voltage at a particular transistor's drain, the voltage is typically labeled Vd. Likewise, the voltage measured at a transistor's source is Vs. A supply like 5 V_{DC} that goes to many FET transistor drains in a chip is labeled Vdd, and 0 V, which tends to be connected to many transistor sources is labeled Vss.

The PropScope can stand in for a voltmeter for measuring the supply voltages on your board. In this activity, you will first test the PropScope's probes to verify that they measure Vss as 0v. Then, you will use the PropScope to measure and verify that Vdd is 5 V_{DC}, and also to measure Vin. These measurements are useful for the sake of making sure your board's voltage supplies are in working order and properly connected. They are also useful for verifying that your PropScope is in working order and that you have correctly adjusted the controls for the measurements.

Steps before, between, and after measurements.

Before: This is your checklist for getting ready to work on activities in this book:

- ✓ Connect your PropScope to your computer with a USB cable.
- ✓ Run the PropScope software.
- ✓ Connect your BASIC Stamp prototyping board to your computer with a programming cable (USB or serial depending on the board and/or adapter).
- ✓ Connect power to your board (either the Board of Education or BASIC Stamp HomeWork Board), and if it has a 3-position power switch, turn the power on – to position 1.
- ✓ In many cases, the instructions will also involve loading a PBASIC program into your BASIC Stamp, so open your BASIC Stamp Editor software.

Between: If instructed to modify a circuit on your board, or build a different circuit:

- ✓ Disconnect power from your board before modifying your circuit
- ✓ Reconnect power after you have modified the circuit.

After: If you are done for the day, or leaving your circuit unattended for a while:

- ✓ If your board has a 3-position switch, move it to position 0.
- ✓ Disconnect the board's power source. (Even if the 3-positing switch is off, it' still a good idea to disconnect the power source when the board is unattended.)

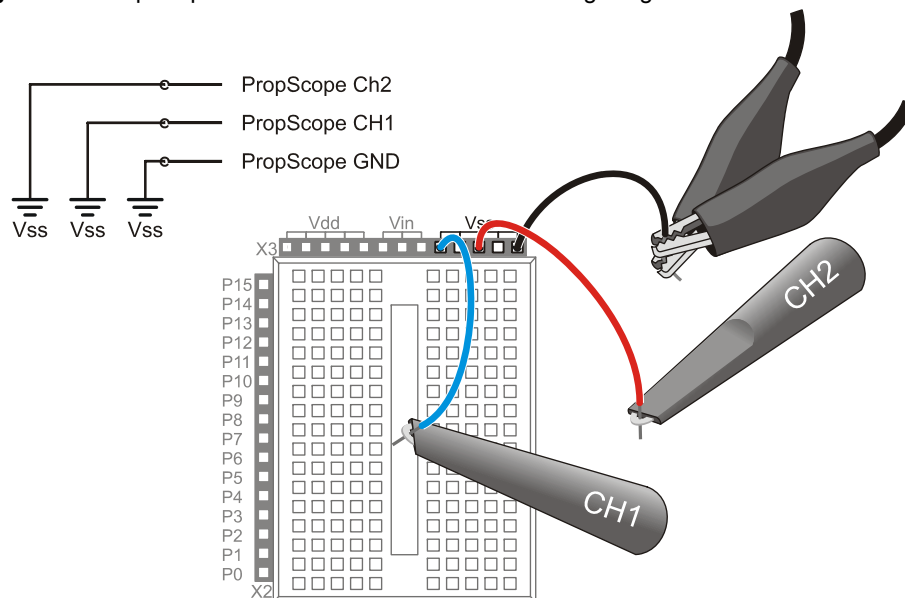**2**

Ground Test Parts List

(3) Jumper wires

Ground Test Circuit

Figure 2-3 shows how to connect the PropScope's probes to verify that they measure 0 V at Vss.

- ✓ Disconnect power from your board.
- ✓ Connect the PropScope probes as shown in Figure 2-3.
- ✓ Reconnect power to your board.

Figure 2-3: PropScope Ground Test Schematic and Wiring Diagram

Ground Test Measurements and Settings

The next step for a voltage measurement is to configure the PropScope so that it can display voltage levels in its oscilloscope screen. We will look more closely at what these configurations do in later activities. For now, just follow these steps using Figure 2-4 as a reference:

✓ Click the upper-left Oscilloscope tab to navigate to the PropScope's Oscilloscope view.
✓ Set both Vertical dials to 5 V.
✓ Set the Horizontal dial to 50 μs.
✓ Click the Trigger tab, and set the Mode slider switch to Off.
✓ Set both coupling switches (under the Vertical dials) to DC.
✓ Test the Run button by clicking it a few times to make it toggle between bright green (running) and dark green (not running).
✓ Make sure your Run button is bright green so that the oscilloscope is running.

Your display should now resemble Figure 2-4.

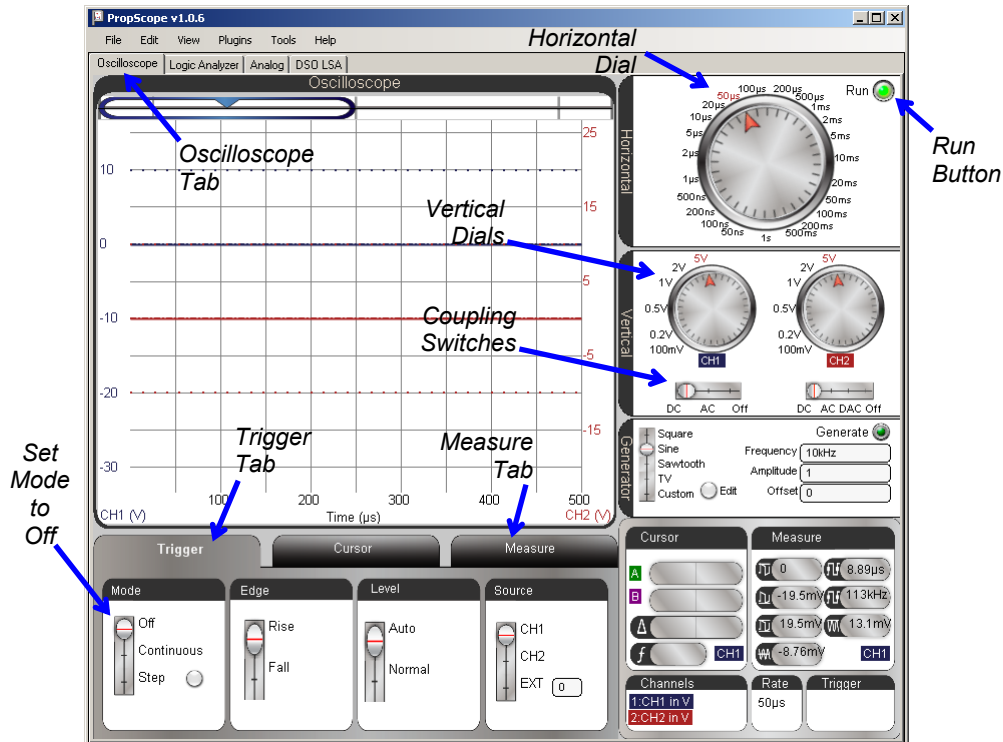**Figure 2-4:** PropScope Settings for DC Voltage Measurements

2

Figure 2-5 shows a close-up of the oscilloscope display after some adjustments. Note that there are two bold colored lines, called traces, that cross the Oscilloscope screen. You can grab these traces with your cursor and drag them up and down so that their locations match Figure 2-5.

- ✓ In your PropScope software, use your mouse to point at, click and hold the blue channel 1 trace.
- ✓ Drag the channel 1 trace either up or down to make its position in your Oscilloscope display roughly match the location in Figure 2-5.

As you move the channel 1 trace, the numbers in the voltage scale on the left should move with it, and the trace should stay level with the 0 on the left, which indicates 0 V.

- ✓ Once you have the blue channel 1 trace adjusted so that it matches the figure, move the red channel 2 trace so that it also matches the figure.

Similar to the channel 1 trace, the scale on the right side should move as you move the channel 2 trace, and the red 0 V indicator on the right should stay level with the red channel 2 trace.
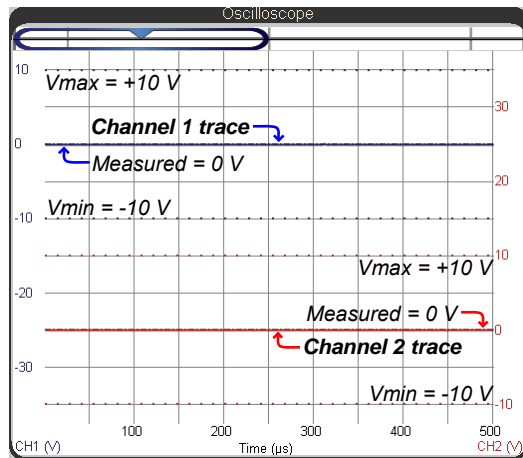

Figure 2-5
Voltages on the Oscilloscope

…with both Vertical scale knobs set to 5 V.

Alright, so what are the traces in the Figure 2-5 oscilloscope screen telling us? Since the probes are connected to Vss along with the ground clips, both traces should indicate 0 V measurements. The blue trace should be level with the blue 0 on the left side of the

Oscilloscope screen, indicating that the voltage measured by the channel 1 (CH1) probe is zero volts. The voltage at the channel 2 (CH2) probe is also 0 V, so the red CH2 trace should be level with a red 0 on the right side of the Oscilloscope screen.

The Vertical (Voltage) Scales

The blue CH1(V) label at the Oscilloscope screen's lower-left indicates that the numbers above it (along the left side of the display) are the channel 1 voltage scale. Likewise, the red CH2 (V) label on the lower-right side of the screen indicates that the numbers along the right side of the display represent the voltage scale for channel 2.

When you adjusted the Vertical dials (commonly called the vertical scale or voltage scale dials) back in Figure 2-4, you adjusted the number of volts each square height represents on the Oscilloscope screen. Since you adjusted both dials to 5 V, each square on the oscilloscope screen grid is currently 5 V high. With the Vertical dials set to 5 V, it also establishes the maximum voltage the PropScope can measure, which is + 10 V to –10 V. These maximum and minimum voltages are indicated in Figure 2-5 by dotted lines that are level with the 10 and –10. The blue dotted lines should be level with 10 and –10 on the left, and the red dotted lines should be level with the 10 and –10 on the right. With the current settings, if you were to apply +12 V to channel 1, it would only report 10 V.

For larger voltage ranges. The probe switches can be adjusted to 10x. The probe settings in the PropScope software's Tools → Manage Probes menu have to be adjusted to match the probe switches. We are using 1x probe settings because the voltage ranges are better suited the measuring the voltages on your board.

The numbers along the bottom of the Figure 2-5 oscilloscope display indicate the Horizontal scale, which is often referred to as the "time scale". This scale can be adjusted with the Horizontal dial. The Horizontal dial was set to 50 μs back in Figure 2-4, and that makes each square 50 μs wide. Since there are ten squares, the display is 500 μs wide. We are currently viewing signals that do not vary with time, so the Horizontal scale setting does not matter. It would be a flat line, regardless of what time scale you choose since the voltage does not vary. Later, you will have to select horizontal scales based on how quickly a signal varies with time to get the best view.

### Your Turn: Check Voltage Limits for Certain Vertical Scales

If you change the CH1 Vertical scale dial from 5 V to 2 V, each square height for CH1 on the Oscilloscope grid will represent 2 V. If you make this change, the blue values along

2

the left side of the screen will also change so that they represent the smaller voltage level increments. The vertical scales are independent, so if you only change the Channel 1 Vertical scale, the Channel 2 squares will still represent 5 V per square.

- ✓ Look carefully at Figure 2-6. The CH1 (V) scale is now in units of 2 V, while the CH2 (V) scale is still in units of 5 V.
- ✓ Try adjusting your CH1 vertical scales to 2 V. You may need to re-adjust the positions of the traces if you want it to closely resemble Figure 2-6.

Figure 2-6: Channel 1 and 2 with Different Vertical Scales
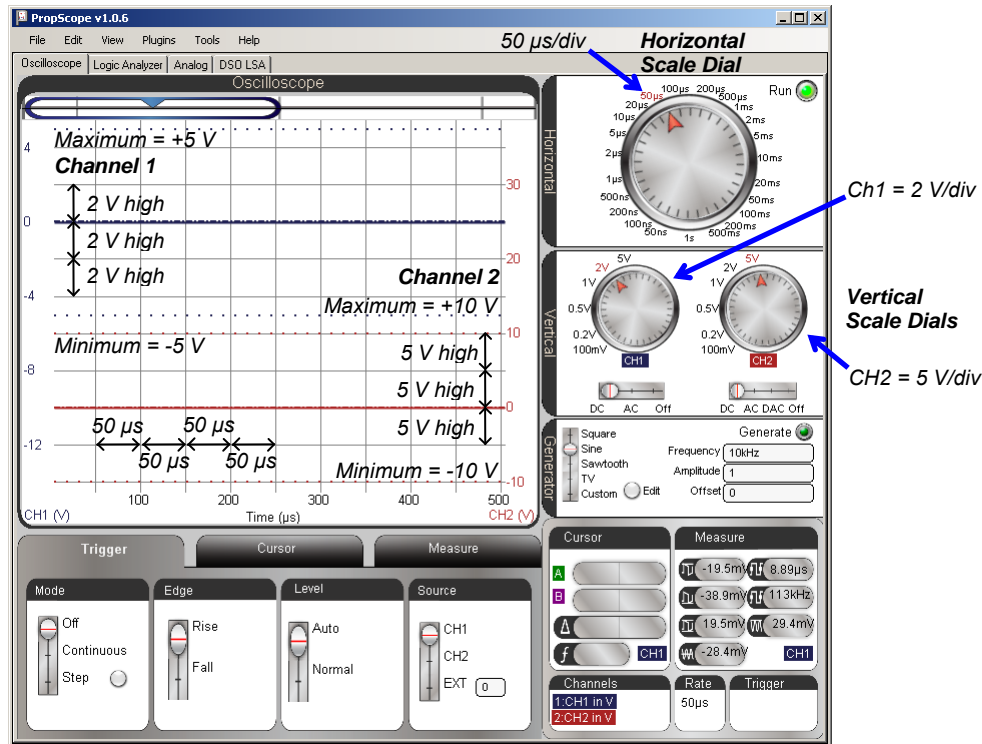
> **What do "per division" and "/div" mean?** The lines on the oscilloscope screen divide it into a grid, so they are called division lines, or more commonly just divisions. The vertical distance between two divisions represents a voltage increment. The size of each voltage increment depends on the Vertical dial settings. The numbers around each Vertical dial indicate the number of volts per division or V/div. Likewise, the horizontal distance between divisions represents time increments, and they depend on the Horizontal dial settings. The numbers around the horizontal dial indicate the number of time units (s, ms, µs, ns) per division.

Another important detail about changing the voltage scale is that certain settings affect the maximum and minimum measurements the channel can display. In Figure 2-6, the dotted lines that indicate the maximum and minimum input voltages for Channel 1 now line up with 5 and –5 V on the CH1 voltage scale. If you try to use this voltage scale to measure Vin, which should be in the 6 to 9 V range, it would only report 5 V.

- ✓ Adjust the Vertical scales for each channel, and pay close attention to the maximum and minimum measurement limitations for each setting.
- ✓ Make sure to restore both Vertical dial settings to 5 V before continuing.
- ✓ Also, make sure to restore the relative positions of Channels 1 and 2 to the locations you moved them to earlier (in the checklist instructions above Figure 2-5 on page 31).

ACTIVITY #2: VDD AND VIN DC SUPPLY VOLTAGES

Next, let's verify that Vdd = 5 V_{DC} and measure your particular battery or DC supply voltage by probing Vin. We'll measure Vdd with channel 1, and Vin with channel 2. Figure 2-7 shows how to connect your probes. The ground clips don't move because they are tied to a reference voltage of Vss = 0 V.

Supply Voltage Test Circuit

- ✓ Disconnect power and plug the CH1 and CH2 probes into the sockets shown in Figure 2-7.
- ✓ Reconnect power to your board.

Figure 2-7: Probe Supply Voltages with the PropScope
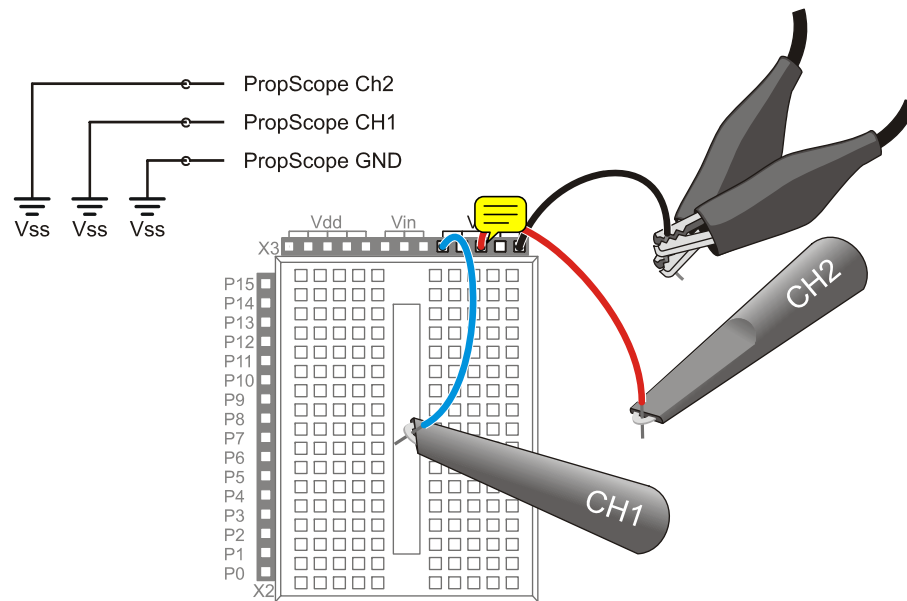
Supply Voltage Measurement Settings

When you reconnect your board's power, dashed lines will still remain at the 0 V levels for each channel to give an "at a glance" indication of ground voltage. The blue dashed line indicates 0 V ground for channel 1, and the red dashed line indicates 0 V for channel 2. The bold trace lines should move to new levels that indicate the voltages for each channel. The Oscilloscope screen's bold, blue channel 1 trace should indicate 5 V by aligning with the 5 V division line (the one between the 0 and 10 numbers on the left-hand channel 1 vertical scale). The oscilloscope's bold, red channel 2 trace should indicate the Vin voltage level. The example in Figure 2-8 is a little more than ~~half way~~ between the 5 and 10 V divisions along the right side, so let's call it 8 V.

- ✓ Check where the voltage trace intersects with the channel 1 voltage scale on the left. Is it 5 V?
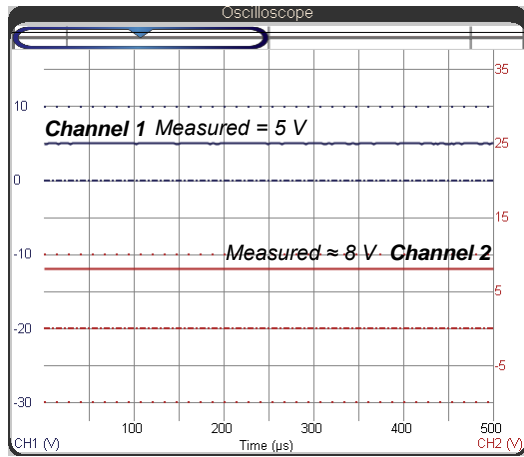- ✓ Repeat for Vin and the channel 2 voltage scale on the right. It should be in the 6 to 9 V range.

Figure 2-8
DC Signals on the Oscilloscope

…with both Vertical scales set to 5 V/div, CH1 connected to Vdd and CH2 connected to Vin.

The Oscilloscope view has a Measure tab that automates common signal measurements. While these measurements are designed mostly to quantify voltages that vary with time, the average voltage measurements circled in Figure 2-9 are essentially DC voltmeter measurements. As you will see later, the average voltage field can also give you information about DC components in periodic signals.

- ✓ Click the Oscilloscope view's Measure tab.
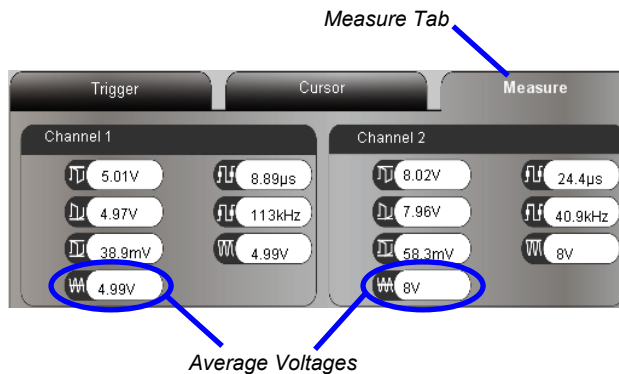- ✓ Examine the average voltage values.

Figure 2-9
Measure Tab Information

The average voltage fields display DC values.

2

Your Turn: Battery Tests

The voltage across a 9 V battery terminals can give you an indication of how much charge is left. If the supply in Figure 2-9 is an alkaline battery, it has already supplied a significant portion of its charge, but still has some life left.

- ✓ Obtain a new 9 V alkaline battery, one that has been in service for a while but is still 'good', and a 'dead' one.
- ✓ Plug each battery into your Board, and make notes of the Vin voltage for each.

> **i** **Testing battery voltage directly.** You can also connect a ground clip directly to a battery's negative terminal and the probe to the positive terminal to measure its voltage.

ACTIVITY #3: DIGITAL TO ANALOG (D/A) DC VOLTAGE

Both the BASIC Stamp and PropScope have digital to analog conversion (abbreviated D/A or DAC) features that allow you to generate DC voltages in the 0 to 4.98 V range. Digital to analog conversion is the process of taking a number (a digital value), and converting it to a corresponding output voltage (an analog value).

Dual DAC Parts List

(2) Resistors – 1 kΩ (brown-black-red)
(2) Capacitors – 1 μF
(misc) Jumper Wires

Dual DAC Circuit

Figure 2-10 shows a schematic and Figure 2-11 shows a wiring diagram for two BASIC Stamp D/A conversion (DAC) circuits along with the PropScope probes attached for measuring the DAC output voltages. These circuits can be useful for setting DC voltages in projects and prototypes. Some D/A converter application examples you will see in this textbook include BASIC Stamp controlled light sensor and amplifier adjustments.

> **CAUTION: This capacitor has a positive (+) and a negative (-) terminal.** The negative terminal is the shorter lead that comes out of the metal canister closest to the stripe with a negative (–) sign. Always make sure to connect these terminals as shown in the circuit diagrams. Connecting one of these capacitors incorrectly can damage it. In some circuits, connecting this type of capacitor incorrectly and then connecting power can cause it to rupture or even explode.
>
> **CAUTION: Do not apply more voltage to an electrolytic capacitor than it is rated to handle.** The voltage rating is printed on the side of the canister.
>
> **CAUTION: Safety goggles or safety glasses are recommended.**

✓ Disconnect power from your board.
✓ Build the circuits shown in Figure 2-10 and Figure 2-11.
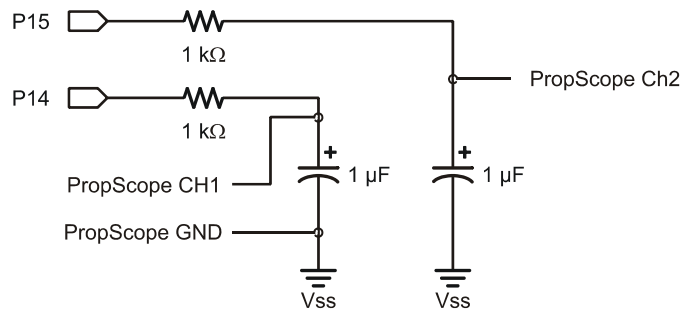✓ Verify that the negative terminal for each capacitor is connected to Vss before reconnecting power to your board.

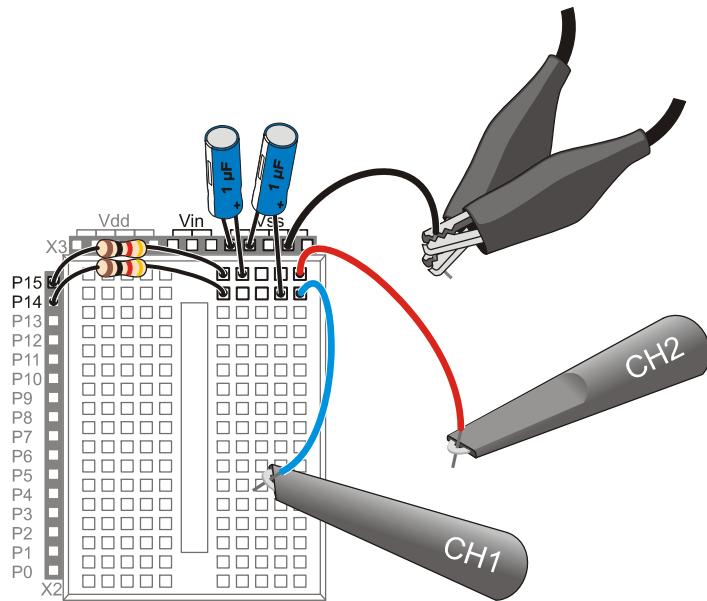**Figure 2-10**

Dual DAC Circuit Schematic

Figure 2-11
Wiring Diagram
Example of Figure 2-10

Make sure to connect the capacitors' negative leads (that come out of the metal can by the – stripe) to Vss.

Example Program: Test 2 Channel Dac.bs2

Test 2 Channel Dac.bs2 is an example program that uses the PBASIC PWM command to repeatedly set voltages across the two capacitors in Figure 2-10 and Figure 2-11. In effect, the program uses the PWM command to make the BASIC Stamp perform D/A conversions, setting output voltages across the capacitors. The PWM command has three arguments, Pin, Duty, and Duration. The Pin argument is for selecting which pin sends the PWM signal. Duty is the number of 256ths of 5 V the capacitor gets charged to, and Duration is the time the command has to deliver the signal.

In Test 2 Channel Dac.bs2, the command PWM 15, 64, 1 sets the voltage across the capacitor in the circuit connected to P15 to 64/256ths of 5 V. That's 1.25 V. Likewise, PWM 14, 192, 1 sets the voltage across the capacitor in the P14 circuit to 192/256ths of 5 V. That's 3.75 V.

✓ Use a calculator to verify that the predicted voltage across the capacitor in the P15 DAC circuit will be 1.25 V. Again, the PWM command will charge the capacitor to 64/256ths of 5 V.

✓ Repeat for the P14 PWM command and capacitor voltage to verify the 3.75 V prediction.
✓ Load Test 2 Channel Dac.bs2 into your BASIC Stamp.

Now that the program is running, the next step will be to test and verify the voltages across the capacitors with the PropScope.

```
' Test 2 Channel Dac.bs2
' Set P15 capacitor voltage to 1.25 V and P14 capacitor to 3.75 V.
' {$STAMP BS2}                              ' Target module = BASIC Stamp 2
' {$PBASIC 2.5}                             ' Language = PBASIC 2.5

DEBUG "Program running..."                  ' Debug Terminal message

DO                                          ' Main Loop

    PWM 15, 64, 1                           ' 1.25 V to P15 capacitor
    PWM 14, 192, 1                          ' 3.75 V to P14 capacitor

LOOP                                        ' Repeat main loop
```

> **For more PWM information and program examples,** download the BASIC Stamp Manual PDF from www.parallax.com → Downloads → BASIC Stamp Documentation. Its official title is the *BASIC Stamp Syntax and Reference Manual*. Look up the PWM command documentation using the Table of Contents. Also, download the Basic Analog and Digital PDF text from www.parallax.com → Downloads → Stamps in Class Downloads, and see Chapter 7.
>
> **More about how PWM works and how to use it:** Different facets of setting voltages with PWM and resistor-capacitor (RC) DAC circuit will be explored in these chapters: Chapter 4: Pulse Width Modulation, Chapter 8: RC Circuit Measurements, Chapter 9: Op Amp Building Blocks.

### Measure 2 BASIC Stamp DAC Channel DC Outputs with the PropScope

Two good tools for testing DC voltages are the Oscilloscope View's Floating cursor shown in Figure 2-12 and the Measure Tab's Average Voltage fields shown in Figure 2-13.

✓ Set both of the Vertical dials to 2 V/div.
✓ Adjust the positions of the traces to match Figure 2-12.

✓ Point at one of the traces with your mouse. It will make the floating cursor appear. The floating cursor will display the voltage measurements for both traces in the upper-left of the oscilloscope screen.
✓ Make a note of the measured voltages. How close are they to your predictions?
✓ Click the Measure tab below the Oscilloscope screen.
✓ Check the average voltage measurements shown in the Average voltage fields.

2

Figure 2-12: Floating cursor DC Voltage Measurements
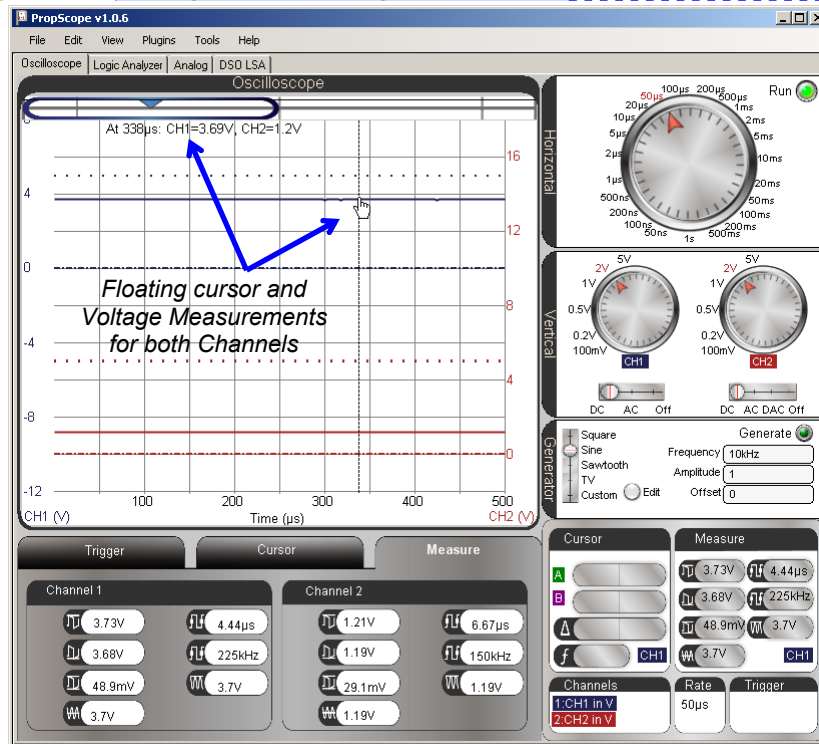
Comment [AL6]: Measured values seem low. May require screen cap retake after adjustment to software/hardware.

HP 54645D scope:
CH1 = 3.758 V
CH2 = 1.242 V

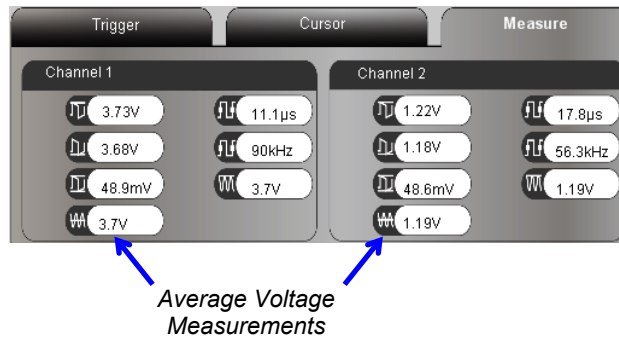Amprobe 37XR-A Meter:
CH1 = 3.73 V
CH2 = 1.234 V

Figure 2-13
Measure Tab DC Voltage
Measurements

*Average Voltage
Measurements*

Floating Cursor vs. Measure Tab

The floating cursor measures the voltage at an instant in time that you point at on the oscilloscope screen. The Measure tab's average voltage takes the average of the measurements over a period of time. Since even DC voltage fluctuates slightly, the average voltage is typically the more reliable means of obtaining DC measurements. However, if all you need is a quick and approximate DC voltage measurement, the floating cursor may save you a mouse click.

Your Turn: Calculate, Set and Test a Voltage with PWM

Let's say a device needs to have 3.5 V applied to one of its inputs. You may not be able to generate 'exactly' 3.5 V, but with PWM, you can probably find a digital value that will result in an analog voltage output that is close enough. Ideally, it should be within about 19.5 mV, which is 1/256th of 5 V. Knowing that the PWM command charges the DAC circuit's capacitor to voltages in terms of 256ths of 5 V, we can make a formula for calculating the PWM command's Duty argument for a given voltage in the 0 to 5 V range.

$$V_{PWM} = Duty \times 5V \div 256$$
$$Duty = V_{PWM} \div (5V \div 256)$$
$$Duty = V_{PWM} \div 0.01953125 \ V$$

Next, solve for Duty with V_{PWM} = 3.5 V. You will have to round to the nearest integer since the PWM command's Duty argument accepts an integer value between 0 and 255.

$$Duty = 3.5 \ V \div 0.01953125 \ V = 179.2 \approx 179$$

So, the command PWM 14, 179, 1 should set a voltage of just under 3.5 V at the P14 DAC circuit's output.

2

- ✓ Modify the PWM command to P14 in Test 2 Channel Dac.bs2 so that it transmits 3.5 V.
- ✓ Test with the PropScope.
- ✓ Repeat for 2.50 V.

Keep in mind that each PWM Duty value represents a certain member of 19.54 mV increments. The goal is to get within about 20 mV of the target voltage.

> **What does LSB mean?** For digital to analog (D/A) and analog to digital (A/D) converters, an LSB describes the smallest voltage increment the device can work with. Under ideal conditions, 0.01953125 V is the voltage level the command PWM Pin, 1, Duration should establish across the DAC circuit's capacitor. The value 1 would be stored in the least significant bit (LSB) of the 8-bit Duty argument that controls the voltage output. Datasheets for D/A and A/D converters speak in terms of an LSB because their devices may be operating on a scale that's different from 0 to 5 V, so they keep it general. For example, if the scale is instead 0 to 3.3 V, the number of levels might still be 256 (8-bits), but the LSB would instead be 3.3 V ÷ 256 = 0.012890625 V. Same LSB, but a different voltage scale results in a different voltage increment.

Set DC Voltages with the PropScope's DAC CARD

The PropScope can also set DC voltages, which is useful if a test circuit needs to be examined with a voltage applied. To generate test voltages with the PropScope, the CH2 Probes should be disconnected from the PropScope's CH2 input and connected to the DAC card's Function Generator output.

- ✓ Disconnect the CH2 probe from the circuit in Figure 2-11 on page 39.
- ✓ Disconnect the probe from the PropScope's CH2 BNC connector, shown in Figure 2-14.
- ✓ Connect the BNC end of the free probe to the DAC CARD's Function generator output BNC connector, also shown in Figure 2-14.
- ✓ Connect the free probe end, which is now the DAC output, to the CH1 probe using Figure 2-15 and Figure 2-16 as a guide.
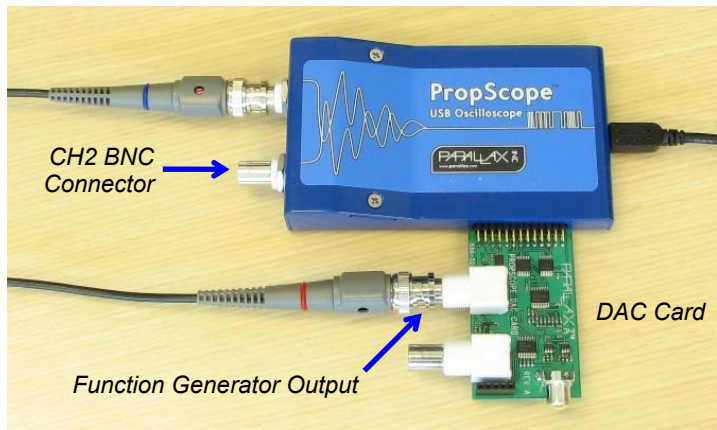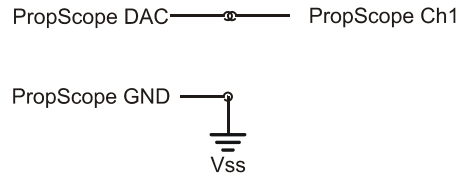
Figure 2-14
DAC Card Function
Generator Output
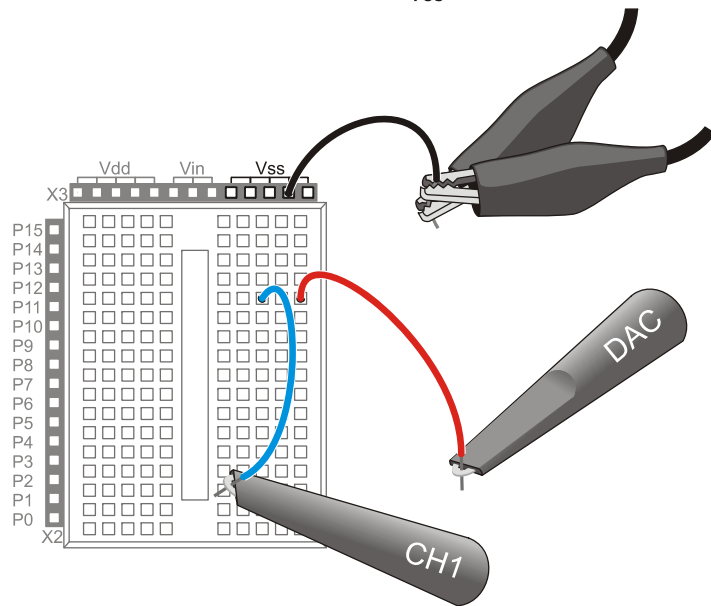

Figure 2-15
Probe DAC Output
with Channel 1

Figure 2-16
Wiring Diagram for
Figure 2-15

2

> **Shortcut:** You can bypass the breadboard and just hook the DAC output probe directly to the CH1 probe for this test.
>
> **1x for the Function Generator Probe:** The probe connected to the DAC Card's Function Generator output should always be set to 1x. If you inadvertently set it to 10x, it will divide down the voltage to 1/10th of what you would expect.

Set DC Signal with Function Generator, Probe with Channel 1

The Oscilloscope View's Generator panel is the PropScope's Function Generator control, and it will be used to generate a variety of signals. The first one will be a simple DC test signal. Let's try a 3.5 V signal. Figure 2-17 shows the settings for a 3.5 V $_{DC}$ signal. In the Generator panel:

- ✓ Set the wave type to Si
- ✓ Set the Amplitude to 0.
- ✓ Set the Offset to 3.5.
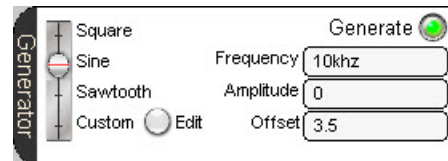- ✓ Click the Generate button to start the digital to analog conversion.

Figure 2-17

DC 3.5 V with the Function Generator

DC Voltage with the Function Generator

A function generator is a device that makes voltages vary over time according to mathematical functions. Square, sine, sawtooth and other voltage variation patterns that function generators synthesize can all be plotted by graphing math equations called functions. The plots will look similar to what you'll see on the Oscilloscope screen when it measures the voltage variations. We will experiment with this, starting in the next chapter.

The function generator's Amplitude sets the total amount of voltage fluctuation, and the Offset sets the average voltage. The Frequency sets the rat of voltage fluctuations. So, if the function generator transmits a 1 V amplitude square wave with a 2 V offset, the square wave's high signals would be 2.5 V, and its low signals would be 1.5 V. That's a total voltage fluctuation of 1 V, with an average value of 2 V. If you change the amplitude to zero, the signal does not fluctuate any more, and you are left with a DC voltage at 2 V.

For DC voltages, it does not matter which function or frequency you choose, so long as the Amplitude is set to zero.

Figure 2-18 shows the measured voltage with the Floating cursor and Measure tab.

- ✓ Set the CH1 Vertical dial to 1 V/div.
- ✓ Adjust the CH1 trace's position (point at the trace, click and drag up/down) so that it resembles Figure 2-18.
- ✓ Use your mouse to point at the Channel 1 trace get the CH1 floating cursor measurements and keep in mind that this is an instantaneous measurement that will fluctuate slightly with electrical noise and other factors.
- ✓ Check the value in the Measure tab's Channel 1 average voltage field, and keep in mind that this measurement is an averaged value that is more similar to a DC voltmeter's measurement.

Figure 2-18: Channel 1 Probe of the Function Generator's 3.5 V Output
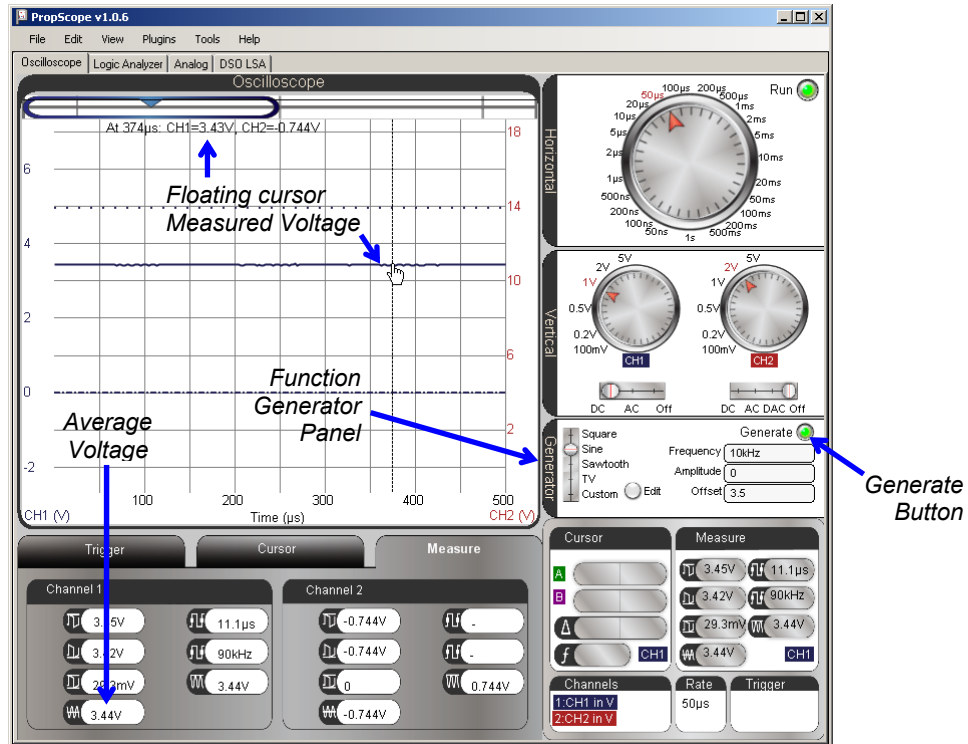
Your Turn: Set and Measure Different Voltages

✓ Try setting the Offset to 3.75 V and repeat the measurements.

2

ACTIVITY #4: VOLTAGE DIVIDERS

Many electronic products and prototypes have circuits that depend on a DC voltage that may not be included in the device's supply voltages. We just finished looking at one way to provide set a voltage for the device, with a DAC. However, a DAC can take I/O pins, processing time, and code. Provided the voltage is between two of the supply voltages, Vdd and Vss for example, a quick solution for setting a voltage is to use two resistors in series.

Voltage Divider Parts List

(2) Resistors – 1 kΩ (brown-black-red)
(2) Resistors – 10 kΩ (brown-black-orange)
(1) Resistor – 2 kΩ (red-black-red)

Voltage Divider Circuit

Two resistors can be connected in series (end to end) with a voltage applied, like V_I and Vss in Figure 2-19. The voltage at the node where the two resistors meet will be "divided" according to the voltage divider equation in the figure.
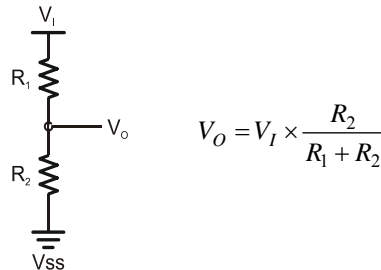

$$V_O = V_I \times \frac{R_2}{R_1 + R_2}$$

Figure 2-19
Voltage Divider Circuit
and Equation

> **The circuit in Figure 2-19 is designed to supply voltage, but not current.** The RC DAC you experimented with has a similar limitation. Many devices have voltage inputs that are called "high impedance". They do not draw current, and are compatible with voltage dividers and RC DACs.
>
> Op-amp buffer circuits will be introduced in Chapter 9. A buffer's output voltage can be determined by a voltage divider or an RC DAC, and it can maintain its output voltage and still supply current to circuits. For example, the PropScope DAC card's function generator has an op amp buffer circuit built-in, so it can drive certain current loads.

**Comment [AL7]:** To-do: Find out how much current from docs or hardware designer.

If you substitute V_I = Vdd = 5 V and R_1 = R_2 = 1 kΩ, the result of V_O should be 2.5 V.

✓ Try substituting the values into the voltage divider equation. Do your calculations agree? What happens if you use two 10 kΩ resistors instead? How about R_1 = 1 kΩ and R_2 = 2 kΩ? Also, try R_1 = 2 kΩ and R_2 = 1 kΩ.

Figure 2-20 shows a test circuit to verify the voltage divider output with R_1 = R_2 = 1 kΩ, and V_I = Vdd = 5 V.
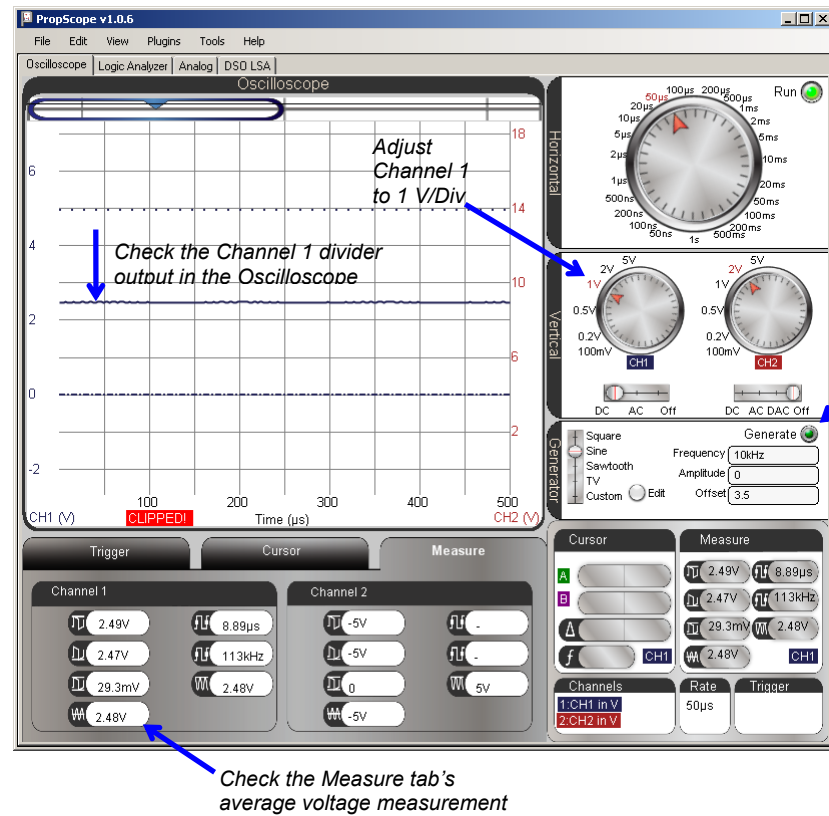
✓ Build the circuit shown in Figure 2-20.

Figure 2-20: Voltage Divider Measurement Schematic and Wiring Diagram
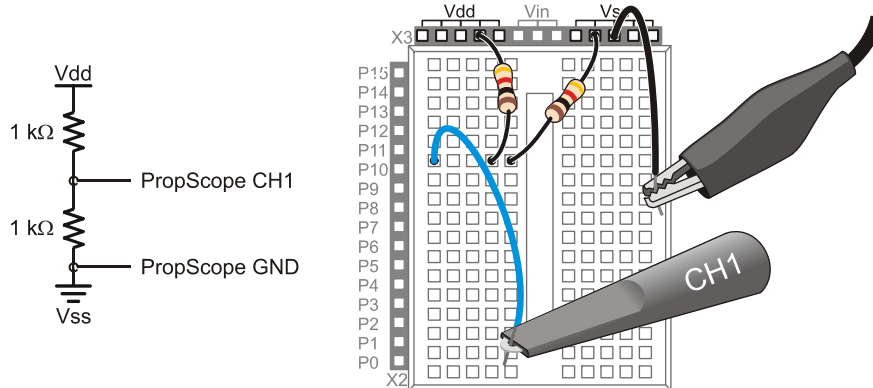
✓ Click the Generate button to turn off the function generator. The button's color should change from bright green to dark green.
✓ If you have not already done so, set the Channel 1 dial to 1 V/div and adjust the trace's position in the oscilloscope display so that it resembles Figure 2-21.
✓ The CH1 trace level should be about half way between the 2 and 3 V Channel 1 division lines, indicating 2.5 V.
✓ Check the CH1 average voltage in the Measure tab to verify.

Figure 2-21: Test the Voltage Divider Output

Adjust Channel 1 to 1 V/Div

Check the Channel 1 divider output in the Oscilloscope

Turn off the function generator

Check the Measure tab's average voltage measurement

## Your Turn: Other Resistor Combinations

✓ Repeat the voltage divider tests for the other resistor combinations discussed at the beginning of this activity.

The Potentiometer – an Adjustable Voltage Divider

The potentiometer (pot) is introduced as a variable resistor in What's a Microcontroller Chapter 5, and as a variable voltage divider in Basic Analog and Digital, Chapters 1 and 3. In brief, a potentiometer has a resistive element that spans it's A and B terminals (see Figure 2-22) and a knob on top for adjusting where the W terminal contacts that resistive element. As you turn the knob one direction, the resistance between W and B decreases

while the resistance between W and A increases. Turn the knob in the other direction, and the resistance between W and B increases as the resistance between W and A increases. The sum of these to resistances will always add up to the resistance between A and B, which is 10 kΩ for the potentiometer in the Understanding Signals kit.

Figure 2-22: Potentiometer Illustrations from What's a Microcontroller.
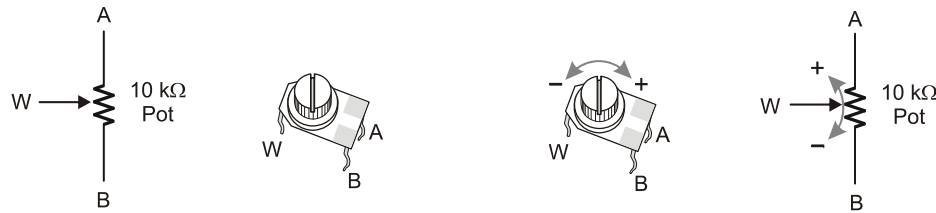
If you connect the potentiometer's A terminal to Vdd and the B terminal to Vss, you will have a voltage divider output at the W terminal that you can adjust by adjusting the knob.

Potentiometer Voltage Parts List

(1) Potentiometer – 10 kΩ
(1) Resistor – 220 Ω (red-red-brown)
(misc) Jumper wires.

Potentiometer Voltage Test Schematic

Figure 2-23 shows a circuit with the pot's A terminal connected to Vdd, its B terminal connected to Vss, and its W terminal connected to the CH1 probe. The divider voltage can be varied simply by turning the potentiometer knob. If you turn the knob clockwise, the pot's W terminal voltage decreases. If you turn it counterclockwise, the voltage increases. By twisting the knob back and forth over its 180° range of motion, you can set a DC voltage anywhere between 0 and 5 V. Since the CH1 probe is connected to the potentiometer's W terminal, you can verify the voltage with the Oscilloscope's tracer cursor, and/or the average voltage in the Measure tab.

   ✓ Build the circuit in Figure 2-23.

Figure 2-23: Potentiometer Voltage Divider Circuit
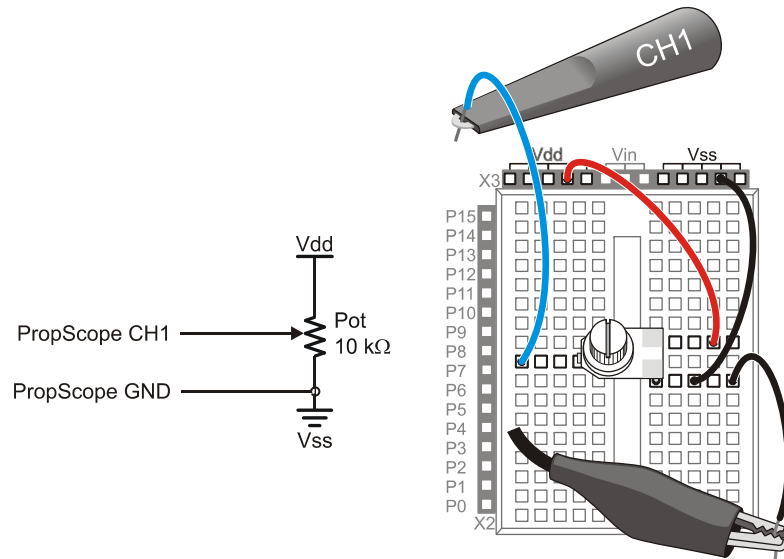
> **Was it necessary to move the ground clip connection?**
>
> No, not really. The ground clip is still connected to Vss, but it could just as easily be left connected to directly to one of the Vss sockets.
>
> **Another Option:** Connect ground clips to the plated holes at the corners of ~~Your~~ board. Like the Vss sockets, the metal in the plated holes at the each corner of your board are also connected to your board's negative power terminal, so they are also Vss connections.

Potentiometer Voltage Measurement with the PropScope

The PropScope's Vertical dial is still set to 50 μs. That means that the ten vertical lines are each 50 millionths of a second apart. The trace line crossing the screen that indicates the voltage is actually a graph of voltage measurements over 500 μs. So, no matter how fast you turned the pot, the voltage trace on the screen will still display as a straight line crossing the screen. The only thing that appears to change as you adjust the pot is the flat trace line's level. In Chapter 3, we will use different time division settings to plot the voltage over time, but for now, we are just interested in the pot's wiper terminal as a DC voltage level.

> ℹ **When you adjust the potentiometer's knob,** make sure to press it downward onto the breadboard so that it keeps electrical contact as you twist its knob.

✓ Rotate the pot's adjustment knob back and forth from one end of its 180° range of motion to the other. Remember to push down on the potentiometer as you adjust it to keep it seated in the board and maintain its electrical contacts.

✓ Observe how the vertical position of the line indicating the voltage in the Oscilloscope screen moves up and down.

✓ As you adjust the pot's knob slowly from one end of its range to the other, monitor the voltage with the floating cursor and/or the Measure tab's average voltage measurement. How does the voltage relate to the pot's adjusting knob's position?

Determining I/O Pin Threshold Voltage

A BASIC Stamp I/O pin set to input interprets voltages above 1.4 V as binary-1 and below 1.4 V as binary-0. The 1.4 volt level is called the I/O pin's logic threshold. This threshold voltage level can vary slightly from one I/O pin to the next as well as from one BASIC Stamp to the next. These variations are typically small and are unlikely to exceed a tenth of a volt.

You can use the PropScope to determine your BASIC stamp's I/O pin threshold voltage. The circuit will need to be modified so that the pot's W terminal is connected to an I/O pin. Then, run a program that makes the BASIC Stamp display the voltage state the I/O pin detects. As the pot is adjusted, you can monitor the I/O pin state in the Debug Terminal. When the pot reaches a position that causes the Debug Terminal to report a change in state, the W terminal voltage has reached the I/O pin threshold. At that point, the PropScope will display the threshold voltage.

✓ Add the 220 Ω resistor shown in Figure 2-24 that connects the pot's W terminal to I/O pin P7.

Figure 2-24: Potentiometer Voltage Divider Circuit Connected to a BASIC Stamp I/O Pin
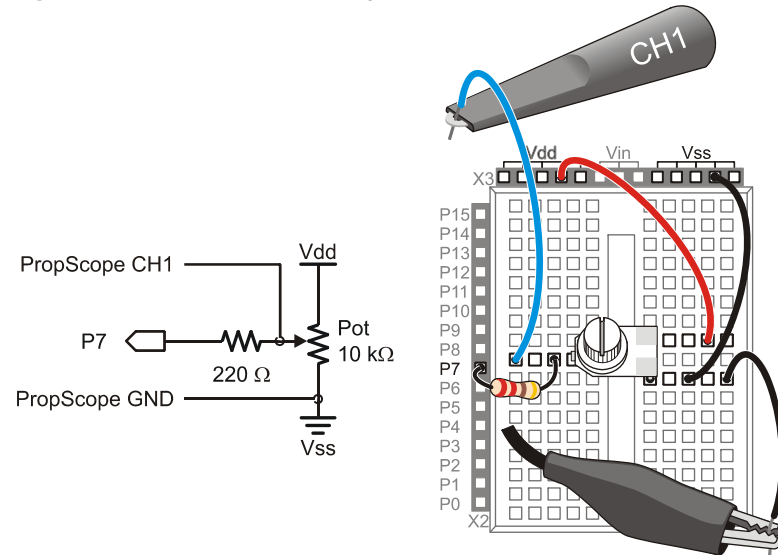
> **Why not just connect W to P7 with a wire?** The 220 Ω resistor protects the I/O pin from certain prototyping mistakes. For example, what if a previous program run by the BASIC Stamp was sending a high signal to P7, meaning the I/O pin supplies 5 V to the circuit. Further, what if the pot's knob is turned all the way counterclockwise, which shorts W to Vss (ground). If there's a 220 Ω resistor in the way, the current from the I/O pin to the W terminal (which is grounded) is limited to acceptable levels. If a wire was used in place of the 220 Ω resistor, the resistance would be almost zero, and the resulting current the I/O pin would try to supply the circuit trying to pull the 0 V ground connection up to 5 V would quickly damage the I/O pin.
>
> **If you have a BASIC Stamp HomeWork Board,** there are 220 Ω resistors built-in to protect the I/O pins, and you actually could use a wire instead of the 220 Ω resistor.

The next step in testing the I/O pin's threshold voltage is to write a program that displays the binary state the I/O pin detects (above threshold = binary-1 or below threshold = binary=0). Test Threshold Voltage.bs2 does this with a DEBUG command that displays the value of the BASIC Stamp's IN7 register. IN7 stores the state I/O pin P7 detects.

✓ Enter Test Threshold Voltage.bs2 into the BASIC Stamp Editor and load it into the BASIC Stamp.

```
' Test Threshold Voltage.bs2
' Display P7 state for testing threshold voltage.

' {$STAMP BS2}                          ' Target module = BASIC Stamp 2
' {$PBASIC 2.5}                         ' Language = PBASIC 2.5

PAUSE 1000                              ' Wait 1 s before values display

DO                                      ' Main loop

  DEBUG HOME, "State = ", BIN1 IN7      ' Display state of signal at P7
  PAUSE 100                             ' Wait 100 ms

LOOP                                    ' Repeat main loop
```

> (i) **For more information about this program,** go to www.parallax.com/go/WAM, and download What's a Microcontroller (.pdf or .zip). Work through Chapter 3, Activity #1 and Activity #2.

When you run the program, it makes the BASIC Stamp send the Debug Terminal the "State = 1" message when the pot's W terminal voltage is above the threshold voltage (Figure 2-25 left) or the "State = 0" message when the voltage is below the threshold (Figure 2-25 right).

✓ Test this with your potentiometer.

Figure 2-25: Debug Terminal State Displays
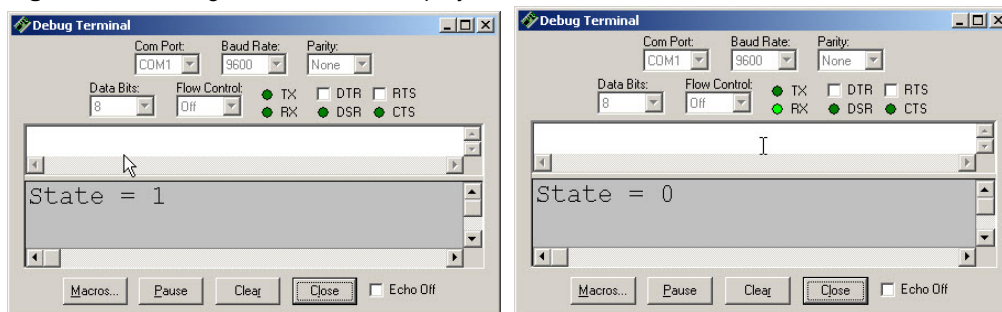
The trick to verifying the approximate threshold voltage is to adjust the pot until you find the point where only a slight adjustment results in a state change. Turn it the slightest amount possible to get a transition from 0 to 1 in the Debug Terminal, then check the

voltage in the PropScope while the Debug Terminal displays State = 1. Turn the pot slightly back to transition from State = 1 to State = 0, and measure the voltage in the PropScope again. The approximate threshold voltage is the average of the two values.

✓ Try it.

ACTIVITY #5: ADVANCED TOPIC – I/O PIN VOLTAGE VS. CURRENT

A BASIC Stamp I/O pin is designed to send a high voltage of 5 V, or a low voltage of 0 V. The I/O pin can also supply small amounts of current to circuits like indicator lights. In this activity, you will examine the affect of the current a circuit draws on an I/O pin's high signal voltage level. You will also test voltages in the circuit and use them to determine the amount of current the I/O pin supplies to the circuit.

No Load Test Circuit

First, let's test an I/O pin's high signal voltage with no load applied. We'll use I/O pin P14. In the previous activity, this I/O pin had a circuit attached to it that allowed it to use binary signals to control an analog voltage output. In this activity, we are looking at the voltages of the raw binary (high/low) signals the I/O pin transmits.

No Load Test Parts

(misc) Jumper wires

No Load Test Circuit

Figure 2-26 shows a no load circuit for testing the high signal voltage transmitted by BASIC Stamp via I/O pin P14.
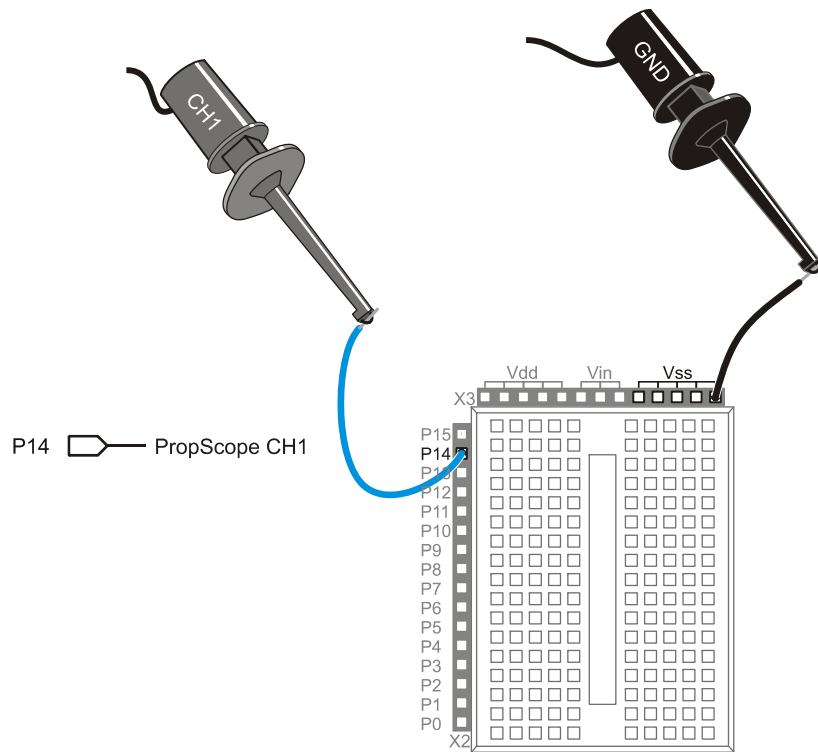
✓ Build the test circuit in Figure 2-26.

Figure 2-26
No Load Test Circuit

Comment [AL9]: To-do: Update probe drawings.

No Load Test Code: High P14.bs2

High P14.bs2 is a test program that transmits a high signal at I/O Pin P14. After the HIGH command, the STOP command prevents the BASIC Stamp from automatically going into low power mode after it runs out of commands.

✓ Enter High P14.bs2 into the BASIC Stamp Editor, and then load the program into your BASIC Stamp.

```
' High P14.bs2
' Sends a high signal to P14.

' {$STAMP BS2}                          ' Target module = BASIC Stamp 2
' {$PBASIC 2.5}                         ' Language = PBASIC 2.5

DEBUG "Program Running!"                ' Program running message
```

```
HIGH 14                                 ' P14 LED on

STOP                                    ' Halt execution but don't sleep
```

2

No Load Test Measurements

Figure 2-27 shows an example of a high signal measurement with no load 4.92 V. Your measurement value may differ slightly.

> **Comment [AL10]:** To-do: Repeat test and get value from latest PropScope software.

✓ Use your PropScope to measure your I/O pin high signal with no load, and make a note of it.
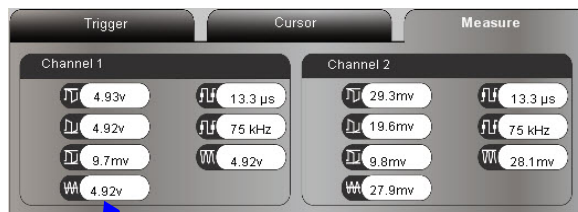
Figure 2-27
P14 High Signal Voltage
Measurement – No Load

> **Comment [AL11]:** To-do: Retake screen cap with latest PropScope software.

*P14 I/O Pin HIGH
signal voltage*

Signal Load Test Circuit Parts

(1) LED – green
(1) Resistor – 220 Ω (red-red-brown)
(misc.) Jumper Wires

LED Load Circuit

Figure 2-28 shows a light emitting diode circuit with a probe connected at the junction between P14 and the LED circuit's input. When the I/O pin sends a high signal to this circuit the light will turn on as a result of electric current flowing from the I/O pin, through the circuit, and into Vss.

✓ Build the circuit shown in Figure 2-28, and connect your PropScope probe as shown.

Figure 2-28: PropScope Probe Monitoring I/O Pin Voltage with LED Circuit Load

> **Comment [AL12]:** To-do: Update probe drawings.
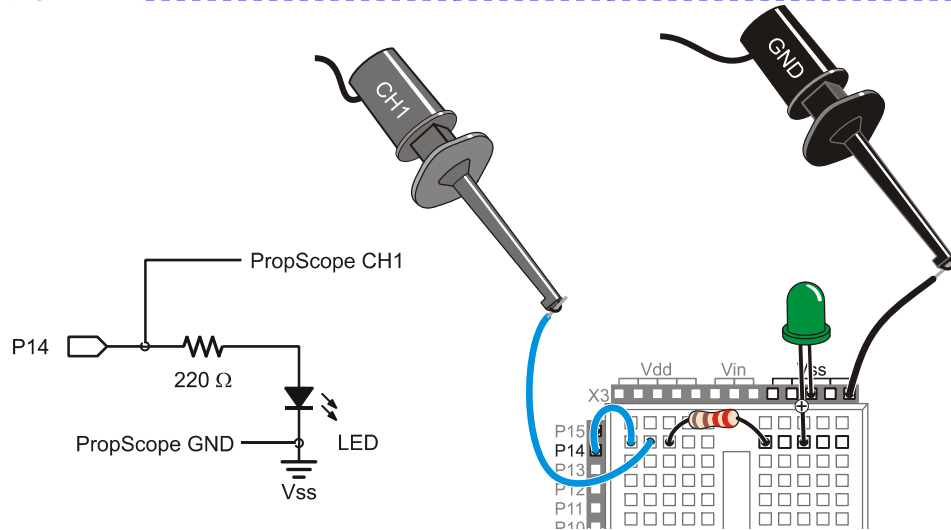
Voltage Measurements

Figure 2-29 shows the P14 high signal voltage measurement with an LED circuit load on the Board of Education, and Figure 2-30 shows the same measurement on the BASIC Stamp HomeWork board. The circuit load on the Board of Education reduced the P14 high signal to 4.24 V, and on the BASIC Stamp HomeWork Board, it reduced it to 3.25 V.

✓   Make a note of the high signal voltage measurement with load for your board.

P14 I/O socket HIGH signal voltage with LED circuit load (Board of Education)
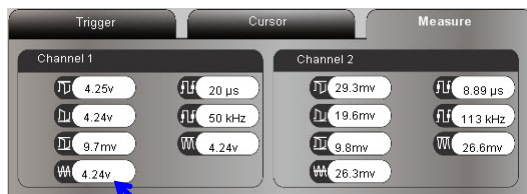
Figure 2-29

P14 High Signal Voltage Measurement with LED Circuit Load

Measurement taken on a Board of Education

> **Comment [AL13]:** To-do: Retake screen cap with latest PropScope software.
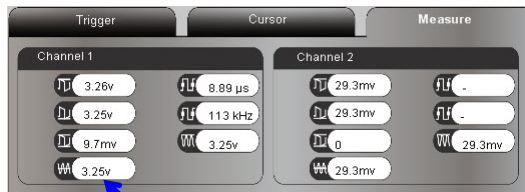
P14 I/O socket HIGH signal voltage with LED circuit load (BASIC Stamp HomeWork Board)

Figure 2-30
P14 High Signal Voltage Measurement with LED Circuit Load

Measurement taken on a BASIC Stamp HomeWork Board

Comment [AL14]: To-do: Retake screen cap with latest PropScope software.

Inside "with Load" Voltage Measurements – Board of Education

The more current a circuit draws, the lower the I/O pin's high signal voltage. Figure 2-31 shows how the I/O pin driver circuit inside the BASIC Stamp's Interpreter Chip is supplied with 5 V. With the LED circuit's current draw, the I/O pin driver's output is only 4.3 V. If you replace 220 Ω with a larger resistance, like two 220 Ω resistors in series, the LED circuit would draw less current from the I/O Pin. So the I/O pin driver circuit would output a high signal voltage that's closer to 5 V. The CH1 measured voltage would probably be in the 4.6 V neighborhood. A 1 kΩ resistor would make the LED circuit draw even less current, and the CH1 voltage measurement would be even closer to 5 V. Of course, we saw earlier that with no load, the high signal voltage is very close to 5 V.

Comment [AL15]: Except that the previous software was returning lower values. Updated captures will be closer to 5 V.
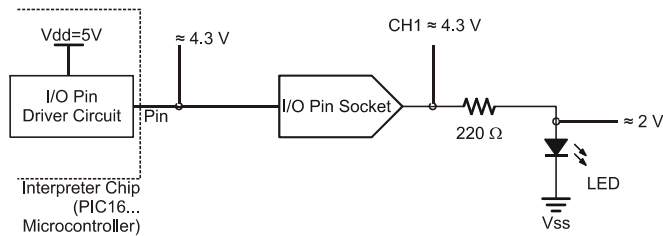

**Figure 2-31**
I/O Pin Driver's Response to Current Load

(Board of Education)

Inside the "with Load" Voltage Measurements – HomeWork Board

The BASIC Stamp HomeWork Board has 220 Ω resistors built into the board between the Interpreter Chip I/O pins and the I/O pin sockets you use to make connections to the breadboard. As mentioned earlier, they help protect the I/O pins from certain prototyping mistakes. Figure 2-32 shows the LED circuit on the BASIC Stamp HomeWork Board. Starting inside the Interpreter chip, the LED circuit loads the I/O pin driver, so it only

outputs about 4.6 V instead of a full 5 V. The reason the voltage drops to 3.3 V at the I/O pin socket is because the 220 Ω resistor built into the HomeWork Board, in series with the 220 Ω resistor on the breadboard forms a voltage divider. The output of that voltage divider is right at the I/O pin socket. Recall that the voltage divider output for two equal resistors is ½ the voltage applied to both ends of the circuit. The ½ voltage between 4.6 V at the I/O pin driver's output and 2 V at the LED is about 3.3 V.

Figure 2-32: I/O Pin Driver and Voltage Divider Responses to Current Load
(BASIC Stamp HomeWork Board)
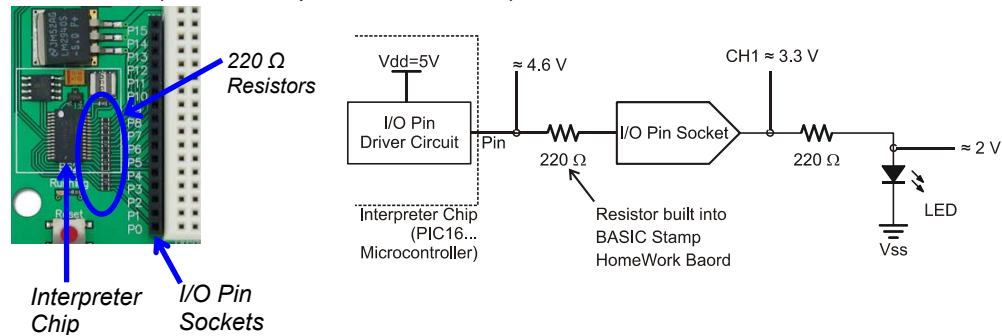
Your Turn: How Much Current Does a Single LED Draw?

In the BASIC Stamp Manual, the BASIC Stamp Model Comparison table states that the BASIC Stamp 2 can "source" up to 40 mA per 8 I/O pin bank, or sink up to 50 mA. This current could all be supplied by a single I/O pin or evenly distributed by a several I/O pins within a given bank of eight. The I/O pin banks are P0..P7 and P8..P15. Two questions to ask before turning on both LEDs at once are: (1) how much current does the I/O pin supply one LED circuit, and (2) would it be safe to deliver twice that current to supply two at once?

If you can measure the voltage across a resistor, you can use the resistor's value and Ohm's Law to calculate the current passing through the resistor. Ohm's Law states that the voltage measured across a resistor (V) is equal to the current (I) passing through the resistor multiplied by its resistance (R). Depending on which two terms you know (or have measured), you can rearrange the terms in Ohm's Law and then calculate the third quantity.
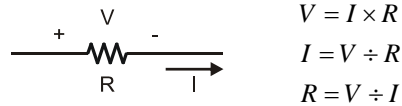
$$V = I \times R$$
$$I = V \div R$$
$$R = V \div I$$

Figure 2-33

Ohm's Law for a Resistor

2

We know the resistance R in the LED ~~circuit, it's 220 Ω,~~ so the only other value we need to calculate the current through the resistor with $I = V \div R$ is the voltage V across it. One quick way to measure the voltage across the resistor is to measure the voltages at both ends of the resistor. The difference between the two voltages is the voltage drop across the resistor.

✓ Move the CH1 probe as shown in Figure 2-34.

Figure 2-34: Measure Voltage at Both Resistor Terminals

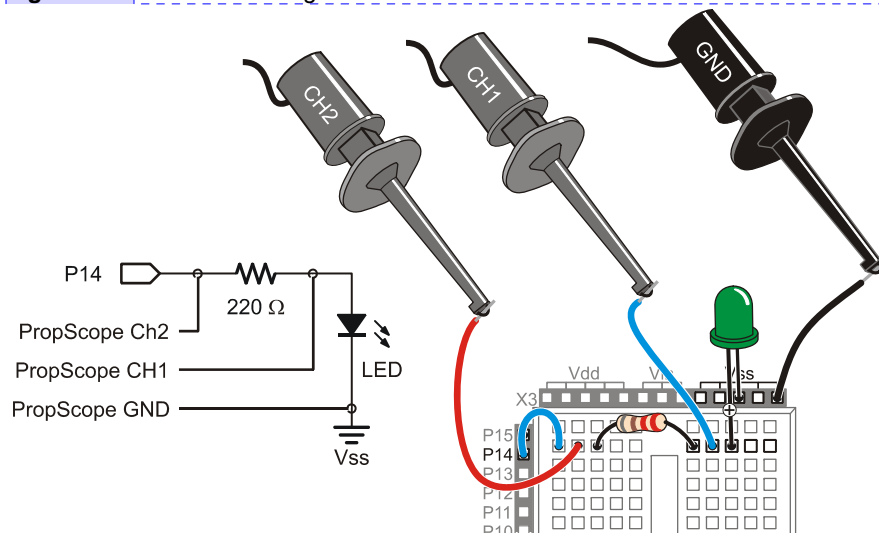> **Comment [AL16]:** To-do: Update probe drawings.

Figure 2-35 shows the resistor voltage measurements and current calculations for the Board of Education, and Figure 2-36 shows the same measurements and calculations for the BASIC Stamp HomeWork board. The voltage V_R across the $R = 220\ \Omega$ resistor in the LED circuit was the Measure tab's average voltage measurement for channel 1 minus the average voltage for channel 2. Knowing both V_R and R, the calculations for $I_R = V_R \div R$ are shown at the right side of each figure.

✓ Measure the voltage at both resistor terminals while the LED circuit is connected to the I/O pin and emitting light.
✓ Calculate the voltage V_R across the 220 Ω resistor (V_R) by taking the difference of the voltage at both terminals.
✓ Use V_R and Ohm's Law to calculate the current draw for your particular circuit and board.

Comment [AL17]: Channel math would come in handy here.

**Figure 2-35:** Resistor Voltage Measurements and Current Calculations *(Board of Education)*

Comment [AL18]: To-do: Retake screen cap with latest PropScope software.
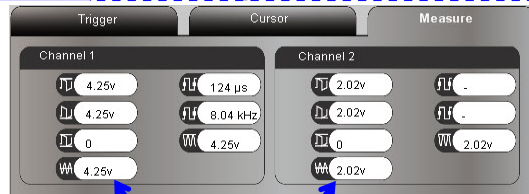
Resistor Voltage
V_R = 4.25 V – 2.02 V = 2.23 V

$$I_R = V_R \div R$$
$$= 2.23V \div 220\Omega$$
$$= 0.01013636...V/\Omega$$
$$\approx 0.0101A$$
$$= 10.1mA$$

Figure 2-36: Resistor Voltage Measurements and Current Calculations *(HomeWork Board)*

Comment [AL19]: To-do: Retake screen cap with latest PropScope software.
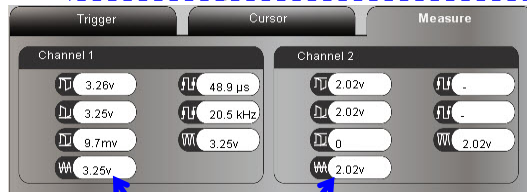
Resistor Voltage
V_R = 3.25 V – 2.02 V = 1.23 V

$$I_R = V_R \div R$$
$$= 1.23V \div 220\Omega$$
$$= 0.005590909...V/\Omega$$
$$\approx 0.00559$$
$$= 5.59mA$$

The first question was, "how much current does the I/O pin supply one LED circuit?" The answer is: about 10.1 mA on a Board of Education, or 5.59 mA on a BASIC Stamp HomeWork Board. The second question was, "would it be safe to deliver twice that current to supply two LEDs at once?"

2

The solution is: The BASIC Stamp would have to deliver twice as much current as it does to one LED circuit load and still not exceed 40 mA.. For the Board of Education, that would be I = 10.1 mA × 2 = 20.2 mA, which is still which is well below the BASIC Stamp Manual's 40 mA limit. For the HomeWork Board, it's I = 5.59 mA × 2 = 11.18 mA, which is even less, and well within the 40 mA limit too. So, in both cases, the BASIC Stamp can safely deliver current to two LEDs at once.

Your Turn: More Current Measurements

- ✓ Repeat by replacing the 220 Ω resistor with a 1 kΩ resistor. Could your BASIC Stamp safely drive eight LEDs with a bank of 8 I/O pins?

SUMMARY

This chapter examined power supply voltages and surveyed a variety of circuits and measurement techniques for fixed DC voltages. DC voltages that were measured included Vdd, Vin, Vss, voltage dividers outputs, and DAC circuit outputs set by the BASIC Stamp, and the PropScope DAC Card's DAC output. The Oscilloscope's voltage divisions, floating cursor, and Measure tab were used to measure these voltages. The effects of circuit load on I/O pin high signal voltages were examined. Higher current draws resulted in lower I/O pin driver output voltages. Ohm's Law was used to determine the current through a circuit by measuring the voltage at each of the resistor's terminals. The voltage across the resistor and its resistance can be used in I = V ÷ R to calculate the current passing through the resistor.

Questions

1. Where should the PropScope's ground clips be connected for measurements on your board?
2. What does the Oscilloscope view's Horizontal dial adjust?
3. Is it possible for the distance between two horizontal divisions to mean two different things?
4. How do the Oscilloscope view's Vertical dials affect the measurement ranges?
5. If the resistors in a voltage divider are equal, what will the voltage be?
6. How does the current an I/O pin supplies affect its signal level?
7. Name the three different quantities you can use Ohm's Law to determine.
8. What kind of output does a DAC control, and what determines the output?
9. How many DAC channels does the PropScope's DAC card have?
10. How many DAC channels can your BASIC Stamp have?

Exercises

1. Calculate the voltage of a voltage divider output with 5 V applied across it. R1 = 10 kΩ, R2 = 2 kΩ.
2. Configure your PropScope Oscilloscope to display DC voltages in the 3 to 5 V range on channel 1, with channel 2 disabled.
3. You probed two leads of a 1 kΩ resistor and found the voltage to be 1 V. How much current is passing through it?

Projects

1. The LED in Figure 2-28 is forward biased when the BASIC Stamp sends a HIGH signal. A foreword biased LED allows current through the circuit and emits light. If you plug an LED into the circuit backwards it will be reverse biased. It will not allow current through the circuit when the BASIC Stamp sends a high signal, and it will not emit light. Assume that a product you are designing has the LED in an enclosure so that it cannot be visually ~~inspect~~ for emitting light, but the circuit board gives you access to the LED's terminals. (An example of a device with an LED in an enclosure is called an optocoupler, which allows microcontrollers to monitor and control other devices without being electrically connected to them. Optocouplers also use infrared LEDs, which emit light that cannot be detected by the human eye.) Develop a PropScope voltage test a technician could use to detect if the LED is reverse biased.
2. Design and test a circuit that allows the BASIC Stamp to detect when the battery needs to be changed. Assume that when the battery's voltage decays to 7.5 V, it's dead. Hint: Save time, use a Potentiometer. IMPORTANT: Use a 2 kΩ resistor between the potentiometer's W terminal and the I/O pin to protect from voltages that may be up to 9 V, or even slightly higher when the battery is new.

Solutions

Q1. The PropScope's ground clips should be connected to Vss.
Q2. Oscilloscope display time divisions.
Q3. Yes, the distance between two horizontal divisions might be a certain number of volts per division on the channel 1 scale, and a different number in the channel 2 scale.
Q4. Each vertical dial setting might have a different maximum and minimum voltage measurement.
Q5. Half the voltage applied to the circuit.

2

Q6. The more current an I/O pin supplies, the lower its HIGH voltage.

Q7. Voltage, current and resistance.

Q8. Voltage output is set based on digital values.

Q9. One

Q10.　　　　One for each I/O pin, up to 16 provided you have enough resistors and capacitors.

E1. Vo = Vi×[R2 ÷ (R1 + R2)] = 5 V × [2 kΩ ÷ (10 kΩ + 2 kΩ)] = 5 V × (2/12) = 5/6 V = 0.833…V

E2. Set the coupling slider below the CH2 Vertical dial to Off. Set the CH1 coupling to DC, and set the vertical dial to 1 V for best viewing. 2 V or 5 V would work too, but the display will not be as detailed.

E3. I = V ÷ R = 1 V ÷ 1 kΩ = 1 V ÷ 1000 Ω = 0.001 V/Ω = 0.001 A = 1 mA

P1. Step 1: With High P14.bs2 running and the circuit connected as shown in Figure 2-28, probe the voltage at the LED's anode terminal. See the location of the CH1 probe in Figure 2-34.

Step 2: Remove the LED from the circuit, give it a half turn, and plug it back in. Then, measure the voltage at the LED's cathode terminal, which is now connected to CH1 because you reverse biased the LED.

Step 3: Notice that the voltage across the LED is about 2 V (Figure 2-37) when it's forward biased and about 5 V when it's reversed biased.

Figure 2-37: Forward and Reverse Biased LED Voltage Measurements

Comment [AL20]: To-do: Retake screen cap with latest PropScope software.

Forward Biased LED　　　　*Reverse Biased LED*
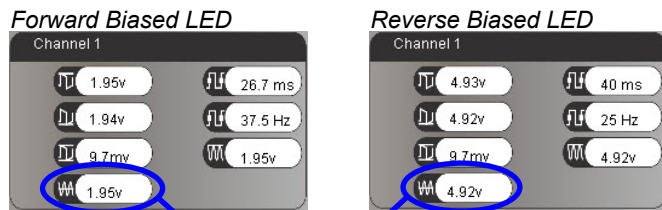
Channel 1 DC Voltage Measurements

Step 4: Instructions for the technician: "Probe the voltage across the LED using Figure 2-34 as a guide. If the voltage is in the 1.5 to 2.5 V range, the device passes. If the voltage is outside this range, the device fails testing."

P2. With A and B connected to Vin and Vss, the potentiometer can be adjusted so that its output is 1.4 V when Vin is 7.5 V.
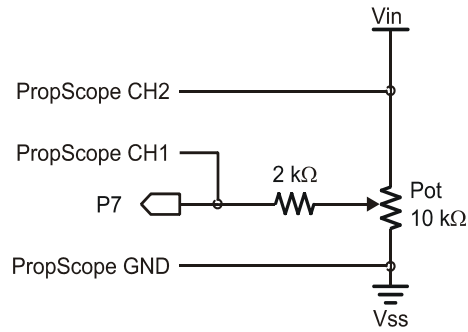
Figure 2-38
Voltage Divider
Output for Low
Battery Detector

Step 1: Measure Vin for a new alkaline battery.
Step 2: Write code that will display "Replace Battery" P7 is below 1.4 V or "Battery OK" if P7 is above 1.4 V

```
' Battery Warning.bs2
' Uses a pot with A and B connected to Vin and Vss.

' {$STAMP BS2}                          ' Target module = BASIC Stamp 2
' {$PBASIC 2.5}                         ' Language = PBASIC 2.5

PAUSE 1000                              ' Wait 1 s before values display

DO                                      ' Main loop

  DEBUG HOME, "State = ", BIN1 IN7, CR  ' Display state of signal at P7
  PAUSE 100                             ' Wait 100 ms
  IF IN7 = 1 THEN                       ' If Vtrim > 1.4 V
    DEBUG "Battery OK", CLREOL          ' OK message + clear to line end
  ELSEIF IN7 = 0 THEN                   ' else if Vtrim < 1.4 V
    DEBUG "Replace battery!"            ' Replace msg + clear line end
  ENDIF

LOOP                                    ' Repeat main loop
```

Step 3: What value would you adjust the pot's voltage divider output to with a good battery? $V_{TRIM} = 1.4 \text{ V} \times$ Vin (new battery) ÷ 7.5 V. For example, with a brand new alkaline battery connected, Vin measures 9.4 V. $V_{TRIM} = 1.4 \text{ V} \times 9.4 \text{ V} ÷ 7.5 \text{ V} \approx 1.75 \text{ V}$.

Step 4: Use your PropScope to set the pot's voltage to V$_{TRIM}$. See Figure 2-39 for an example Note that both the average voltage and the floating cursor measurements show 9.4 V for Vin and 1.75 V for V$_{TRIM}$. Also, note that the CH2 voltage scale was adjusted to 5 V per division to prevent it from clipping the Vin measurement while the CH1 scale is set to 1 V per division for a closer look at the trim voltage.

2

Figure 2-39: Vin and VTRIM with Measure Tab and Floating Cursor
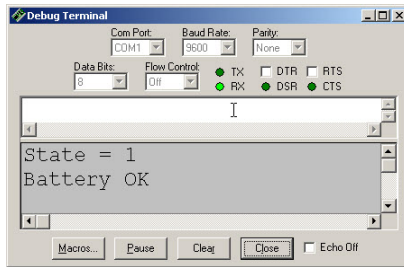

Comment [AL21]: To-do: Retake screen cap with latest PropScope software.
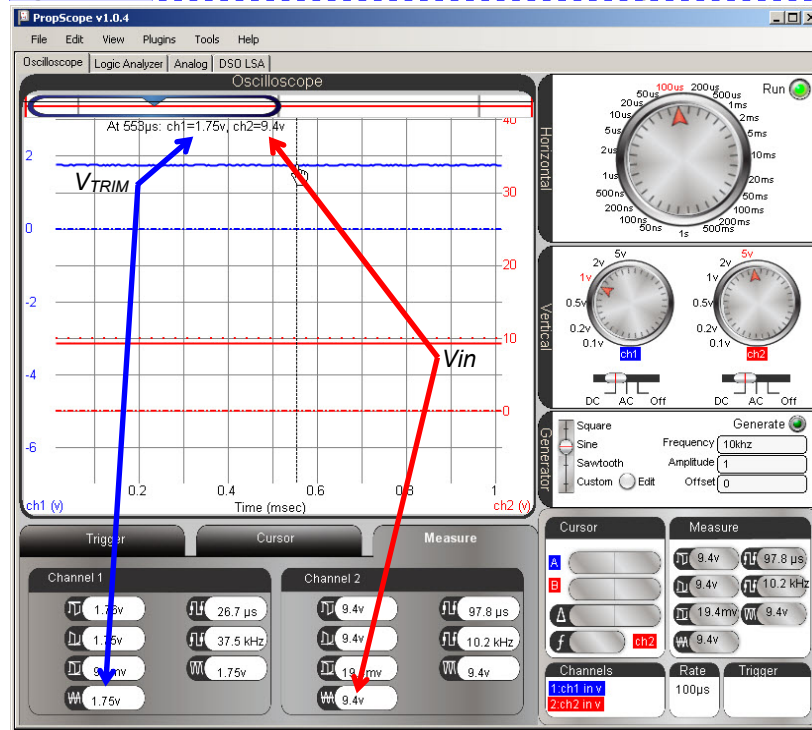
Step 5: Test it with a good battery and a low battery (that measures 7.5 V or less). Example Debug Terminal displays in Figure 2-40:

Figure 2-40: Debug Terminal Good and Low Battery Tests

Good battery test   *Low battery test*