Experiment No. 1

Voltage Dividers, DC & AC Signals, Time & Frequency Domains

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Purpose

The goal of Experiment #1 is to build a voltage divider, check the validity of the KVL and KCL equations and learn how to use the equipment in the lab. (KVL = Kirchhoff's Voltage Law; KCL = Kirchhoff's Current Law.)

- Read this Experiment and answer the pre-lab questions before you come to the lab.

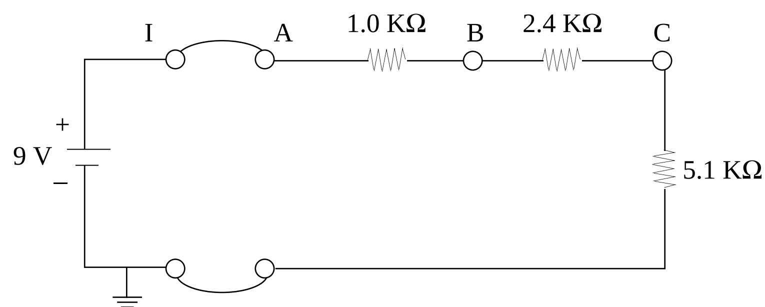
1.0 Voltage Divider; KVL and KCL Rules:

Equipment:

1. Agilent 34401A Multimeter
2. Agilent E3631A Triple Power Supply

Experiment Set-up:

1. Measure the resistance of the 1 KΩ, 2.4 KΩ and 5.1 KΩ resistors using the Agilent 33401A multimeter.
2. Connect the following circuit on your proto-board. The TA (Teaching Assistant) will explain the layout of the protoboard and how to put components in it.

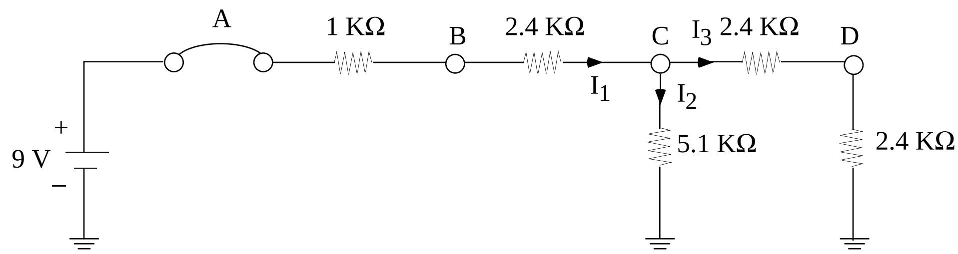


3. Connect the Agilent E3631A power supply to your circuit and set it at +9V.
4. ❑ Using the Agilent 33401A multimeter, measure the node voltages V_A, V_B, V_C (with respect to ground).

   Also, measure the voltage drop, V_{AB} and V_{BC}. Check that the KVL rule is satisfied around the loop.

   Compare the measured voltages with your pre-lab calculations.
5. ❑ Break the circuit at node A (or node B or node C), and measure the current I in the circuit using the Agilent 33401A multimeter.

   Compare this value with your pre-lab calculation.
6. Connect now the 2.4 KΩ resistors from node C to ground as shown below:



- ❑ Measure V_A, V_B, V_C, V_D with respect to ground. (Be sure that the Agilent 33401A multimeter is set for voltage measurement).
- ❑ Measure the currents I_1, I_2, I_3. Check that the KCL rule is satisfied.

  In the lab report, you will be asked questions about this section.

2.0 Time Domain Measurements (or Learning the Agilent Oscilloscope):

Equipment:

a. Agilent 33120A Waveform Generator

b. Agilent 54645A Oscilloscope

1. Connect the output of the Agilent 33120A waveform generator to the Agilent scope using a coaxial cable.
2. Set the waveform generator to deliver a sinewave at 1 KHz and 2 Vppk. Also, set the offset voltage to be zero (see p. 4).
3. If you do not see a waveform on the scope, press the [Auto-scale] key. This key resets a large portion of the scope settings and displays the waveform. (Do not use this key often. You can develop a very bad habit and never learn how to use a scope well!)
4. Turn the VERTICAL Volts/Div knob of Channel 1 and see how you can expand or compress the waveform depending on your selection. You will find that you can easily "saturate" a scope and you should never do this. The waveform must always be within the display area.

   Turn the Position knob to see how you can move the center of the waveform up and down. Now, center the waveform and choose a 500 mV/div setting.
5. Turn the HORIZONTAL Time/Div knob and see how you can expand or compress the waveform depending on your timebase selection. If you choose a 200 µs/div setting, the 1 KHz (/msec period) sinewave "looks" expanded. If you choose a 2 msec/div setting, the 1 KHz sinewave "looks" compressed. Choose a 500 µs/div setting.

   Turn the Delay knob to the right to see how you can delay the triggering time. Look at the dark small arrows (on top and bottom of the screen). These define the actual trigger point. Return the delay back to 0.00 s (align the arrows).
6. Trigger Selection: The scope needs a signal to trigger its sampling circuitry. The triggering signal could be derived from the signal itself or from external or internal references.

   a. Press the [Source] key under the TRIGGER section. You will find on the bottom of the screen:

      Ch.1 Ch. 2 External Line

Press Ch. 2: Since you have no input to Channel 2, you will lose your lock and the signal will not be stable on the screen.

Press Line: The scope is now triggering on the 60 Hz AC line voltage. Since it is not locked to the 1 KHz waveform, the signal will not be stable on the screen.

Press External**:** The scope triggers on an external signal provided by the external trigger input. Since you have no input, the signal will not be stable on the screen. You can connect the SYNC output of the Agilent 33120A waveform generator to the External Trigger input. Your signal will then be stable on the screen. Do it if you wish.

Press Ch. 1: The scope is triggering back on the input signal and the signal is stable on the screen. (Remove the external trigger if you have connected it.)

7. Slope/Glitch Triggering: A scope can trigger on the rising edge or falling edge of a waveform. Look at the left side of the screen. You will find two small dark arrows, on top and bottom of the screen. These arrows define the triggering plane.
   a. Press the Slope Glitch key and choose the rising edge key (see the screen). Look at the waveform at the "arrow" reference plane. Note that you are triggering at the rising slope of the sinewave.
   b. Choose the falling edge and note that you are triggering at the falling edge of the sinewave.
   c. Return to rising edge trigger mode (we do not use TV or Glitch triggering).
8. Mode/Coupling Triggering: A scope needs a certain voltage level to trigger. Normally, this is set automatically, but in certain cases, you want to control this level so that you do not trigger on low level signals or noise.
   a. Press the Mode Coupling key and look at the bottom of the screen. The Auto Level is highlighted.
   b. Press the Auto option on the screen, and turn the Level knob under the TRIGGER section. Look at the waveform. As the triggering level is raised (or lowered), the scope triggers a bit late (or earlier) so as to align the set level with the triggering reference plane. When the level is above the waveform peak, the scope does not trigger anymore and you lose lock.
   c. Press the Normal option on the screen and repeat. When the level is above the waveform peak, you lose the trigger and the waveform freezes. The scope is not running anymore.
   d. Press back the Auto Level option.
   e. The Coupling key, AC or DC, means that the signal is either AC or DC coupled. If it is AC coupled, then the scope will not show the DC level of the signal.
   f. The Reject key introduces low-pass filter with a corner freq. of 50 KHz to reject all noise above 50 KHz, or a high-pass filter with a corner freq of 50 KHz to reject all noise below 50 KHz. We rarely use this key.
9. Voltage Measurements: Look at the top of the scope under the Measure section and press the Voltage key. Now look at the bottom of the screen.
   a. Make sure that you are on Source 1 (for Channel 1).
   b. ❑ Press Vpp, Vavg, and Vrms and write these values in your notebook.
   c. Press Clear Meas and then Next Menu.
   d. Press Vmax, Vmin, Vtop, Vbase. Do not write them in your notebook.

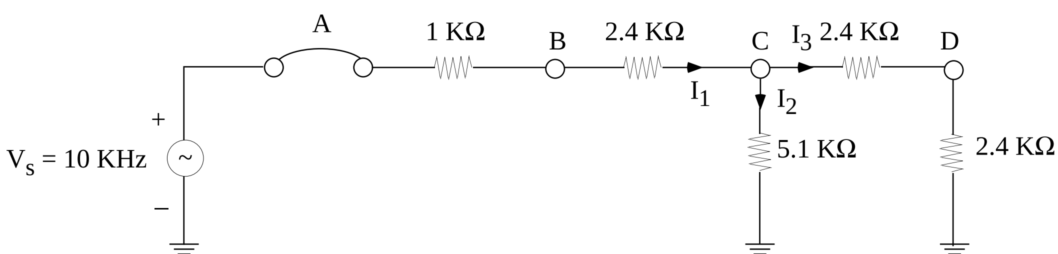
10. Time Measurements: Press now the Time key and look at the bottom of the screen.
    a. Make sure that you are on Source 1 (for Channel 1 signals).
    b. ❑ Press Freq, Period, Duty and write these values on your notebook.
    c. Press Clear Meas and then Next Menu.
    d. Press +Width (positive part of waveform), –Width, Risetime (defined at 10% to 90% of the waveform).

11. Cursor Measurements: Press the Cursors key and look at the bottom of the screen.
    a. You have two cursors, V1 and V2 and you can read any voltage on these cursors. Also, you can read the difference between V1 and V2 (ΔV). Read Vpeak and Vppk using the cursors.
    b. Same for time measurements with t1, t2 and Δt.

       Note that if you want to read the Degrees (or phase of a signal), you need to calibrate first. Put a cursor at a zero crossing (t1) and put the other cursor one period away Δt = 1 ms). Press the Deg key and the Set 360˚ key. You have now calibrated the phase.

3.0 Linear Circuits in Time Domain:

1. Set the Agilent 33120A to give a 10 KHz sinewave with V_{ppk} = 2 V and connect it to circuit shown in section 1.6:



2. ❑ Measure V_B, V_C and V_D and plot the waveforms on your notebook.
3. Set the source to give a 10 KHz triangular wave with V_{ppk} = 2 V.

   ❑ Measure V_C and V_D and plot the input (V_s) and output waveforms (V_C, V_D) on your lab notebook.

   (You will note that in linear circuits, the output signals have exactly the same shape as the input signal but with different amplitudes.)

4.0 Square-Wave Risetime Measurement:

1. Connect now the Agilent 33120A waveform generator directly to the scope. Set the Agilent 33120A to give a 10 KHz square-wave with Vppk =2 V.

   On the Scope, choose a 500 mV/div setting for Vertical, and a 20.0 µs/div for Horizontal.
2. ❑ Go to the Measure section, press the Time key, then go to the Next Menu and press the Risetime key. Write your measurements it on your lab notebook.
3. Choose now a 50 ns/div timebase. Notice how the waveform is still triggered underneath the arrows and you only see the rising edge of the square wave. Draw the

waveform in your lab notebook. (You will see some oscillations called "ringing" and you will study this in EECS 211.)

4. ❑ Measure the risetime and write it in your lab notebook.

5.0 Frequency Domain Measurements:

1. Set the Agilent 33120A to give a 10 KHz sinewave with V_{ppk} = 2V. Connect it to Channel 1 of the scope.

2. Choose the vertical settings at 0.5 V/div and a horizontal setting (timebase) at 500 µs/div. You will see a lot of sinewaves on the screen.

Entering Math Mode:

3. Press the Math Mode [±] button.

4. At the bottom of the screen, you will see Function 1 and Function 2.

Function 1 does addition (+), subtraction (–) or multiplication (*) on signals of Channels 1 & 2.

Function 2 does integration (∫dt), differentiation (dv/dt) or a Fast Fourier Transform (FFT) on signals of Channels 1 or 2, or of the resulting waveform of Function 1 (F1).

5. Press Function 2: ON and Menu

Operand: 1, 2, F1 (Choose the operand to be Channel 1)

Operation: FFT, ∫dt, dv/dt (Choose FFT).

Units/div	10 dB	(Sets the units in dB for the vertical lines)
Ref Level	0.00 dBV	(Sets the top horizontal line in dBV)
FFT Menu		(Goes into the FFT menu)

6. Press FFT Menu, you will see at the bottom of the screen:

Center Freq	48.8 KHz	(Shows the center freq. Controlled by timebase (horizontal) settings)
Freq Scan	97.7 KHz	(Shows the freq. scan. Controlled by timebase (horizontal) settings).
Window	Hanning	(Can be selected between Hanning, flat-top, Exponential and Rectangular. Always choose Hanning.)
Autoscale FFT		(Moves 0 Hz to left and autoscales the vertical settings. I do not like it.)

7. Press Channel 1 button [1] twice to get rid of the time domain representation.

(To view Channel 1 in the time domain, press [1] at any time.)

8. Press Math Mode button [±] to get back into the FFT menu at the bottom of the screen.

You have in front of you a clear representation of a sinewave signal in frequency domain. Notice the single peak at 10 KHz (the rest is sampling noise).

9. ❑ Press [Cursors]. Using V_1, V_2 and f_1, f_2, measure the amplitude of the sinewave (in dBV) at 10 KHz and the average amplitude of the noise. (Note: cursor SOURCE must be set to F2.) Write them in your lab notebook.

10a. ❑ Change the amplitude of the sinewave to 100 mVppk and using the Cursors mode, measure the voltage in dBV. Write it down on your notebook.

Return the amplitude back to 2 Vppk.

10b. ❑ Using the knob on the function generator, vary the frequency in 1 KHz steps to 100 KHz and see the peak moving on the screen. Notice what happens above 100 KHz. The signal returns to the screen and moves backward!! This is not correct and is due to the sampling circuitry/firmwave of the scope. THEREFORE, ALWAYS BE SURE THAT YOUR FREQUENCY SPAN (AT THE TOP OF THE SCREEN) is LARGER THAN YOUR SIGNAL!

Return the sinewave frequency to 10 KHz.

11. ❑ Now comes the interesting part: Press the Square-Wave button (10 KHz, Vppk = 2V) and measure the amplitude of the fundamental (f_o) and of each harmonic ($3f_o$, $5f_o$, $7f_o$ and $9f_o$). Write them in your lab notebook.

12. Press back the sinewave button. Now play with the timebase settings and see how you change the center frequency and frequency span of the display. Always choose a setting which puts your fundamental and harmonic frequencies within the set frequency span!

To view Channel 1 in the time domain, press [1] at any time.

To view Channel 1 in the frequency domain, press [±] at any time.

The dB Scale: In time domain, the unit is volts or "V." You can have V_{ppk}, V_{rms} or V_{av}. In frequency domain, the units are usually expressed in dB since the rms voltage is needed to calculate the power carried by a signal. The conversion is quite easy if you have a calculator. The term dB, or decibel, is a logarithmic ratio between two signals. The term dBV refers to a ratio between the unknown voltage and a one volt reference.

$$dBV = 20 \log (Voltage_{rms}(V) / 1)$$

For a sine wave:

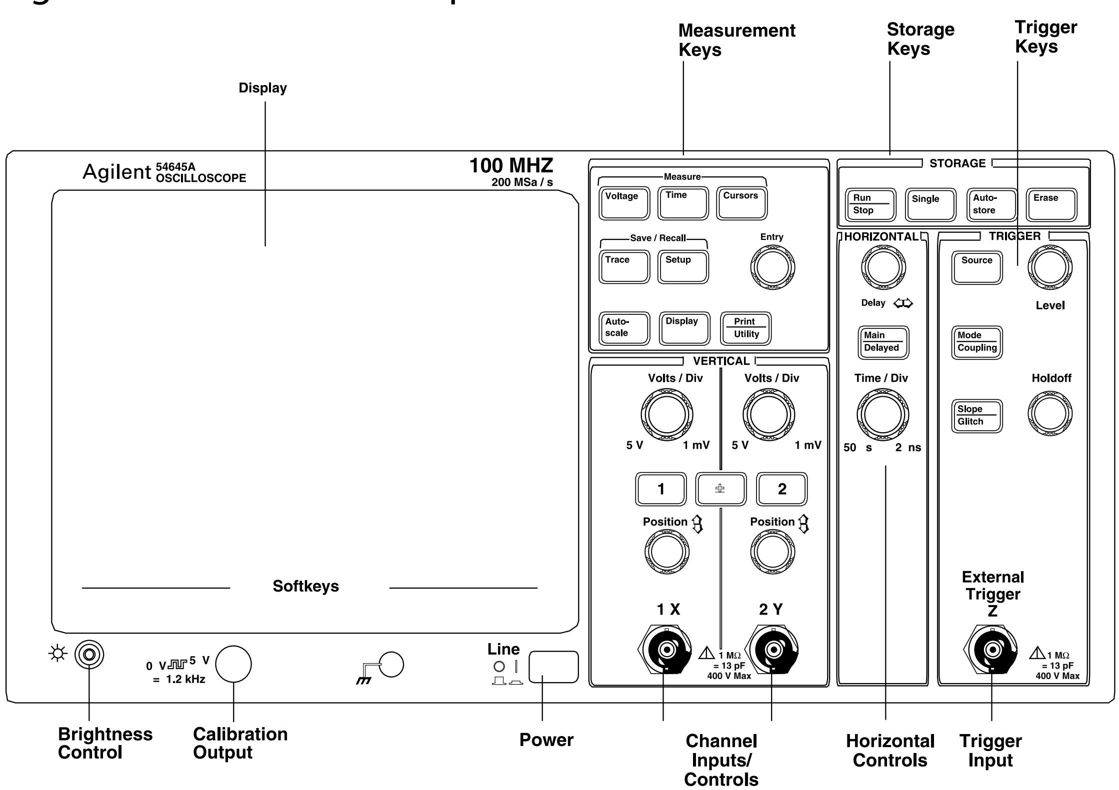
$$V_{rms} = \frac{V_{pk}}{\sqrt{2}} = \frac{V_{ppk}}{2\sqrt{2}}$$

$Voltage_{(rms)}$ (V)	dB
10	20
1	0
0.1	–20
0.001	–40
0.001 (1 mV)	–60

and

$Voltage_{(rms)}$ (V)	dB
1.0	0
0.8	–2
0.5	–6
0.4	–8
0.2	–14
0.1	–20

Agilent 54645A Oscilloscope Front Panel



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Pre-Lab Assignment

1. Calculate V_A, V_B, V_C and I in the circuit of experiment #1 (Section 1.6, p. 2) for a 9V DC input voltage.
2. ❑ Translate the following dB numbers into rms and ppk voltages: Relative to one volt rms, translate.

   6 dB = ________ V –38 dB = ________ V

   –12 dB = ________ V –60 dB = ________ V
3. ❑ Translate the following rms voltages into dB (20 log (V_{rms})).

   10 V = ________ dB 60 mV = ________ dB

   4 V = ________ dB 6 mV = ________ dB
4. ❑ Translate the following ppk voltages into dB.

   2 V = ________ dB 100 mV = ________ dB

   0.5 V = ________ dB 2 mV = ________ dB
5. ❑ What is the meaning of a signal period (T)?

   What is the period and frequency of a DC signal?

   What is the period of a 10 kHz signal in msec?
6. Using the Fourier-Series expansion of a square-wave, calculate the Fourier coefficients of a 10 KHz, 2 V_{ppk} (f_o) square wave up to 13 f_o.

   Write your answers in Volts and dB for the fundamental and each harmonic frequency.

Lab Report Assignment:

1. Using the measured values of the resistors, calculate V_A, V_B, V_C and I. Compare with measurements (down to mV levels).
2. For the circuit with the additional 2.4 KΩ resistors (on p. 17), calculate V_A, V_B, V_C, V_D, I_1, I_2, I_3 and compare with measurements.

   Why did V_C change?
3. Compare the measured dB values of the 10 KHz square-wave (fundamental and harmonics) with the calculated values in your pre-lab.
4. ❑ Take the measured spectrum of the 10 kHz square-waveform at f_o, $3f_o$, $5f_o$, $7f_o$, $9f_o$ and plot the following waveforms from t=0 to t=0.3 msec. Note that V_{f_o}, V_{3f_o}, ... are rms values!

$$v_1(t) = \sqrt{2}\,V_{(f_o)} \sin(2\pi f_o t) \quad \text{(fundamental)} \quad \underline{\text{V in rms!}}$$

$$v_2(t) = v_1(t) + \sqrt{2}\left[V_{(3f_o)} \sin(2\pi(3f_o)t) + V_{(5f_o)} \sin(2\pi(5f_o)t)\right] \quad \text{(Up to the 5th harmonic)}$$

$$v_3(t) = v_2(t) + \sqrt{2}\left[V_{(7f_o)} \sin(2\pi(7f_o)t) + V_{(9f_o)} \sin(2\pi(9f_o)t)\right] \quad \text{(Up to the 9th harmonic)}$$

You can do these summations on any mathematical program you choose (Matlab, MathCad, Pascal, C, ...). The 3 plots should be well detailed with an x axis in msec (0–0.3 msec) and a y-axis in volts ($\pm$2 V). Your time steps should be small enough to clearly see the waveforms.

The essential point behind this exercise is to clearly "see" how any periodic waveform (square wave or other) is actually composed of a fundamental component (f_o) and a series of higher frequencies called harmonics. In the case of a square wave, you need at least up to $5f_o$ before it starts looking like a square wave and up to $9f_o$ before it becomes a good square wave. This means that a 100 MHz square-wave clock computer must be designed so that the computer lines (on-chip and off-chip) pass at least up to 500 MHz sinusoidal signals for proper operation. DO NOT FORGET THIS!

Note: The essence of this idea can be seen on the Agilent Educator's Corner Website

Under Experiments, Java Animations, then Generating Pulses.

http://www.educatorscorner.com/experiments/spectral/SpecAn2.shtml