Dyson School of Design Engineering, Imperial College London

DE1.3 Electronics 1

Lab 2 – Electronic Circuits

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Introduction

In this lab, you will be building and testing simple circuits involving resistors, capacitors and an LED. By the end of the Lab, you should be able to:

- Apply the principle of voltage divider to either predict voltage values or choose resistors for a given output voltage.
- Measure and calculate the internal resistance of a voltage source.
- Explain why when you load a circuit, the voltage changes, and predict such a change using Thévenin's Theorem.
- Apply KCL to predict voltages and currents in a resistor network.
- Predict the output voltage of an RC circuit when a step signal is applied.
- Plot the frequency response of an RC circuit and explain the purpose of filtering.
- Explain why an RC circuit reduces the noise in a signal.
- Explain the behaviour of a CR circuit and why it prevents dc voltage getting through from input to output.
- Generate a dc voltage using PWM signals and an RC low pass filter circuit.
- Control the light intensity of a LED using PWM.

Task 1: Calibrating the DC voltage source

The signal generator SIG_GEN produces the output signal Vout in two forms: digital signals (i.e. CLOCK, PWM, UART) and analogue signals (i.e. SINE, NOISY, EXPONENTIAL and DC) using an 8-bit digital-to-analogue converter (DAC).

Unfortunately, the DAC is not very accurate. Therefore you must calibrate this before using with the help of the multimeter.

Set the DC output to the voltage setting show, measure the output voltage and complete the following table. Note that error here is relative to the full scale voltage which is 3.3V.

Voltage Setting	3.0V	2.5V	2.0V	1.5V	1.0V	0.5V
Measured voltage						
Error in % FS						

In preparation for Task 2, complete the following table. Here you need to find out for your EPS32, what is the voltage setting in order to obtained at the output a voltage of 3.0V, 2.0V and 1.0V (as measured on the multimeter).

Measured voltage	3.0V	2.5V	2.0V	1.5V	1.0V	0.5V
Voltage Setting						

Task 2: Finding the source resistance of SIG_GEN

For this task, you would need the following resistors: 68, 100, 1k and 10k. You should take them from the card store, prepare a sheet of paper and label them accordingly as shown in the diagram below. You will find that unless you do so, you will loose a resistor or two. Further, when you finish this task, you must return the resistors back to your stores. Further, you must bring the output signal Vs from Pin 26 to the breadboard area ready to construct your circuit. You may use loose wire or a couple of header pins to allow easier access to the signal for measurement.

- Set the DC source Vs to the correct setting to produce an open-circuit voltage of 3.0V, 2.0V and 1.0V in turn.

- Connect a load resistor RL between the output and GND, where RL is given above.

- Measure how much Vs is reduced by the resistor load.

- Complete the following table for the different value of RL:

Vs (measured)	V setting	10k	1k	100	68
3.0					
2.0					
1.0					

- Using the measurements for RL = 68 ohms only, derive and complete the following table:

| Vs	$V_{measured}$	I_{out}	Rs (Ω)
3.0			
2.0			
1.0			

- Discuss among your team members what conclusions you may draw from this measurements.
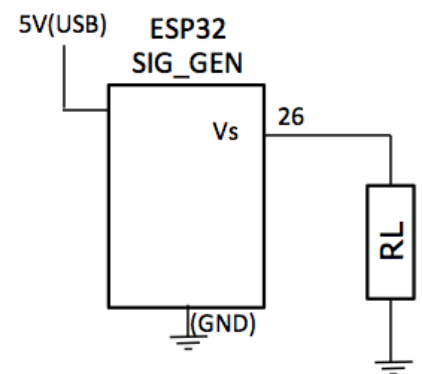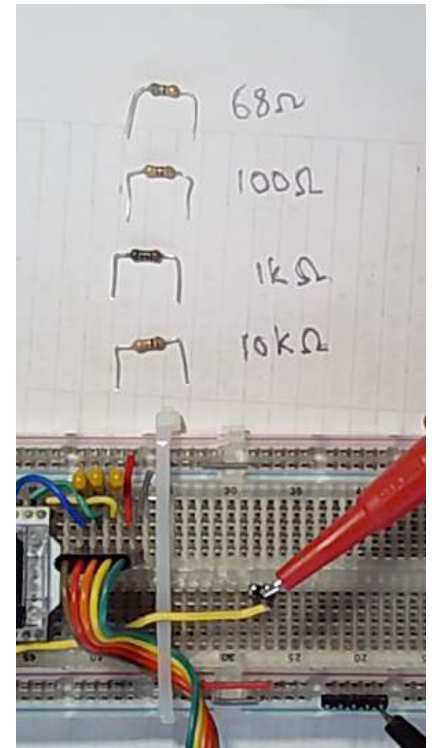
Task 3: Voltage Divider Circuit

Return the components used in Task 2 back to your stores, and bring out the following:
2 x 10k, 1 x 20k resistors.

- Set Vs to 3V. With R1 = R2 = 10k, predict Vout, and confirm with measurement.

- Substitute R2 with a 20k resistor. What do you expect Vout to be? Confirm with measurement.

- Use KCL, Ohm's law or any other theory, calculate theorectically the predicted Vout value.

- Now apply a sine wave at 1kHz, and the maximum pk-pk voltage from SIG_GEN and measure Vout. Confirm that the voltage divider works for both dc and ac signals.
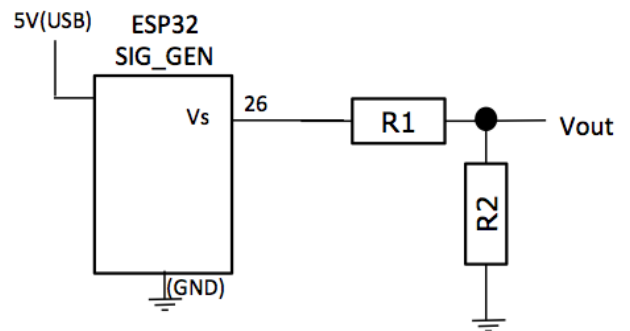
Task 4: Thévenin's Equivalent Network

For this part, you would use the same circuit as Task 3 – no new components required.

- For the circuit shown here, assume that R1 = 10k, R2 = 20k. Derive the Thevenin equivalent network for the circuit inside the grey box. (See below).

- Set Vs = 2V. Confirm your predication by measuring the Vth as the open-circuit voltage, and work out the value of Rth by measuring the short-circuit current. (Note: your can measure current by moving the probes to the middle two sockets and connect the multimeter the across the Vout terminals. This will short-circuit the output and measure the current flowing through it.)
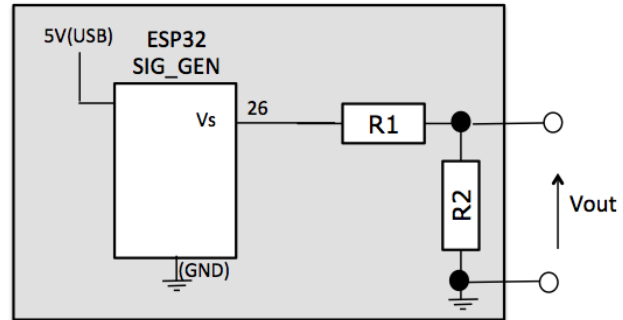
Make sure you understand fully the meaning of Thévenin's equivalent circuit. Discuss with your teammates how you might verigy that your equivalent circuit is correct.

Task 5: Complex Resistor Network (R-2R ladder network)

For this part, you would need: 1 x 20k, 3 x 10k resistors. Construct the circuit shown here:
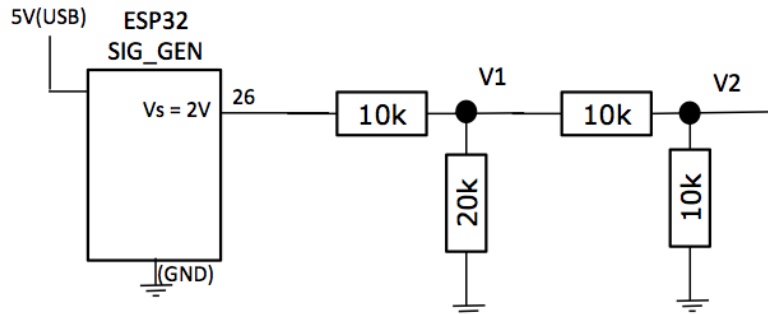
- With Vs = 2V, measure the value of V1 and V2. Verify this with your calculation to make that this is as you expected.

- The network is the basic for DAC, and is known as a R-2R ladder network. How would you add to this circuit so that a third voltage V3 make sure that this circuit has a third stage and continues the same voltage dividing patent? This would be a good topic for discussion among your team.

Task 6: RC circuit and exponential signal

For this task, you need the follow components: 1 x 1k, 1 x 10k, 1 x 0.01uF, 1 x 0.1uF.
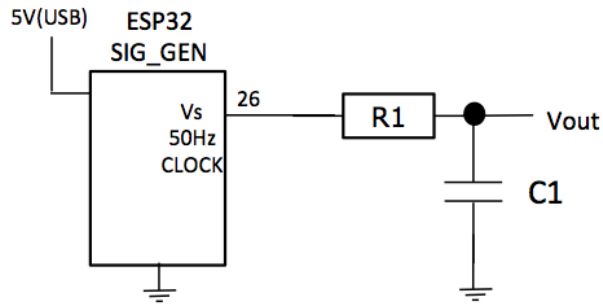
- Construct the following circuit using R1 = 10k and C1 = 0.01uF. Use SIG_GEN to generate a 50Hz CLOCK signal. Measure Vout using the scope. Explain the measured waveform. What is the time constant of this RC network, both in theory and in measurement? You must measure the time-constant both for Vs going from low to high (rising step signal), and from high to low (falling step signal).

- Change R1 = 1k and C1 = 0.1uF, and repeat your measurement. What conclusion can you draw from this?
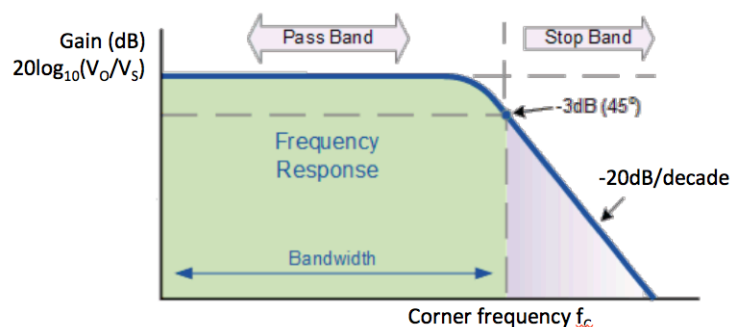
Task 7: RC circuit as a lowpass filter

For this task, you need: 1 x 10k ohm and 1 x 0.01uF (10nF).

Use the same circuit as Task 6, but with R1 = 10k and C1 = 0.01uF. Apply to this circuit a sine wave signal at Vpk-pk = 3.3V, Vdc_offset = 1.65V and variable frequency.

- Now change the frequency in reasonable steps between 100Hz and 100kHz. Measure the ratio of Vout vs Vs. You may use peak-to-peak voltage for this measurement. You will find that at low frequency, Vout/Vs is approximately 1. As you increase the signal frequency to 100kHz, Vout/Vs becomes much smaller.

- The ratio Vout/Vs is known as the "gain" of the circuit. The fact that it is almost 1 at low frequency and decreases at higher frequency means that the circuit passes low frequency signals and suppresses high frequency signals. Hence it is known as a "**lowpass filter**".

- Gain of electronic circuits are often express not in linear scale, but in log scale. It is usually calculated in dB (decibel) with the following equation:

  $$\text{Gain (in dB)} = 20 \log_{10} (\text{output voltage} / \text{input voltage})$$
  $$= 20 \log^{10} (\text{Vout} / \text{Vs})$$

- Plot the Gain(dB) vs frequency in a linear/log graph paper that you can download from the course webpage. Your plot should look a bit like this:

- Using the formula in the notes, derive the corner frequency fc for your circuit.

- Now apply the NOISY (noisy sine wave at 1kHz) to the input of your RC circuit and measure the output. Explain what you see.

Task 8: PWM signal and lowpass filter

For this task, you use the same circuit as the previous task.

- Select PWM signal at 1kHz and duty cycle of 50% on SIG_GEN, and measure the output of the RC circuit with R1 = 10k, and C1 = 0.01uF.

- Increase the frequency to 10kHz and then 100kHz. Explain your observation of the output voltage.

- Using 100kHz PWM signal, adjust the duty cycle from 0% to 100% in steps of 10. Use the multimeter to measure the output voltage. Plot the curve Vout (dc) vs Duty Cycle. Explain the results.

- Discuss with your teammate what you conclude from this task.

Task 9: PWM and brightness of LED

Connect the following circuit using a 100 ohm resistor in series with any of the five LEDs. Note that the positive terminal of the LED is the longer leg.
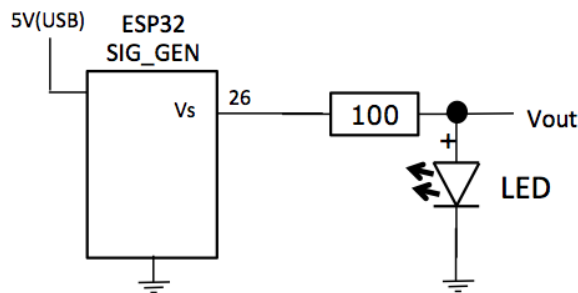

- Set SIG_GEN to provide a DC voltage between 0 to 3.3V. Measure Vout with a multimeter and determine the minimum voltage and current that the LED is lid up.

- Discuss in your Team why controlling the light intensity of the LED using a DC voltage is a bad idea.

- Now drive the LED with a PWM signal at, say 10kHz and observe the output light intensity when the duty cycle is changed from 0% to 100%.

- Change the PWM signal frequency over the frequency range of 20Hz to (say) 20kHz and comment on your observation.

- We see the light intensity varied because the brightness is the result of some lowpass filtering (smoothing) effect. However, we did not use a RC circuit. What is the lowpass filter of the system?

Task 10: CR circuit and DC block property

For this final task, you will need: 0.01uF capacitor and 1k ohm resistor.

Construct the circuit shown here:
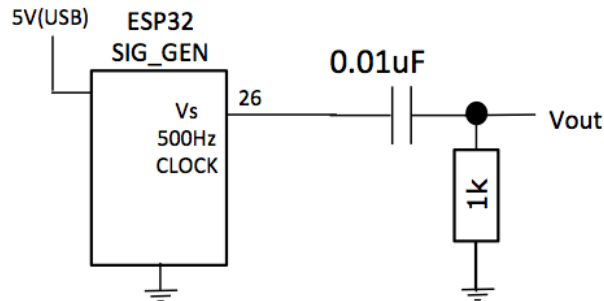
- Apply to this circuit a clock signal at 500Hz. Measure Vout using the scope and comment on the results.

- Not that the wave form you measure is identical no matter whether you set the scope to DC or AC mode. Why? (The sliding switch to select scope measure mode is on the top of the instrument.)

- Change the frequency to 30kHz. Observe and comment on the results.

Tidying up

Now that you have completed Lab 2, you must take time to put all components away and stick them back in your Card Store. You will find that you may need to use some of them again in Lab 3.