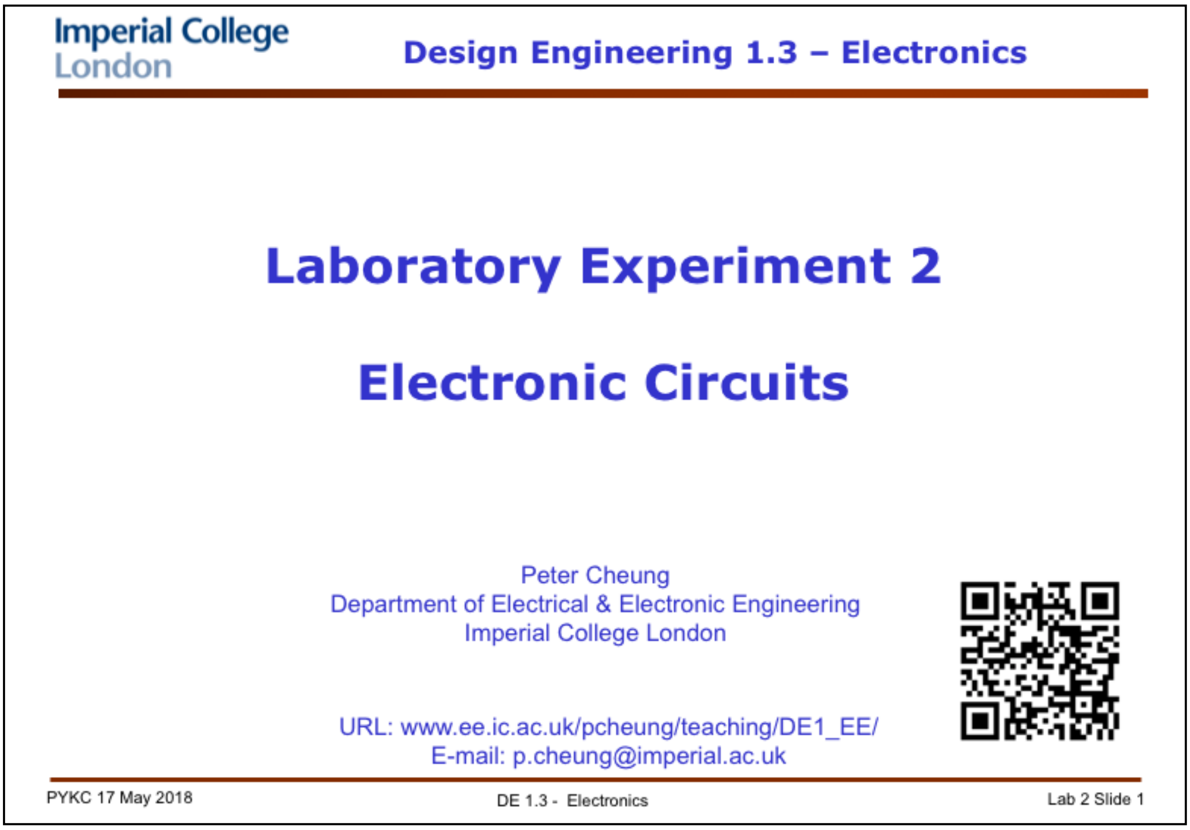
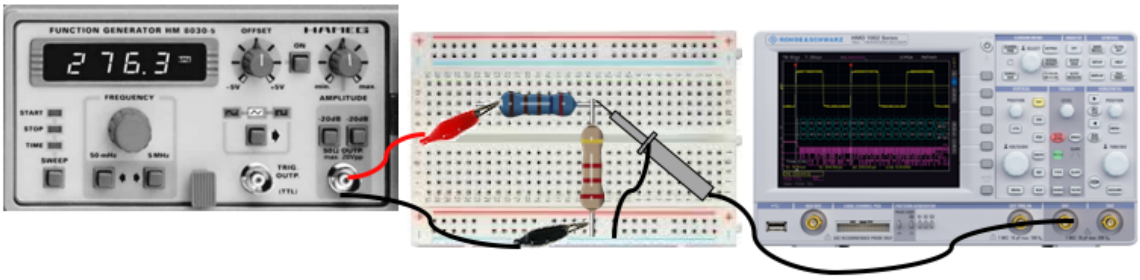


Welcome to your second Electronics Laboratory Session. In this session you will learn about how to use resistors, capacitors and inductors to make simple circuits. You will find out how these circuits behave when you apply to the circuit sine wave signals at different frequencies. You will also explore the transient behaviour of some of these circuits.

Experimental Setup

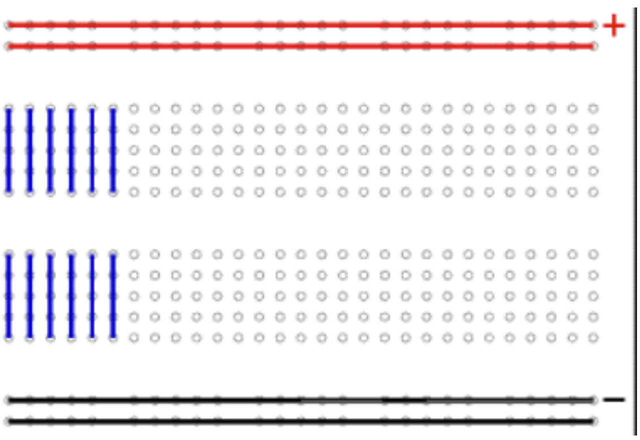


- You will be using the function generator to produce a digital waveform or a sine wave as the voltage source at different frequencies to drive your circuits.
- You will build your circuits on the breadboard.
- You will measure the voltages on your circuits using the scope with the high impedance probe, or using a DMM (e.g. for resistance measurements).

As in Lab 1, you will finish this experiment by conducting a test, where you will be given a number of unknown components. Your job is to discover the values of the components.

The diagram below shows how the holes on the breadboards are connected. The top and bottom rows (2 + 2) are horizontally connected. These are used for +ve power supply and for Ground (0v).

The remaining breadboard holes are linked as two separate sets, consisting of vertical connections shown in blue.



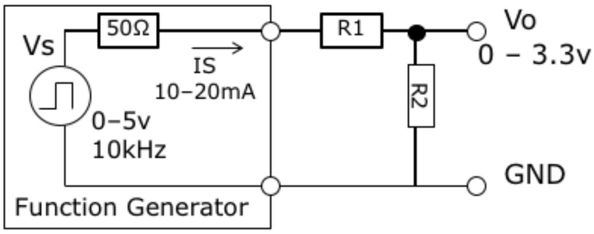
Task 1: Voltage Divider Circuit

- Old digital circuits use 5v TTL signals as standard. Here logical '1' is at around 5v. Logical '0' is at around '0'.
- Modern digital circuits use lower voltages. We will be using digital circuits operating at 3.3v level.
- In Task 1, you will build a voltage divider to reduce 0 to 5v logic levels to 0 to 3.3v. Also, the current to be drawn from the function generator is specified to be 10mA to 20mA.
- The circuit is simple. ➔
- To calculate R1 and R2, we have:

  $V_S = 5, V_O = 3,3$

  $V_O = V_S * R_2/(R_1+R_2+50)$

  $V_S /(R_1+R_2+50) = 10mA$



- Therefore, using preferred value resistors (E24 series), we get:

  $R_1+R_2+50 = 500\Omega$, $R2 \approx 330\Omega$, $R1 \approx 110\Omega$

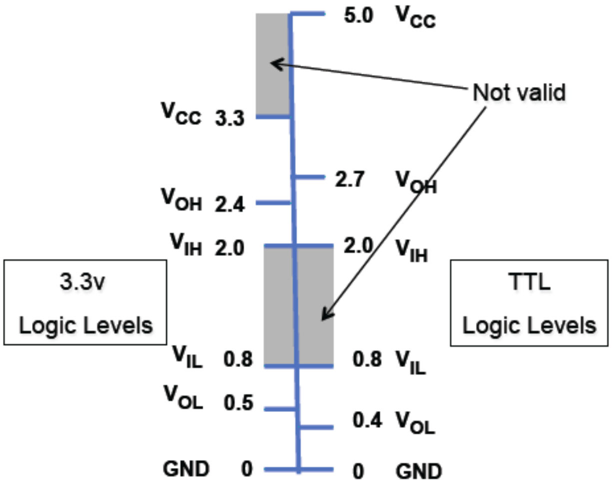
> ➢ Generate 10kHz digital clock, 50% duty cycle, 0 to 5v logic, and verify the voltage levels at V_O.

The objective here is to use a voltage divider and translate a digital signal at TTL levels (0 to 5v) to 3.3v logic levels.

Use the function generator in pulse mode, and adjust it to produce a 0 to 5v pulse signal at 10kHz. Then build the voltage divider as shown here. Measure Vo with the oscilloscope.

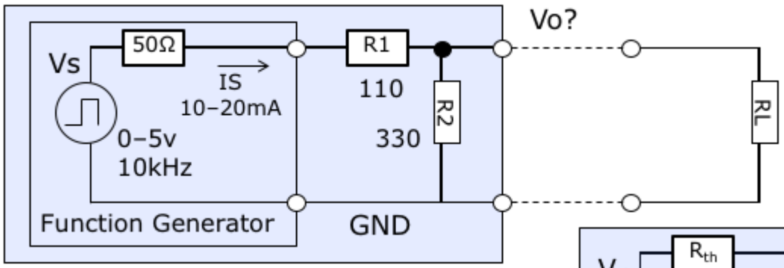
Check that your circuit works as logic signal deriving a 3.3v logic circuit. (See L2S4.)

Check that it obeys the specification on current: current drawn from the function generator should be between 10mA and 20 mA.



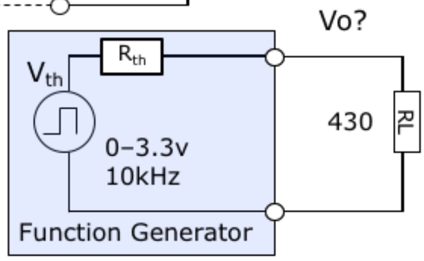
Task 2: Loading and Equivalent Circuit

- What happens if we connect a load R_L to this logic signal? How would it affects the value of V_O?



- We can compute the Thévenin equivalent circuit for everything inside the shaded box. We get:

  V_{th} = 0 to 3.3v, R_{th} = R2||(R1+50)=108Ω



> The lowest valid '1' output voltage (V_{OH}) for 3.3v logic is 2.4v. Given that RL = 430Ω, verify theoretically, and on the circuit, that V_O is valid, and that the current drawn from the source is under 20mA.

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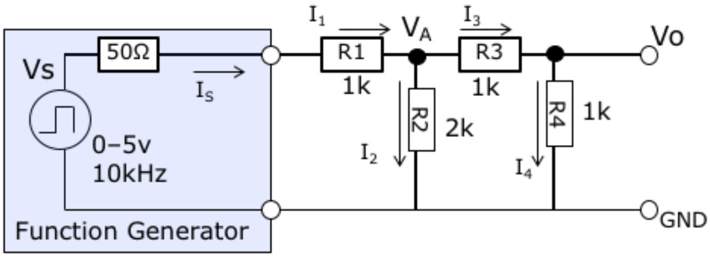
This test is to examine the effect of LOADING, i.e. connecting a source to a external load.

Incorporate your resistor divider into the function generator circuit as shown here. Now you have a Thévenin equivalent source with Vth being the 0 to 3.3v pulse signal, and Rth is 108Ω. Make sure you understand this.

Work out in theory what Vo will be if you now connect 430Ω resistor to the output of your source. Then check this with your scope. With this loading, is the 3.3v logic level still valid?

Task 3: Kirchhoff's Current Law (KCL)

- Construct the circuit shown here.
- Let us now calculate the peak values at V_A and V_O. Using KCL.
- KCL at node V_A:



$$I_1 = I_2 + I_3$$

$$\Rightarrow \frac{V_S - V_A}{R_1 + 50} = \frac{V_A}{R_2} + \frac{V_A}{R_3 + R_4}$$

$$\Rightarrow V_A = \frac{1}{2} V_S \quad (ignore\ \ 50\Omega)$$

- KCL at node V_O:

$$I_3 = I_4$$

$$\Rightarrow \frac{V_A - V_O}{R_3} = \frac{V_O}{R_4}$$

$$\Rightarrow V_A = 2V_O$$

- Therefore: $V_O = \frac{1}{4} V_S$

> - Verify that V_O and V_A are as expected on your circuit.
> - **Do this at home**: re-calcuate V_A and V_O using Thévenin equivalent circuit, first find the equivalent circuit for source and R1, R2, then, add R3 and R4. You should get the same answer.

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In this test, work through the nodal analysis shown here and make sure that you understand it.

Then build the circuit and check that your analysis and the actual circuit agree.

Later at home, you should apply Thévenin equivalent method to cross check the analysis, and show that KCL and Thévenin will both give you the same answer.

Also at home, take on this challenge:

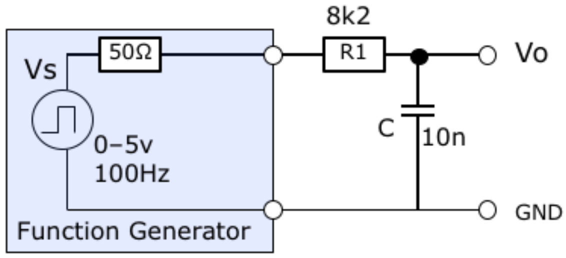
- How would you modify this circuit so that you also obtain nodal voltages of 1/8 Vs and 1/16 Vs etc?

Task 4: RC circuits – transient response 1

- Construct this circuit. Measure V_O.
- The equation for V_O is:

$$V_O = V_S \times (1 - e^{-\frac{t}{RC}})$$

$$where \quad R = R_1 + 50$$



- Measure the time it takes for V_O to reach 63% of fullscale, and compare this with the expected value $\tau = RC$.
- Measure the rise time t_r – the time it takes to go from 10% to 90% of the final value.

> - If you know R (or C), you can estimate the value for C (or R) by measuring τ.
> - Build another circuit with R1 = 82kΩ and C = 1nF. Compare the two outputs and confirm that both outputs are the same. That is, you can trade R with C, i.e. use larger R for smaller C.

Construct this circuit and apply to it a 0 – 5V pulse signal at 100Hz. Since the load has a 8k2 resistor, you can ignore the effect of the 50Ω source resistance

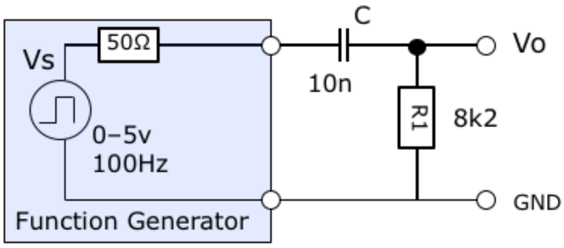
Measure the time constant and check that it is indeed RC. Measure the rise and fall time (i.e. between 10% and 90%) and check at home that the theory agrees with the measurement.

Task 5: RC circuits – transient response 2

- Construct this circuit.
- The equation for V_O is:

$$V_O = V_S \times e^{-\frac{t}{RC}}$$

$$where \quad R = R_1 + 50$$

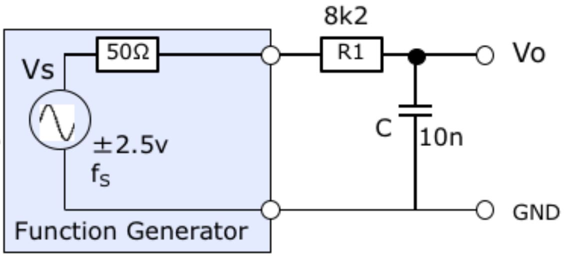


- Repeat the measurements as in Task 4. Confirm that they are what you expected.

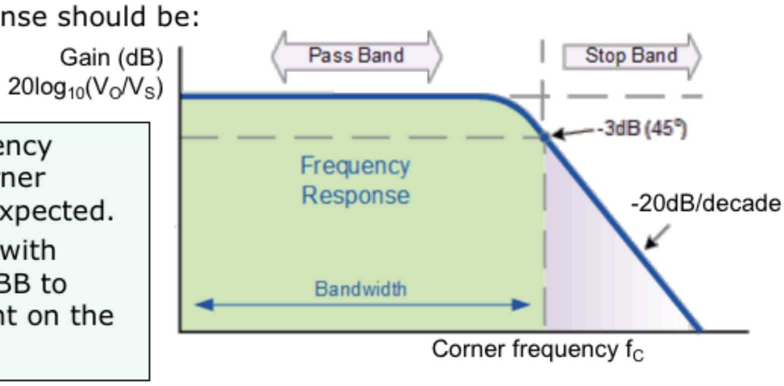
Now swap the two component as shown here and measure Vo. Make sure that what you see is what you expect.

Task 6: RC circuits – frequency response (LP)

- Go back to the circuit in Task 4, but drive it with a sine signal at different frequencies from 100Hz to 1MHz, and measure the ratio V_O/V_S.
- Plot frequency response, $20\log_{10}(V_O/V_S)$ vs frequency on the linear-log graph paper provided.



- The frequency response should be:



> - Verify that the frequency response and the corner frequency f_C are as expected.
> - Apply V_{OUT_1} (Green) with switch = 7 from the BB to your circuit. Comment on the output.

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In this test, we will examine how the RC circuit response to sine wave signals at different frequencies. Connect Ch1 of the scope to the function generator signal, and Ch2 to Vo. The function generator can quickly provide a ±2.5v sine wave signal at different frequency while maintaining the same amplitude. So you should really only need to measure the amplitude of Ch2 signal.

You should sweep the frequency over a wide range, but DO NOT go in small steps. Instead do the following:

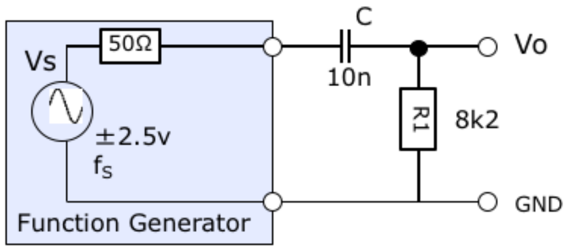
1. Since you know the circuit, you should be able to work out the theoretic corner frequency $f_C = 1 / 2*pi*R_1C \approx 2kHz$.
2. Pick a frequency one decade lower than the corner frequency, i.e. 200Hz. Check that Vo = Vs. Therefore Gain = 0dB.
3. Measure Vo at frequencies one and two decades higher than the corner frequency, i.e. 20kHz and 200kHz.
4. Find the corner frequency by finding the frequency when the Gain = -3dB, or the amplitude drops to 0.7Vs.
5. Fill in more points around this corner frequency.

This RC circuit is low pass filter circuit because is passes low frequency signals, but blocks high frequency signals.

Now use the Black board to generate the sinewave + noise signal (switch setting = 5), and apply Vout_1 (BLUE) to the RC circuit (replacing the function generator). You should have a significantly reduced noise signal on top of a sinewave. Noise signal is at a high frequency.

Task 7: CR circuits – frequency response (HP)

- Swap the R and C from the previous last as shown here.
- Plot the frequency response.
- Add a DC offset to the function generator output, and check that the DC is indeed BLOCKed by the capacitor.



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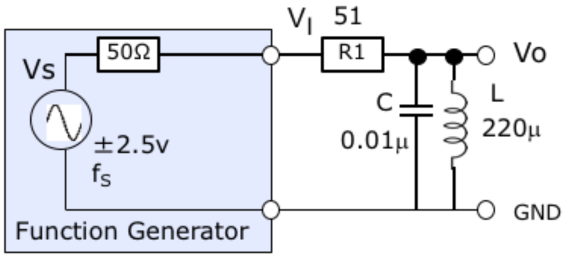
Now, swap the R and C, and plot the frequency response for this circuit. The corner frequency remains the same, but now this is a high pass filter. It allows high frequency signals to pass through, but blocks all low frequencies, including DC.

If you only gets here after TWO HOURS, you should skip Task 8, which are optional, and attempt Tests 1 & 2.

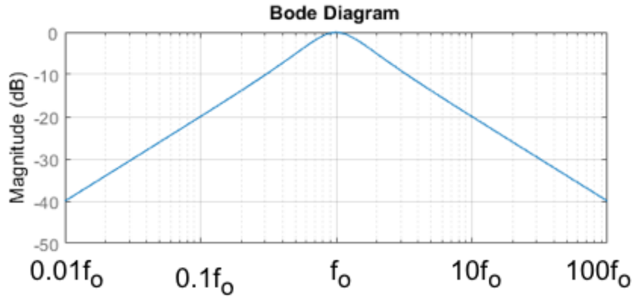
Task 8 (optional): RLC circuits – frequency response (BP)

- Construct this circuit.
- Now the resonance frequency fo is given by the equation:

$$f_o = \frac{1}{2\pi}\omega_o = \frac{1}{2\pi\sqrt{LC}}$$



- In this case, fo ≈100kHz.
- Measure and plot the frequency response as shown, by:
  1. Find the frequency fo where Vo is maximum. Measure Vo/Vs at fo.
  2. Repeat that for 0.01fo, 0.1fo, 1fo and 10fo.



This task is definitely optional. It is a resonant circuit involving R, L and C.

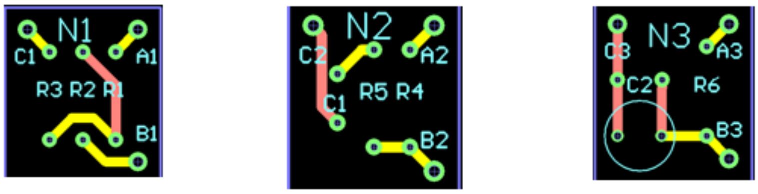
The plot here is shown as Bode Diagram. This is an alternative name to the frequency response plots.

Be careful. Since R1 is now only 51Ω, you can no longer ignore the 50Ω source resistance.

So the Gain of the RLC network is V_O/V_I, not V_O/V_S. You will see that V_I in fact varies at different frequencies. Why? If you are not sure, ask somebody.

Test Yourself

- Go to Peter Cheung's bench and pick up one "test circuit" from each of the bins: N1, N2, N3, each containing "unknown" components with three terminals.
- You are required is to apply techniques you have learned in this experiment and identify the equivalent circuits for each of these as viewed from all the terminals. The next few slides will give you the structure of the circuit, and you need to find the values of the components.
- Test 3 is optional.
- Each module has three terminals. They are as shown in this diagram.



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You will be using three different "unknown" networks: N1, N2 and N3 to test how well you have understood this lab session.

There are four variants of these circuits. Variant number is indicated by a mark on the back of the PCB.

Variant 1 – Red dot

Variant 2 – Blue circle

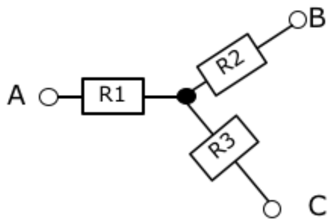
Variant 3 – Black cross

Variant 4 – no marking

You will need to identify which type you have to check the answer to the three tests.

Test 1: Resistor network

- The circuit for N1 is:



- Find R1, R2 and R3.

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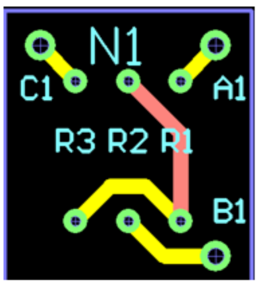
Again, you can check the correct answer via the Lab's self-test link on the course webpage. You may of course use any of the following equipment:

1. Function generator
2. Digital Multi-meter
3. Oscilloscope

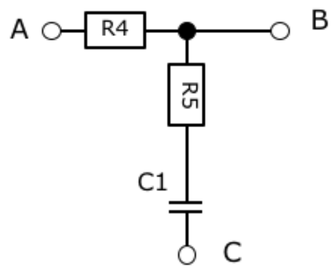
After you have done the measurements, check your findings against the following solution:



Version	1	2	3	4
R1	1k1	2k2	3k3	4k3
R2	470	560	680	820
R3	6k8	3k3	5k6	2k2

Test 2: RC network

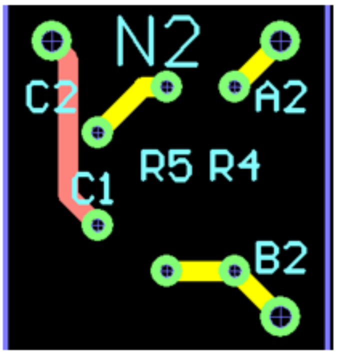
- The circuit for N2 is:



- Find R4, R5 and C1.

Consider using the frequency response to find the corner frequencies (there should be two).

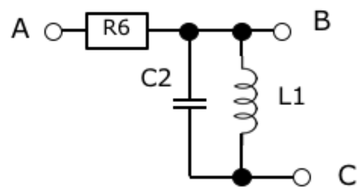
Check your findings against this solution:



Version	1	2	3	4
R4	12k	18k	33k	47k
R5	120	180	330	470
C1	33nF	22nF	10nF	47nF

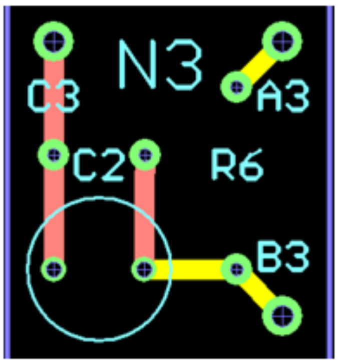
Test 3 (optional): RC network

- The circuit for N3 is:



- It is known that L1 could be one of two possible values: 220μH or 470μH.

Do this only if you have completed the optional task 8.



Version	1	2	3	4
R6	100	100	100	100
C2	1uF	1uF	0.47uF	0.47uF
L1	220uH	470uH	220uH	470uH