EEEN203. Measuring Frequency response.

Due: 24.05.2024

A frequency response is a measurement of the gain and phase of a system as a function of frequency. It allows us to simultaneously assess how different sinusoidal signals will be amplified (or attenuated) by a system, as well as how the output signal will be delayed. Measurement of the frequency response is one of the most common laboratory procedures used by electronic engineers.

In this laboratory we will measure the frequency response of a serial RLC circuit. While learning how to measure a frequency response is important, the "hidden" purpose of this lab is to develop your skills in using the laboratory equipment. You are encouraged to experiment with the equipment and learn its limitations.

A frequency response is a pair of plots, one of which shows the gain of the system as we change the frequency, and the other which shows the phase vs frequency.

1 Equipment

1.1 Signal Generator

Use use Tektronix AFG3102 as source of sinusoidal signal.

1. Select **Sine** from **Function** panel.

2. Select **Amplitude** option and set amplitude so that you can see waveform clearly on the screen of the scope.

3. Select **Sine** from **Function** panel again.

4. Select **Frequency** this time. We are ready to change frequency - do it by turning the knob.

5. **Setting the Function Generator Load Impedance** There is unfortunately a catch with setting the amplitude on these function generators, because by default the generators expect that the load is 50 Ohm. This

is not true in our case as we will measuring circuit with low impedance. To adjust load impedance, start by pressing More in the function menu, and then use the buttons by the screen to follow the commands as follows. More → Output Menu → Load Impedance → High Z When you are done you will need to again press Sine to return to your desired mode. Notice that the amplitude reported by the function generator will now have changed.
Set expected load to 50 Ohm.
What is displayed by generator is calculated voltage which generator will try to deliver to the load, not the actual voltage.
Do not trust Amplitude displayed by generator. Measure it with the scope.

Switch output on - **On** button at the bottom.

1.2   Oscilloscope

We will use Tektronix TDS 2000 series scope. It can measure:

1. Amplitude of input voltage

2. Amplitude of output voltage

3. Phase difference between output and input voltages

1.2.1   Measuring Amplitude

1. Click **Measure** button (top row).

2. Select top measurement channel from **MEASURE** menu.

3. Select Channel1 as a source for the measurement and Pk-Pk (Peak-to-Peak) as a value to measure.

4. Do same for second measurement channel, but now use Channel2 as a source.

1.2.2   Measuring Phase

Select third from the top measurement channel and select **Phase** as a value to measure (phase difference between input channels 2 and 1). Beware: scope requires certain number of periods to measure the phase.

We are set to measure everything we need.

1.3   Components

We provide resistor, capacitor and inductor for this Lab.

1. Measure resistance of resistor using multi-meter.

2. Capacitor (ceramic type) is labelled **103**. Figure out what it is in Farads Hint.

3. Here is the link to inductor datasheet: Datasheet. Notice inductance tolerance and resistance. Assume capacitor tolerance 20 percent.

> To submit:
> Include in your report values of the components.

2   RC circuit measurement and simulation

We investigate serial RC circuit first. We will check measurement against calculated results. Capacitor voltage is an output.

2.1   Model

Using values of R and C from previous section, write Matlab code to calculate capacitor voltage amplitude and phase (do not forget to include resistance of the inductor into your calculations).

Prepare arrays in Matlab file to store measured data.
We can use **interp1()** Matlab function to interpolate measured voltages.

```
vq = interp1 (f, am, a), where\\
f: Vector containing the measured frequency points.
am: Corresponding measured voltage values at the measured points.
a: Coordinates of the query points
 (in this case − frequency values used in calculation).
```

2.2   Measurement

Assemble RC circuit using bread-board.
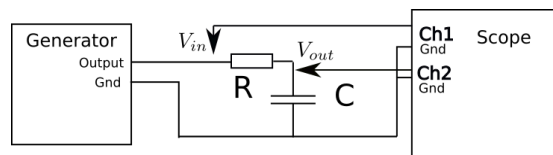
Change input signal frequency from 10 kHz to 100 kHz.

Read measured values from scope screen. Record frequency, input and output voltage amplitude and phase difference between V_{out} and V_{in}.

There is no fixed rule for selecting measurement frequencies. If changes are small and monotonous you can use larger frequency step.

Decrease step if changes are fast.

If you are measuring the peak - try to find the maximum and "gate" your measurement with two value which are less than maximum.

Check "sanity" of your measurements - it is recommended enter measured value straight away (see previous section) to compare with simulated values.

To submit:

- Plot of measured and calculated amplitudes and phase on same graph.

- Comment on how close model was to the measurements.

- Comment on how values of R and C had to be changed to bring model closer to measurement. Are changed values of R and C within manufacturer tolerances?

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3   LC resonant circuit
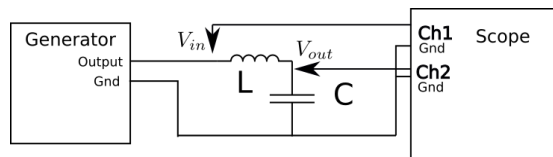
Capacitor voltage again is an output.

Measuring resonance usually is not easy. You will see that components and measurement equipment tolerances become critical for reliable measurements.

3.1   Matlab model

Using values of L and C, write Matlab code to calculate capacitor voltage amplitude and phase (do not forget to include resistance of the inductor from its data sheet into the calculations).

As we did for RC circuit, prepare arrays to store measured data. Include V_{in} in measurements as well.

3.2   Measuremnts

Assemble LC resonant circuit using bread-board. Measure amplitude of input
and output voltages and phase difference between them.

3.3   Matlab Model vs Measurements

Plot measured and calculated input voltage, capacitor voltage and phases on
the same plot.
Input voltage at frequencies close to resonance can be different from expected,
do not be surprised.

> - Include Matlab code in your report.
>
> - Include plots of measured and calculated (Matlab) input and out-
>   put voltages and phase difference in your report.

You can see significant difference between measured and calculated data.
Now we will try to bring measured and calculated data closer to each other.

> - Which circuit elements have influence on value of resonance fre-
>   quency ω_0? Can you find combination of values of these elements
>   which bring measured and calculated ω_0 are closer?
>
> - How close are amplitudes of measured and simulated peaks of V_{out}?
>   Which circuit elements are important for amplitude of this peak?
>
> - What is expected behaviour of V_{in} as function of frequency? How
>   measured values are different from expected?

3.4   Explaining discrepancies between measured and cal- culated frequency responses

Introduce into the model inductor resistance R_L. It is likely that discrepancies
between measured and calculated data are still significant.
We need to consider signal generator internal resistance.
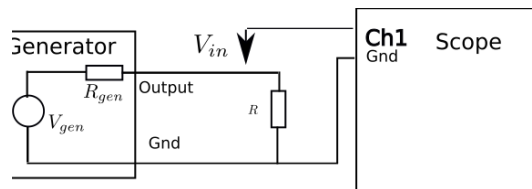Modify Matlab code so that signal generator internal resistance is taken into
account.
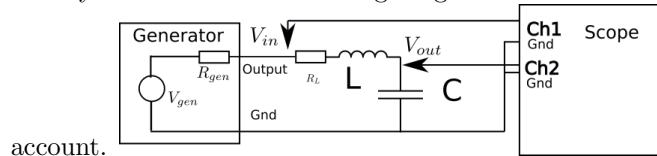
Tune R_{gen} and R_L so that measured and calculate values are close.

> - Include modified Matlab code in your report
>
> - Include values of R_{gen} and R_L

3.5 Measuring generator internal impedance

There is a way to measure generator internal resistance in more direct way.

- Connect resistor of known value to the generator.L

- Measure voltage across the resistor: V_1 for R_1

- Repeat for another resistor of different value: V_2 for R_2

$V_1 = \frac{V_{gen} \cdot R_1}{R_1 + R_{gen}}$
$V_2 = \frac{V_{gen} \cdot R_2}{R_2 + R_{gen}}$

Solve this system of equations to find R_{gen}.

> - Include values of R_{gen} in your report
>
> - Comment on how close this value is to one determined by tuning RLC circuit model.

3.6 LTSpice model

As a confirmation for our Matlab model and measurement make LTSpice models of both RC and RLC circuits. Use values of R_{gen}, R, L and C which

> Include following in this part of the report:
>
> - Schematics of both circuits
>
> - V_{in} and V_{out} amplitude plots for both circuits
>
> - Phase difference (between V_{out} and V_{in} for both circuits