EXERCISES in ELECTRONICS
and SEMICONDUCTOR ENGINEERING

Valery Vodovozov and Zoja Raud
http://learnelectronics.narod.ru

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Introduction

This is a tutorial aid to implement exercises in electronics. The students are expected to have acquired knowledge of electrical engineering, standard electrical wiring, electrical schematic symbols, and Multisim of National Instruments. The manual complies with the curriculum and the syllabus of the course AAR3320 "Electronics and Semiconductor Engineering".

The student tasks are as follows:

- development and calculation of electronic circuits before the lesson,
- selection of electronic components,
- schematic assembling,
- voltage and current measuring,
- voltage and current waveforms analyzing,
- explanation and documentation of the results.

Components and instruments:

- Supplies: dc voltage source, ac voltage source, function generator, and a ground.
- Basic: resistor and potentiometer, capacitor, inductor.
- Diodes: diode and Zener diode.
- Transistor: npn BJT.
- Analog IC: 3-terminal opamp, comparator.
- Indicators: voltmeter, ammeter.
- Instruments: oscilloscope, function generator, Bode plotter.

Reference data:

- load resistance 1 to 100 kΩ,
- load voltage (dc or rms) 1 to 10 V,
- supply frequency 1 to 10 kHz.
Circuits for study are shown in Figures 1…7.

Fig. 1. Linear circuits

Fig. 2. Diode circuits

Fig. 3. Amplifiers

Fig. 4. Opamps

Fig. 5. Filters

Fig. 6. Math converters
1. Linear Circuits

Report contents: circuit diagrams, calculations and diagrams of input voltage and output current, their time and phase shift and attenuation at the reference point, frequency responses, comparative data tables, and conclusions.

Exercise 1.1. RL Circuit

1. To begin with, design a schematic using a resistor, an inductor, and a ground. Select an inductance about 100 mH and the reference resistance. Sketch expected voltage and current traces and frequency responses. Calculate the required supply, the circuit current, its phase, and voltage drops in the components.

2. Add a function generator. Feed the inductor from the positive terminal of the function generator and ground the common terminal and the resistor. Connect the inductor and resistor in series. In the function generator, set the sine waveform and assign the reference frequency.

3. To measure the rms voltages and current, add three multimeters. Set their modes of performance. Connect the first multimeter across the resistor and the second one across the inductor to measure the voltage drops. Connect the third one in series to measure the current.

4. Add an oscilloscope and connect its A channel to the inductor input to view the input voltage. Connect the B channel to the inductor output to view the load voltage and current. Then add a Bode plotter to view the frequency response. Connect its input to the inductor input and its output to the inductor output.

5. Activate the circuit simulation and view the results. Tune the oscilloscope and Bode plotter settings either before or during simulation. Set the horizontal scale in the range of a hertz to gigahertz. Set the vertical scale magnitude between about 0 and −200 dB and phase between about 100 and −100 degrees.

6. Measure the circuit current, the component voltage drop, and the phase shift between the current and voltage traces. Compare the calculated results with the measured ones. Fill the calculated and measured data into the table. Plot the signal traces and the frequency responses.
Exercise 1.2. RC Circuit
1. In the previous circuit, place a capacitor rather than the inductor and assign the capacity about 1 µF. Sketch expected voltage and current traces and frequency responses. Calculate the required supply, the circuit current, its phase, and voltage drops in the components.

2. Activate the circuit simulation and tune the oscilloscope and the Bode plotter to view the results.

3. Measure the circuit current, the component voltage drop, and the phase shift between the current and voltage traces. Compare the calculated results with the measured ones. Fill the calculated and measured data into the table. Plot the signal traces and the frequency responses.

Exercise 1.3. RLC Circuit
1. Return the inductor to the previous circuit. Connect the inductor, capacitor, and resistor in series. Sketch expected voltage and current traces and frequency responses. Calculate the required supply, the circuit current, its phase, and voltage drops in the components.

2. Connect the positive terminal of the function generator to the inductor and ground the common terminal and the resistor. Assign the amplitude, frequency, resistance, inductance, and capacitance values.

3. Activate the circuit simulation and view the results. Tune the oscilloscope and the Bode plotter settings.

4. Measure the circuit current, the component voltage drop, the phase shift between the current and voltage traces. Compare the calculated results with the measured ones. Fill the calculated and measured data into the table. Plot the signal traces and the frequency responses.

Exercise 1.4. Series Resonant Circuit
1. In the previous circuit, find the inductance and capacitance that provide the voltage resonance. Sketch expected voltage and current traces and frequency responses. Calculate the required supply, the circuit current, its phase, and voltage drops in the components.

2. Assign the required values. Activate the circuit simulation and view voltages, currents, and the phase shift as well as the magnitude and phase Bode diagrams.

3. Measure the circuit current, the component voltage drop, the phase shift between the current and voltage traces. Compare the calculated results with the measured ones. Fill the calculated and measured data into the table. Plot the signal traces and the frequency responses.

Exercise 1.5. Parallel Resonant Circuit
1. In the previous circuit, reconnect the capacitor and the inductor in parallel to get the current resonance. Sketch the expected voltage and current traces and frequency responses. Calculate the required supply, the circuit current, its phase, and voltage drops in the components.
2. Assign the required voltage, inductance and capacitance. Then, add multimeters in series with each reactive component to measure their currents.

3. Activate the circuit simulation and view voltages, currents, and the phase shift as well as the magnitude and phase Bode diagrams. Compare the calculated results with the measured ones. Fill the calculated and measured data into the table. Plot the signal traces and the frequency responses.

2. Diode Circuits

Report contents: circuit diagrams, calculations of the rectifier, clipper, and limiter circuits for the reference conditions, input and output voltage traces, data table and diagram of the volt-ampere characteristic of the forward and reverse biased diode, replacement circuits, and conclusions.

Exercise 2.1. Diode Rectifier

1. Design a schematic with a diode and the load resistor connected in series. Sketch expected voltage and current traces at the sinusoidal supply. Calculate the required supply amplitude as $\pi$ times the reference dc voltage.

2. Assemble the circuit. Feed the diode-resistor pair with a function generator and a ground. Connect the positive terminal of the function generator to the diode anode and link the ground with the common terminal and the resistor.

3. In the function generator, assign the sine waveform of the reference frequency and calculated amplitude. Set the required resistance.

4. To measure the voltage and current, add three multimeters. Connect the first of them across the diode, another across the load, and the latter in series. Set their modes of performance.

5. Add an oscilloscope and connect its A channel to the anode to view the diode voltage. Connect the B channel to the cathode to view the load voltage and current. Inspect and plot the supply and load traces.

6. Switch the axes of the oscilloscope to view one channel against the other, B/A. Now, the scale of the x-axis is determined by the volts-per-division setting for the B channel and vice versa. Activate the circuit simulation, tune the oscilloscope, and inspect the volt-ampere characteristic.

7. Replace the function generator with the dc voltage source and decrease smoothly the supply amplitude from the positive supply level via the zero to the negative supply level. In every point, activate the circuit simulation and measure the diode voltage drop and current. Plot the volt-ampere diagram of the forward and reverse biased diode.

8. Build the tangent at the reference operating point and calculate the differential impedance as the slope, $\Delta U_{AC}/\Delta I_A$. Find the knee voltage.

Exercise 2.2. Series Clippers

1. Design and assemble a schematic using a function generator, a dc voltage source, a diode, a resistor, and a ground. Connect the diode cathode to the voltage source “+”
through the load resistor. Connect also the positive terminal of the function generator to the diode anode and ground the common terminal and the voltage source “-“.

2. Set the required resistance. In the function generator, set the triangular waveform of the reference frequency with the amplitude above the reference voltage and the same offset.

3. Add an oscilloscope and connect its A channel to the anode to view the input voltage. Connect the B channel to the cathode to inspect the output voltage.

4. Using the replacement circuit, find the required level of the dc voltage source that will provide the reference clipping voltage level on the resistor. Activate the circuit simulation, tune the oscilloscope, view and measure the result. Plot the signal traces.

5. Reconnect the diode to the reverse bias, repeat the experiment, and explain the result. Plot the signal traces.

Exercise 2.3. Parallel Clippers

1. Design and assemble a schematic using a function generator, a dc voltage source, a diode, a ground, a buffer resistor, and the load resistor. Link both resistors with the diode anode. Connect the positive terminal of the function generator to the current buffer. Link the voltage source “+” with the diode cathode, and ground the common terminal, the voltage source “-“ and the load resistor.

2. Assign the load resistor and set the buffer by a factor smaller. In the function generator, set the triangular waveform of the reference frequency with the amplitude above the reference voltage and the same offset.

3. Using the replacement circuit, find the required dc voltage source value that will provide the reference clipping voltage level on the load resistor.

4. Add an oscilloscope and connect its A channel to the positive terminal of the function generator to inspect the input voltage. Connect the B channel to the diode anode to view the output voltage.

5. Activate the circuit simulation, tune the oscilloscope, view, and measure the result. Compare the clipping level with the required value. Fine tune the dc voltage source to obtain the reference clipping level. Plot the signal traces.

6. Change the diode orientation and repeat the experiment. Evaluate the clipping level and explain the result. Plot the signal traces.

Exercise 2.4. Diode Limiters

1. Design and assemble a series limiter with referenced upper level and halved lower level. Use a function generator, a ground, a load resistor, and in twos dc voltage sources, diodes, and resistors. Connect both diodes in series, back-to-back with their cathodes. Connect the “+” terminal of each voltage source to the appropriate resistor and ground their “-“ terminals, the load resistor, and the common terminal of the function generator. Link the positive terminal of the function generator with the anode of the first diode, the first resistor with both cathodes, and the second resistor with the load and the anode of the second diode.
2. Assign the load resistor and select other resistors much less. In the function generator, set the triangular waveform the reference frequency with amplitude above the reference voltage and the same offset. Calculate and establish the voltage sources.

3. Add an oscilloscope and connect its A channel to the positive terminal of the function generator to view the input voltage. Connect the B channel to the second anode to view the output voltage.

4. Activate the circuit simulation, tune the oscilloscope, view, and measure the result. Compare the clipping levels with the reference values. Fine tune the dc voltage sources to obtain the required clipping levels. Plot the signal traces.

5. Turn the series limiter into the parallel one. To this aim, move away the second resistor, change the first diode with the first resistor (anode to “+”) and connect the second diode between the first resistor and the second voltage source (cathode to “+”). Activate the circuit simulation, tune the oscilloscope, and view the result. Plot the signal traces and compare them with the series limiter.

Exercise 2.5. Zener Circuits

1. Design and assemble a clipper using a function generator, a Zener diode, the buffer and load resistors, and a ground. Link both resistors with the cathode of the Zener diode. Connect the positive terminal of the function generator to the buffer resistor and ground the negative terminal, the anode and the load resistor.

2. Assign the load resistor and select the buffer by a factor less. In the function generator, establish the triangular waveform of the reference frequency and the amplitude above the reference voltage. Assign the Zener breakdown voltage to the reference voltage.

3. Add an oscilloscope and connect its A channel to the positive terminal of the function generator to view the input voltage. Connect the B channel to inspect the output voltage.

4. Activate the circuit simulation, tune the oscilloscope, view, and measure the clipping level. Plot the signal traces.

5. Turn the clipper into the limiter by adding the second Zener diode in series, back-to-back with the first one. Activate the circuit simulation, tune the oscilloscope, and view the result. Plot the signal traces and compare them with the clipper.

3. Amplifiers

Report contents: circuit diagrams, calculations of the dc and ac current/voltage/power gains input/output impedances, cutoff voltage and saturation current, data tables, input characteristics, output characteristics with the load lines, and conclusions relatively the comparative properties of the amplifiers.

Exercise 3.1. Common Emitter Amplifier

1. Design the CE amplifier using an npn BJT, a function generator to drive and bias the base, a dc voltage source to bias the collector, three resistors, and a ground.

2. To assemble the circuit, connect the positive terminal of the function generator to the base through the base resistor. Connect the “+” terminal of the voltage source to the
collector through the collector resistor. Connect the load resistor to the collector. Then ground the common terminal of the function generator, the “–” terminal of the voltage source, the emitter, and the load.

3. In the function generator, set the sine waveform of the reference frequency with amplitude of half the reference load voltage. Set there also an offset equal to the reference load voltage. In the dc voltage source, set a level of the twofold reference load voltage. Assign the reference load resistance and about 100 kΩ for the base and 1 kΩ for the collector resistors.

4. Add an oscilloscope and connect its A channel to the base to view the input ac voltage. Connect the B channel to the collector to inspect the output ac voltage. Embed four multimeters to measure the collector and base dc voltages and currents.

5. Activate the circuit simulation and fine tune the function generator to obtain the unclipped sinusoidal collector voltage in the operating point \( I_C^*(U_{CE}^*) \). Find the related input values \( I_B^* \) and \( U_{BE}^* \), and the load current \( I_C^* \) and fill the data into the table. Calculate the dc current gain \( I_C^*/I_B^* \), dc voltage gain \( U_{CE}^*/U_{BE}^* \), and dc power gain as their product.

6. To find the leftmost point of the output characteristic, increase the collector resistance by a factor of ten and write down the data. To find the rightmost point of this characteristic, decrease the collector resistance by a factor of ten and write down the data. Then, return to the initial resistances.

7. Develop the replacement circuit, find the saturation current and the cutoff voltage, and build the load line via these points. Plot the output characteristic via the leftmost, operating, and rightmost points.

**Exercise 3.2. Study the CE Amplifier**

1. Approach the saturation region by the twofold decrease of both the base and the collector resistances and fill the data into the table. Find the leftmost and the rightmost points of the output characteristic at saturation using the above described procedure. Plot the output characteristic via the leftmost, initial, and rightmost points. Then, return to the initial resistances.

2. Approach the cutoff region by the twofold increase of both the base and the collector resistances and fill the data into the table. Again, find the leftmost and the rightmost points of the output characteristic at cutoff using the above described procedure. Plot the output characteristic via the leftmost, initial, and rightmost points. Then, return to the initial resistances.

3. Build an input characteristic \( I_B(U_{BE}) \) via the saturation, operating, and cutoff points.

4. Calculate the input impedance \( \Delta U_{BE}/\Delta I_B \), output impedance \( \Delta U_{CE}/\Delta I_C \), ac current gain \( \Delta I_C/\Delta I_B \), ac voltage gain \( \Delta U_{CE}/\Delta U_{BE} \), and ac power gain.

**Exercise 3.3. Common Base Amplifier**

1. Design the CB amplifier using an npn BJT, a function generator to drive and bias the emitter, a dc voltage source to bias the collector, three resistors, and a ground.

2. To assemble the circuit, connect the positive terminal of the function generator to the emitter through the emitter resistor. Connect the “+” terminal of the voltage source to the
collector through the collector resistor. Connect the load resistor to the collector. Then ground the common terminal of the function generator, the “−” terminal of the voltage source, the base, and the load.

3. In the function generator, set the sine waveform of the required frequency with amplitude equal to the reference load voltage. Set there also the negative offset of the twofold reference load voltage. In the dc voltage source, set a level of the twofold reference load voltage. Assign the reference load resistance and about 1 kΩ for the emitter and collector resistors.

4. Add an oscilloscope and connect its channel A to the emitter to view the input ac voltage. Connect the channel B to the collector to inspect the output ac voltage. Embed four multimeters to measure the collector and emitter ac voltages and currents.

5. Activate the circuit simulation and fine tune the function generator to obtain the unclipped sinusoidal collector voltage in the operating point $I_C^*(U_{CB}^*)$. Find the related input values $I_E^*$ and $U_{EB}^*$, and the load current $I_C^*$ and fill the data into the table. Calculate the dc current gain $I_C^*/I_E^*$ and dc voltage gain $U_{CB}^*/U_{EB}^*$, and dc power gain as their product.

6. To find the leftmost point of the output characteristic, increase the collector resistance by a factor of ten and write down the data. To find the rightmost point of this characteristic, decrease the collector resistance by a factor of ten and write down the data. Then, return to the initial resistances.

7. Develop the replacement circuit, find the saturation current and the cutoff voltage, and build the load line via these points. Plot the output characteristic via the leftmost, operating, and rightmost points.

**Exercise 3.4. Study the CB Amplifier**

1. Approach the saturation region by the twofold decrease of both the emitter and the collector resistances and fill the data into the table. Again, find the leftmost and the rightmost points of the output characteristic at saturation using the above described procedure. Plot the output characteristic via the leftmost, initial, and rightmost points. Then, return to the initial resistances.

2. Approach the cutoff region by the twofold increase of both the emitter and the collector resistances and fill the data into the table. Again, find the leftmost and the rightmost points of the output characteristic at cutoff using the above described procedure. Plot the output characteristic via the leftmost, initial, and rightmost points. Then, return to the initial resistances.

3. Build an input characteristic $I_E(U_{EB})$ via the saturation, operating, and cutoff points.

4. Calculate the input impedance $ΔU_{EB}/ΔI_E$, the output impedance $ΔU_{CB}/ΔI_C$, the ac current gain $ΔI_C/ΔI_E$, ac voltage gain $ΔU_{CB}/ΔU_{EB}$, and ac power gain.

**Exercise 3.5. Emitter Follower**

1. Design the CC amplifier (emitter follower) using an npn BJT, a function generator to drive and bias the base, a dc voltage source to bias the collector, three resistors, and a ground.
2. To assemble the circuit, connect the positive terminal of the function generator to the base through the base resistor. Connect the “+” terminal of the voltage source to the collector. Connect the emitter and the load resistors to the emitter. Then ground the common terminal of the function generator, the “−” terminal of the voltage source, the emitter resistor, and the load.

3. In a function generator, set the sine waveform of the required frequency with amplitude equal to the reference load voltage. Set there also the offset of the twofold reference load voltage. In the dc voltage source, set a level of the twofold reference load voltage. Assign the reference load resistance and about 1 kΩ for the emitter and base resistors.

4. Add an oscilloscope and connect its A channel to the base to view the input voltage. Connect the B channel to the emitter to inspect the output voltage. Embed four devices for the measurement of the collector and emitter ac voltages and currents.

5. Activate the circuit simulation and tune the function generator to obtain the unclipped sinusoidal emitter voltage in the operating point $I_E^*(U_{EC}^*)$. Find the related input values $I_B^*$ and $U_{BC}^*$, and the load current $I_E^*$ and fill the data into the table. Calculate the dc current gain $I_E^*/I_B^*$, dc voltage gain $U_{EC}^*/U_{BC}^*$, and dc power gain as their product.

6. To find the leftmost point of the output characteristic, increase the emitter resistance by a factor of ten and write down the data. To find the rightmost point of this characteristic, decrease the emitter resistance by a factor of ten and write down the data. Then, return to the initial resistances.

7. Develop the replacement circuit, find the saturation current and the cutoff voltage, and build the load line via these points. Plot the output characteristic via the leftmost, operating, and rightmost points.

**Exercise 3.6. Study the CC Amplifier**

1. Approach the saturation region by the twofold decrease of both the emitter and the base resistances and fill the data into the table. Again, find the leftmost and the rightmost points of the output characteristic at saturation using the above described procedure. Plot the output characteristic via the leftmost, initial, and rightmost points. Then, return to the initial resistances.

2. Approach the cutoff region by the twofold increase of both the emitter and the base resistances and fill the data into the table. Again, find the leftmost and the rightmost points of the output characteristic at cutoff using the above described procedure. Plot the output characteristic via the leftmost, initial, and rightmost points. Then, return to the initial resistances.

3. Build an input characteristic $I_B(U_{BC})$ via the saturation, operating, and cutoff points.

4. Calculate the input impedance $\Delta U_{BC}/\Delta I_b$, the output impedance $\Delta U_{EC}/\Delta I_e$, the ac current gain $\Delta I_E/\Delta I_B$, ac voltage gain $\Delta U_{EC}/\Delta U_{BC}$, and ac power gain.
4. Opamps

Report contents: circuit diagrams, voltage gain and cutoff frequency calculations, comparative data tables, input/output voltage traces and characteristics, bandwidth/gain diagrams, and conclusions.

Exercise 4.1. Non-Inverting Voltage Amplifier

1. Design a schematic using an opamp, input, feedback and load resistors, and a ground. Assemble the non-inverting voltage amplifier and drive it by the function generator.

2. In a function generator, set the sine waveform of the required frequency and the input resistance in the range of 1...10 kΩ.

3. Calculate and assign the required feedback resistance and the function generator amplitude to provide the reference MPP unclipped output.

4. Add an oscilloscope and connect its channel A to the function generator to view the input voltage and channel B to the opamp output to inspect the output voltage. Then add a Bode plotter to build the frequency response and connect its inputs across the oscilloscope. To measure voltages, add two multimeters and connect them across the input and output.

5. Activate the circuit simulation and measure the voltages as well as the magnitude and bandwidth. Calculate the voltage gain.

6. Smoothly raise the resistances approaching the maximum voltage gain that provides an MPP unclipped output. At every step, activate circuit simulation and measure the voltages, the gain, and the bandwidth. Then, plot the dependence of the bandwidth versus voltage gain.

Exercise 4.2. Inverting Voltage Amplifier

1. Design and assemble an inverting voltage amplifier using the same components.

2. Calculate and assign the required feedback resistance and the function generator amplitude that provide the required MPP unclipped output.

3. Activate the circuit simulation and view voltages as well as the magnitude and bandwidth. Calculate the voltage gain.

4. Again, find the bandwidth dependence on the voltage gain and plot the new diagram of the bandwidth versus voltage gain.

Exercise 4.3. Detectors on Comparators

1. Design and assemble a zero-crossing detector using a comparator with a balanced supply, a load resistor, and a ground, and drive it by the function generator. Connect the positive terminal of the function generator to the first comparator input. Then ground the common terminal of the function generator and the second input of the comparator. Connect the load.

2. Provide the comparator with the required supply. Set the sine waveform of the function generator with the reference frequency and amplitude above the comparator supply.
3. Add an oscilloscope and connect its channel A to the function generator to view the input voltage and channel B to the comparator output.

4. Activate the circuit simulation and view voltages versus time. Switch the axes of the oscilloscope to show one input channel against the other, B/A. Find and measure the hysteresis.

5. Develop a positive reference detector rather than a zero-crossing detector. For this purpose, add a dc voltage source between the second input of the comparator and the ground. Keep its voltage on the reference level. Again, view voltages versus time and input/output characteristics of the positive reference detector.

6. Assemble a negative reference detector instead of the positive reference detector. To this aim, turn the polarity of the dc voltage source. Again, inspect voltages versus time and input/output characteristics of the negative reference detector. Find and measure the offset and hysteresis.

**Exercise 4.4. Schmitt Trigger**

1. Design and assemble a Schmitt trigger using a comparator with a balanced supply, three resistors, and a ground, and drive it by the function generator. Connect the positive terminal of the function generator to the first input of the comparator. Tie both resistors with the second input of the comparator. Connect the comparator output to the first resistor. Then ground the common terminal of the function generator and the second resistor. Connect the load.

2. Provide the comparator with the required supply. Set the sine waveform of the function generator with the reference frequency and amplitude.

3. Add an oscilloscope and connect its channel A to the function generator to view the input voltage and channel B to the comparator output.

4. Activate the circuit simulation and view voltages versus time. Switch the axes of the oscilloscope to show one input channel against the other, B/A.

5. Consequentially reduce the second resistor by two, five, and ten times. At each value, activate the circuit simulation and measure the hysteresis width. Then, plot the diagram of the width versus positive voltage gain.

**5. Filters**

**Report contents:** circuit diagrams, calculations and diagrams of input and output voltages, their time and phase shifts and attenuations at the reference point, frequency responses, comparative data tables, and conclusions.

**Exercise 5.1. RC Filters**

1. Design a simple low-pass filter using a filter resistor and the load resistor, a capacitor, and a ground. Sketch expected voltage and current traces and frequency responses. Assemble a schematic.
2. Drive the circuit by a pair of the series connected ac voltage sources. In the former, assign the reference frequency and the reference rms voltage. In the latter, set the same voltage and the frequency about $10^3$ of the reference frequency.

3. Add the oscilloscope and connect its A channel to the low-frequency voltage source to view the input signal and the B channel to the load to view the output voltage. Add a Bode plotter to inspect the frequency response. Connect its input to the supply source and its output to the load. Add also a multimeter to measure the output rms voltage.

4. Set the filter resistance of about $1 \, \text{k}\Omega$. Calculate and set the capacity to provide the cutoff frequency above the reference one.

5. Activate circuit simulation, tune the oscilloscope, view, and measure the output rms voltage and frequency. Tune the Bode plotter: set the horizontal scale in the range of a hertz to a gigahertz, the vertical scale magnitude between 20 and –200 dB, and phase between 100 and –100 degrees. Using the time and frequency responses, ensure that the output signal follows the signal of the low-frequency voltage source. Plot the signal traces and the frequency responses and fill into the table measured and calculated circuit voltages, currents, phases, gains, and delays.

6. Turn the low-pass filter into the high-pass filter by changing the placement of the capacitor and the filter resistor. Calculate and assign the capacity, which provides the cutoff frequency below the high-frequency ac voltage source. Using the time and frequency responses, ensure that the output signal follows the signal of the high-frequency voltage source. Write down the measured and calculated data and plot the signal traces and the frequency responses.

**Exercise 5.2. LC Filters**

1. Design a simple low-pass filter using an inductor, a capacitor, a load resistor, and a ground. Sketch expected voltage and current traces and frequency responses. Assemble a schematic.

2. Assemble the same signal sources and add the measuring instruments as in the previous exercise.

3. Set an inductance of about $1 \, \text{mH}$. Calculate and assign the capacity, which provides a cutoff frequency above the reference frequency.

4. Activate the circuit simulation, tune the oscilloscope and the Bode plotter, view, and measure the output voltage. Using the time and frequency responses, ensure that the output signal follows the signal of the low-frequency voltage source. Plot the signal traces and the frequency responses and fill into the table measured and calculated circuit voltages, currents, phases, gains, and delays.

5. Turn the low-pass filter into the high-pass filter by changing the placement of the capacitor and the inductor. Calculate and assign the capacity, which provides the cutoff frequency below the high-frequency ac voltage source. Repeat the experiment and compare the results. Write down the data and plot the signal traces and the frequency responses.
Exercise 5.3. Band-Pass Filter

1. Design a band-pass filter using 2 inductors, 2 capacitors, the load resistor, and a ground. Connect the first pair of the inductor and capacitor in series and the second pair in parallel, link them with the load, and ground the load output.

2. Combine the signal source with 3 series connected ac voltage sources. Select their voltages equal to the required output. In the first of them, set the reference frequency. Set the frequency $10^3$ times below the reference frequency for the second source and $10^3$ times above the reference frequency for the third one. Sketch expected voltage and current traces and frequency responses.

3. Add the oscilloscope and connect its A channel to the suppliers to view the input signal and the B channel to the load to view the output voltage. Connect the Bode plotter across the filter to view the frequency response. Use a multimeter to measure the output voltage.

4. Set equal inductances of about 1 mH. Calculate and set the capacitances that provide the midband frequency equal to the reference frequency and suppress the signals of other ac voltage sources.

5. Activate the circuit simulation, tune the oscilloscope and the Bode plotter, and view the voltages. Using the frequency response, measure the output magnitudes and phases at the low, middle, and high frequencies. Write down the data and plot the signal traces and the frequency responses.

Exercise 5.4. Band-Stop Filter

1. Design a band-stop filter using 2 inductors, 2 capacitors, the load resistor, and a ground. Connect the first pair of the inductor and capacitor in parallel and the second pair in series, link them with the load, and ground the load output.

2. Assemble the same signal source and add the measuring instruments as in the previous exercise. Sketch expected voltage and current traces and frequency responses.

3. Set equal inductances of about 1 mH. Calculate and set the capacitances that provide the midband frequency equal the reference frequency and pass the signals of other ac voltage sources.

4. Activate the circuit simulation, tune the oscilloscope and the Bode plotter, and view the voltages. Using the frequency response, measure the output magnitudes and phases at the low, middle, and high frequencies. Write down the data and plot the signal traces and the frequency responses.

6. Math Converters

Report contents: circuit diagrams, calculation of the dc and ac input/output voltages, input/output voltage traces at the reference point, comparative data tables, and conclusions.

Exercise 6.1. Adder

1. Design and assemble a dual-input adder using an opamp, 4 resistors, and a ground. First, build an inverting voltage amplifier with two resistors at the negative input of the
opamp. Next, provide the separate supply for both the input resistors: feed the first resistor by the function generator and the second resistor by the dc voltage source. Connect the load.

2. Let all the circuit resistances be equal in the range of 1...10 kΩ. Set the sine waveform of the function generator with the reference frequency. Calculate and assign the voltages for both the function generator and the dc voltage source that ensure the reference MPP unclipped output of the adder.

3. Add an oscilloscope and connect its A channel to the function generator to view the input voltage and the B channel to the opamp output. To measure the voltage, add a pair of multimeters and connect them across the output. Provide measuring of the ac voltage particle by the first multimeter and the dc particle by the second one.

4. Activate the circuit simulation, view and measure the sum of the input voltages. Compare the output voltage with the calculated one.

**Exercise 6.2. Subtractor**

1. Design and assemble a dual-input subtracter using an opamp, a function generator, a dc voltage source, 5 resistors, and a ground. First, build the adder. Next, move the dc supplied resistor from the negative to the positive input of the opamp. As well, place an additional resistor between the positive opamp input and the ground.

2. Let all the circuit resistances be equal in the range of 1...10 kΩ. Set the sine waveform of the function generator with the reference frequency. Calculate and assign the voltages for both the function generator and the dc voltage source that ensure the reference MPP unclipped output of the subtracter.

3. Add an oscilloscope and a pair of multimeters similarly to the previous exercise.

4. Activate the circuit simulation and view the difference of the function generator and the dc voltage source voltages. Compare the output voltage with the calculated one.

**Exercise 6.3. Integrator**

1. Design and assemble an integrator using an opamp, a function generator, a capacitor, 3 resistors, and a ground. First, build the inverting voltage amplifier. Then, add a capacitor across the feedback resistor.

2. Set the square-wave waveform of the function generator with the reference frequency and the input resistance in the range of 1...10 kΩ. Calculate and assign the capacitance, the feedback resistance, and the function generator amplitude that provide the reference unclipped triangle output signal. Take care that the opamp voltage swing is above the reference output voltage, as well as the opamp slew rate and the open loop gain have maximum possible values.

3. Add an oscilloscope and connect its channel A to the function generator to view the input voltage and channel B to the opamp output.

4. Activate the circuit simulation and view voltages. Compare the output voltage with the calculated one.
Exercise 6.4. Differentiator

1. Design and assemble a differentiator using an opamp, a function generator, a capacitor, 3 resistors, and a ground. First, build the inverting voltage amplifier. Then, place the capacitor across the input resistor.

2. Set the triangle-wave waveform of the function generator with the reference frequency and the feedback resistance in the range of 1…10 kΩ. Assign the same capacitance and the function generator amplitude as in the previous experiment.

3. Add an oscilloscope and connect its channel A to the function generator to inspect the input voltage. Connect the channel B to the opamp output.

4. Activate the circuit simulation and view voltages. Then, find the input resistance that provides the reference rectangular output signal.

Exercise 6.5. PID-regulator

1. Design and assemble a PID-regulator using an opamp, a function generator, 2 capacitors, 3 resistors, and a ground. First, build the inverting voltage amplifier. Next, add the first capacitor in series with the input resistor and the second capacitor across the feedback resistor.

2. Set the triangle waveform of the function generator with the reference frequency. Assign the resistances, capacitances, and the function generator amplitude from the previous circuits.

3. Add an oscilloscope and connect its channel A to the function generator to view the input voltage and channel B to the opamp output.

4. Activate the circuit simulation and view voltages. Then, find the resistances that provide the reference sinusoidal output signal.

7. Oscillators

Report contents: circuit diagrams, calculation of the circuit components, input/output voltage traces at the reference point, and conclusions.

Exercise 7.1. Astable Multivibrator

1. Design and assemble an astable multivibrator using an opamp with unipolar supply, a dc voltage source, 4 resistors, a capacitor, and a ground. Connect the first resistor between the negative input of the opamp and its output. Connect the capacitor between the negative input of the opamp and the ground. Link the second and third resistors with the opamp positive input. Connect the opamp output to the second resistor. Then connect the “+” of the voltage source to the third resistor and ground the “−” of the voltage source. Connect the load.

2. Set all the resistances in the range of 1…10 kΩ. Calculate and assign the capacitance and dc voltage value that provide the reference frequency and output.

3. Add an oscilloscope and connect its channel A to view the opamp input voltage and channel B to the opamp output.
4. Activate the circuit simulation and view input and output voltages.

**Exercise 7.2. Astable Multivibrator With a Balanced Supply**

1. Design and assemble an astable multivibrator with a balanced supply using a 5-terminal opamp with balanced supply, 4 resistors, a capacitor, and a ground. The circuit is similar to that of the astable multivibrator without the dc voltage source.

2. Add an oscilloscope and connect its channel A to view the opamp input voltage and channel B to the opamp output.

3. Activate the circuit simulation and view input and output voltages. Compare them with the previous result.

4. Turn this multivibrator into the asymmetrical astable multivibrator. To this aim, add an extra resistor across the negative feedback. Then, add a Zener diode in series with each negative feedback resistor. These diodes must be aligned back-to-back to pass the feedback current in either direction. Activate the circuit simulation and view voltages smoothly alternating the value of the new feedback resistor.

**Exercise 7.3. Wien Bridge Oscillator**

1. Design and assemble a Wien bridge oscillator using an opamp with unipolar supply, a dc voltage source, 5 resistors, 2 capacitors, a diode, and a ground. First, build the non-inverting voltage amplifier using the opamp, first and second resistors, and a ground. Second, arrange a positive feedback using the series connected third resistor and the first capacitor. Next, add the parallel-connected fourth resistor and the second capacitor between the positive opamp input and the ground. Finally, add the series counter-connected diode and the dc voltage source between the opamp negative input and output.

2. Set the equal resistors in the feedback and in the positive input (about 1-10 kΩ) and the twice smaller resistor in the negative input. Calculate and assign the equal capacitances and dc voltage value that provide the reference frequency and output voltage.

3. Add an oscilloscope and connect its channel A to view the opamp input voltage and channel B to the opamp output.

4. Activate the circuit simulation and explore the input and output voltages.

**Exercise 7.4. Wien Bridge Oscillator with a Balanced Supply**

1. Design and assemble a Wien bridge oscillator with a balanced supply using a 5-terminal opamp with a balanced supply, 6 resistors, 2 capacitors, 2 Zener diodes, and a ground. First, build the non-inverting voltage amplifier using the opamp, the first and second resistors, and the ground. Second, arrange a positive feedback using the series connected third resistor and the first capacitor. Then, add the parallel-connected fourth resistor and the second capacitor between the positive opamp input and the ground. At last, add the series counter-connected diode and the dc voltage source between the opamp negative input and output.

2. Set the new feedback resistance twice below the positive feedback resistance.
3. Add an oscilloscope and connect its channel A to view the opamp input voltage and channel B to the opamp output.

4. Activate the circuit simulation and view input and output voltages. Compare them with the previous oscillator.