NON-INVERTING OPERATIONAL AMPLIFIER

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1. ENROLLMENT

A **NON-INVERTING OP-AMP** is an electronic circuit essential for amplifying electrical signals, using an op-amp (OpAmp). The non-inverter configuration is popular due to its high input impedance, phase-free output signal, and precise input signal amplification. In this presentation we have detailed the relevant aspects. The relevant aspects are detailed below:

2. CIRCUIT CONFIGURATION:

a) ***An operational amplifier with two inputs:*** • Non-inverting input (+);
- Inverter input (-).

b) ***Two resistors in mains voltage divider configuration for gain setting:***
- Resistor Rg (connected between the output and the inverter input, but also to GND); • Resistor Rf((connected between the inverter input and ground).

3. CIRCUIT DIAGRAM:

(kicad)

4. KEY FEATURES:

- The signal input is applied to the "+" (non-inverting) terminal;
- The "-" terminal (inverter) is connected by a resistive network at ground and output, forming a negative feedback circuit;
- The output is proportional to the input voltage, with no phase reversal.

5. WIN FORMULA:

a) ***The Av voltage gain*** for a non-inverting amplifier is:

$$\mathrm{Av} = 1 + \frac{\mathbf{R}}{\mathrm{Rgf}}$$

b) ***Explanation:***
- Term 1 comes from the forward amplification (the input voltage occurs directly on the non-inverting input); • The $\frac{Rf}{Rg}$ ratio determines how much the signal is amplified.

6. ADVANTAGES OF THE NON-INVERTING AMPLIFIER:

a) ***High Input Impedance:***
- The non-inverting input has a high impedance, which prevents it from influencing previous circuits.

b) ***Output without phase reversal:***
- The output signal has the same phase as the input signal.

c) Precise Gain Control:

- The values of the Rg and Rf resistors can be easily adjusted to achieve the desired gain.

d) Stability:

- Negative feedback configuration provides stability in operation.

7. MATHEMATICAL ANALYSIS:

Using the knot theorem (Kirchhoff) and Op-Amp characteristics:

- The voltage at the inverting and non-inverting input is equal: $V+ = V-$, due to the negative reaction;
- The current through the Op-Amp inputs is negligible ($I_{in} \approx 0$);
- The output voltage is calculated as: $V_{out} = (1 + \frac{R_f}{R_g}) *$ Wine.

8. GRAPHIC REPRESENTATION:

a) Input Signal Graph:

- <u>*Features:*</u>
  - **Shape:** Sinusoidal, square or triangular, depending on the signal source applied.
  - **Amplitude:** Usually low, within the limits allowed by the amplifier, to avoid saturation.
  - **Frequency:** May vary depending on the application. It is usually chosen in the field of audio frequencies (20 Hz – 20 kHz) or radio frequency signals.
  - **Meaning:** It is the raw signal to be processed by the amplifier circuit.

- <u>*Analysis:*</u>
  - The input signal is considered the basis of the reference for the evaluation of the gain.
  - The chart must be well-defined and stable to allow for accurate measurements.
  - Input deformation or noise issues will affect the output of the amplifier.

- *Example:*
  - A sinusoidal signal with an amplitude of 0.5 V and a frequency of 1 kHz is applied as the input signal. Its graph is a repetitive sine wave, centered at 0 V (no DC offset).

b) Output signal graph:

- <u>*Features:*</u>
  - **Shape:** Similar to that of the input signal, but with higher amplitude (depending on the circuit gain);

- **Amplitude:** Proportional to the input signal and gain set by the circuit components;
- **Phase:** Identical to that of the input signal for the non-inverting amplifier;
- **Limits:** The output voltage cannot exceed the amplifier supply voltages ($V_{out,max} = \pm V_{dc}$).

• *Analysis:*

- The output signal must be an amplified version of the input signal, without major deformations.
- Possible problems: distortion (if the amplifier is in the saturation zone), voltage limiting (clipping), or added noise.
- If the output signal is clipped ("clipped"), this indicates that the amplifier is overloaded.

• *Example:*

- A sinusoidal signal with an amplitude of 2.5 V is obtained at the output for an input of 0.5 V, indicating a gain of 5 (A_v=5). The output graph should be a higher amplitude sine wave with no visible distortion.

Comparison of Input Signal and Output Signal

• *Aspects to observe:*

- **Amplitude ratio:** Indicates the value of the gain Av.
- **Shape preservation:** The output signal must retain the shape of the input signal (in the absence of distortion).
- **Phase Synchronization:** The output signal must be in phase with the input signal (for the non-inverting amplifier).
- **Noise or interference:** Visual comparison allows you to identify any anomalies or noises added by the amplifier.

c) Graph of the input signal with the output signal (depending on t):

• *On the horizontal axis (X):*

- The time "t", expressed in seconds, shows how the signal varies over time;

• *On the vertical (Y) axis:*

- Voltage, expressed in volts (V);

• *Curves:*

- Vin Input Signal: A sinusoidal signal with the amplitude given by the user.
- Vout Output Signal: The amplified signal, having the same waveform, but with a higher amplitude.

• *Objective:*

This graph clearly illustrates that:

- The non-inverting amplifier amplifies the signal without reversing its phase.
  - ❖ In the case of the sinusoidal signal, the peaks and minimums of the output signal coincide in time with those of the input signal.
- The ratio of output to input amplitude is the gain of the amplifier (Av).

- *Observations:*
  - If the amplitude of the Vin signal is 1V and the gain is 10, the amplitude of Vout will be 10V.
  - If the input signal is variable over time, the graph shows how the output follows the same dynamics, but amplified.

- *Practical usefulness:*
  - Check that the output signal is free of distortion and respects the desired amplification.
  - It is useful for understanding the correct operation of the amplifier in applications such as microphone preamplifiers or sensor signals.

d) Gain vs. Rg Resistance Chart:

- *On the horizontal axis (X):*
  - Resistance Rg , expressed in ohms (Ω);
- *On the vertical (Y) axis:*
  - The gain Av, which is the ratio of output to input, without unity (it is dimensionless)

- *Objective:*
  - This graph shows how the gain of the amplifier (Av) depends on the resistance Rg.
  - If Rg increases, the term Rf/Rg decreases, thus the gain decreases.
- *Observations:*
  - The relationship between Rg and Av is inversely exponential. Thus, a small variation of R1 can cause a big change in winning.
  - For high values of Rg, the gain tends towards 1, which makes the amplifier almost useless for amplification.

- *Practical usefulness:*
  - It is useful for determining the proper strengths in a project. It helps to precisely choose the values of Rg and Rf to get the desired gain.

e) Gain vs. Vin Input Voltage (CSTV) Graph

- *On the horizontal axis (X):* The input voltage Vin, expressed in volts (V). • *On the vertical (Y) axis:* The output voltage Vout, expressed in volts (V).

- *Objective:*
  - This graph demonstrates the linear relationship between Vin and Vout, according to the equation:

$$Vout=Av \cdot Vin$$

    - ❖ La Vin=0V, Vout=0V (point of origin).
    - ❖ As Vin increases, Vout increases in proportion to Av's gain.

- *Observations:*
  - The slope of the graph is given by the value of the gain Av. If Av=10A, the slope of the graph is 10.
  - The Vout output voltage cannot exceed the maximum supply voltage of the Op-Amp (saturation), usually Vdc or −Vdc.

- *Practical utility:*
  - It helps to understand the operating limits of the amplifier (especially the saturation region).
  - It is useful for applications where the amplifier is used for converting analog signals to specific voltage ranges.

9. Applications of Signal Analysis:

a) **Audio Systems:**

- The input is the signal from a microphone, and the output is amplified to be transmitted to the speakers.
- Testing involves observing whether the amplified signal adheres to the fidelity of the original signal.

b) **Precision Instrumentation:**

- The input signal can come from a sensor (e.g., thermocouple), and the amplification must be accurate.
- Graph analysis helps calibrate the amplifier.

c) **Communication Circuits:**

- The input signal is a modulation wave that needs to be amplified losslessly.
- The shape of the output signal is essential to guarantee the correct transmission.

10. USES OF NON-INVERTING AO:

a) ***Preamplifiers for weak signals***

- *Description:*
  - A non-inverting amplifier is ideal for amplifying weak signals from sensors, microphones, or other low-amplitude signal sources. It works to raise the signal level so that it can be processed by subsequent stages of

the circuit, such as analog-to-digital converters (ADCs) or other processing modules.

- *Example:* A temperature sensor: Produces a 10mV signal, which is far too small to be detected by a microcontroller.
  - The non-inverting amplifier boosts this signal by a configurable gain (e.g., Av=100), bringing it to 1 V, enough to be read accurately.

- *Advantages:* The non-inverting configuration provides amplification without phase reversal, maintaining signal fidelity.
  - The high input impedance prevents interference with the signal source.

b) *Buffer Amplifiers*

- *Description:*
  - When the gain of the non-inverting amplifier is set to Av=1 (i.e., Rf=0), it functions as a buffer amplifier. The main purpose is to isolate the stages of the circuit without altering the amplitude of the signal.

- *Example:*
  - Isolating a voltage source: A circuit that measures voltage from a voltage divider can have a high load. The buffer amplifier picks up the signal and provides enough current to power subsequent stages without affecting the source circuit.

- *Advantages:*
  - Very High Input Impedance: The source signal is not affected.
  - Very Low Output Impedance: Allows connection to large loads.

c) *Audio Signal Boosters*

- *Description:*
  - Non-inverting amplifiers are used in audio processing circuits to amplify signals from microphones, electric guitars, or other audio sources.

- *Example:*
  - In an audio preamplifier, the microphone signal is amplified to be transmitted to a power amplifier or directly to the speakers.
  - Non-reverse amplification ensures that the signal stays in phase with the source, which is critical for high-fidelity sound.

- *Advantages:*
  - It allows precise adjustment of the gain for different signal sources.
  Maintains signal quality without phase distortion.

d) *Instrumentation Amplifiers*

- *Description:*

- A non-inverting amplifier is used as part of an instrumentation amplifier, which is designed to amplify small differential signals and reject common noise.

- *Example:*
  - In medical applications such as electrocardiograms (ECGs) or electroencephalograms (EEGs), the electrical signals generated by the human body are very weak and can be affected by noise.
  - The non-inverting amplifier contributes to the differential amplification of the useful signal while rejecting common noise.
- *Advantages:*
  - The high input impedance allows connection to sensors without disturbing the signal.
  - High signal-to-noise ratio, essential for critical applications.

e) Active Filtering (Amplifiers Integrated in Filters):

- *Description:*
  - Non-inverting amplifiers are used in active (higher-order) filters to amplify and select certain frequencies in a signal.

- *Example:*
  - **Up-pass/low-pass filters:** The non-inverting amplifier, together with passive components (resistors and capacitors), creates a filter that amplifies only the frequencies of interest.
  - In an audio system, a low-pass filter with amplification selects the low frequencies for a subwoofer.

- *Advantages:* It allows the combination of amplification and filtering in a single circuit. Configurable for different cutting frequencies and gains.

***f)* Signal conversions in the electronic control field**

- *Description:*
  - Non-inverting amplifiers are used to tailor signals to specific domains in control systems.

- *Example:*
  - In an industrial control system, a temperature sensor can generate a signal of 0−100 mV, but a PLC (Programmable Logic Controller) requires a signal of 0 -10 V.
  - The non-inverting amplifier increases the signal to the required range.

- *Advantages:*
  - The simple configuration allows for quick adaptation to different specifications.

- Stable and linear performance.

***g)* Measurement and monitoring circuits**

- *Description:*
  - Non-inverting amplifiers are used to amplify measurement signals, such as voltage or current, before they are processed.
- *Example:*
  - In a current measurement circuit, a shunt resistor creates a voltage proportional to the current. This voltage is amplified by a non-inverting amplifier for easier measurement.
- *Advantages:*
  - Increases the resolution of the measurement.
  - It can be calibrated for different measuring ranges.

***h)* Analog-to-digital converter (ADC) amplifiers**

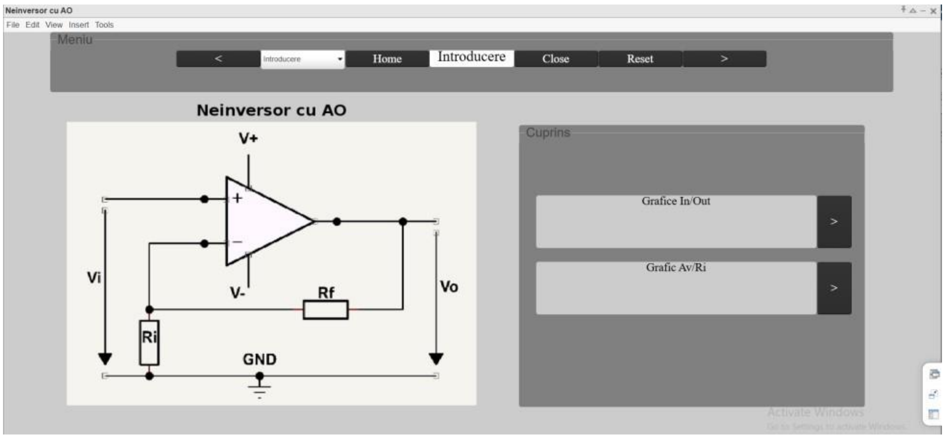
- *Description:*
  - Non-inverting amplifiers are used to prepare analog signals for conversion into digital signals, ensuring that the signal falls within the input range of the converter.
- *Example:* In an embedded system, a non-inverting amplifier amplifies the analog signal from a sensor so that it is correctly detected by the microcontroller's ADC.
- *Advantages:*
  - Avoids cutting the signal at the edges of the ADC range.
  - Reduce the impact of noise on conversion.

11. CONCLUSION:

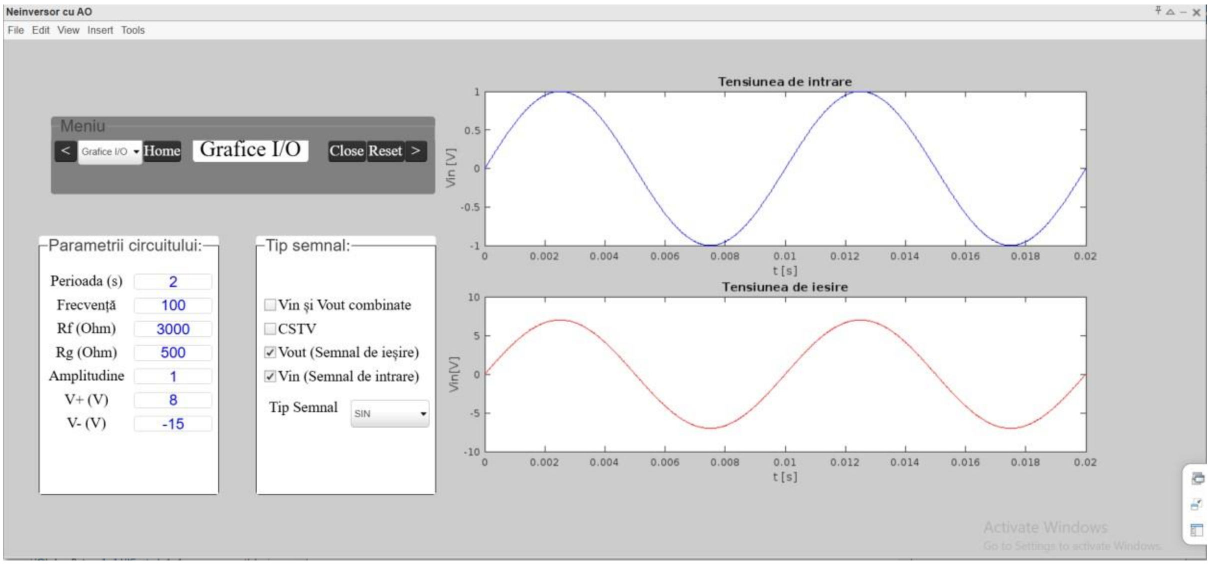
- Non-reverse amplifiers are versatile and essential in numerous electronic applications. Their uses range from amplifying weak signals to industrial control circuits and accurate measurements. High input impedance, phase-free amplification, and adjustable gain make them indispensable in modern circuit design.

12. APP INTERFACE:

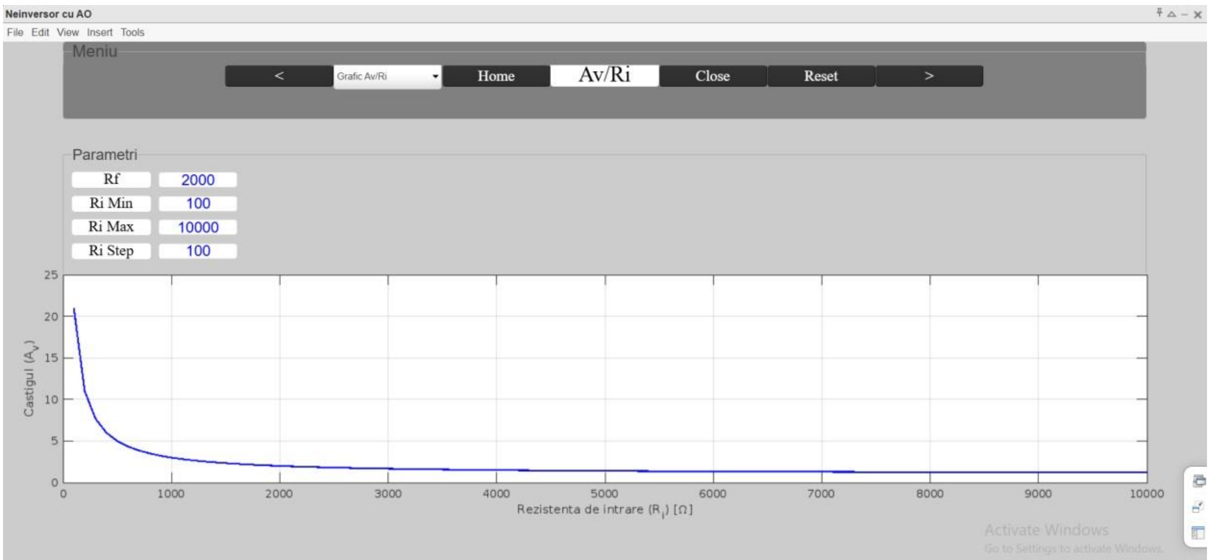
- **Introduction:**



- **Input and output signals + CSTV:**



- **Amplification with Variable Input Resistance Ri**



13. EXPLANATION OF THE CODE:

Introduction:

1. Window initialization and image reading

- **Get the screen size:** screenSize = get(0, 'ScreenSize'); This line gets the screen size to set the size of the window in which the image will be displayed.

- **Creating the Picture Window:**
  Fig = figures('Name', 'Non-inverter with AO', ...
  It creates a figure window with dimensions that occupy the entire screen and sets various options, such as window title, toolbar removal, and background color setting.

- **Image reading and resizing:** x = imread('AON.jpg');
  This line reads the image 'AON.jpg'. x_resized = imresize(x, scale_factor);
  The image is resized using a scaling factor of 2, so the image size doubles.

- **Image position calculation:**
  The position of the image on the screen is determined so that it is placed on the left side, in the middle of the screen (vertically).

- **Image display:** imshow(x_resized);
  The resized image is displayed in the previously created figures window.

- **Title setting:**
  title('Non-Investor with AO', 'FontName', 'Times New Roman', 'FontSize', 18); Set the window title with a specified font and the desired size.

- **Setting the axes:**
  axis([0 cols 0 rows]);
  Set the boundaries of the axes to match the dimensions of the image.

- **Removing axes for a cleaner view:** axis off;
  Hide the axes to allow a clear view of the image.

2. Creating the interactive menu

- **Create a menu button group:**
  GroupMenu = uibuttongroup('Visible', 'on', ...
  Create a group of buttons where various controls (buttons and drop-down lists) will be placed. These buttons will serve to navigate between the different chapters.

- **Create a title for the button group:** textTitle = uicontrol('Style', 'text', ...

Here a text control is created that will display the title "Introduction" in the interactive menu.

- **Creating a drop-down menu for chapters:**
  capitoleList = uicontrol('Style', 'popupmenu', ...
  This is a drop-down menu that allows the user to choose between the different chapters (Introduction, I/O Graphs, Av/Ri Graph). Each chapter will activate a corresponding function when selected.

3. selectChapter function for managing menu choices

- The selectChapter function is a callback that is called when the user selects a chapter from the drop-down menu.

- Depending on the chapter chosen, the function calls a different function:

  a **Introduction:** Recalls the input() function. a

  I/O Graphics: Recalls the non-inverting()

  function. a **Av/Ri Graph:** Recalls the win()

  function.

4. Create navigation and action buttons

- **Home button:** homeButton = uicontrol('Style', 'pushbutton', ...
  The "Home" button allows the user to return to the main input window. When pressed, the current window is closed and the input() function is called again.

- **"<" button:** backButton = uicontrol('Style', 'pushbutton', ...
  The "<" button allows the user to go back to the previous chapter (gain() function).

- **"Close" button:** closeButton = uicontrol('Style', 'pushbutton', ... The "Close" button closes the current window.

- **"Reset" button:** resetButton = uicontrol('Style', 'pushbutton', ...
  The "Reset" button allows the user to reset the current window by closing it and calling back the input() function.

- **">" button:** nextButton = uicontrol('Style', 'pushbutton', ...
  The ">" button allows the user to proceed to the next chapter (non-inverting() function).

5. Create a new group of buttons for Table of Contents

- **Create a table of contents group:**
  GroupContents = uibuttongroup('Visible', 'on', ...
  This creates another group of buttons that contains information about the different chapters.

- **Texts for each chapter:**
  graphicsIOText = uicontrol('Style', 'text', ...
  It adds texts for the chapters "In/Out Charts" and "Av/Ri Chart" in the table of contents group.

- **">" buttons for each chapter:**
  The buttons corresponding to the chapters allow the user to navigate to the non-inverter() and gain() functions.

6. Navigation features

- Each ">" or "<" button activates the corresponding functions to change windows or navigate between different chapters. For example, the ">" button in the "I/O Graphs" table of contents will open the non-inverting() function window.

Conclusion

This code creates a complex interactive interface for navigating between different sections of a project or document, including an image, drop-down menus, and navigation buttons for the user. It is an example of a MATLAB application with a GUI (Graphical User Interface) that combines visuals and navigation functionality.

NON-INVESTOR:

1. Create the main window (GUI)

- Get the screen size (screenSize = get(0, 'ScreenSize');) to set the size of the main window (figures) so that it occupies the entire screen.

- The main window is defined by a figure, titled "Non-Inverter with AO", without the toolbar and with a light gray background color (color, [0.8, 0.8, 0.8]).

2. Creating the navigation menu

- A uibuttongroup is created that contains a group of navigation (Menu) buttons.

- The menu includes a "I/O Graphs" heading, and the user can select from a list of chapters, such as "Introduction", "I/O Graphs", and "Av/Ri Graphs" using a popupmenu.

- There are buttons to navigate between chapters or close the app:
  - **Home button** (homeButton): When pressed, the window is closed and the input function is called.
  - **Back button** (backButton): Similar to the Home button, but uses the goBackHome() function.

- **Close button** (closeButton): Closes the app. a **Reset button** (resetButton): Recalls the non-inverting() function to reset the application. a **Next button** (nextButton): Navigates to another chapter.

3. Circuit Parameter Panel

- The paramPanel panel contains elements for entering the values of the circuit parameters:
  - **V+** and **V-**: The supply voltages of the operational amplifier. a **Period(s)** and **Frequency (Hz)**: Input signal parameters. a **Rf** and **Rg**: Feedback and input resistors.
  - **Amplitude**: The amplitude of the input signal.
- Each of these control elements is an edit field, where the user can enter numeric values. When the user changes a value, the update_graph() function is called to update the graphs.

4. Input signal panel

- The signalPanel allows the user to select the type of input signal (sinusoidal, triangular, or square) from a popupmenu.
- There are also a few checkboxes to choose which graphs to view:
  - **Wine (Input signal)**. a **Vout (Output Signal)**. a **Wine and Vout combined**.
  - **CSTV** (output current-voltage characteristic).

5. Output Graphs

- Charts are created using axes and are placed in a grid of charts that automatically adjust based on the number of charts selected.
- Each axis (hAxes) can contain one of the following graphs:
  - **Wine**: The input signal. a **Vout**: The output signal. a **Wine and Vout combined**: Both signals on the same chart.
  - **CSTV:** The current-voltage characteristic of the circuit.

6. Function update_graph()

- This function is called every time the user changes a parameter or checkbox.
- Reading the values entered by the user:
    - Read the values of the Vp, Vn, T, f, Rf, Rg, and amplitude parameters from the corresponding controls (edit fields).
    - Read the signal type (signal_type) from the popupmenu.
- Input signal generation:
    - Depending on the type of signal selected, the Vin input signal is generated:
        - **Sinusoidal**: Vin = amplitude * sin(2 * pi * f * t)
        - **Triangular**: Vin = amplitude * sawtooth(2 * pi * f * t, 0.5)
        - **Quadratic**: Vin = amplitude * square(2 * pi * f * t, 50)
- Calculation of the output signal (Vout):
    - The output signal is determined using the amplification formula for a non-inverting amplifier: Av = 1 + Rf / Rg, and the output is limited between the values Vn and Vp (the supply voltages of the operational amplifier):
        - Vout = min(max(Av * Fri, Vn), Vp)
- Check which charts are selected by reading the values of the checkboxes, and only create the corresponding charts.
- Adjust the dimensions and positions of the chart axes based on the number of charts displayed.

7. Conclusion

This code provides an interactive interface for simulating a negatively feedback non-inverting amplifier. The user can adjust the circuit parameters, choose the input signal and view the results in an interactive way. Input/output graphs are updated in real-time based on changed parameters, providing an effective visual learning tool.

WIN:

1. Create the main window

An application window is created that occupies the entire size of the screen. This window has the title "Non-Investor with AO" and a light gray background.

2. Create the menu button group

A group of buttons is created to add a selection menu between the different chapters of the app. The menu is placed at the top of the window and has a dark gray background with white text.

3. Add title text to the selection menu

Inside the button group, text with the title "Av/Ri" is added to describe the active section of the app. It is centered and has the font "Times New Roman" with size 24.

4. Creating the Chapter Drop-Down Menu

A drop-down menu is added that allows the user to choose from three options: "Av/Ri Graph", "I/O Graphs" and "Input". Choosing a chapter from this menu triggers a function that navigates to that section of the app.

5. Create navigation buttons

Several buttons are added to allow the user to navigate between different sections:

A "Home" button that closes the current window and takes the user back to the main section (Introduction).

The "<" and ">" buttons allow navigation between different sections.

A "Close" button that closes the app.

6. Setting input parameters

A few variables are defined to establish the initial parameters of the application, such as:

Feedback Resistance (Rf)

Minimum and maximum input resistance value (Ri_min and Ri_max)

Input resistance step (Ri_step)

These values will be able to be modified by the user through edit fields.

7. Create a panel for editable dimensions

A panel is created to allow the user to change the parameter values. It contains four editing fields for:

Feedback Resistance (Rf)

Minimum Input Resistance (Ri_min)

Maximum Input Resistance (Ri_max)

Step for Input Resistance (Ri_step)

Each edit field allows the user to enter a value and triggers a function that updates the chart when one of the values changes.

8. Creating the chart

A graph is created that shows the "Gain (Av)" according to the "Input Resistance (Ri)". This chart is automatically updated when the parameter values are changed by the user.

Overall, the app provides an interactive way to adjust the parameters of a non-inverting amplifier and visualize how the gain varies depending on the input resistance. Navigating between chapters and adjusting parameters is done through an intuitive graphical interface.

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