

# XycLOps II

Comprehensive System Documentation & Technical Reference

Fall 2025

**Status:** Stable / Active Development

**Backend Engine:** Xyce (Sandia National Labs)

**Framework:** Python 3.10+ / Tkinter / SciPy

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## 1 Executive Summary & Introduction

XycLOps (**Xyce Loop Optimizer system**) is an automated circuit optimization platform. It interfaces with the Xyce parallel electronic simulator to iteratively tune analog component values (resistors, capacitors, inductors) until the circuit's behavior matches a specific target curve.

**XycLOps II** represents a complete architectural overhaul of the original prototype. While the core “Least Squares” optimization logic remains, the surrounding infrastructure has been rebuilt to support multi-physics simulations, interactive visual data entry, and enterprise-grade logging.

### 1.1 Key Upgrades in XycLOps II

- **Multi-Physics Engine:** Now supports AC Frequency Response and Noise Analysis in addition to Transient analysis [**XycLOps II Upgrade**].
- **Asynchronous Threading Architecture:** The optimization engine now runs on a dedicated background thread, completely decoupling simulation logic from the UI. This ensures the interface remains responsive and interactive even during computationally intensive multi-physics sweeps [**XycLOps II Upgrade**].
- **Interactive Visual Editors:** Users can “draw” target curves (Piecewise Linear or Step) using drag-and-drop plot interfaces instead of manually creating CSV files [**XycLOps II Upgrade**].
- **Data Stream Optimization:** Implemented smart downsampling algorithms to reduce massive simulation datasets (100k+ points) into manageable visual payloads, preventing memory exhaustion and GUI lag [**XycLOps II Upgrade**].
- **Safe Process Management:** A robust “Abort” mechanism using thread-safe events allows users to instantly terminate runaway simulations without crashing the application or leaving orphaned processes [**XycLOps II Upgrade**].
- **Modern UI Framework:** A centralized theming engine replaces the standard Tkinter look with a modern, flat design system [**XycLOps II Upgrade**].
- **Workspace-Aware Logging:** A new session management system creates structured, versioned logs for every optimization run [**XycLOps II Upgrade**].
- **Performance Tooling:** Includes a startup profiler and headless stress-test harnesses [**XycLOps II Upgrade**].

## 2 Installation & Environment

### 2.1 Prerequisites

- **Operating System:** Windows 10/11, macOS, or Linux.
- **Python:** Version 3.10 or higher.
- **Simulator:** [Xyce](#) must be installed and added to the system PATH. XycLOps II relies on Xyce for all circuit simulations.

## 2.2 Dependencies

The application relies on a strictly versioned set of libraries. [XycLOps II Upgrade] The dependency list was expanded to support the new plotting and theming engines.

- **Core Logic:** numpy==2.2.3, scipy==1.15.2 (Optimization & Interpolation)
- **Visualization:** matplotlib==3.10.1 (Real-time plotting & Visual Editors)
- **GUI & Imaging:** pillow==11.1.0, tkinter (Standard Lib)

## 2.3 Installation Strategy

To ensure stability, XycLOps II is designed to run within a virtual environment.

### 2.3.1 Windows Setup

```
1 python -m venv xyclopsvenv
2 .\xyclopsvenv\Scripts\activate
3 pip install -r requirements.txt
```

### 2.3.2 macOS/Linux Setup

```
1 python -m venv xyclopsvenv
2 source xyclopsvenv/bin/activate
3 pip install -r requirements.txt
```

## 2.4 Startup Profiling [XycLOps II Upgrade]

A new utility, `analyze_startup_time.py`, was added to diagnose slow application launch times. It measures the import overhead of heavy libraries like `matplotlib` and `scipy`.

- **Command:** `python analyze_startup_time.py`
- **Output:** A “snail/lightning” report identifies bottlenecks.

## 3 System Architecture

XycLOps II follows a **Model-View-Controller (MVC)** pattern with strict thread separation to prevent UI freezing during heavy calculations.

### 3.1 Directory Structure

The codebase is organized into modular subsystems:

```
1 project_root/
2   |-- main_app.py                  # Application Bootstrap (Freeze Support)
3   |-- analyze_startup_time.py      # [XycLOps II Upgrade] Profiler
4   |-- backend/                     # THE MODEL (Logic)
5     |-- curvefit_optimization.py  # Main Solver Loop (SciPy + Xyce)
6     |-- netlist_parse.py          # SPICE Parser & Injection Logic
7     |-- optimization_process.py   # Threading Wrapper
8     |-- xyce_parsing_function.py # Output Parser (.prn files)
9   |-- frontend/                   # THE VIEW/CONTROLLER (UI)
10    |-- app_controller.py         # Central State Manager
11    |-- ui_theme.py              # [XycLOps II Upgrade] Design System
12    |-- optimization_summary.py  # Dashboard & Real-time Plotting
```

```

13 |     |-- optimization_settings/ # Configuration Modules
14 |     |-- visual_curve_editors.py # [XycLOps II Upgrade] Interactive Editors
15 |     |-- ac_settings_dialog.py # [XycLOps II Upgrade] AC Config
16 |     |-- noise_settings_dialog.py# [XycLOps II Upgrade] Noise Config
17 |     |-- ...
18 |-- netlists/                 # Example Circuits

```

## 3.2 Data Flow

1. **User Input:** The user interacts with the **Frontend**, loading a netlist and configuring parameters.
2. **State Storage:** The **AppController** aggregates this data into a session dictionary.
3. **Dispatch:** When “Run” is clicked, **OptimizationSummary** spawns a **Backend Thread**.
4. **Simulation Loop:**
  - The **Backend** writes a modified netlist to disk.
  - **Xyce** is invoked via subprocess.
  - **Backend** parses the output, compares it to the target, and calculates the error (residual).
  - **SciPy** calculates the next set of component values.
5. **Feedback:** The Backend pushes status messages and plot data into a thread-safe **Queue**.
6. **Visualization:** The Frontend polls this Queue and updates the Real-time Graph and Logs.

## 4 Frontend Subsystem (UI)

The frontend uses `tkinter` but abandons the default OS look for a custom “Modern” theme.

### 4.1 Entry Point & Safety

The `main_app.py` script includes `multiprocessing.freeze_support()`. This is crucial for Windows compatibility if the application is packaged into an `.exe` using PyInstaller, ensuring background threads behave correctly.

### 4.2 Modern Theme Engine [XycLOps II Upgrade]

Located in `frontend/ui_theme.py`, this module enforces a cohesive design language.

- **Palette:** Defines semantic colors (`accent`: Blue `#3b82f6`, `success`: Green `#10b981`, `bg_secondary`: Slate `#f8fafc`).
- **Widget Factories:** Helper functions like `create_card` and `create_primary_button` ensure consistent padding, fonts (“Segoe UI”), and border radii across the entire application.

### 4.3 App Controller

The **AppController** manages the navigation stack. It allows the user to move non-linearly between the **Netlist Uploader**, **Parameter Selection**, and **Settings** windows while preserving state (e.g., keeping selected resistors active even if you go back to the upload screen).

## 4.4 Optimization Settings & Dialogs

This module handles the complex configuration required for multi-physics optimization.

### 4.4.1 AC Analysis Settings [XycLOps II Upgrade]

Managed by `ac_settings_dialog.py`.

- **Sweep Types:** Supports Decade (DEC), Linear (LIN), and Octave (OCT).
- **Validation:** Prevents invalid inputs (e.g., Start Freq  $\geq$  Stop Freq, or negative frequencies).

### 4.4.2 Noise Analysis Settings [XycLOps II Upgrade]

Managed by `noise_settings_dialog.py`.

- **Inputs:** Requires the user to select an **Output Node** (parsed from the netlist) and an **Input Source**.
- **Quantity:** Users can choose between Output Noise Density (`onoise`) or Input-Referred Noise (`inoise`), with optional dB conversion.

### 4.4.3 Visual Curve Editors [XycLOps II Upgrade]

Located in `visual_curve_editors.py`, this is a major usability enhancement. It embeds `matplotlib` directly into the settings window to allow interactive target definition.

- **Heaviside Editor:** A dedicated GUI for Step Responses. Users drag handles to set Amplitude, Start Time ( $t_0$ ), and window width.
- **Piecewise Linear (PWL) Editor:** A point-and-click interface.
  - **Interaction:** Double-click to add points; drag points to adjust timing/voltage.
  - **Constraint Visualization:** The `LegacyConstraintsBar` allows users to visualize constraints (e.g., “Voltage must be  $< 5V$ ”) as shaded regions directly on the target graph.

## 4.5 Optimization Dashboard

Managed by `optimization_summary.py`, this window acts as the mission control center.

- **Real-time Plotting:** Embeds a Matplotlib figure that updates every time the backend produces a new simulation result.
- **Sidebar Logging [XycLOps II Upgrade]:** A collapsible sidebar streams text logs (e.g., “Xyce Run #45 complete”) in real-time.
- **Convergence Window [XycLOps II Upgrade]:** A floating, “always-on-top” window displays the current convergence percentage:

$$\text{Improvement} = \frac{\text{Initial Cost} - \text{Current Cost}}{\text{Initial Cost}} \times 100\%$$

## 5 Backend Subsystem (Logic)

The backend is responsible for the “loop”: Modify Netlist → Run Xyce → Measure Error → Adjust Parameters.

## 5.1 Netlist Parsing & Injection

The `Netlist` class in `netlist_parse.py` parses SPICE files. In XycLOps II, it was significantly expanded to support dynamic analysis injection.

- **AC Injection [XycLOps II Upgrade]:** The `writeAcCmdsToFile` method injects `.AC` commands and the corresponding `.PRINT AC` directive.
- **Noise Injection [XycLOps II Upgrade]:** The `writeNoiseCmdsToFile` method handles the complex syntax of `.NOISE V(node) Source ...`
- **Unit Robustness:** The parser now handles unicode micro symbols ( $\mu$ ) and diverse engineering suffixes (Mil, Meg, u, p, n) to ensure robustness with various SPICE dialects.

## 5.2 Optimization Engine

This file (`curvefit_optimization.py`) contains the function which drives the entire process.

### 5.2.1 Session Management [XycLOps II Upgrade]

A new “Workspace-Aware” system organizes results.

- **Structure:** `runs/netlist-results/[NetlistName]/[SessionID]/`.
- **Logic:** The system scans the directory for existing session integers (1, 2, 3...) and automatically increments to the next available ID for the new run.
- **Logging:** A `session.log` file captures all events, errors, and the full details of the *last 3 runs* to preserve disk space.

### 5.2.2 Multi-Physics Handling [XycLOps II Upgrade]

The solver now adapts its data processing based on the `analysis_mode`:

- **AC Analysis:** If the user requests “Magnitude (dB)”, the backend converts the raw linear voltage output from Xyce using:

$$V_{dB} = 20 \cdot \log_{10}(\max(V_{linear}, 10^{-30}))$$

The floor of  $10^{-30}$  prevents math errors on zero output.

- **Noise Analysis:** Similar logic applies to noise density values if a dB scale is requested.

### 5.2.3 Data Downsampling [XycLOps II Upgrade]

To prevent the GUI from crashing when Xyce produces massive datasets (e.g., 100,000+ points), the `_downsample_pairs` function reduces the dataset to  $\approx 5,000$  points before sending it to the frontend. The internal optimizer, however, continues to use the full-resolution data for maximum accuracy.

## 5.3 Threading Model

- **Worker Thread:** The optimization runs in a dedicated daemon thread (`backend.optimization_process.optimizeProcess`).
- **IPC Queue:** Communication happens via a `queue.Queue`.
  - (“Log”, `msg`): Text updates.

- ("UpdateYData", (x, y)): Plot updates.
- **Polling Loop:** The Frontend's `update_ui` method executes every 100ms to drain this queue.

## 6 Testing & Validation

### 6.1 Stress Testing Harness [XycLOps II Upgrade]

Located in `backend/manual_tests/`, these scripts bypass the UI to stress-test the solver logic directly.

- `long_instr_amp_test.py`: Optimizes a 7-variable Instrumentation Amplifier (Transient) with strict tolerances ( $10^{-14}$ ) to force long runtimes.
- `long_instr_amp_ac_test.py`: The AC counterpart, sweeping 10Hz to 1MHz.
- **ConsoleQueue:** A lightweight mock of the UI queue used to stream results to the terminal during these headless tests.

## 7 User Workflows

### 7.1 Transient Optimization (Standard)

1. **Upload:** Load a `.cir` file.
2. **Parameters:** Select components (e.g., R1, C1).
3. **Settings:** Ensure “Transient” is selected. Set Stop Time.
4. **Target:** Draw a Step Response (0V to 5V) using the **Heaviside Editor [XycLOps II Upgrade]**.
5. **Run:** The system tunes the parameters to match the step response.

### 7.2 AC Optimization [XycLOps II Upgrade]

1. **Settings:** Select “AC Analysis”.
2. **Configure:** Click “Configure AC Sweep”. Set Sweep to DEC, Start 10, Stop 1Meg.
3. **Response:** Select “Magnitude (dB)”.
4. **Target:** Upload a CSV defining the desired Bode plot (Gain vs. Freq).
5. **Run:** The optimizer adjusts components to match the frequency response.

### 7.3 Noise Optimization [XycLOps II Upgrade]

1. **Settings:** Select “Noise Analysis”.
2. **Configure:**
  - **Output Node:** V(out)
  - **Input Source:** Vsrc
  - **Quantity:** onoise (Output Noise Density)
3. **Target:** Define a flat noise floor target (e.g.,  $10nV/\sqrt{Hz}$ ).
4. **Run:** The system minimizes noise density to meet the target.

## 8 Troubleshooting

- **Xyce Not Found:** Ensure the Xyce binary location is added to your system's PATH environment variable. XycLOps II logs the detected path in the sidebar at startup.
- **Slow Startup:** Run `python analyze_startup_time.py` to check if a specific library (like Matplotlib) is causing delays [**XycLOps II Upgrade**].
- **Convergence Issues:** If the graph flatlines, try enabling "Default Bounds" in Settings or widening the search space for your selected components.