

Plane Sight: A Grid-Guided Human-in-the-Loop System for Accessible Free-Form Circuit Construction

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Abstract

Plane Sight was developed to provide a simple bridge between an electronic circuit and its physical free-form construction. The system combines grid-based component placement, direct user-defined wiring, layered 3D visualization, project storage, and collision awareness within a single desktop application. The presented system places creative and spatial decisions in the hands of the user while using computation for geometric consistency and visualization. The construction of a free-form Fuzz Face circuit demonstrates the complete intended workflow from circuit schematic to 2D layout, 3D representation, and physical assembly. The resulting approach emphasizes accessibility rather than automation and is intended to allow beginners and hobbyists to explore physical electronic construction without first learning conventional PCB-design software.

Key Words : Free-Form Circuit Construction, Human-in-the-Loop Design, Grid-Based Layout, 3D Circuit Visualization, Accessible Electronics, Plane Sight

I. Introduction

Electronic circuits are commonly transformed from schematics into physical devices through printed circuit board (PCB) design. While modern PCB software provides powerful tools for professional development, it also introduces a considerable learning barrier for beginners. Component footprints, routing rules, layers, manufacturing constraints, and specialized design workflows must often be understood before a simple circuit can be physically constructed.

For small experimental circuits, however, a manufactured PCB is not always necessary. Components can instead be arranged directly in space and connected using their leads or additional wire. This form of free-form construction makes the physical structure of a circuit visible and can provide a more intuitive introduction to electronics. The difficulty is that translating a schematic into a practical 3D arrangement still requires spatial planning, measurement, and careful consideration of possible wire and component interference.

Plane Sight was developed to reduce this gap between a circuit idea and its physical construction. The program provides a grid-based 2D workspace in which components can be placed, rotated, connected, and assigned to different vertical planes. The same design can then be viewed as a 3D structure before physical assembly. The 2.54 mm grid corresponds directly to common perfboard spacing, giving the user a familiar physical reference rather than an abstract drawing area.

The final objective of Plane Sight is not to replace conventional PCB design software or automate circuit

engineering. Instead, it provides an accessible intermediate tool for users who already have a circuit they wish to build but may have little or no experience with PCB layout or mechanical CAD. By combining direct component placement, user-defined wiring, exact 2D-to-3D transformation, and collision warnings, the system aims to make free-form circuit construction understandable with a minimal learning curve.

This paper describes the geometric principles behind Plane Sight, the development path from automatic optimization to direct human control, the implementation of the software workflow, and its use in the construction of a working free-form electronic circuit.

II. Theory

2.1 Grid-Based Physical Representation

Plane Sight is based on the standard 2.54 mm (0.1 inch) spacing used by common perfboards. Rather than allowing arbitrary component coordinates, the board is treated as a regular grid. A physical position can therefore be described as:

$$x = i \cdot p, \quad y = j \cdot p$$

where $p = 2.54(\text{mm})$ and i and j represent grid positions.

Using a common physical unit allows the digital drawing to correspond directly to a real board. Component pins, wire endpoints, measurements, and exported coordinates can therefore be interpreted without converting the design into a conventional PCB

layout.

2.2 Parametric Component Geometry

Components are represented using simplified geometric packages rather than detailed CAD models. Each package contains a body width, body height, and a set of pin coordinates relative to the component origin. The program includes packages for resistors, capacitors, diodes, LEDs, transistors, DIP integrated circuits, potentiometers, switches, jacks, and other basic parts.

Components may be rotated by 0°, 90°, 180°, or 270°. The same rotation is applied to both the body and its pin positions. For example, a local point (x, y) rotated by 90° becomes approximately $(h - y, x)$, where h is the original component height.

This simplified representation is sufficient because Plane Sight is concerned mainly with the physical position of a component and its pins rather than reproducing its exact industrial geometry.

2.3 Circuit Connectivity as a Graph

A circuit layout can be represented as a graph in which component pins act as nodes and wires act as edges. This allows the software to determine which physical points belong to the same electrical connection.

Plane Sight also distinguishes between a geometric crossing and an electrical junction. Two wires that simply cross are not assumed to be electrically connected. A connection occurs through a shared component pin or through an explicit junction placed by the user. Wires belonging to the same connected group can then be identified using basic graph traversal.

This rule is particularly useful in free-form construction because several wires may visually cross while remaining physically separated.

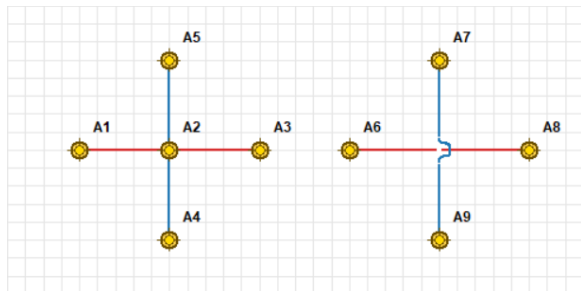


Fig. 1. Anchor (Left) and Jump (Right)

2.4 User-Defined Wire Geometry

The final version of Plane Sight uses the paths drawn by the user rather than automatically generating new routes. A standard wire consists of horizontal and vertical segments, while a diagonal mode allows a

direct connection between two points.

For an orthogonal wire, the planar distance between two endpoints is described by the Manhattan distance:

$$L = |x_2 - x_1| + |y_2 - y_1|$$

For a straight diagonal wire, the ordinary Euclidean distance is used:

$$L = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

The exact wire topology is saved together with the circuit. This is important because knowing that two pins belong to the same electrical net does not necessarily describe how the user intended the physical wire to be shaped.

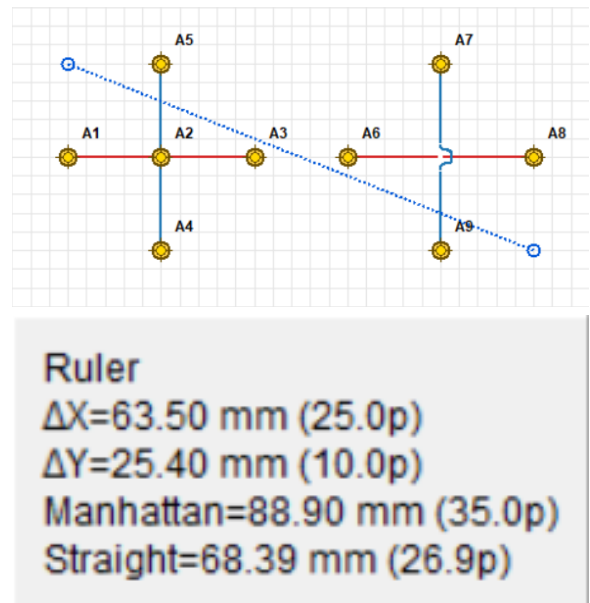


Fig. 2. Ruler Tool

2.5 Layered 3D Representation

The 2D board is extended into 3D by assigning components to discrete vertical planes. Each component has an integer plane index k , with its vertical position given by:

$$z = k \cdot 12.7 \text{ mm}$$

Therefore, plane 0 represents the base plane, plane 1 is 12.7 mm above it, and plane -1 is 12.7 mm below it.

Components are represented in the 3D model as simplified rectangular volumes. Their x and y dimensions are inherited directly from the 2D package, while an approximate height is added for visualization. This provides enough information to understand the spatial arrangement without requiring detailed mechanical CAD models.

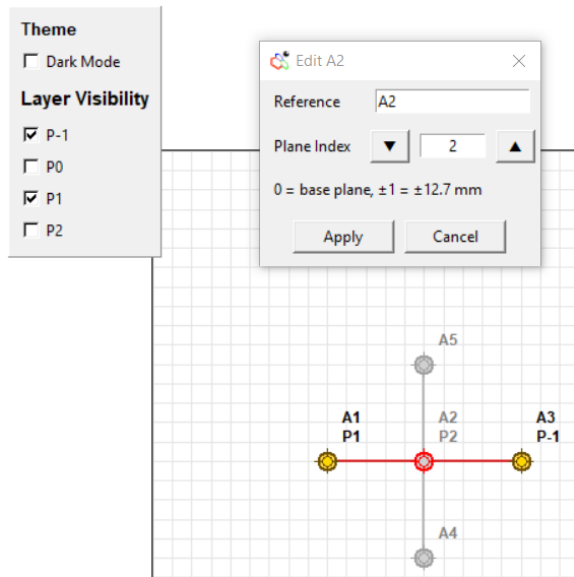


Fig. 3. Height and Layer Visibility Adjustment

2.6 Exact 2D-to-3D Transformation

One of the main principles of the final program is that the 3D representation should preserve the user's 2D drawing. The software therefore does not reroute wires when the 3D model is generated.

If an orthogonal wire was drawn with one bend in the editor, the same XY path appears in the 3D model. When its endpoints lie on different vertical planes, the generated wire first rises or drops vertically at the starting anchor and then follows horizontal X and Y directed segments. Each orthogonal segment therefore changes only one coordinate axis. Intentional diagonal wires remain direct connections between their endpoints.

The result is therefore not a newly calculated circuit layout. It is a 3D interpretation of exactly what the user designed in 2D.

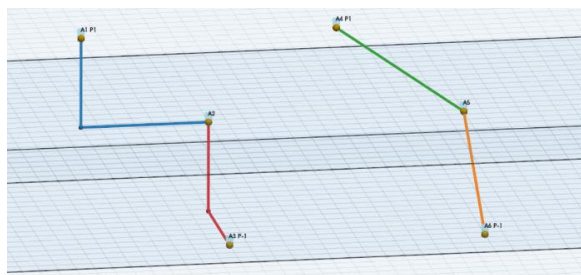


Fig. 4. Orthogonal Wiring and Diagonal Wiring

2.7 Collision and Clearance Detection

Although Plane Sight does not automatically reroute wires, the 3D viewer still assists the user by detecting possible physical conflicts. Wire segments are compared with other wire segments and with simplified component volumes.

When two unrelated wires pass within a small clearance distance, or when a wire intersects a component body, the corresponding location is displayed using a red warning marker. Connections that occur intentionally at shared pins or explicit junctions are excluded from these warnings.

This creates an important distinction between assistance and automation. The software identifies a possible problem, but the user decides how the layout should be changed.

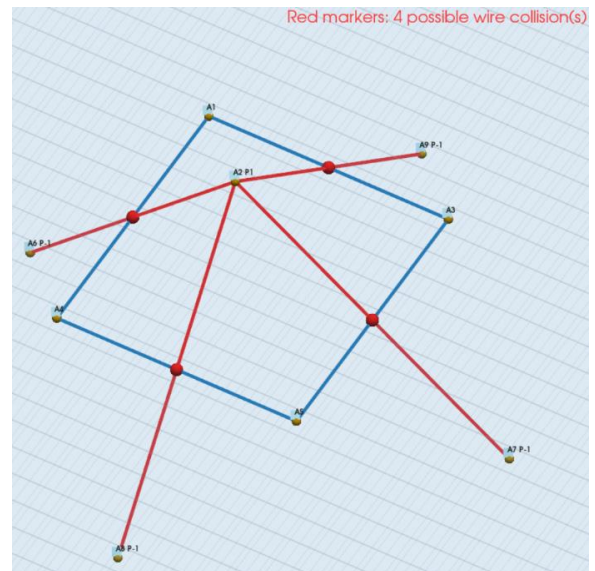


Fig. 5. Red Warning Markers

III. Method & Materials

3.1 Software Environment

Plane Sight was implemented in Python as a desktop application. The 2D editor uses Tkinter¹⁾ for the graphical user interface, while the interactive 3D visualization is produced using PyVista²⁾ and VTK³⁾. Circuit projects are stored in JSON format so that component positions, rotations, wiring, junctions, and layer information can be reconstructed when a design is reopened.

The software was intentionally developed as a self-contained design environment rather than as an extension of an existing PCB package. This allowed the interaction model to remain focused on direct placement and construction rather than conventional PCB-manufacturing rules.

3.2 Board and Component Setup

A new design begins with a perfboard-style workspace. Several board dimensions are provided as presets, while larger custom boards may also be used. All component placement is based on the common 2.54 mm grid described in Section II.

Components are selected from a predefined library containing common passive parts, transistors, DIP integrated circuits, potentiometers, switches, LEDs, jacks, and general-purpose connection ports. Each part is represented by its approximate body footprint and physical pin positions.

After placement, a component may be moved, rotated, renamed, or assigned to another vertical plane. Multiple components may also be selected and moved or raised together.

3.3 2D Layout Procedure

The main design process takes place directly in the 2D editor. The procedure used during this work was:

1. Select an appropriate board size.
2. Place the required electronic components.
3. Arrange and rotate the components according to the desired physical structure.
4. Draw wires directly between component pins (Use diagonal wiring where a direct path is preferred).
5. Add explicit junctions where crossing or touching wires are intended to form one electrical connection.
6. Move individual components or groups to other vertical planes when additional spatial separation is required.
7. Inspect and adjust the layout before generating the 3D representation.

The geometry visible in the editor represents the construction decisions made by the user.

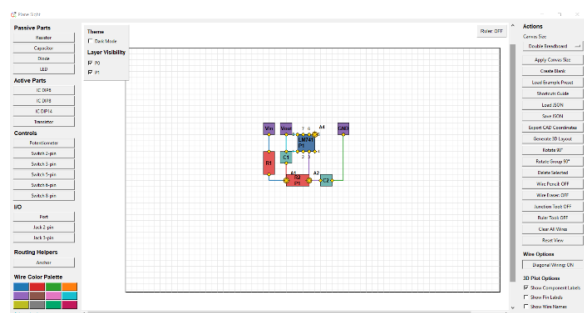


Fig. 6. Plane Sight 2D Editor (Sallen-Key LPF)

3.4 3D Generation and Validation

After the 2D layout is completed, the circuit is converted into a 3D representation. Component coordinates, rotations, pin positions, and plane indices are transferred directly into the 3D model. The stored editor wires are then reproduced using their original paths rather than being recalculated by an auto router.

The interactive viewer allows the model to be rotated, panned, and enlarged so that the structure can be

inspected from different directions. Possible wire-to-wire or wire-to-component interference is displayed using red warning markers. These warnings do not modify the design and are intended only to identify locations that may require attention before construction.

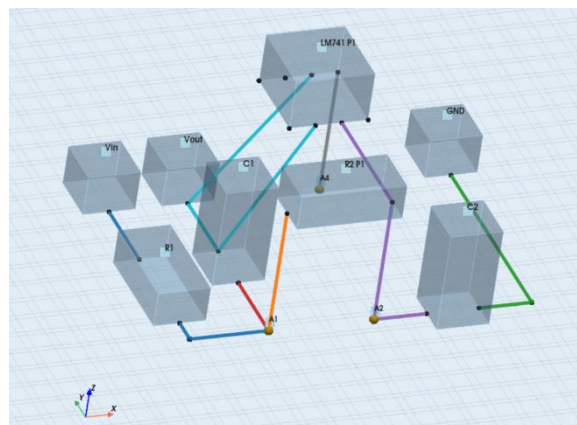


Fig. 7. 3D representation of the Sallen-Key low-pass-filter layout shown in Fig. 6

3.5 Project Storage and Export

Circuit designs can be saved and reopened without losing their physical arrangement. The stored project includes the board dimensions, component references, package types, positions, rotations, plane indices, electrical nets, junction points, and the exact wires drawn in the editor. Wire color and diagonal-routing information are also preserved.

The 3D layout may additionally be exported as structured data containing component geometry, pin coordinates, and wire paths. This makes the geometric result available independently of the editor and allows the design information to be reused by other tools if required.

3.6 CAD-Compatible Pin-Coordinate Export

Plane Sight includes a coordinate-export function that provides a bridge between the circuit layout and external mechanical CAD workflows. The function exports the 3D reference coordinates of component pins as a structured table. Each exported point is identified by its component reference and pin designation and is assigned corresponding X, Y, and Z coordinates.

The user can select the coordinate origin from the top-left hole of the layout, a chosen component pin, or a custom grid position. Coordinates may be expressed either in millimeters or in units of the standard 2.54 mm perfboard pitch. Since the editor's screen coordinates increase downward, the exporter also provides a CAD-style conversion in which the positive Y direction points upward, following the

conventional Cartesian coordinate system used by many CAD applications.

The resulting data can be exported as a CSV file, a tab-delimited TXT file, or an Excel-compatible XML worksheet. These formats allow the coordinate table to be reviewed in spreadsheet software or processed by scripts and macros for creating reference points in an external CAD environment.

The feature exports component-pin reference points rather than complete component bodies, wires, or assembly geometry. It should therefore not be interpreted as a native STEP or DXF exporter. Its purpose is to provide an accurate set of spatial reference points from which further mechanical geometry may be created using external CAD tools.

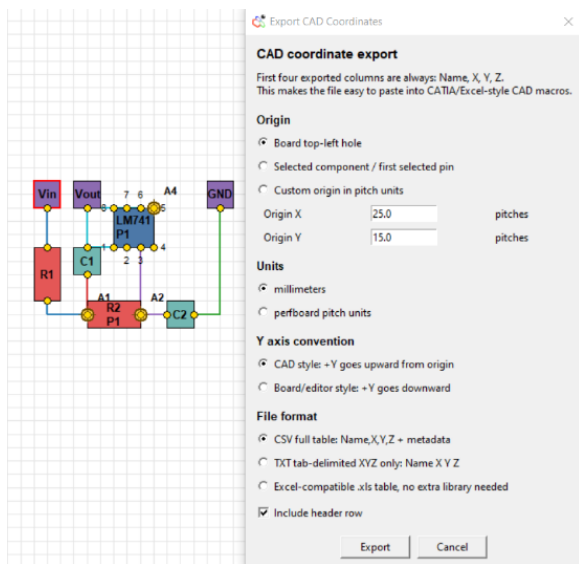


Fig. 8. Pin-Coordinate Export Menu

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Name	X	Y	Z	Component	Pin	Package	Plane	Unit	X_abs_min	Y_abs_min	Z_abs_min	Origin_X	Origin_Y	Y_min	Y_max	
A1_1	71.12	-58.42	0	A1	1	ANCHOR	0 mm	mm	71.12	-58.42	0	0	0	0	0	CAD_Y_UP
A2_1	81.28	-58.42	0	A2	1	ANCHOR	0 mm	mm	81.28	-58.42	0	0	0	0	0	CAD_Y_UP
A4_1	83.82	-38.1	0	A4	1	ANCHOR	0 mm	mm	83.82	-38.1	0	0	0	0	0	CAD_Y_UP
C1_1	71.12	-50.8	0	C1	1	CAP_2	0 mm	mm	71.12	-50.8	0	0	0	0	0	CAD_Y_UP
C1_2	71.12	-45.72	0	C1	2	CAP_2	0 mm	mm	71.12	-45.72	0	0	0	0	0	CAD_Y_UP
C2_1	86.36	-58.42	0	C2	1	CAP_2	0 mm	mm	86.36	-58.42	0	0	0	0	0	CAD_Y_UP
C2_2	91.44	-58.42	0	C2	2	CAP_2	0 mm	mm	91.44	-58.42	0	0	0	0	0	CAD_Y_UP
GND_1	96.52	-38.1	0	GND	1	PORT_1	0 mm	mm	96.52	-38.1	0	0	0	0	0	CAD_Y_UP
LM741_1	76.2	-45.72	12.7	LM741	1	DIP8	1 mm	mm	76.2	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_2	78.74	-45.72	12.7	LM741	2	DIP8	1 mm	mm	78.74	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_3	81.28	-45.72	12.7	LM741	3	DIP8	1 mm	mm	81.28	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_4	83.82	-45.72	12.7	LM741	4	DIP8	1 mm	mm	83.82	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_5	86.36	-45.72	12.7	LM741	5	DIP8	1 mm	mm	86.36	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_6	88.9	-45.72	12.7	LM741	6	DIP8	1 mm	mm	88.9	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_7	91.44	-45.72	12.7	LM741	7	DIP8	1 mm	mm	91.44	-45.72	12.7	0	0	0	0	CAD_Y_UP
LM741_8	93.98	-45.72	12.7	LM741	8	DIP8	1 mm	mm	93.98	-45.72	12.7	0	0	0	0	CAD_Y_UP
R1_1	63.5	-45.72	0	R1	1	AXIAL_2	0 mm	mm	63.5	-45.72	0	0	0	0	0	CAD_Y_UP
R1_2	63.5	-55.88	0	R1	2	AXIAL_2	0 mm	mm	63.5	-55.88	0	0	0	0	0	CAD_Y_UP
R2_1	71.12	-58.42	12.7	R2	1	AXIAL_2	1 mm	mm	71.12	-58.42	12.7	0	0	0	0	CAD_Y_UP
R2_2	81.28	-58.42	12.7	R2	2	AXIAL_2	1 mm	mm	81.28	-58.42	12.7	0	0	0	0	CAD_Y_UP
Vin_1	63.5	-38.1	0	Vin	1	PORT_1	0 mm	mm	63.5	-38.1	0	0	0	0	0	CAD_Y_UP
Vout_1	71.12	-38.1	0	Vout	1	PORT_1	0 mm	mm	71.12	-38.1	0	0	0	0	0	CAD_Y_UP

Fig. 9. Exported Coordinate Table

3.7 Physical Construction Procedure

The completed Plane Sight model is used as a visual construction reference rather than as a manufacturing file. Components are positioned according to their relative locations in the digital layout, and their leads or additional wires are shaped to reproduce the displayed connections.

During assembly, the user may repeatedly compare the physical structure with the 2D layout and 3D

model. Because the program preserves the manually selected component positions and wire paths, the digital model acts as a direct guide to the intended final structure.

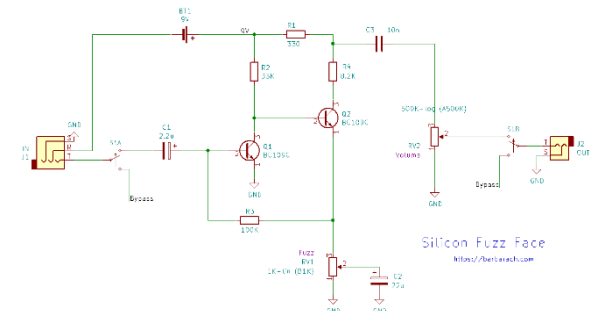
The practical demonstration used in this work was a free-form Fuzz Face circuit. Its digital layout, generated 3D model, and completed physical construction are presented in the following section.

IV. Demonstration and Results

4.1 Demonstration Circuit

To evaluate the complete Plane Sight workflow, a Fuzz Face guitar effect circuit was selected as a practical demonstration. The circuit is sufficiently small for manual free-form construction while still containing several interacting components and external connections. This made it suitable for testing component placement, manual wiring, 3D arrangement, and the transition from a digital layout to a physical object.

The purpose of the demonstration was not to optimize the electronic design itself, but to determine whether Plane Sight could provide a clear construction reference from which the circuit could be physically reproduced.



4.2 2D Plane Sight Layout

The circuit was first reconstructed inside the Plane Sight editor. Components were positioned manually on the 2.54 mm grid and rotated according to the intended physical arrangement. Connections were then drawn directly between the corresponding pins.

The final 2D layout therefore represents the user's construction plan rather than the result of automatic placement or routing. Component spacing, wire direction, and the overall appearance of the structure were adjusted visually until a satisfactory arrangement was obtained.

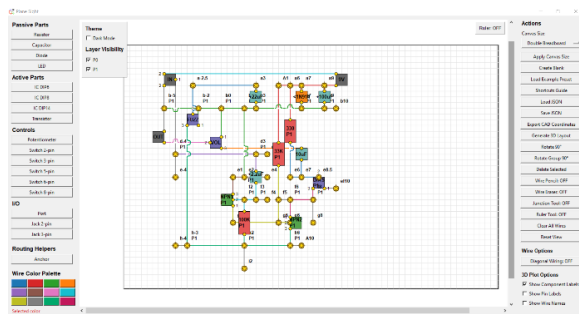


Fig. 11. Final 2D Plane Sight layout of the Fuzz Face circuit

4.3 3D Visualization

The completed 2D layout is then converted into the Plane Sight 3D representation. Component positions and wire paths were preserved during this transformation, allowing the structure to be inspected from different viewing angles before physical construction.

The 3D model was particularly useful for understanding the relative height of components and wires, which is difficult to judge from a conventional schematic or a purely 2D layout. Potential physical contacts could also be visually identified before assembly.

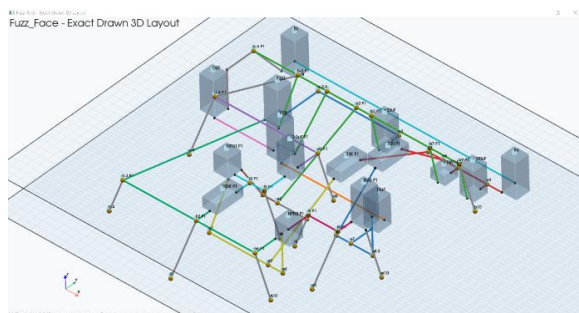


Fig. 12. 3D visualization of Fig. 11

4.4 Physical Free-Form Construction

The digital layout was subsequently used as a reference for constructing the circuit physically. Components and connecting wires were arranged according to the relative positions and paths shown by Plane Sight.

Rather than following a manufactured PCB or printed copper pattern, the circuit was assembled directly from the visual construction model. The completed object could then be compared with both the 2D editor view and the generated 3D representation.

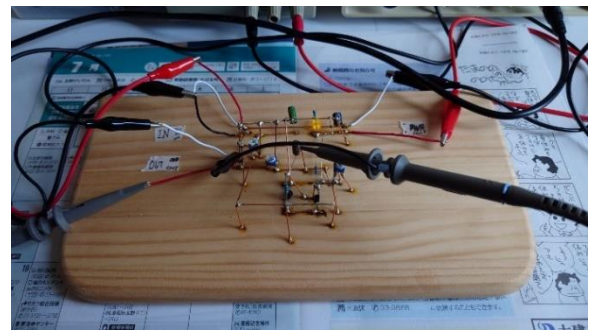


Fig. 13. Completed physical free-form Fuzz Face circuit constructed using Plane Sight

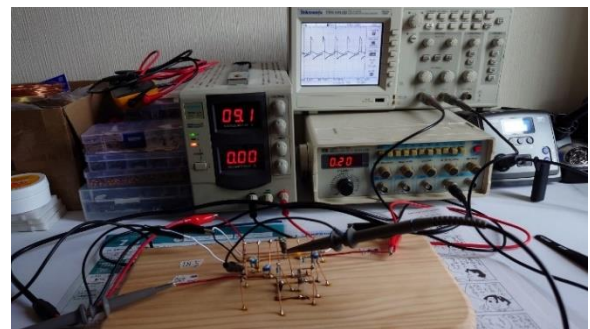


Fig. 14. Experimental setup for prototype

4.5 Comparison of Digital and Physical Results

The component arrangement and wire structure represented in Plane Sight could be recognized in the completed physical construction. In particular, preserving user-defined wire paths made the 3D model useful as a direct construction reference rather than merely a visualization of electrical connectivity.

The demonstration also highlighted the importance of allowing the user to make the final spatial decisions. Several characteristics of a free-form circuit, such as symmetry, spacing, wire shape, and visual appearance, are difficult to define through a numerical optimization function but can be judged immediately by the person constructing the circuit.

The practical result therefore supports the main design objective of Plane Sight: a circuit can be

planned and visualized as a physical structure without requiring the user to first learn a conventional PCB-design workflow.

4.6 Functional Testing

After construction, the completed circuit was powered with approximately 9.1 V DC supply, and driven by a function generator. The input and output signals were observed simultaneously using a two-channel digital oscilloscope. The measurements showed that the physical circuit passed and modified the applied signal, while adjustments of VR1 and the Fuzz control produced clearly observable changes in the output waveform.

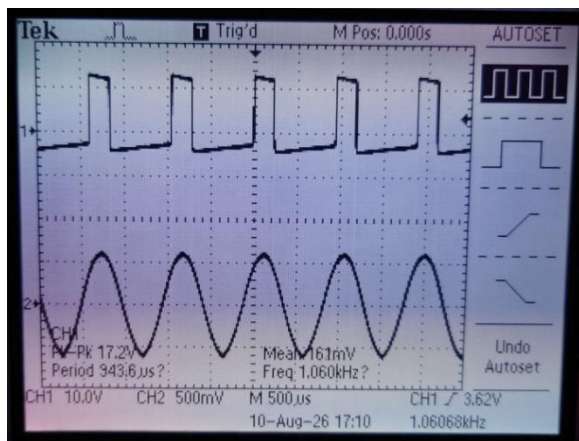


Fig. 15. Output waveform (top) and input waveform (bottom)



Fig. 16. Fuzz Face waveform response with VR1 adjusted to near 0kΩ

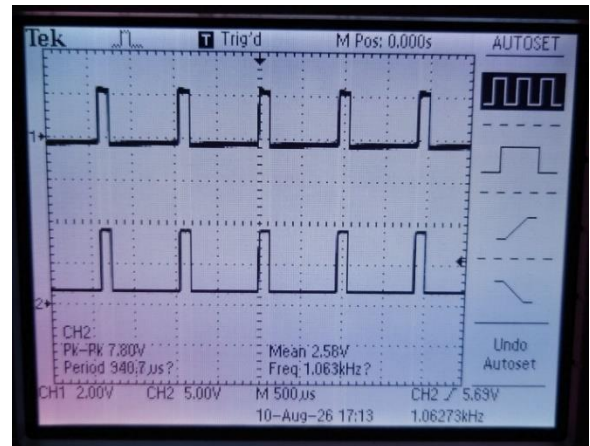


Fig. 17. Fuzz Face waveform response with VR1 adjusted to near 10kΩ



Fig. 18. Fuzz Face waveform response with 'Fuzz Pot' adjusted to near 0kΩ

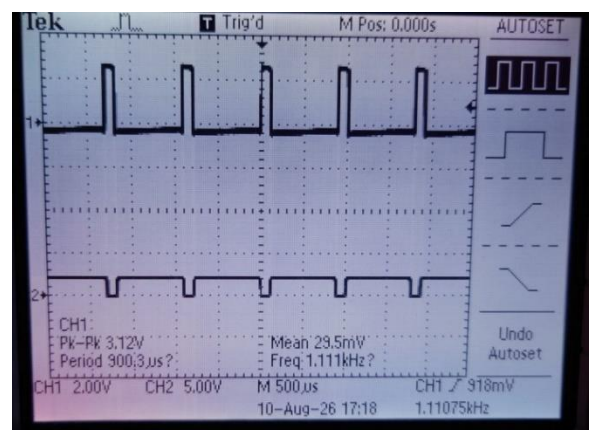


Fig. 19. Fuzz Face waveform response with 'Fuzz Pot' adjusted to near 2kΩ

These measurements provide functional validation of the completed construction. They demonstrate that the circuit was electrically operational and that its adjustable controls influenced its signal response.

Because quantities such as gain, harmonic distortion, and frequency response were not measured systematically, the results are interpreted as practical functional evidence rather than a complete quantitative characterization of the Fuzz Face circuit.

V. Discussion

5.1 Simplicity as a Design Decision

The development of Plane Sight began with the assumption that automatic placement and routing would improve the design process. Several optimization methods were therefore explored, including weighted layout evaluation, randomized component movement, simulated annealing, and grid-based 3D routing. These methods could reduce measurable quantities such as wire length, crossings, or occupied space, but they also introduced additional complexity into the workflow.

During development, it became increasingly clear that free-form circuit construction contains qualities that are difficult to express numerically. A layout that is shorter or more compact is not necessarily easier to solder, easier to understand, or more visually appealing. For this reason, the final version of Plane Sight intentionally places these decisions in the hands of the user.

The removal of automatic routing therefore became a design improvement rather than simply the removal of a feature. The software became more predictable because the 3D result now directly reflects what was drawn in the editor.

5.2 Accessibility and Learning Curve

One of the main objectives of Plane Sight is to allow a beginner to experiment with physical circuit construction without first learning the workflow of conventional PCB design software.

The program reduces the required interaction to familiar actions: selecting a component, placing it on a grid, rotating it, and drawing connections between pins. The 3D model is then generated from these same decisions without requiring the user to define routing algorithms, manufacturing layers, design-rule files, or detailed mechanical models.

This simplicity is especially important for educational and hobby use. A beginner can concentrate on understanding where components are located and how they are electrically connected while gradually developing intuition about physical circuit construction.

Plane Sight therefore does not attempt to hide circuit design behind automation. Instead, it attempts to make the physical consequences of the user's decisions easier to see.

5.3 Limitations

Plane Sight is intended primarily as a layout and visualization tool for relatively small free-form circuits. It does not electrically simulate the circuit or verify that component values, polarities, ratings, or signal behavior are correct.

The physical component models are also intentionally simplified. Their dimensions are sufficient for approximate spatial planning and collision detection but are not intended to replace manufacturer-specific mechanical CAD models.

Collision warnings should similarly be interpreted as guidance rather than a complete mechanical guarantee. Real construction involves wire thickness, lead flexibility, insulation, solder joints, and small manual adjustments that cannot be represented perfectly by the simplified geometric model.

Finally, the workflow relies on the user making reasonable placement and wiring decisions. This is intentional, but it also means that Plane Sight does not guarantee an optimal or even buildable layout automatically.

5.4 Future Development

Future versions of Plane Sight could expand the component library and allow users to define their own packages more easily. More accurate optional component dimensions could also improve the correspondence between the digital model and physical construction while preserving the existing simplified workflow.

Another possible extension would be the import of basic circuit connectivity from external schematic formats. Such a feature could reduce repetitive data entry while still leaving the physical placement and wiring decisions under direct user control.

The central design principle, however, should remain unchanged. Future features should assist the user without replacing the user's spatial judgment. The simplicity of the final workflow is one of the main strengths of Plane Sight and should be preserved as the software develops.

VI. Conclusion

Plane Sight was developed as an accessible tool for translating small electronic circuits into physical free-form constructions. By combining a 2.54 mm grid, simplified component geometry, direct wire drawing, layered 3D representation, and collision warnings, the program allows the user to plan a circuit as a physical object without first learning a conventional PCB-design workflow.

The project originally explored automatic placement and routing through several optimization methods. During development, however, it became clear that numerical measures such as wire length,

compactness, or bend count could not fully represent the qualities that matter in hand-built circuits. Visual clarity, ease of construction, symmetry, and personal preference were often better judged directly by the user. The final system therefore shifted from automatic optimization toward a human-in-the-loop design process.

The Fuzz Face demonstration showed how a circuit could progress from a schematic, to a 2D Plane Sight layout, to a 3D construction model, and finally to a physical free-form circuit. The important result was not the automatic generation of an “optimal” structure, but the ability to preserve the designer’s intended arrangement while providing useful geometric guidance.

The main contribution of Plane Sight is therefore its simplicity. Rather than attempting to replace the designer, the software supports the designer with alignment, visualization, measurement, data storage, and collision awareness. This low-barrier approach is intended to provide beginners, hobbyists, and students with a more approachable way to experiment with the physical side of electronics while still retaining creative control over the final construction.

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