audio.dev CONFERENCE BRISTOL & ONLINE 2026

Model-Based Testing for Audio Devices

How We Test on Hardware Early

Max Bailey & Ray Brien

Introduction



Max Bailey

Software Developer in Test @ Focusrite



Ray Brien

Software Developer in Test @ Focusrite

Previous Talks

Automating Audio Device Testing - A Brief Existential Guide

Joseph Deller & Jake Wignall - ADC22

Focusrite's Hardware Test Platform - Testing Thousands of Little Red Boxes Every Day

Dave Curtis & Adrien Fauconnet - ADC23

Agenda

1. **Test Design** - *Why and how we switched from Script-Based to Model-Based Testing*

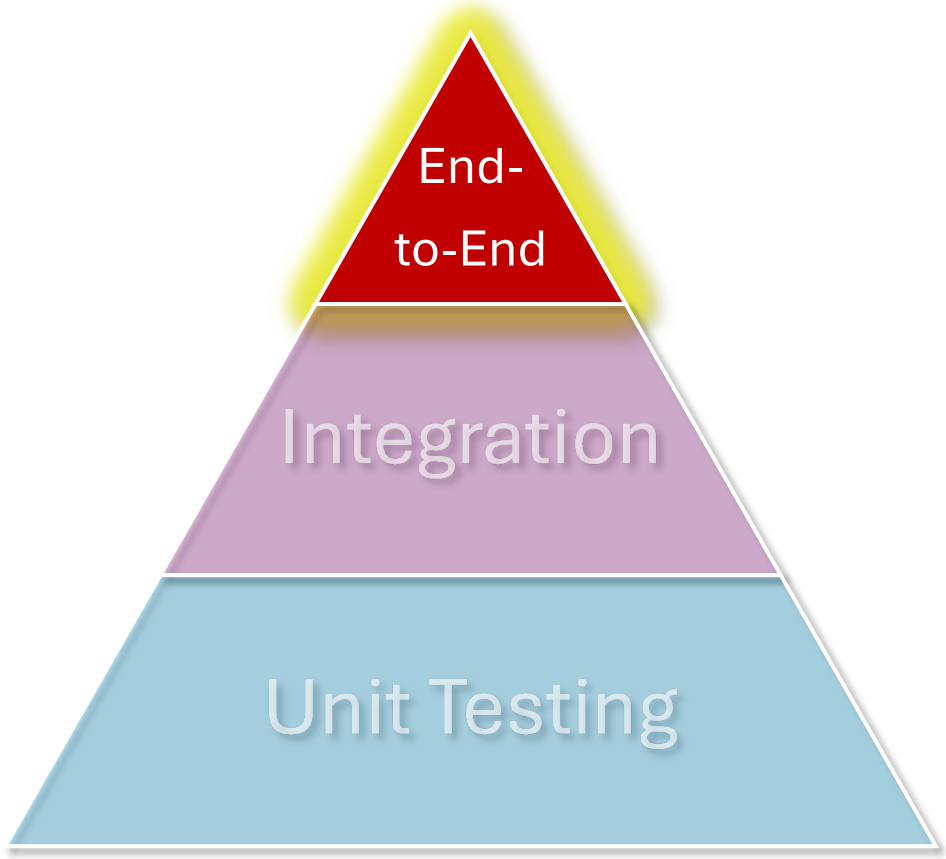
2. **Architecture** - *Putting everything together*

3. **Demo**

4. **Q&A**

Our Focus

- End-to-End
  - Runs on **hardware**
  - Exercising the **complete** system
- Long, **exhaustive** test coverage
- Tests need to be **reliable**, failures need to be **actionable**
- *'Shift-left'* testing for **firmware development**




Focusrite
Scarlett
Focusrite
Focusrite
Focusrite
Focusrite

Focusrite

Exhaustive Firmware Test Library

- Lots of test cases
- 70% **measure audio**

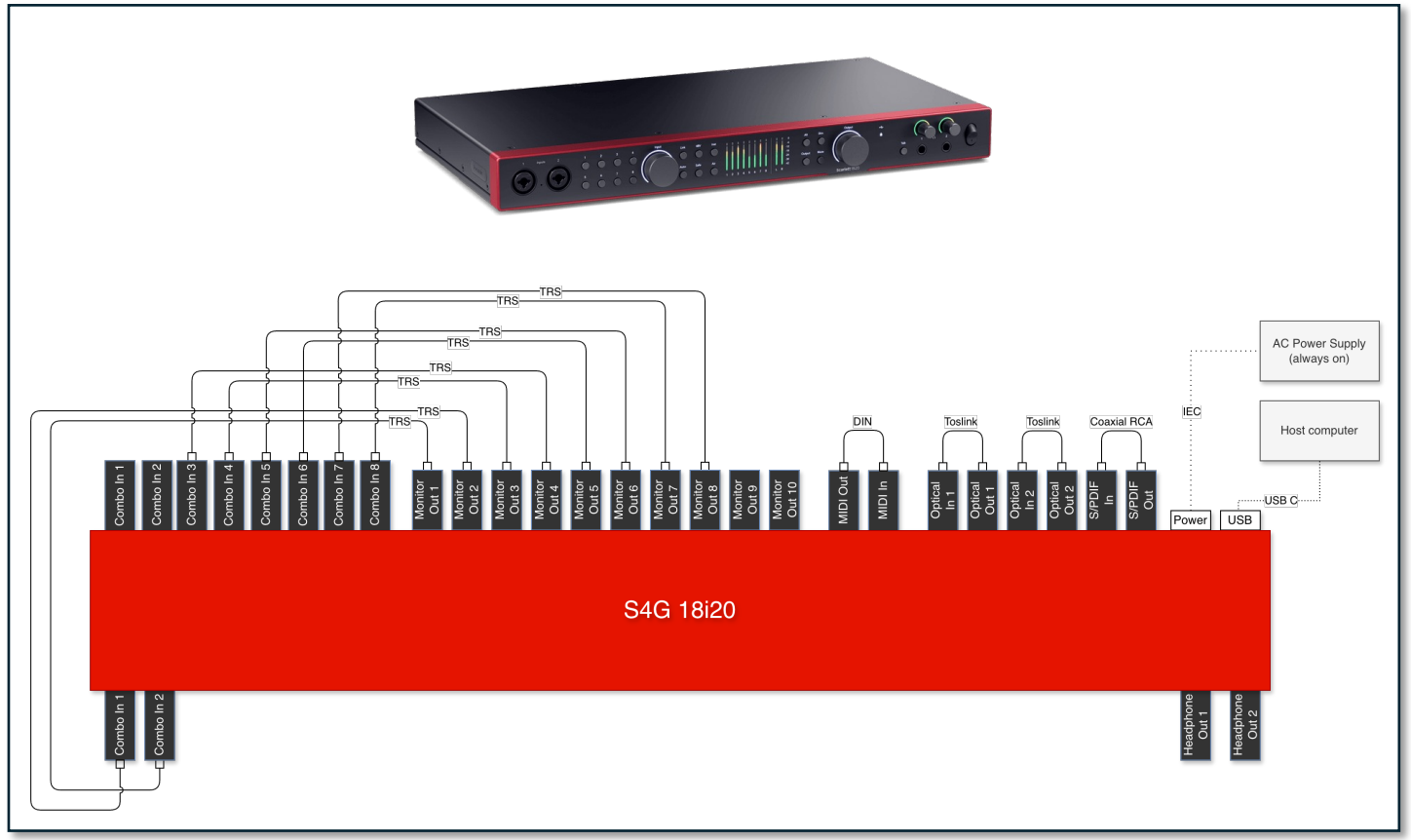
Feature	Description	Time	Audio?
OTA Updates	*Prove the firmware can be updated to and from over USB.*	00:01:47	✗
Factory-Default	*Prove the device can reboot after a factory-default command.*	00:01:00	✗
Easy Start Mode	*Validate the contents of the Easy Start drive.*	00:01:00	✗
MIDI	*Prove MIDI can be sent and received, check data and timing is correct.*	00:01:25	✗
Reset	*Prove the device can reboot with a command.*	00:00:30	✗
Basic Audio	*Validate audio quality across all I/O, at each sample rate. Measure distortion, RMS and RTL.*	00:03:00	✓
Glitch Test	*Prove the device can run for a long time without glitching.*	24:00:00	✓
External Clock Source	*Prove the device can be synced to an external clock source, rather than internal.*	00:03:00	✓
Phantom Power	*Stress toggling phantom power on each preamp. Validate the audio is temporarily muted.*	00:10:00	✓
Preamp Gain	*Stress changing each preamp gain. Validate the correct gain amount is applied to the signal.*	00:10:00	✓
Inst	*Stress toggling input type on each preamp. Validate the audio is temporarily muted.*	00:10:00	✓
Air	*Stress toggling each input's Air. Validate the level changes by the expected amount.*	00:10:00	✓
Routing	*Stress changing routes. Validate the signals appear on the correct channels.*	00:10:00	✓
Mixer	*Stress changing mixes. Validate the signals appear on the correct channels.*	00:10:00	✓
Monitor Control	*Stress changing monitor group features. Validate the levels change accordingly.*	00:10:00	✓

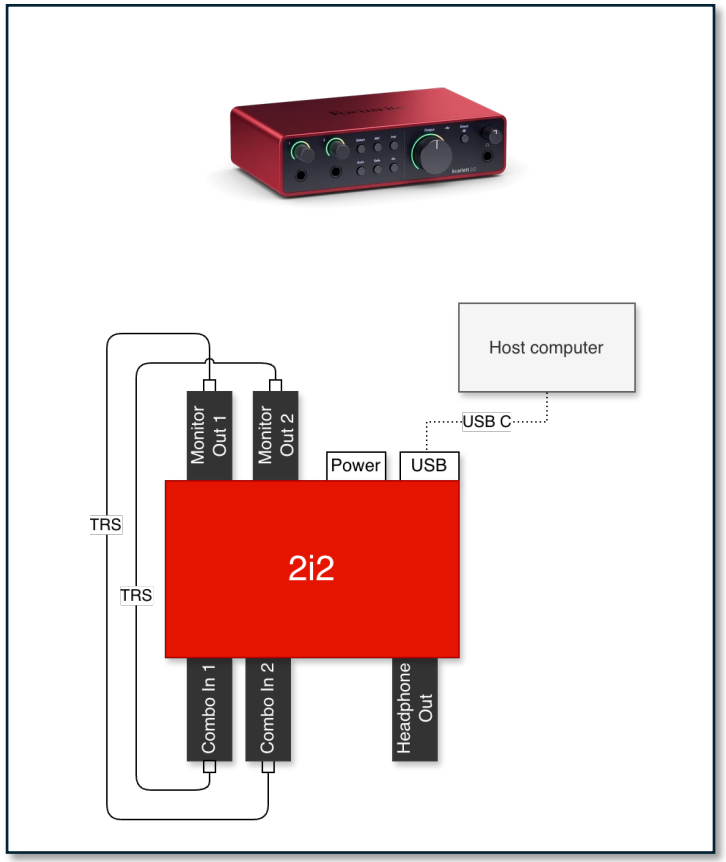
Test Approach

- Black Box
  - Control over USB protocol
    - Like **Focusrite Control 2**
  - Running ‘release’ firmware builds
    - Testing the **release candidate**
    - Building release confidence



Setup Diagrams





ISA C8X

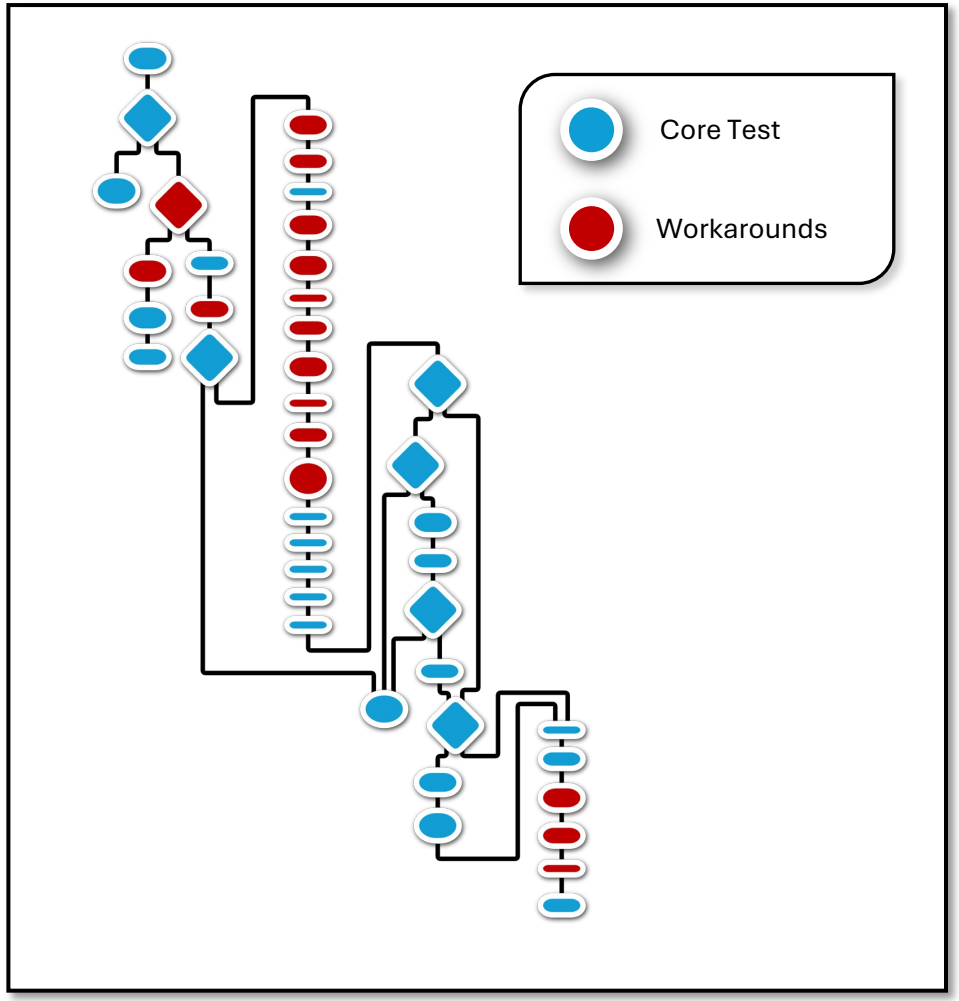


Could We Re-Use Our Tests?

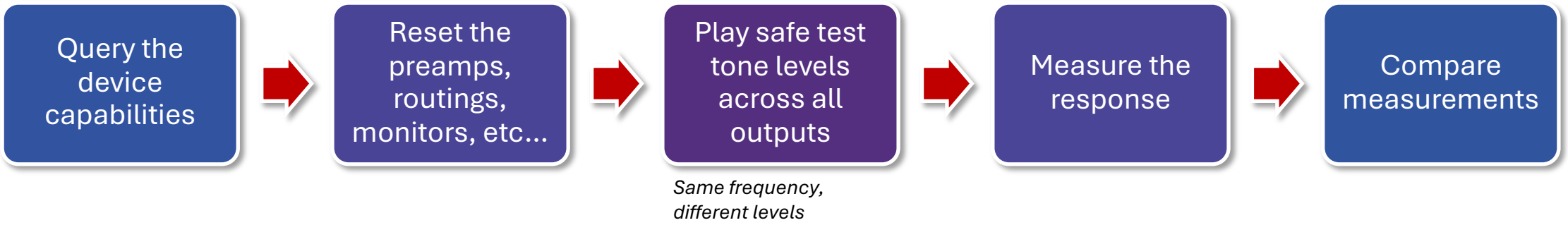
Basic Audio - Audit

- **3,300** lines of code
- **38%** ‘device-specific’ code
  - In-line **workarounds**
- **17** ‘magic numbers’
  - Expected measurements
  - Tolerances
  - Channel indexes

Hard to maintain!



Basic Audio Test Flow



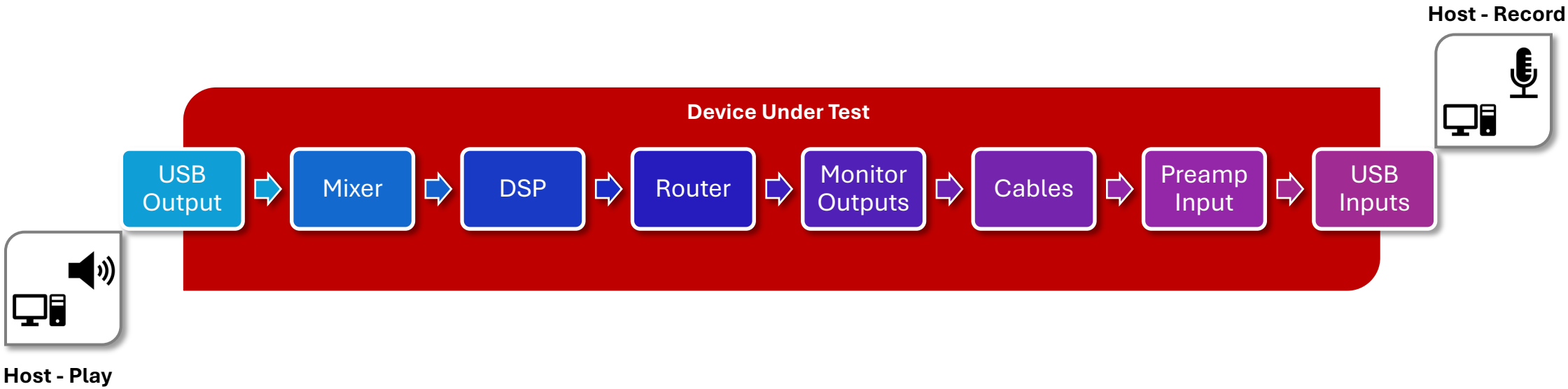
What are the device capabilities?

How to reset the preamps, etc?

What are **safe** test tone *levels*?

What are **expected input** *levels*?

Audio Interfaces



Given the current state, what signal response should I observe?

Test Requirements

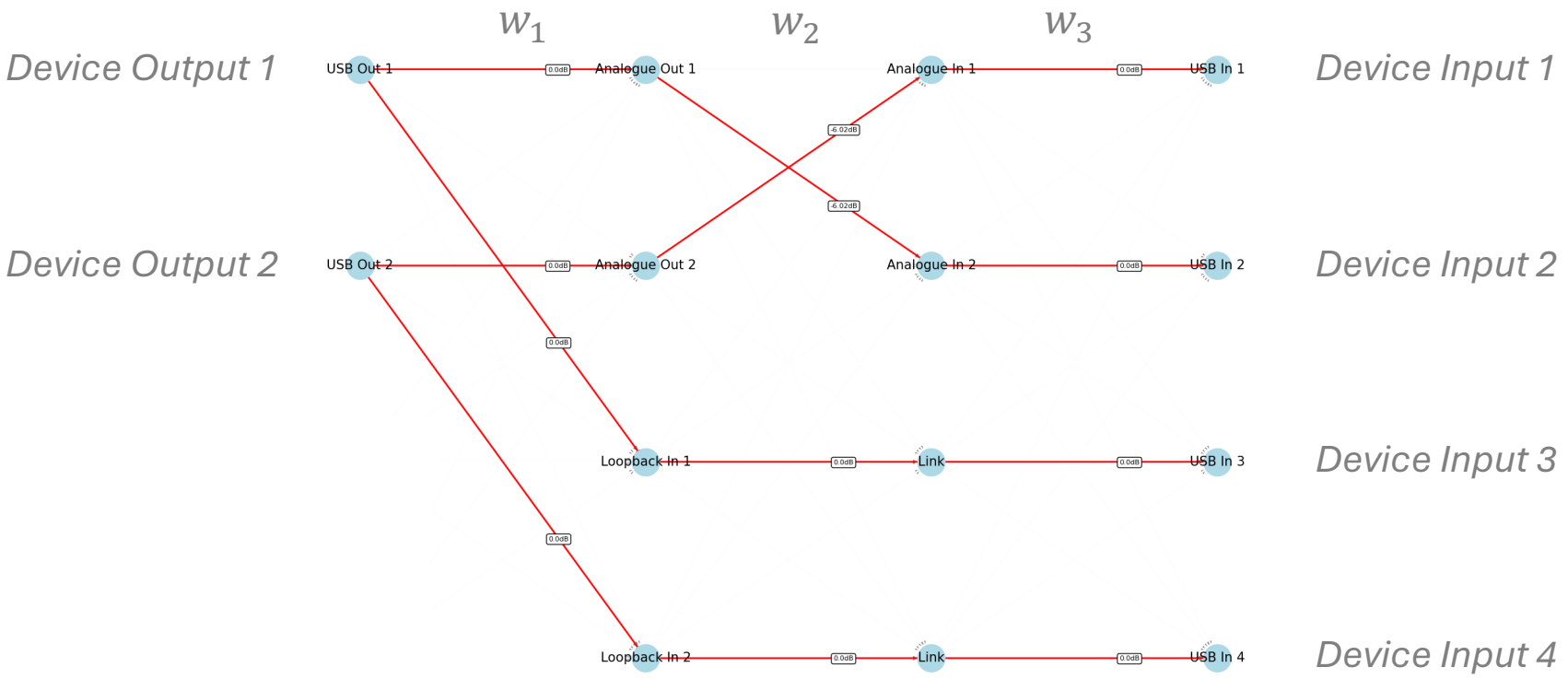
***What** can it do?*

***How** does it do it?*

What's the ***response?***



Network Model V1



Scarlett 2i2 4th Gen

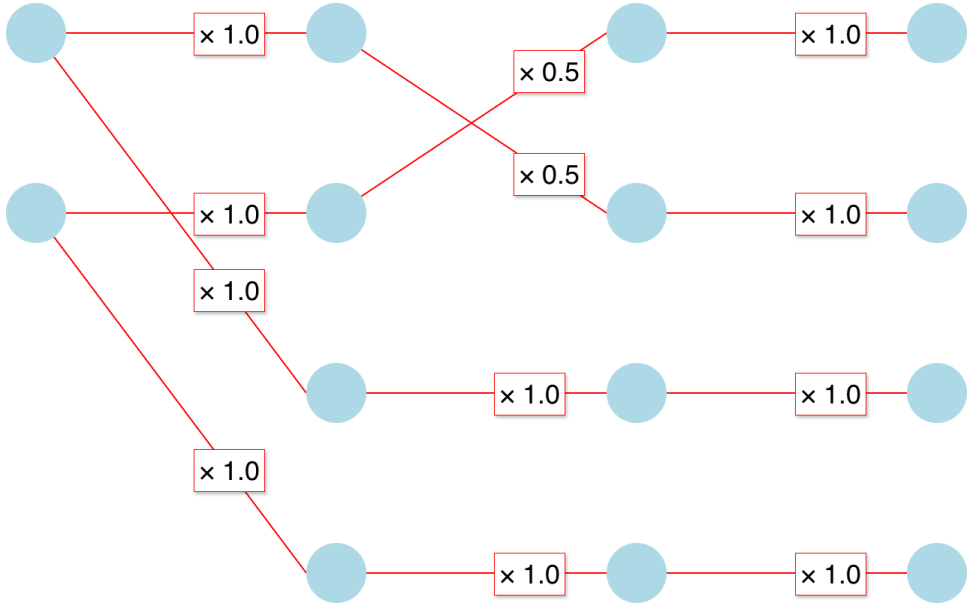
Signals propagate from left to right

Only weights greater than 0.0 shown

Simulating the Model

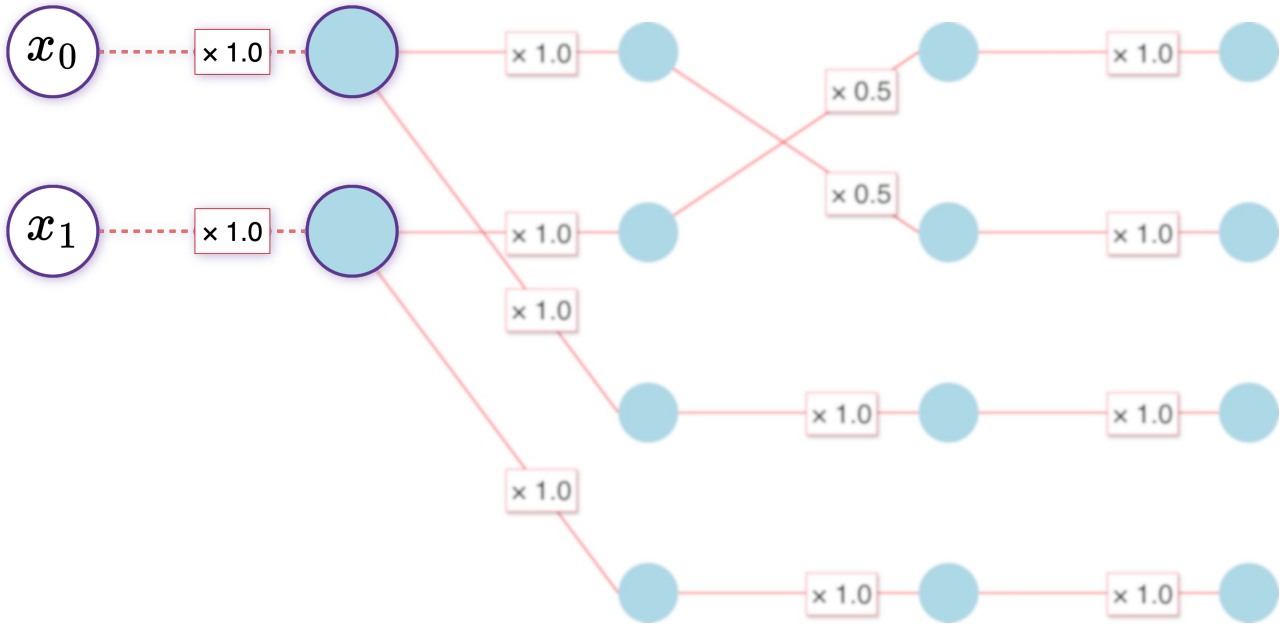
- Directionality
  - Feed-Forward networks are made of **adjacent layers**
  - **Sequential** matrix multiplication
- We’re modelling **signal levels** only
- Between each layer is a **vector of scalars**
  - 0.0 = mute
  - 1.0 = unity gain
  - 0.5 ~= -6dB

Simulating the Model



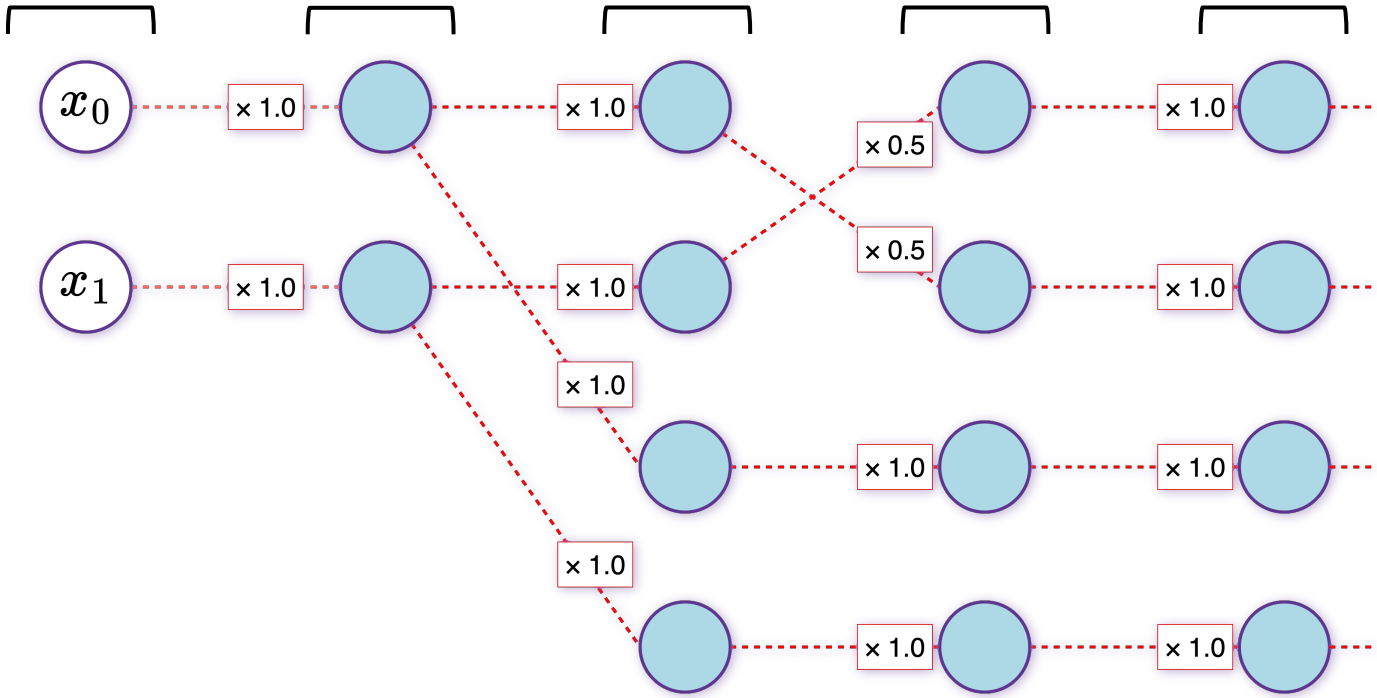
Simulating the Model

1. **Prepend** the network with input signal layer



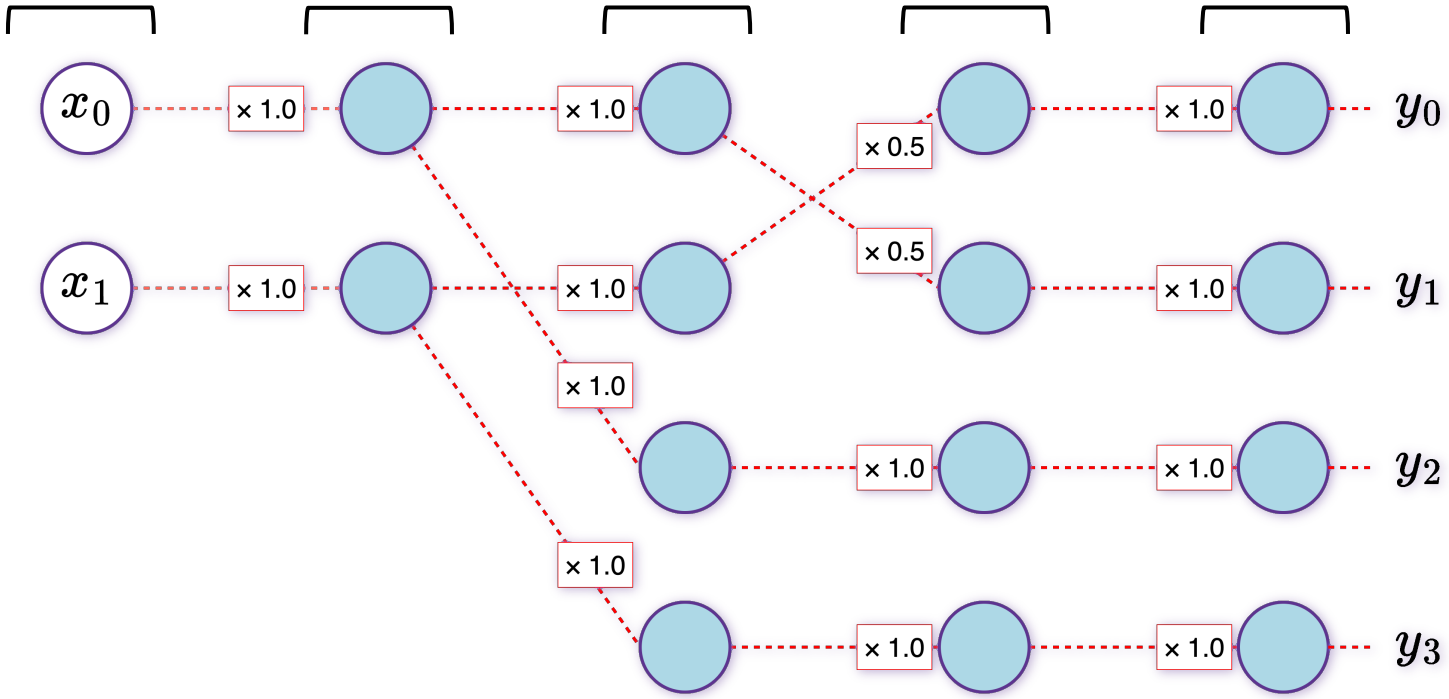
Simulating the Model

1. **Prepend** the network with input signal layer
2. Successively multiply each layer with **matrix multiplication**
   - Signal attenuation is a **linear scalar**, not decibels
   - Signals **accumulate** across connected paths and layers



Simulating the Model

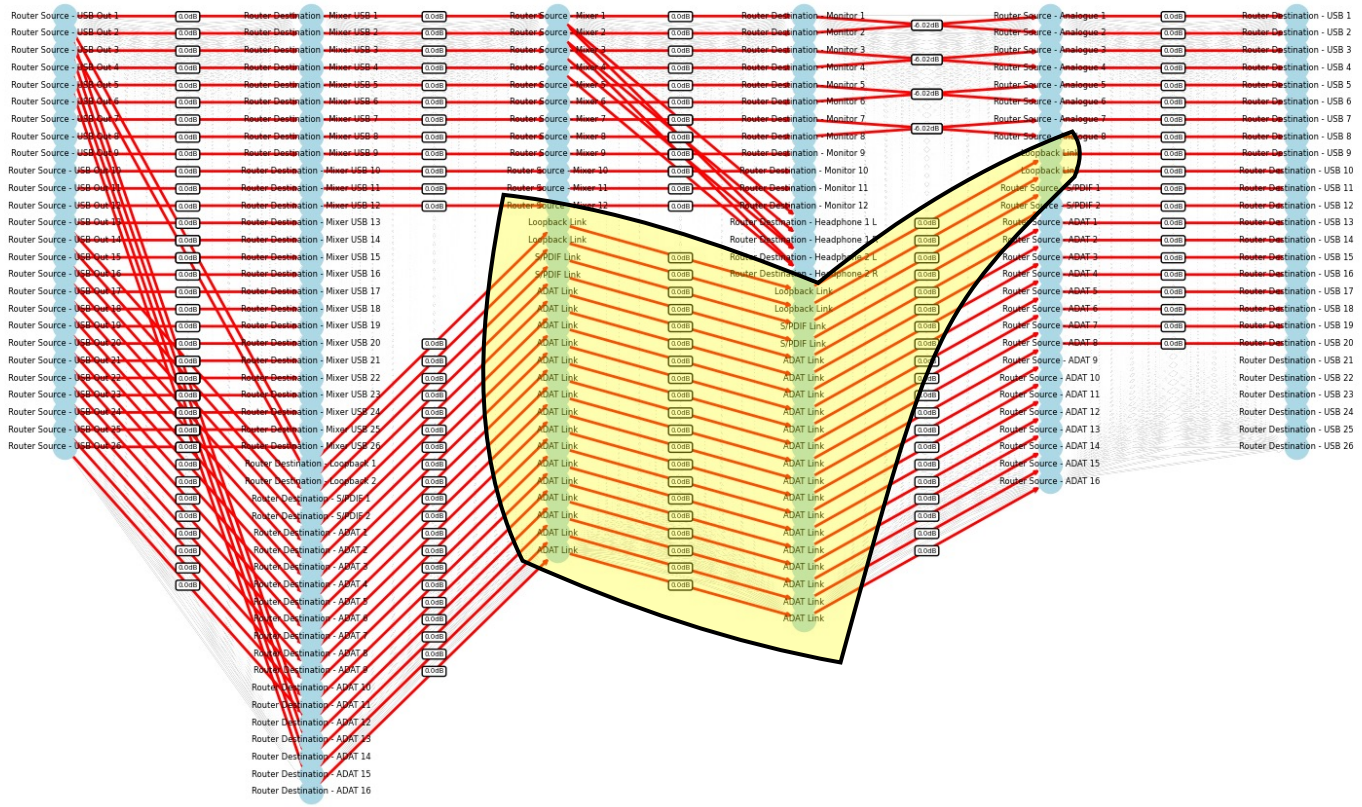
1. **Prepend** the network with input signal layer
2. Successively multiply each layer with **matrix multiplication**
    - Signal attenuation is a **linear scalar**, not decibels
    - Signals **accumulate** across connected paths and layers
- The final matrix multiplication at the last ‘output’ layer gives us the output values
    - Convert back to dB



Network Model Benefits

- ✓ Default state of the DUT is simulated deterministically
- ✓ Graphical debugging
  - ✓ Quickly understand expected device behaviour
- ✓ Reduced complexity in the test script
  - ✓ *Basic Audio* in-line test script was **3,300 lines**
  - ✓ After adding the model, it is **200 lines**
    - ✓ No magic numbers and no in-line device-specific workarounds

Larger Model



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‘Workaround’ nodes highlighted in yellow

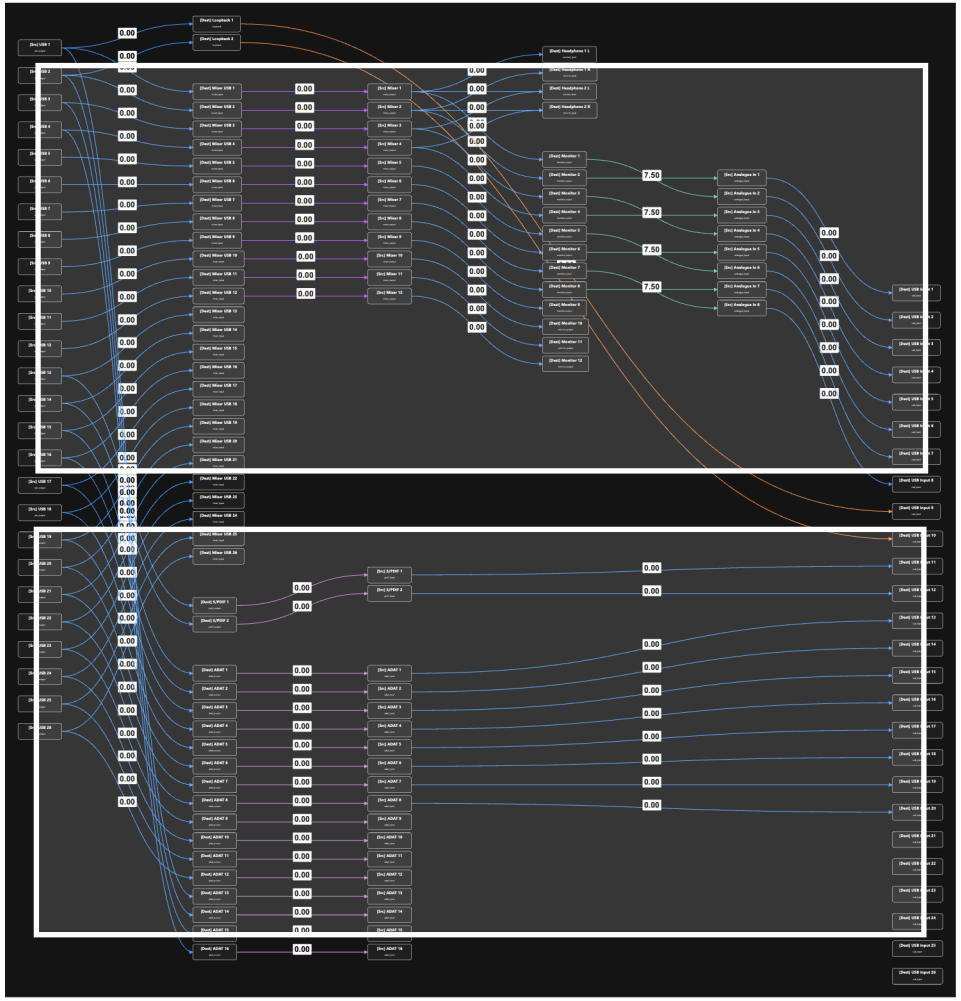
42 ‘workaround’ nodes

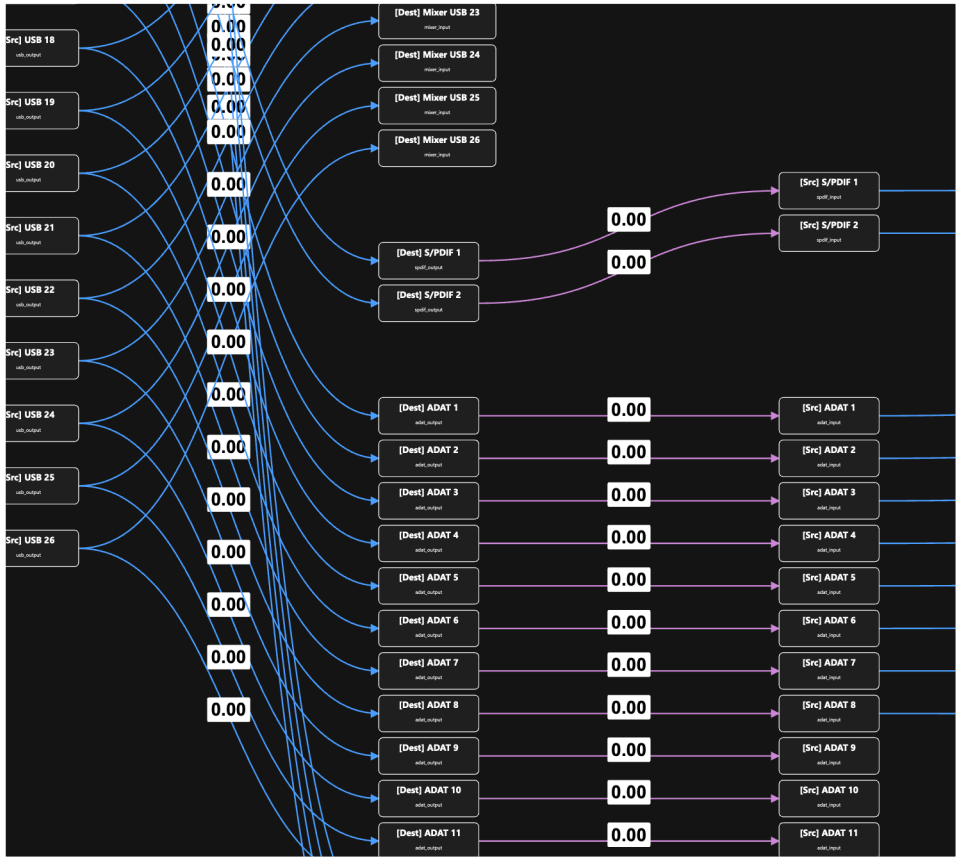
134 meaningful nodes

Feed Forward Network Limitations

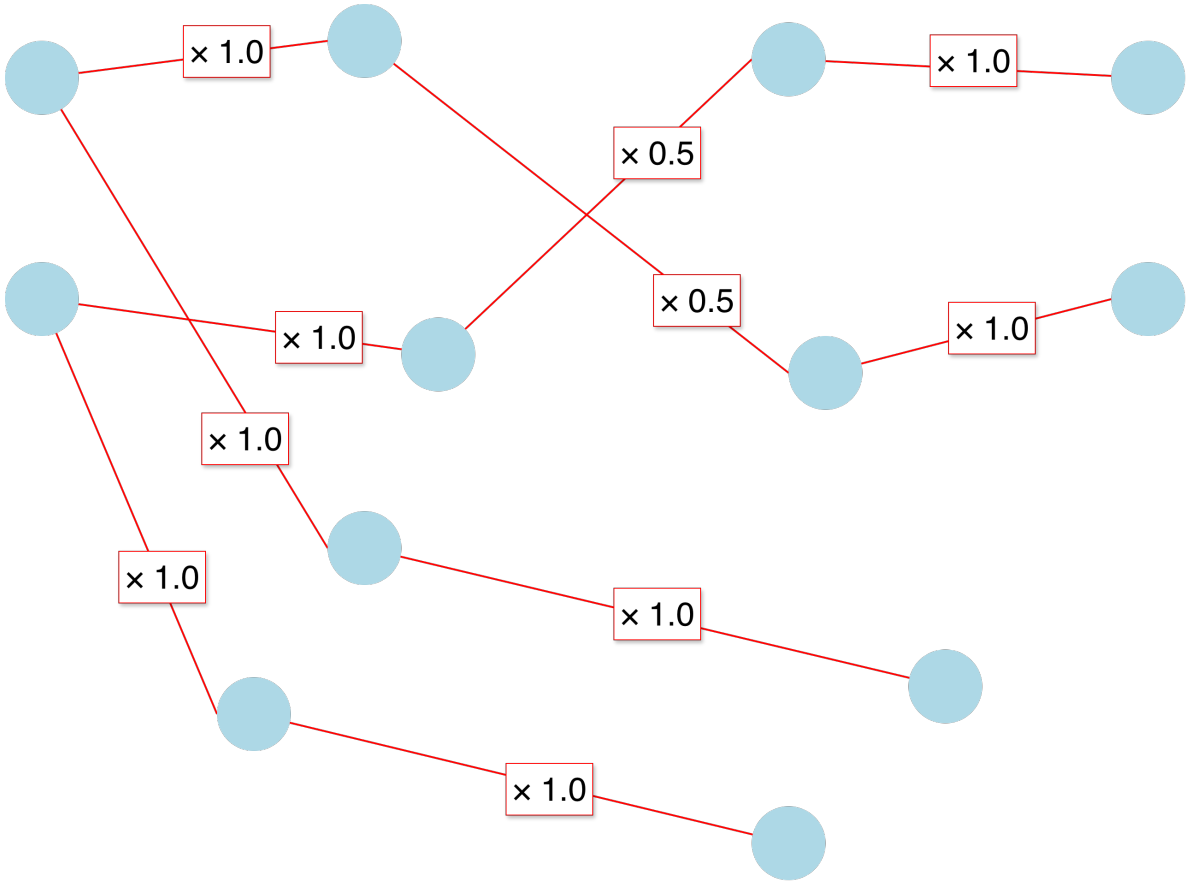
- **Layers** impose limits on configurations
  - Only **adjacent** nodes can be connected
  - ‘Workaround’ nodes are needed to propagate signals through unnecessary layers
- As complexity grows, the number of ‘workaround’ nodes becomes unmaintainable

Graph Model V2



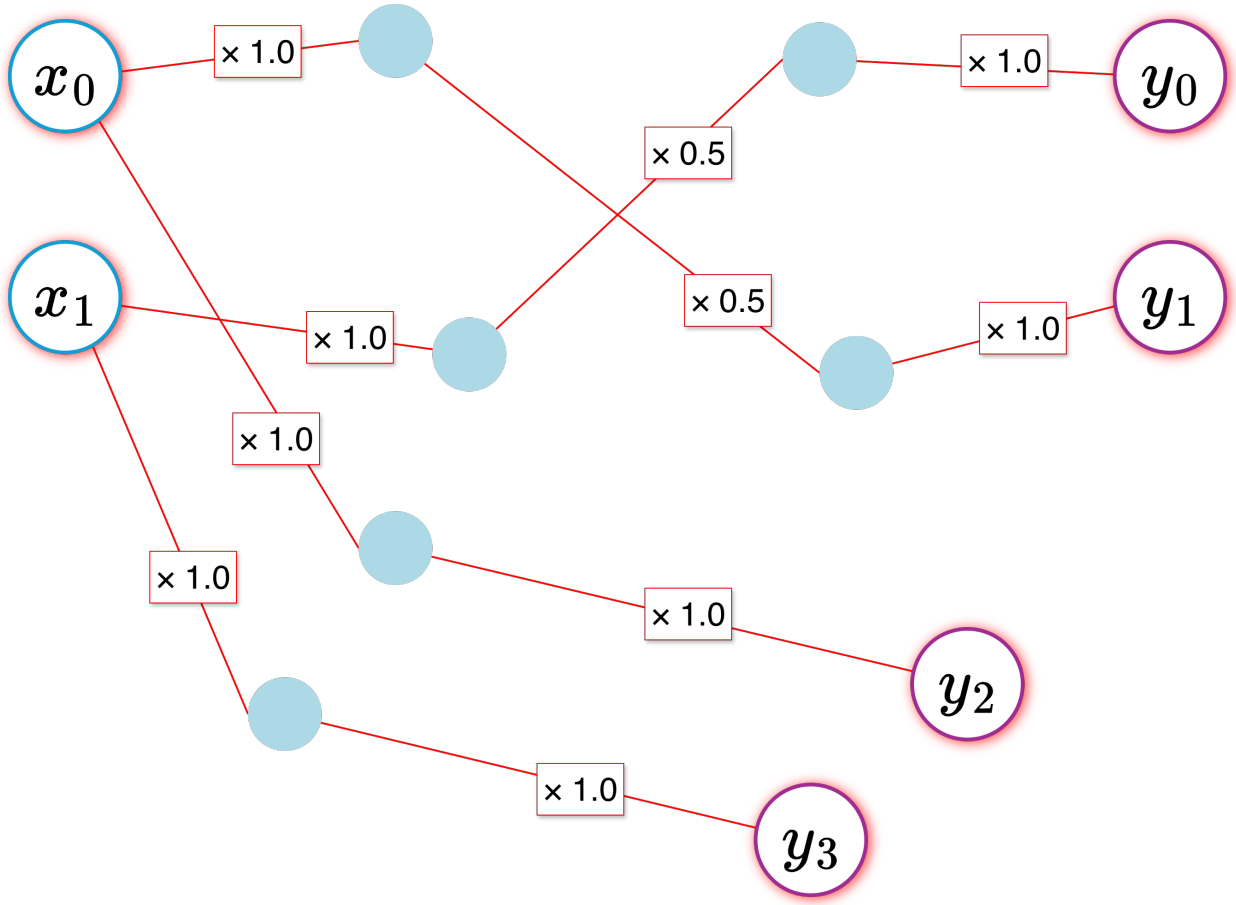


Processing the Network (V2)



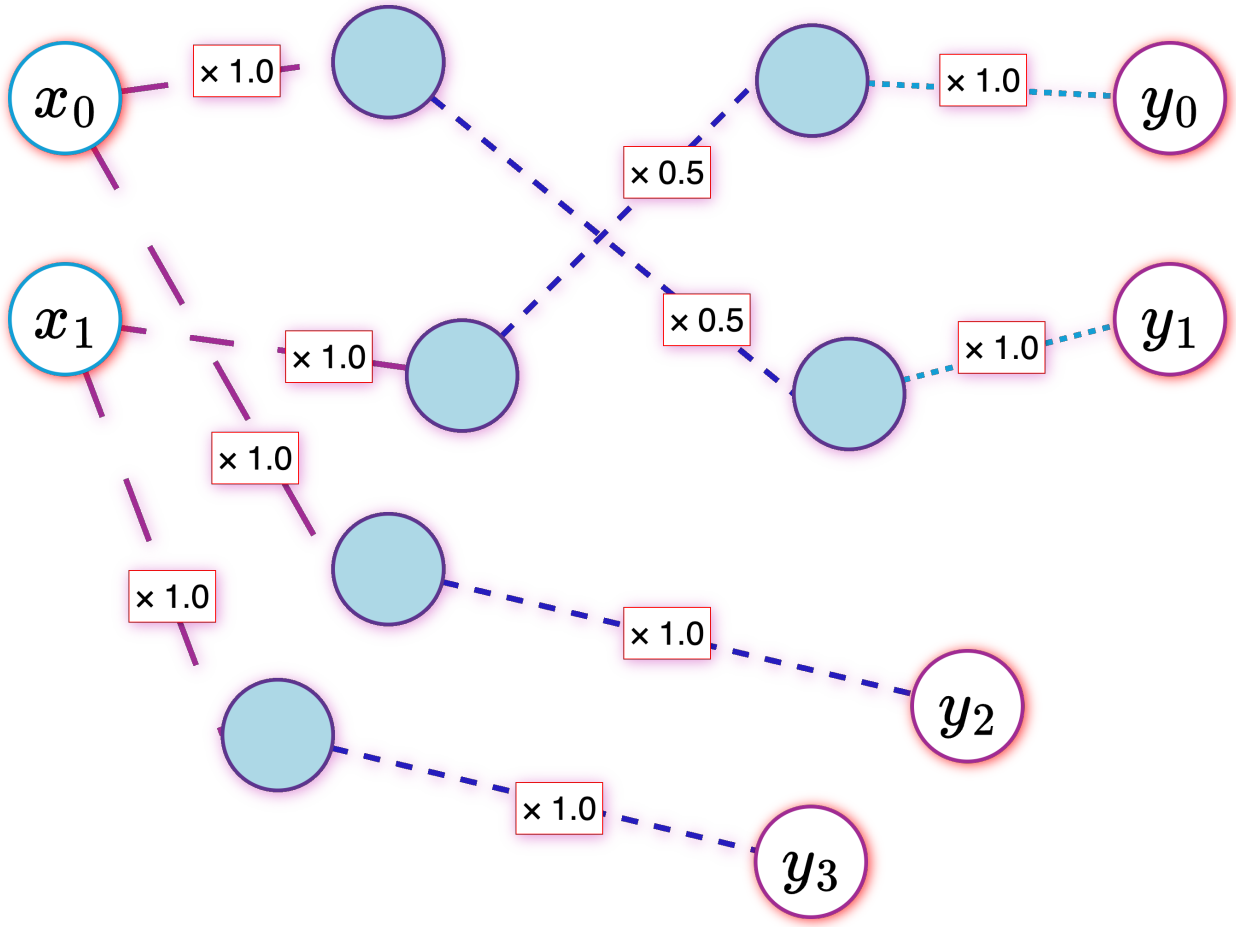
Processing the Network (V2)

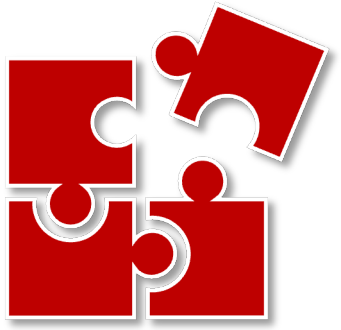
1. Select the **input and output** nodes
   - Convert the input levels to **magnitudes**
   - Place inputs at starting nodes x



Processing the Network (V2)

1. Select the **input and output** nodes
   - Convert the input levels to **magnitudes**
   - Place inputs at starting nodes x
2. Iteratively propagate signals through the network
   1. Scan all nodes, propagating each new signal contribution to the downstream node(s), multiplied by the gain scalar
      - If **multiple paths** lead to the **same node**, their contributions are summed together
   2. Repeat until propagation stops, or iteration limit is reached
3. Values at y now represent the response
   - Convert back to dB



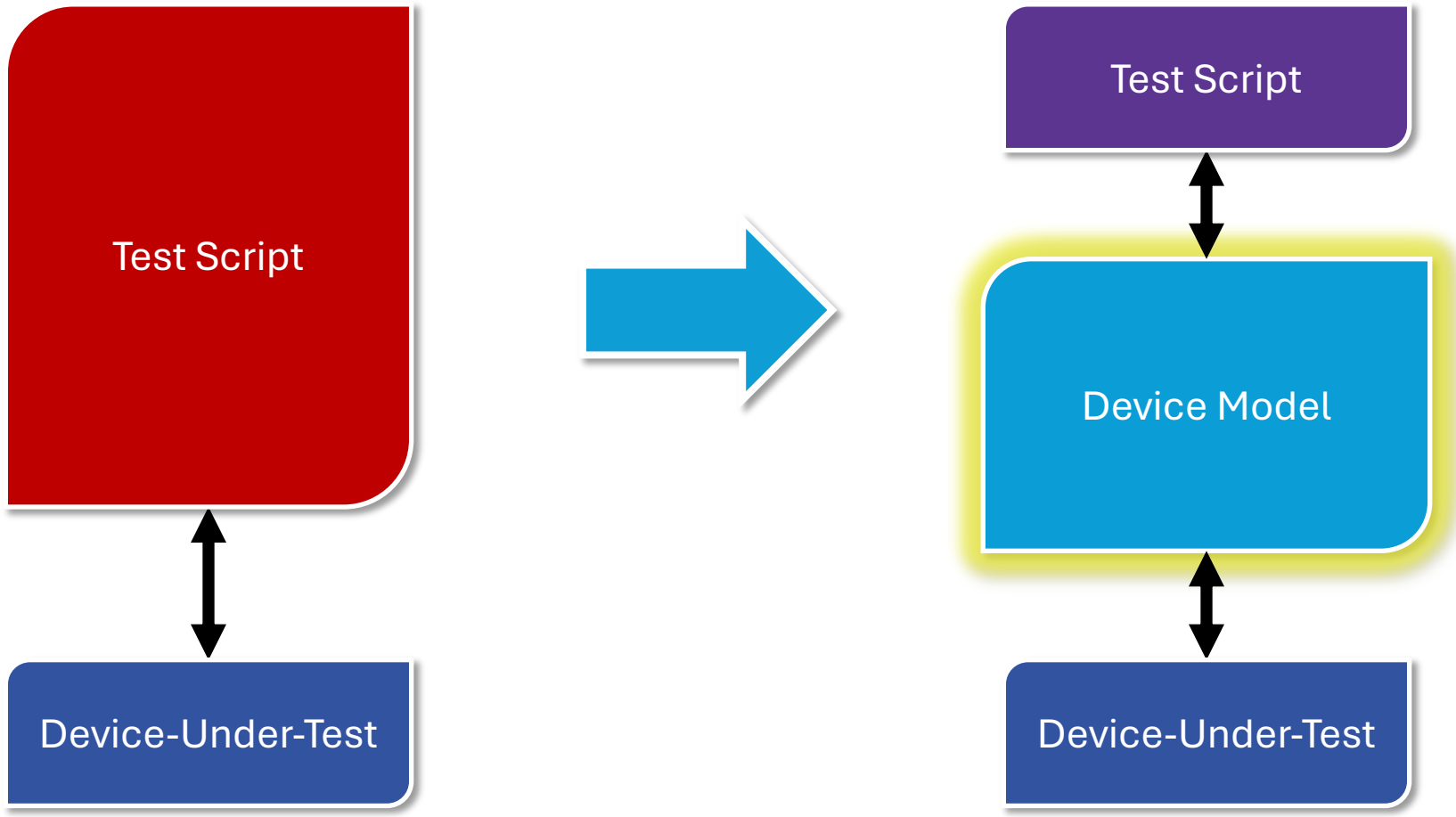


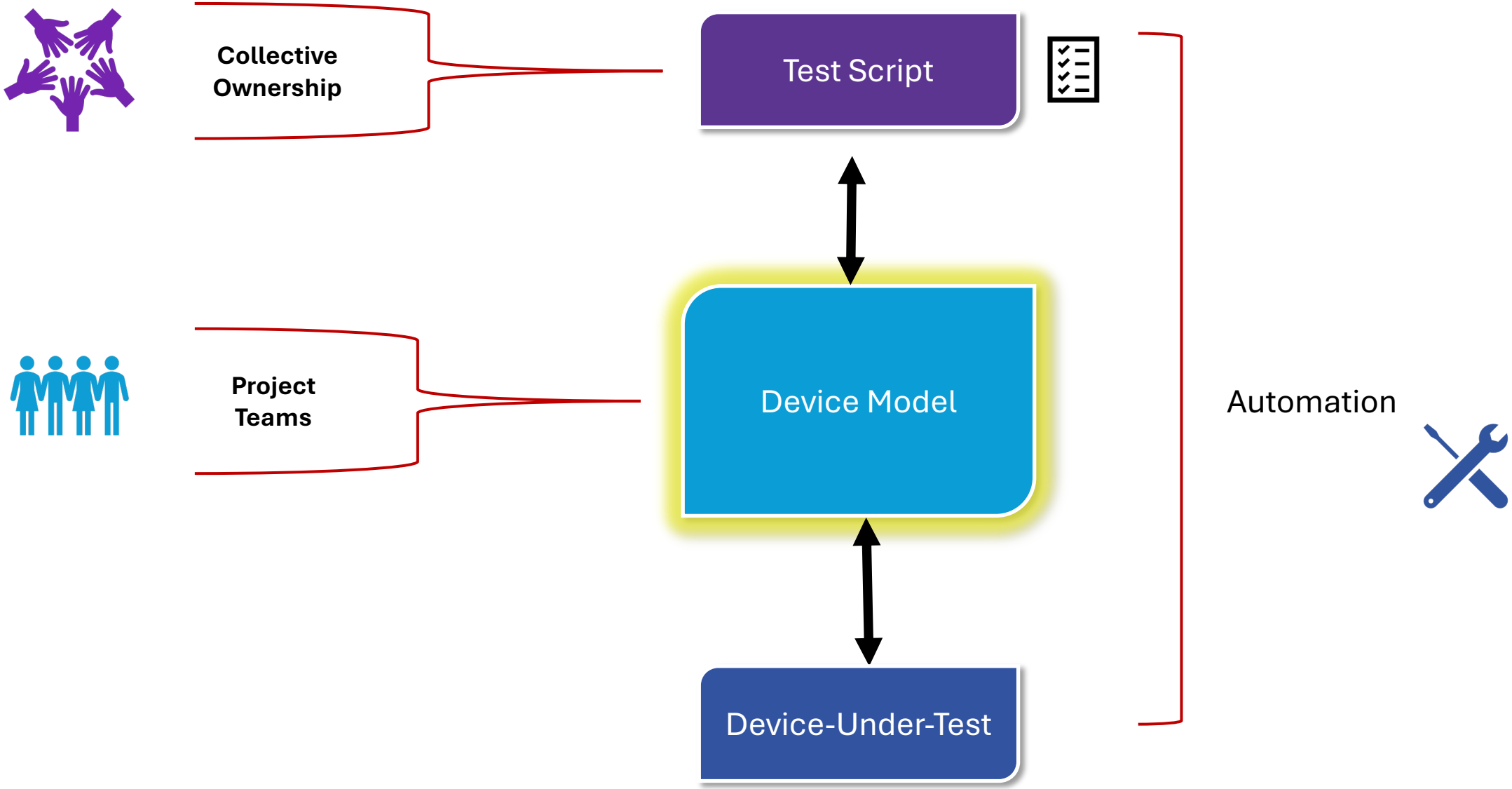
Model-Test Interface

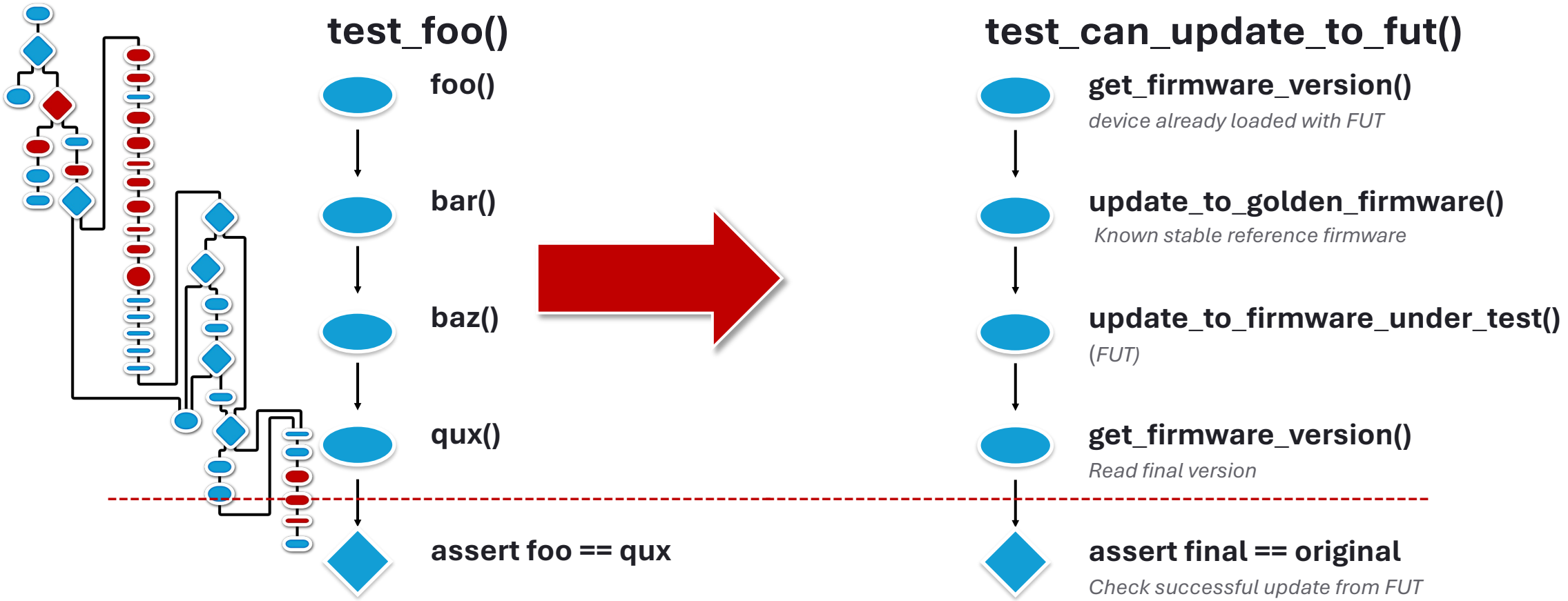
Architecture

Focusrite

Abstraction Layer




Collective Ownership
Project Teams
Test Script
Device Model
Device-Under-Test
Automation


test_foo()
foo()
bar()
baz()
qux()
assert foo == qux
test_can_update_to_fut()
get_firmware_version()
device already loaded with FUT
update_to_golden_firmware()
Known stable reference firmware
update_to_firmware_under_test()
(FUT)
get_firmware_version()
Read final version
assert final == original
Check successful update from FUT

Model-Test Contract

Test

- test_foo():
  - bar()
  - assert bar()

Framework: Abstract base class

```
Class Baz(ABC):
    def bar(self, *args, **kwargs):
        ...
Def
```

Project model

```
Class MyDevice(Bar):
    def bar(self, *args, **kwargs):
        ...
```

Easy model creation

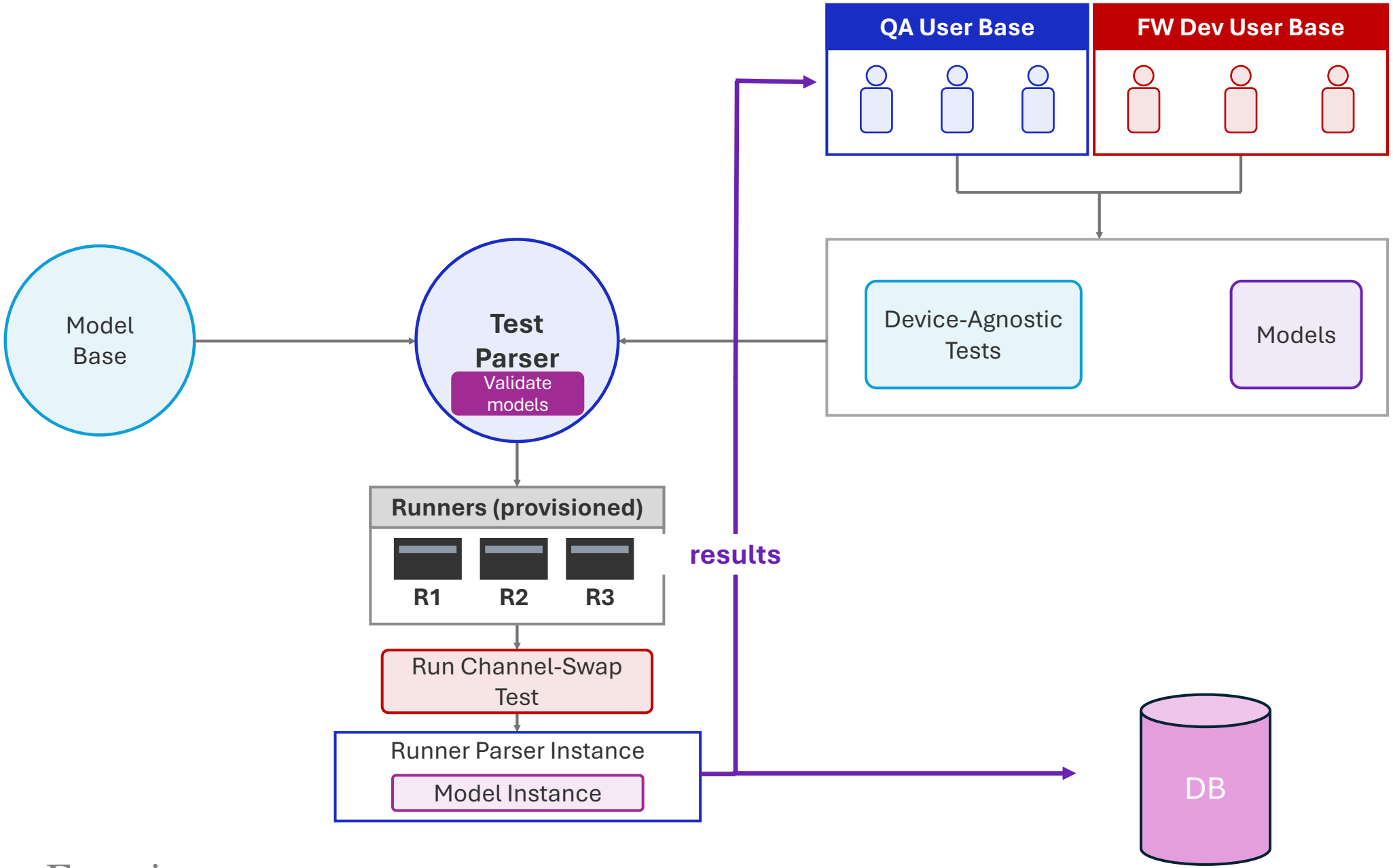


Framework: Abstract base class

```
Class Baz(ABC):
    def bar(self, *args, **kwargs):
        ...
```

Project model

```
Class MyDevice(Bar):
    def bar(self, *args, **kwargs):
        self.do_x(threshold=MY_THRESHOLD)
```


QA User Base
FW Dev User Base
Model Base
Test Parser
Validate models
Device-Agnostic Tests
Models
Runners (provisioned)
R1
R2
R3
results
Run Channel-Swap Test
Runner Parser Instance
Model Instance
DB

Demo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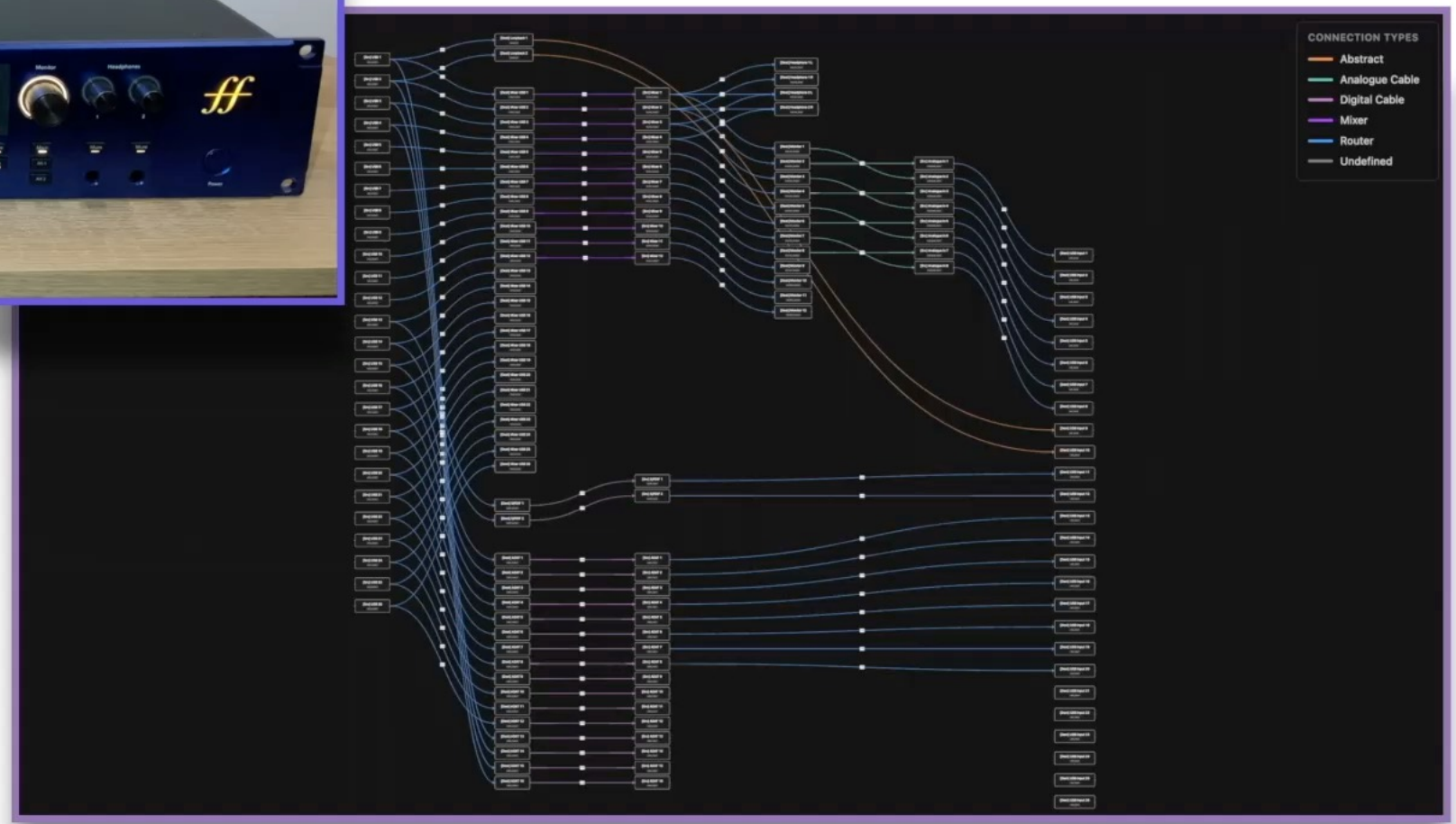
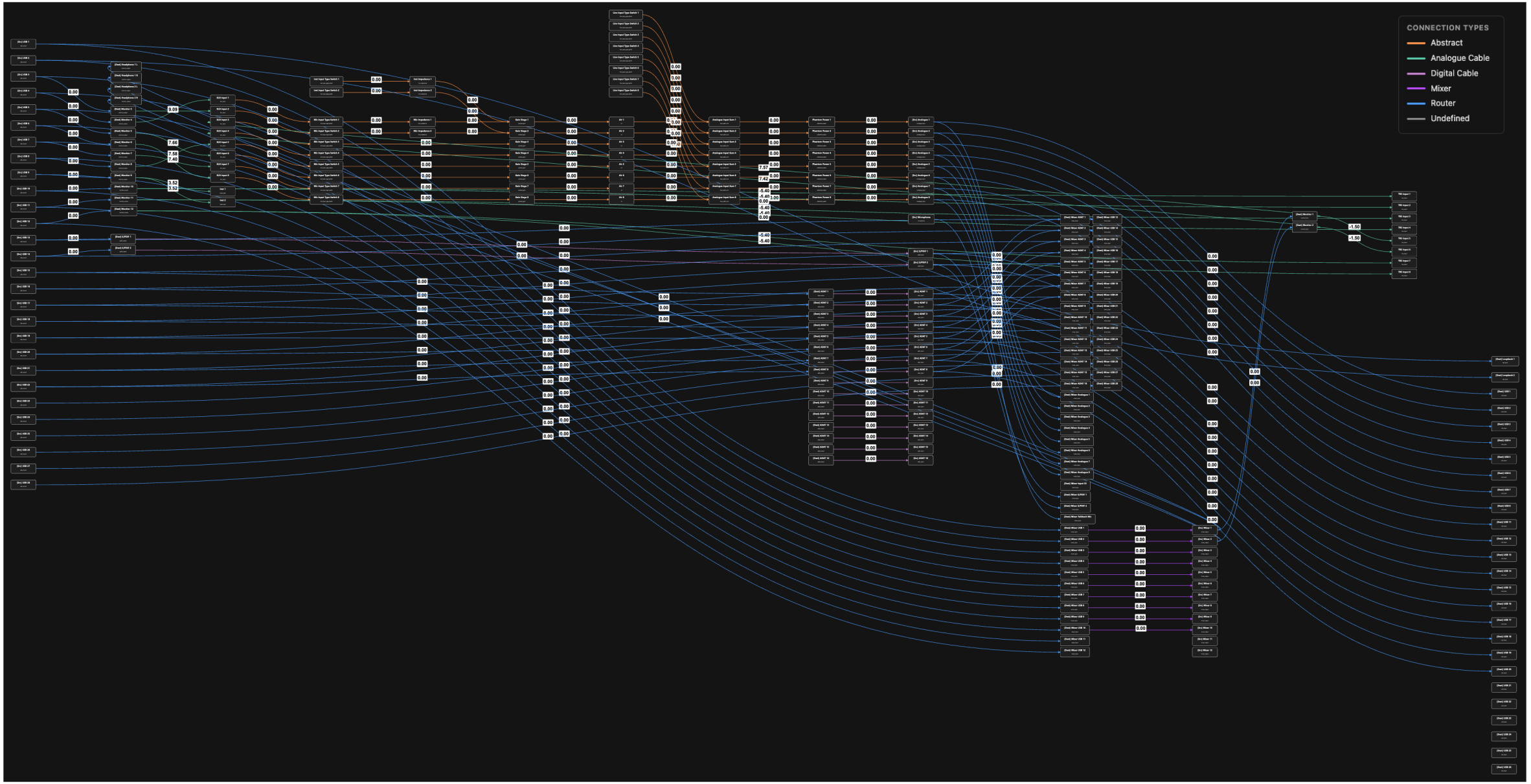

CONNECTION TYPES
Abstract
Analogue Cable
Digital Cable
Mixer
Router
Undefined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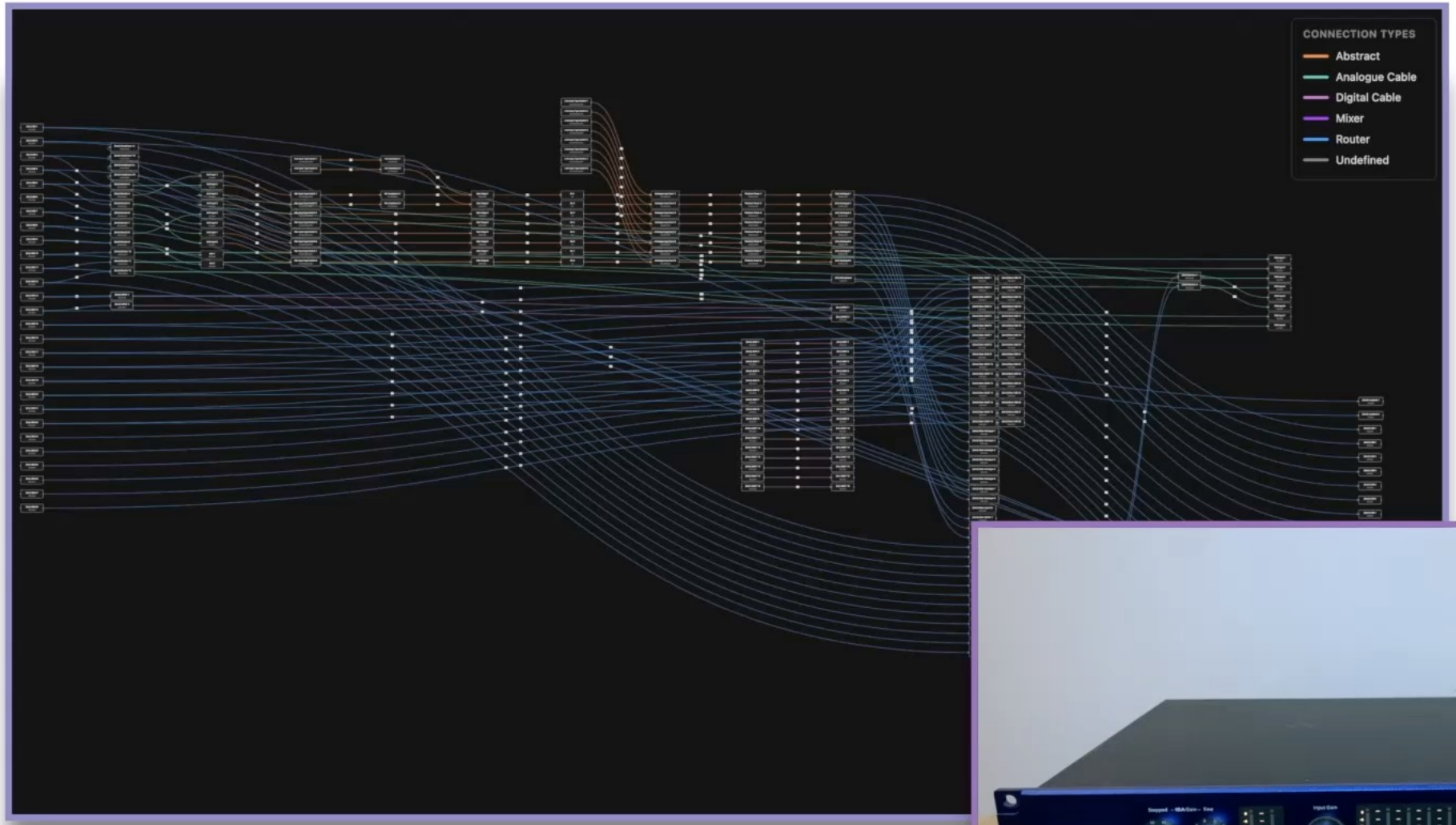
CONNECTION TYPES
Abstract
Analogue Cable
Digital Cable
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Router
Undefined


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Focusrite
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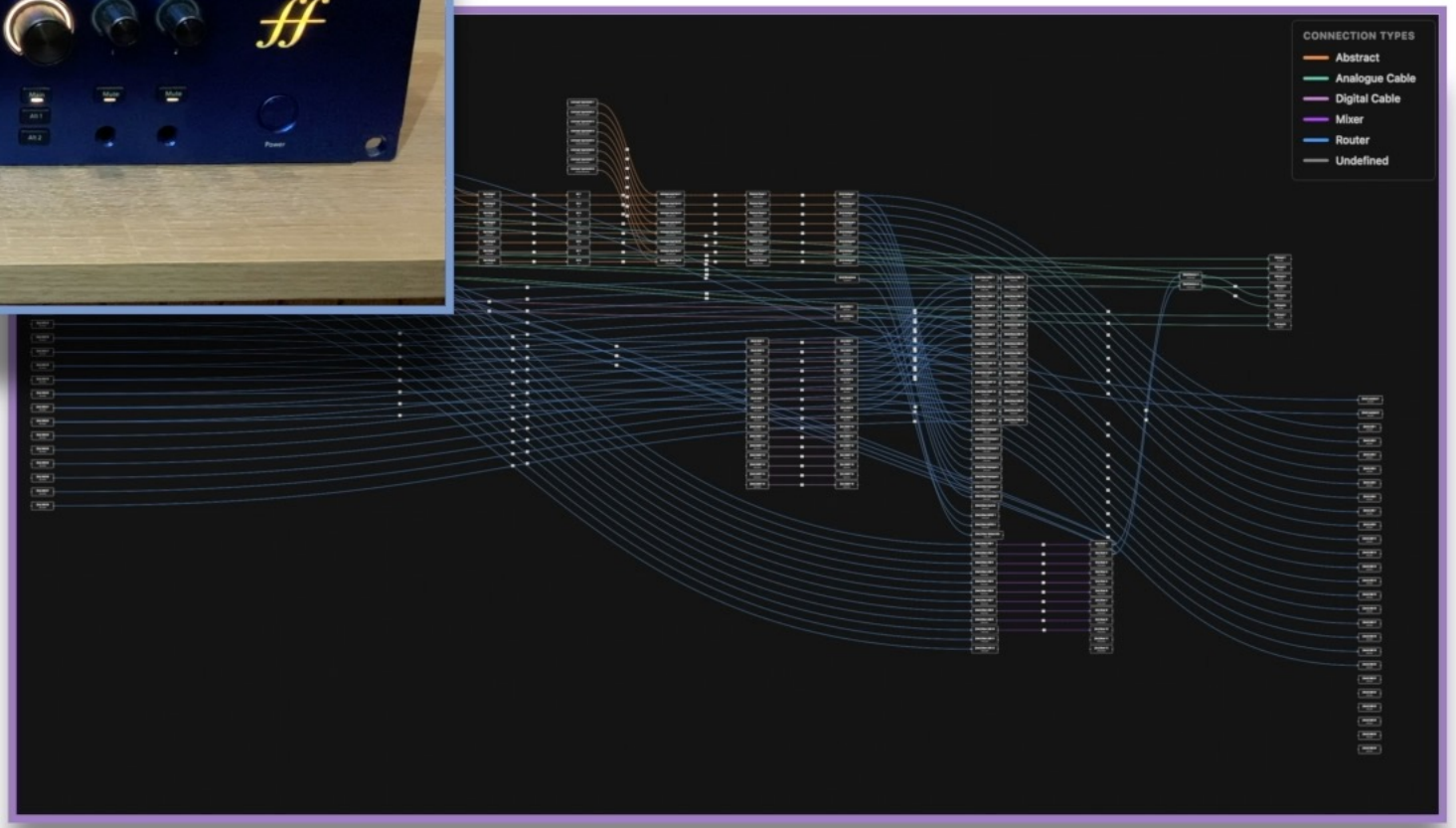
ISA C8X
Focusrite
Stepped
ISA Gain
Fine
Input Gain
Monitor
Headphones
ff
ISA1
ISA2
Power


CONNECTION TYPES
Abstract
Analogue Cable
Digital Cable
Mixer
Router
Undefined

```
E           AssertionError: RMS level mismatch (dB)
E             Channel 1: measured=-116.84 dB, expected=-13.13 dB
E           assert [-116.84, -20..., -13.63, ...] == approx([-13.1...-120.0 ± 1.0])
E
E             comparison failed. Mismatched elements: 1 / 26:
E             Max absolute difference: 103.7123313333797
E             Max relative difference: 0.8876440545479262
E             Index | Obtained | Expected
E             0     | -116.84  | -13.127668666620307 ± 1.0
```

Closing Remarks

- What we have:
  - Simulation model
  - Re-usable tests
  - Infrastructure tooling

- Future improvements:
  - Frequency domain modelling
  - Test case parameterisation
    - Automatic test case generation

Thank you

Q&A

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