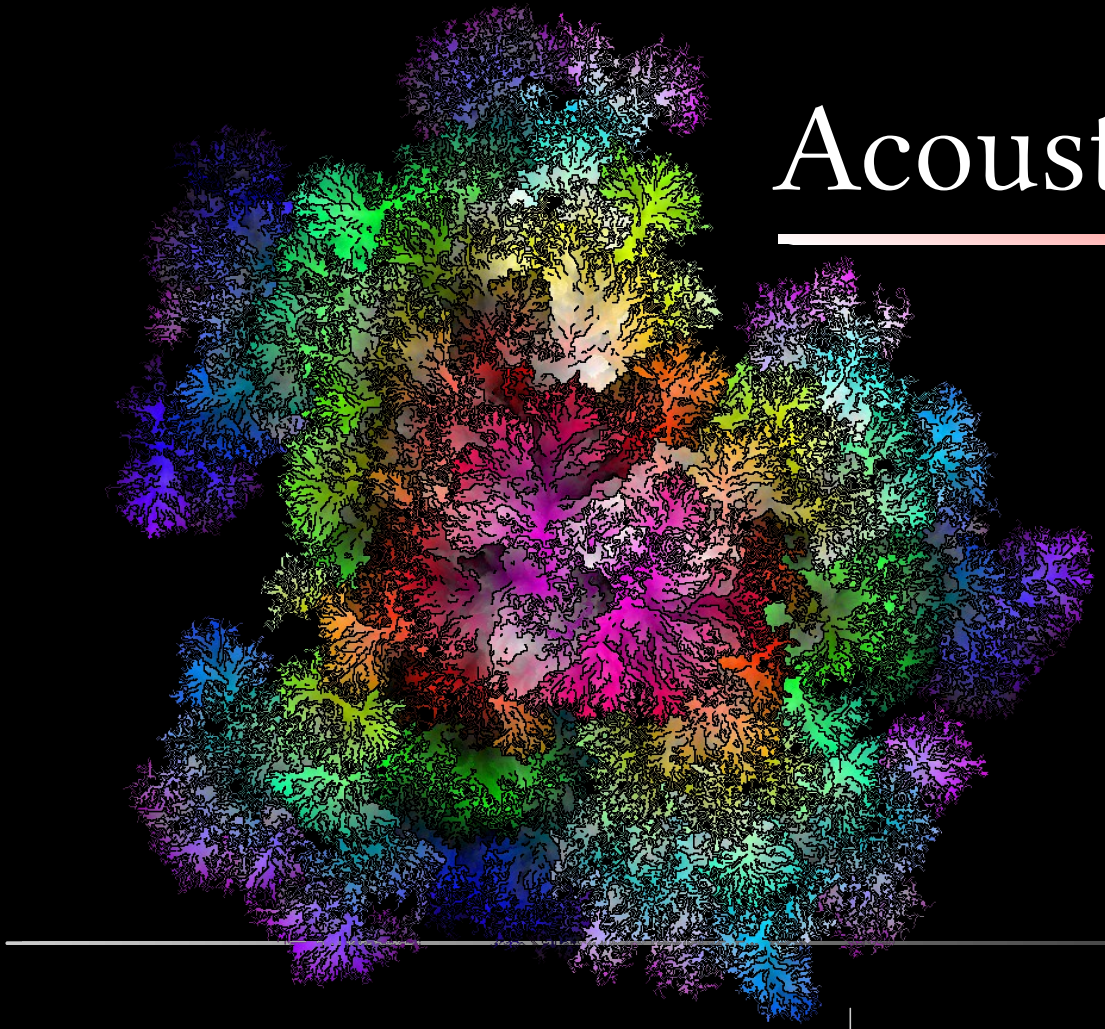


Acoustic Fingerprinting

for predictive maintenance

BELLWETHER, LLC

August 20, 2025 Washington, DC

Situation

Machines are speaking to us.

We must listen.

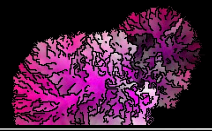
Problem

Machine Malfunction

→ Unexpected Downtime

→ Lost Revenue

Solution

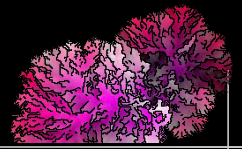


Detect Malfunction

→ Early Intervention

→ Minimize Revenue Loss

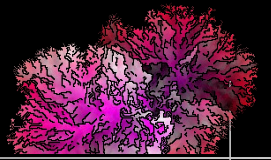
First Market: Transformers



$3B in yearly damage to substations

30% of transformer failures are unrepairable

Electric Transformers



Transformers are difficult to replace

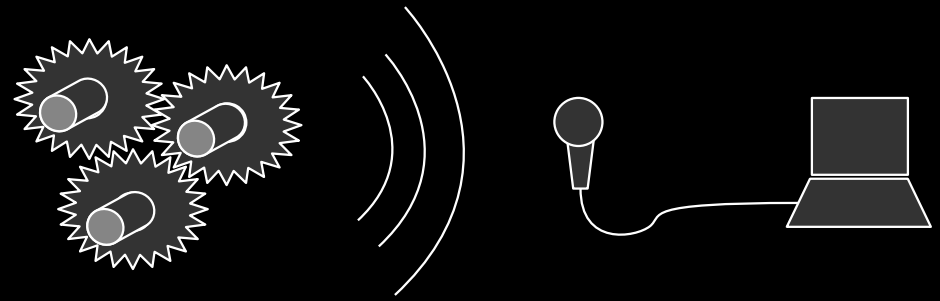
Utilities want 3-5 years' warning

We give exactly that

Solution

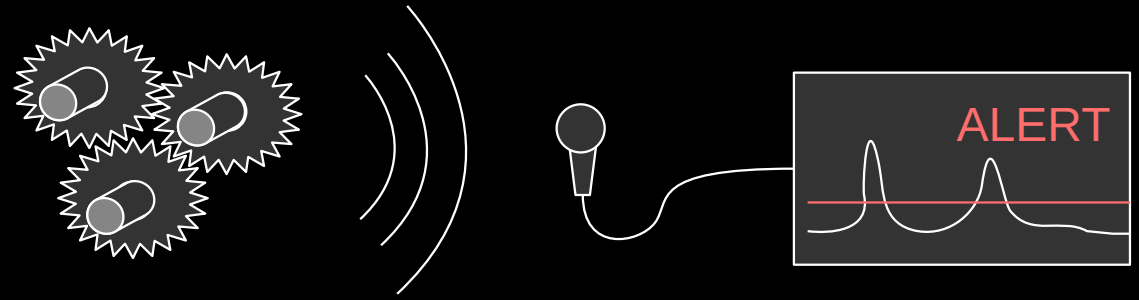
Analyze the acoustic fingerprint

PREPARE



Detect and identify known and unknown sources

DEPLOY



Automated Analysis

Alerting when:

- → Transformer **overloaded**
- → **Unknown** signatures detected
- → **Deviation** in known signature

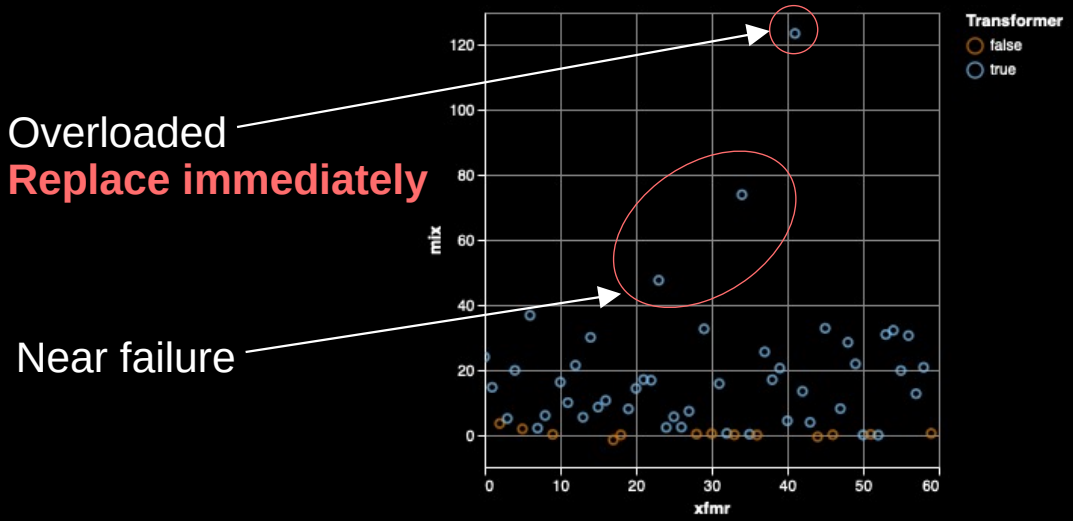
4” x 3” COTS microcomputer
w/ microphone and on-board processing

Current Progress

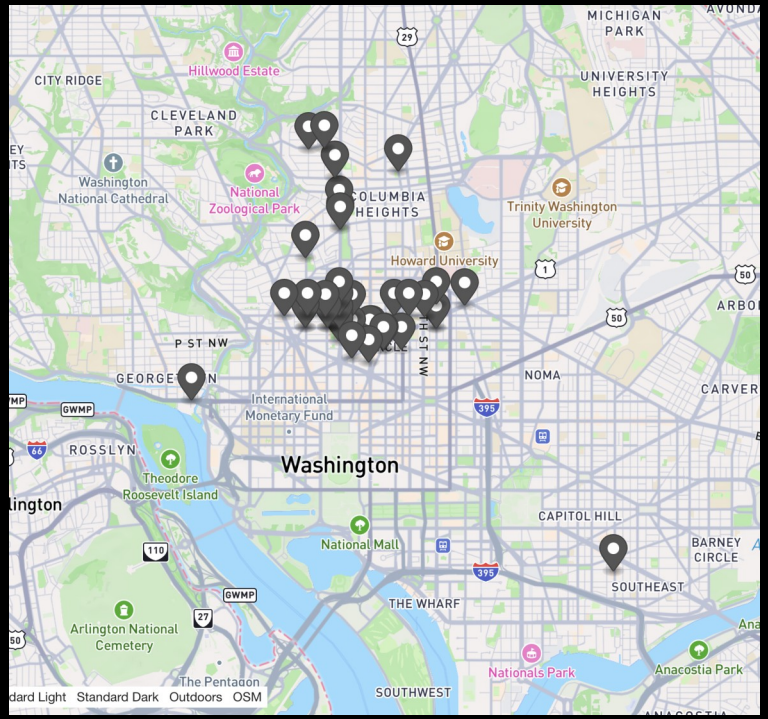
54 distribution transformers analyzed

2 transformers - **replace soon**
1 transformer - **replace immediately**

Proprietary Signature Analysis



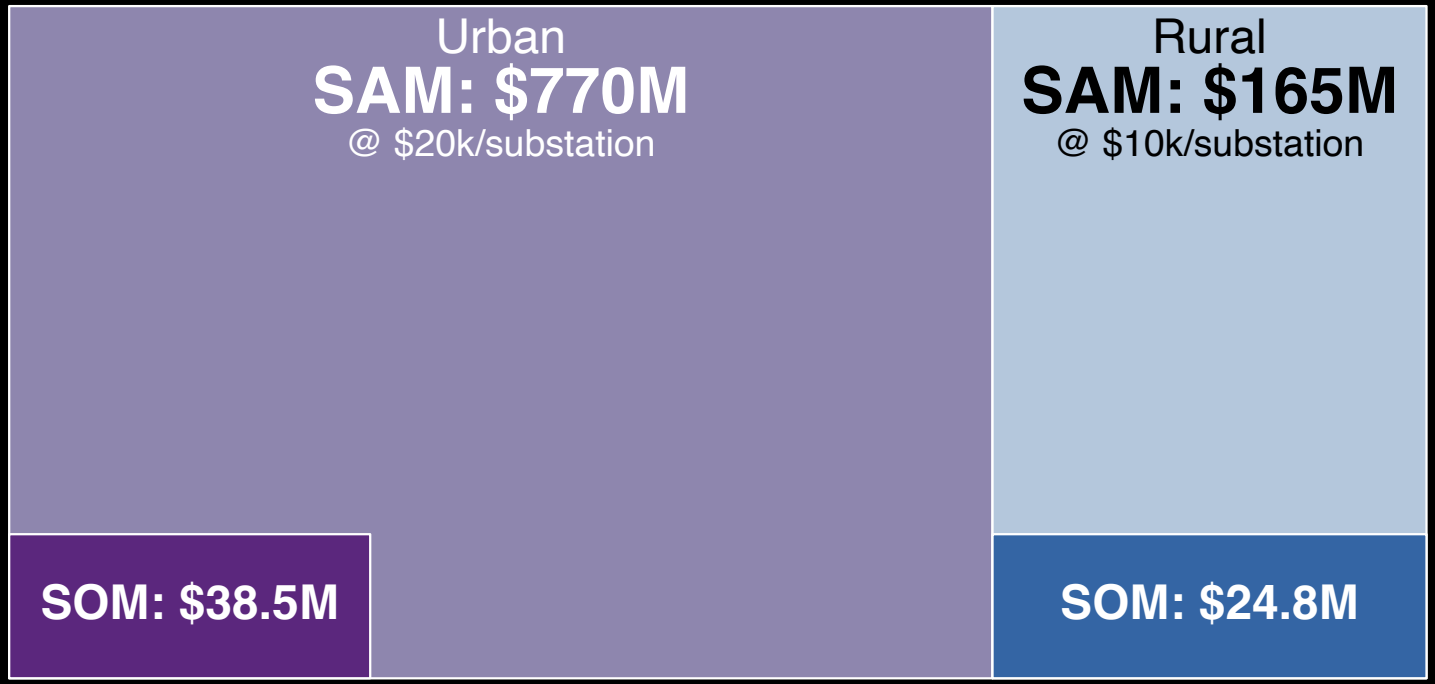
Washington, DC



Market: Electric Substations

TAM: $935,000,000

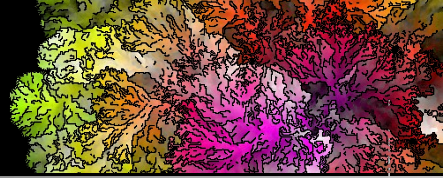
55k electrical substations



80% of US is urban
5% capture of urban substations

20% of US is rural
15% capture of rural substations

Customer Savings



(Per Substation)

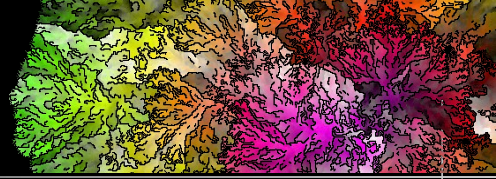
$272k **5 year cost without us**

$90k **5 year cost with us**

67% **Savings**

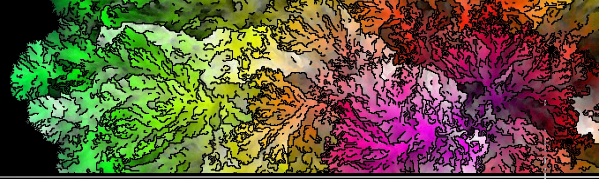
↑ **Reliability**
↓ **Cost**

First Year



Develop catalogue of transformer defects	Month 3
Get 100 recordings of transformers	Month 4
Diagnose transformers according to catalogue	Month 6
Present findings to Pepco Begin partnership	Month 7
Get recordings of substation transformers	Month 12

Business Model Example



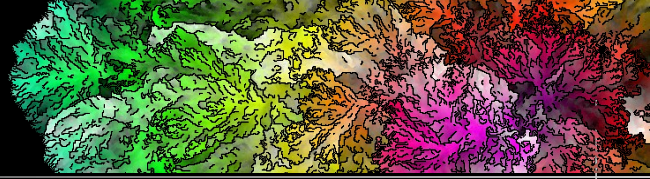
Dominion Energy
400 substations

Full integration in 12 years
with $8M ARR

Government utilities: **$5k**/substation/year
Private utilities: **$20k**/substation/year

Year	Substations	Revenue
1	1	$20k
2	3	$60k
3	10	$200k
4	40	$800k
5	70	$1.4M
6	100	$2.0M
7	150	$3.0M
8	200	$4.0M
9	250	$5.0M
10	300	$6.0M
11	350	$7.0M
12	400	$8.0M

Competitive Advantage



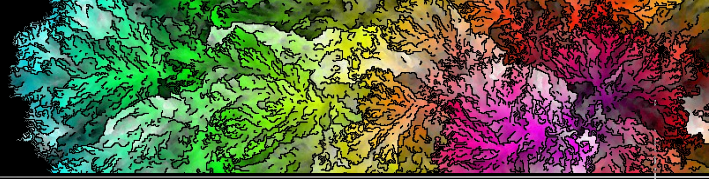
Green-field opportunity

- → Smaller transformers are **completely unmonitored**
  - → Monitoring transformer overloading is **difficult**
    - → Requires invasive metering
- → **No one else** monitors acoustics
- → Utilities are a **natural monopoly**

Passive, non-invasive, easy to install

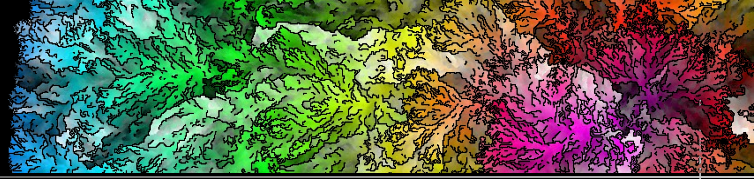
- → Transformers **stay online**
- → **No interruption** of service

Competition



Competitor	What we improve upon
Vibration analyzers	→ **Requires strict installation**
Distributed acoustic sensors	→ **Fiber-optic cable installation** → **$$$**
Ultrasound detectors	→ **Requires active assessment** → **Unable to detect winding issues** → **No automation**

Best Team to Solve This



Hi, I'm **Ari**

I have

→ 8 years as a US Navy submariner

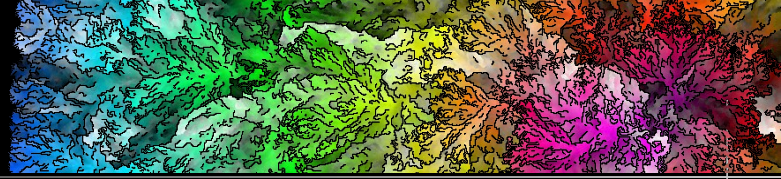
→ certification as a nuclear engineer under the DoE and Naval Reactors

→ 12,000 hours of acoustic analysis

→ 20 years of programming

And there's four of me

Needs

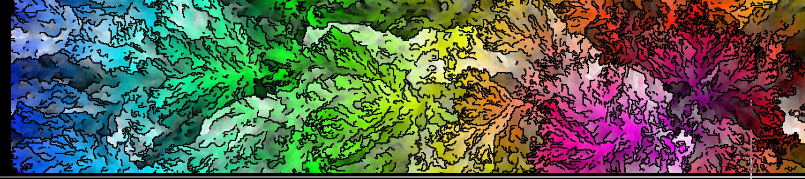


Goal is to raise **$2.5M**

1.5 years of runway

- → 4 FTEs
- → Improve hardware prototype
- → Improve acoustic analysis GUI
- → Catalogue transformer defects
- → Analyze all transformers in DC

Contact

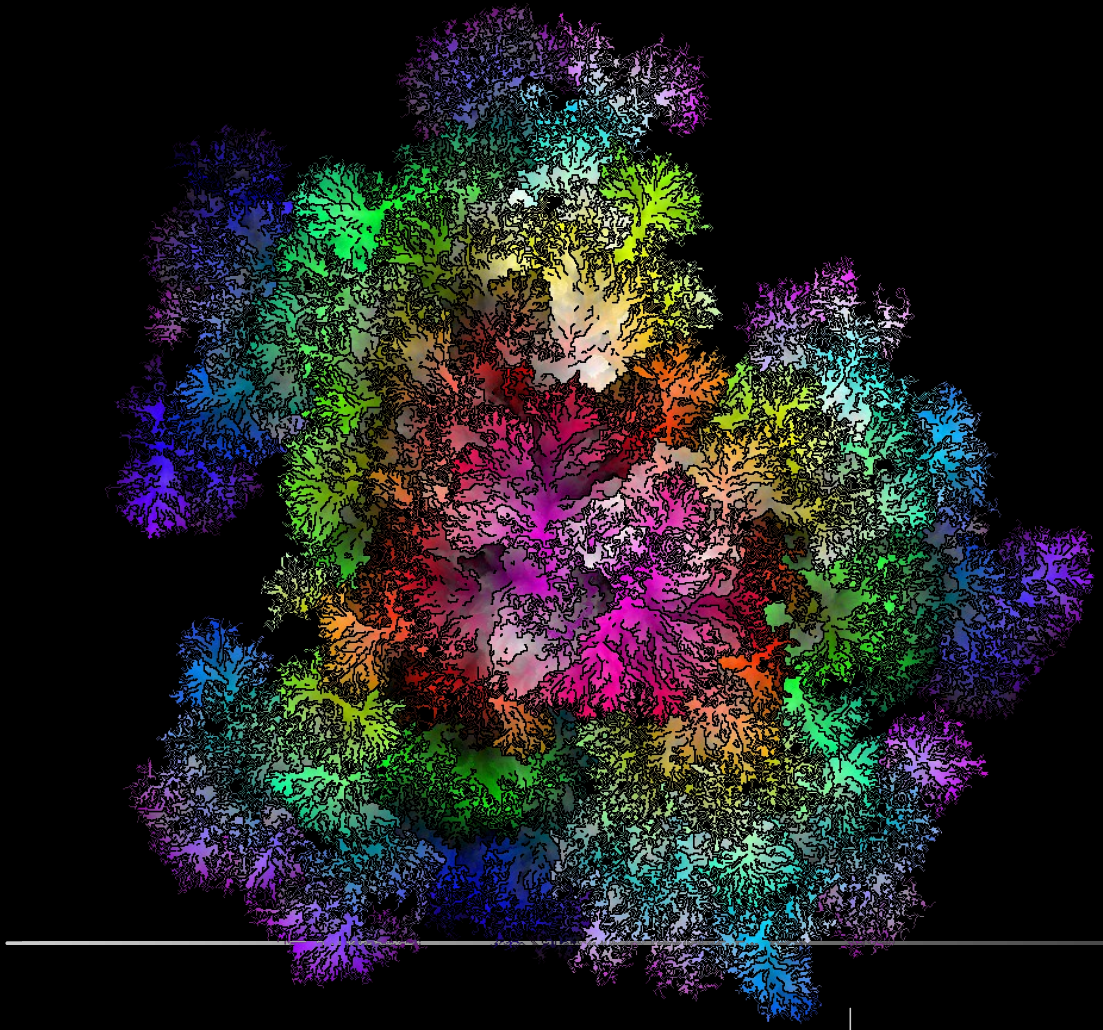


info@bellwether.llc

https://bellwether.llc

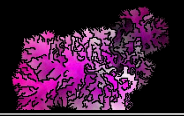
+1 (603) 729-7097

1733 20th St NW
#205
Washington, DC 20009



Appendix

Appendix: Problem



Major transformer failure = $ 14 k/MVA

Standard substation = 28 MVA

Material Costs = $ 392 k

Cost / substation / year = $ 56 k

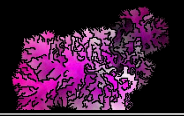
7 days of downtime / major transformer failure
24 hrs of downtime / substation / year, based on 2018 study

Appendix: Problem

45% of transformers fail in their windings

Status Quo

→ Windings come loose
→ Transformer fails
  → 30% of transformer failures are beyond repair
→ 5 year wait for a new transformer
  → $800,000 per transformer
  → Transformers are in short supply
    → US created national reserve of transformers

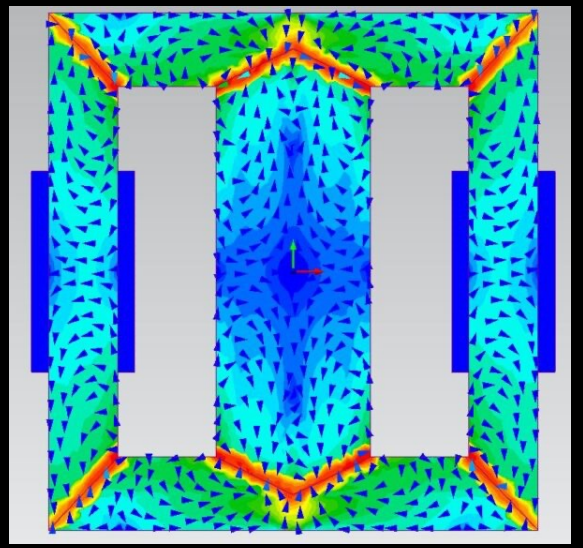


Bellwether Intervention

- → **Windings come loose**
  - → Current diagnosis is through vibration
  - → Better diagnosis through acoustics (2023 paper)
- → **Windings are rewound**
  - → Cheaper and faster than new transformer
  - → Increases efficiency of transformer
  - → Can be done in 24-48 hours, ~$15k for labor
- → **Transformer lifespan is extended**

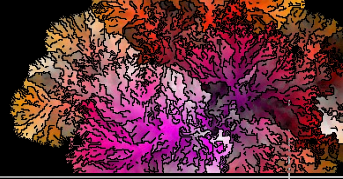
Appendix: Technical Analysis

Windings are cause of 45% of transformer failures



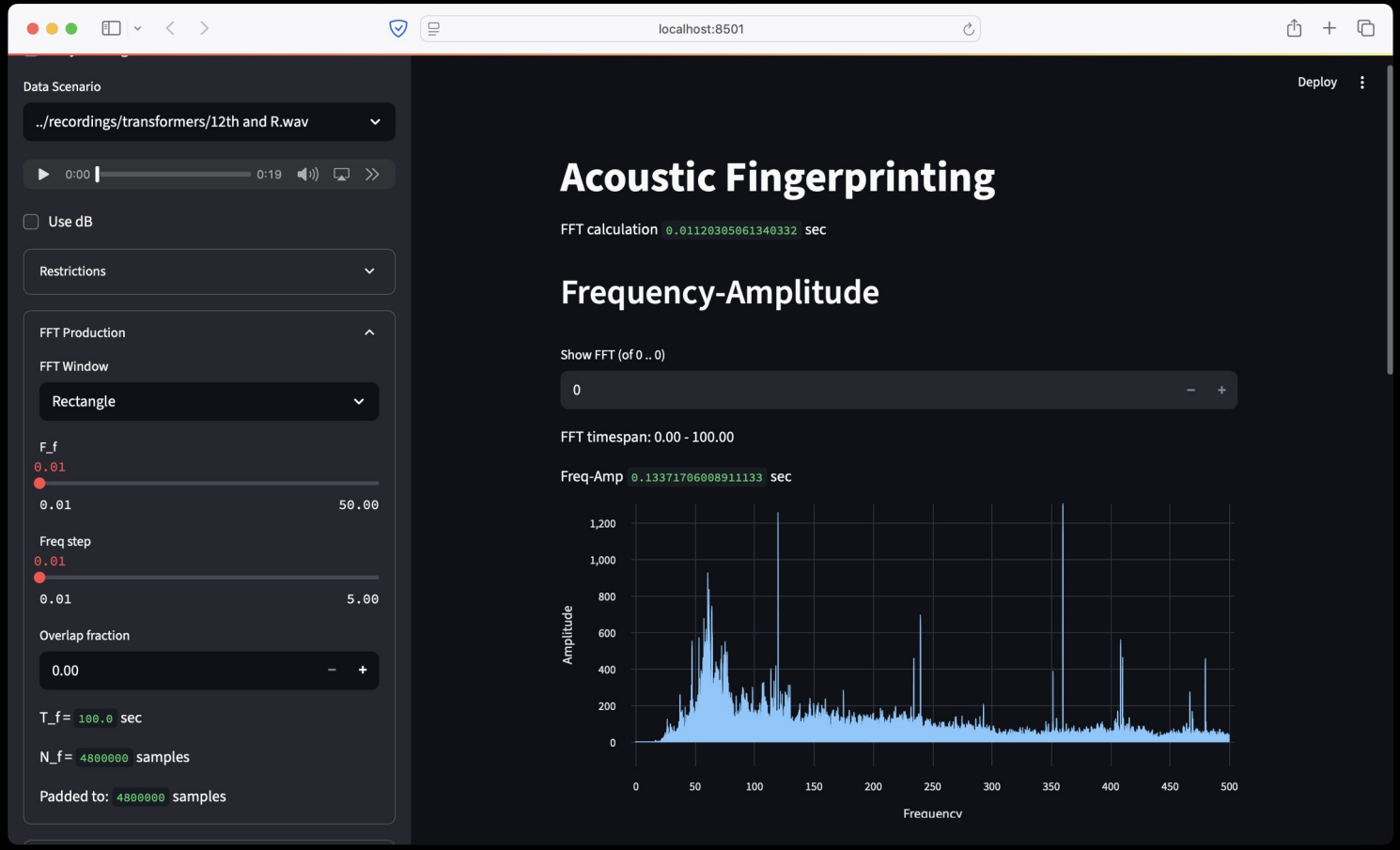
- → **Loose windings**
- → **Decreased reluctance in windings**
- → **Increased vibration of steel core**
  - → 2x the frequency, 120 Hz
  - → $A_v \propto B \propto V$, so vibration amplitude is proportional to voltage
  - → Higher amplitude implies the winding loosening
- → **Audible detection via contact mic**

Appendix: Transformer Issues

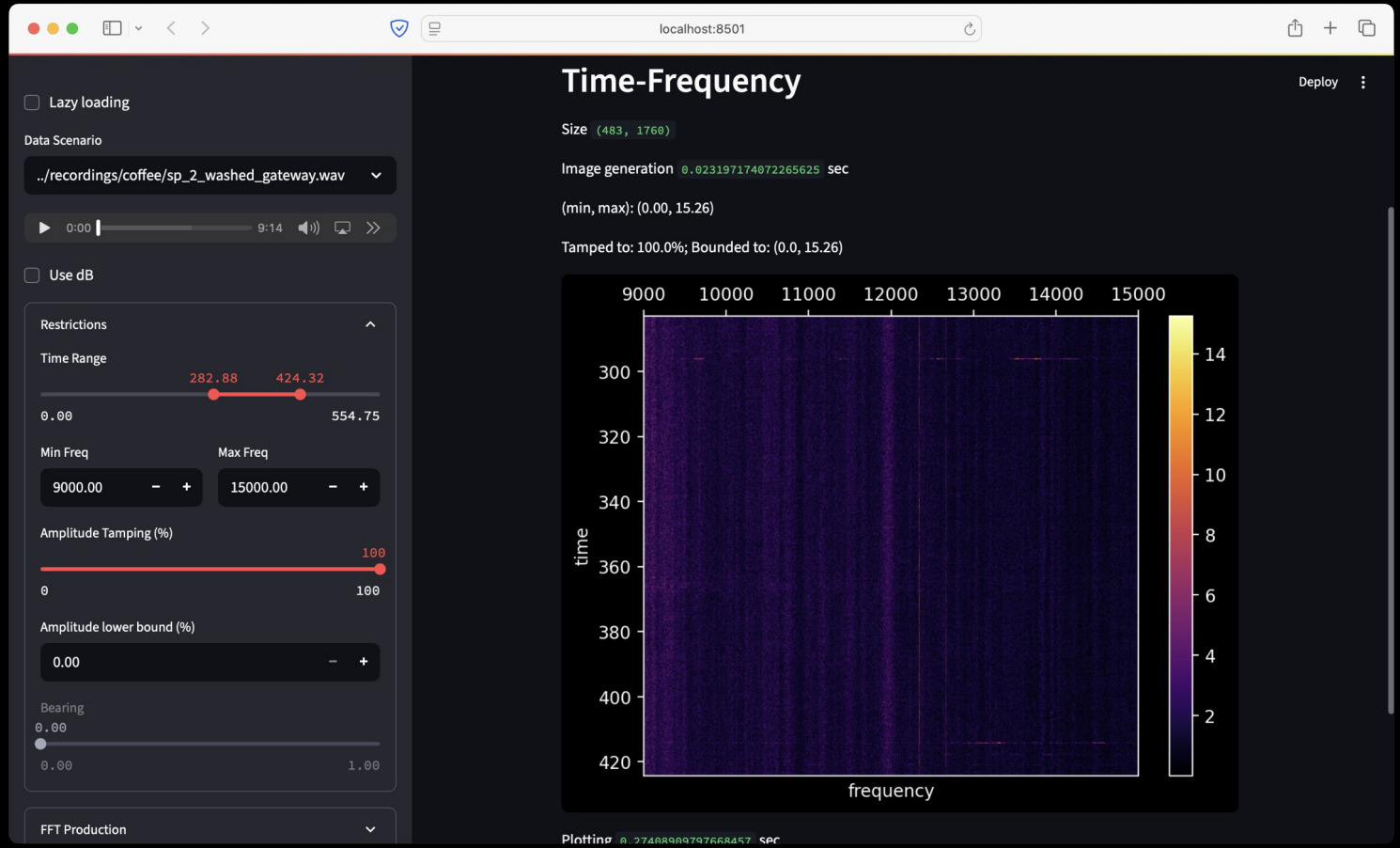


- → Loose 1° windings
- → Loose 2° windings
- → Loose housing
- → Loose core lamination
- → Overloading
- → Damaged bushings
- → Moisture

Appendix: Software

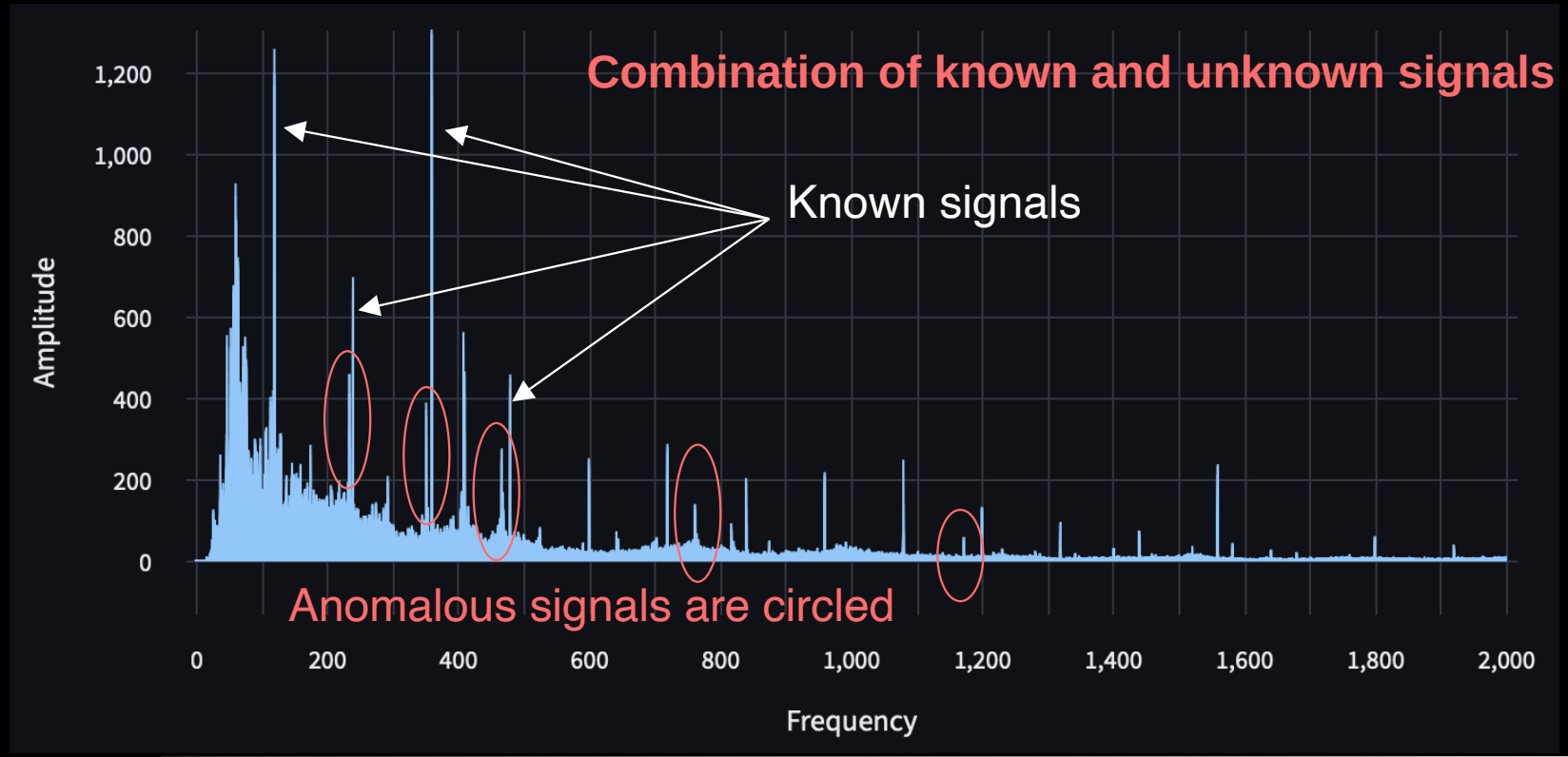


Appendix: Software



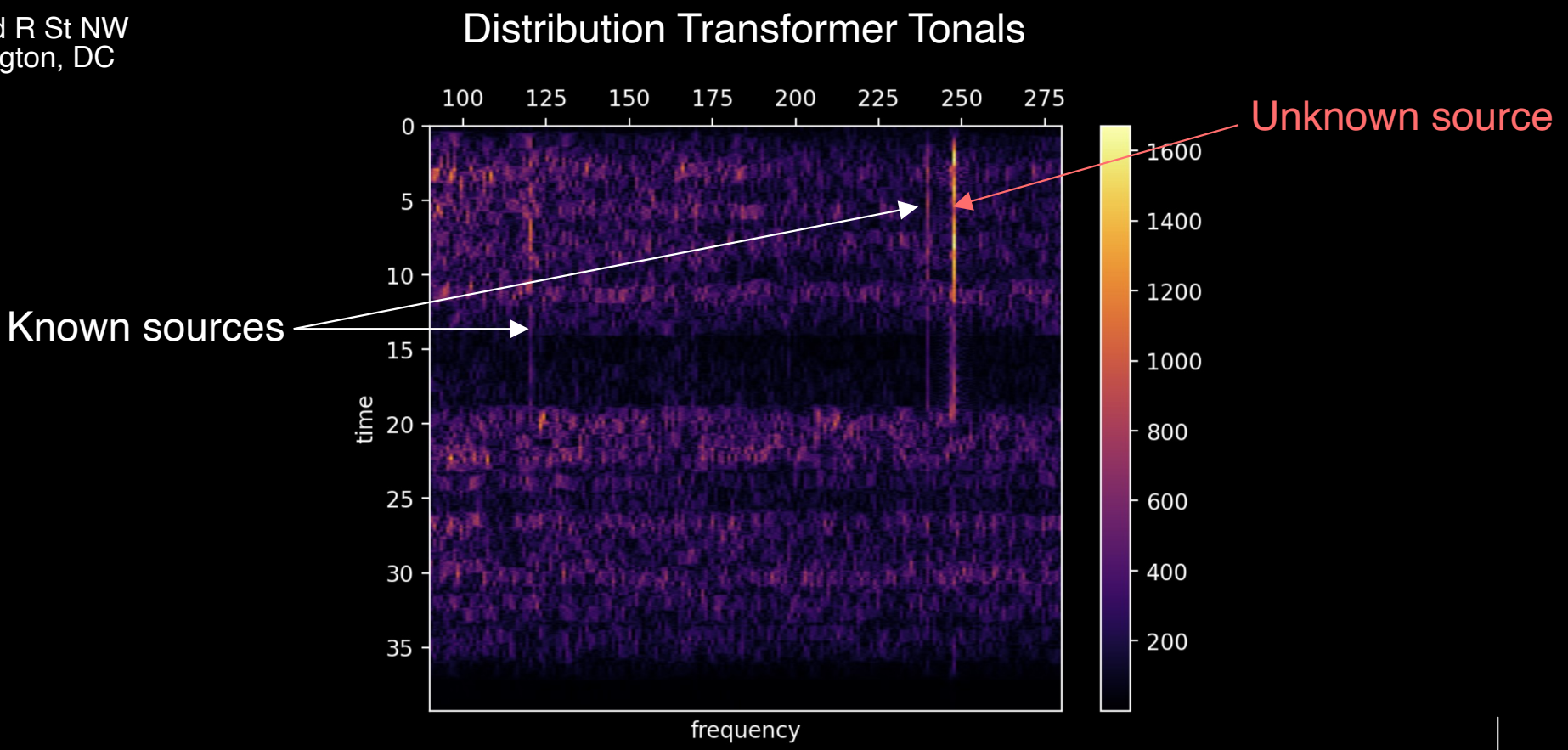
Appendix: Sound Profile

12th and R St NW, Washington, DC



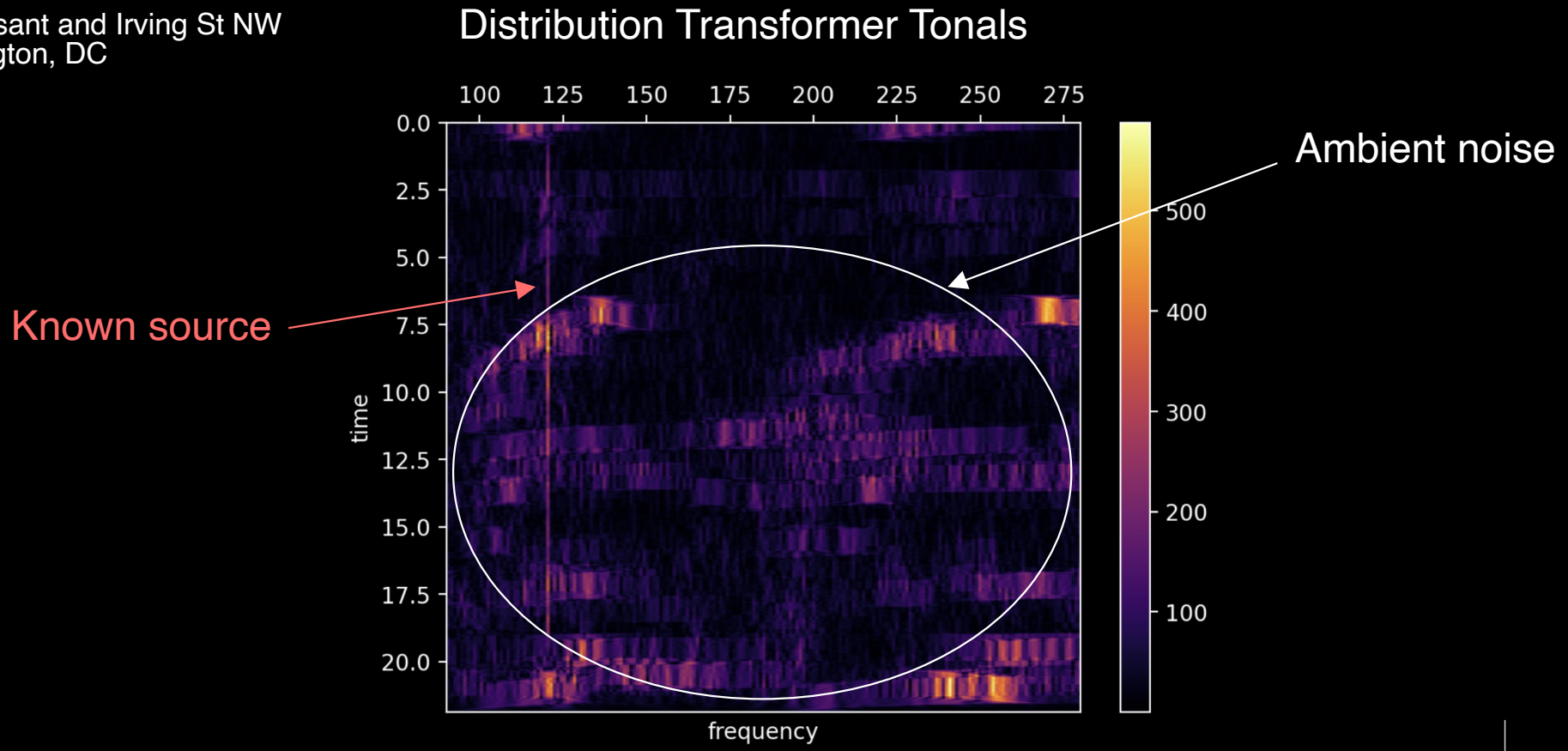
Appendix: Acoustic Analysis

12th and R St NW
Washington, DC

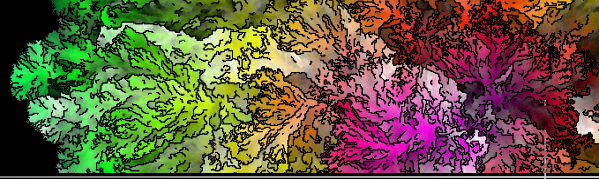


Appendix: Acoustic Analysis

Mt Pleasant and Irving St NW
Washington, DC



Appendix: Business Model

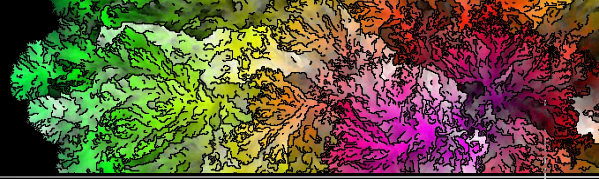


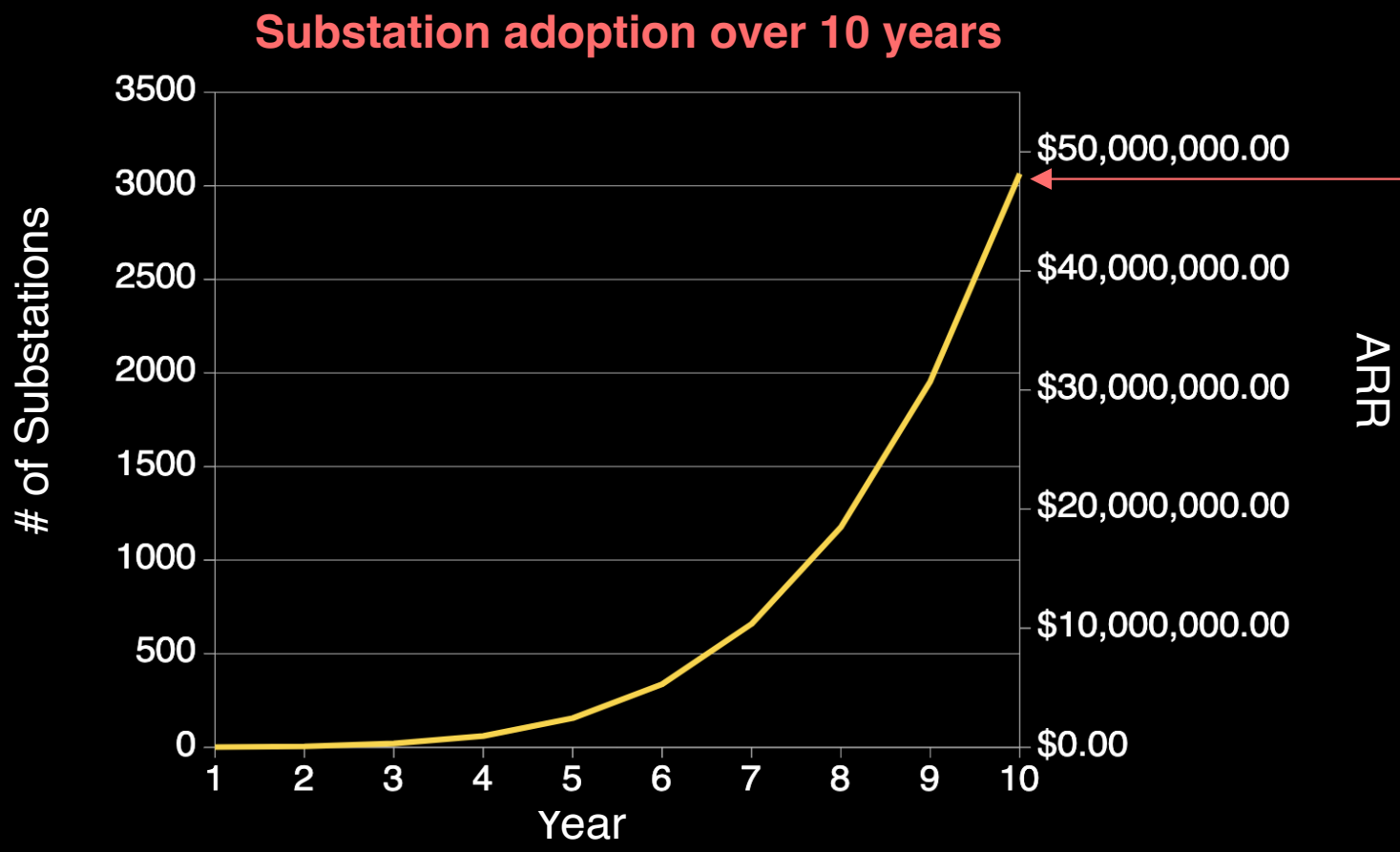
Utility Example

Month 1: Install equipment; take recordings
2: Analyze recordings
3: Current signatures identified
4: Update automated analyzer

“Increased core vibrations” → Loose windings
“Frequency fluctuations” → Unbalanced generation
“Gunshot” (NC attack 2022) → Substation attack

Appendix: Business Model





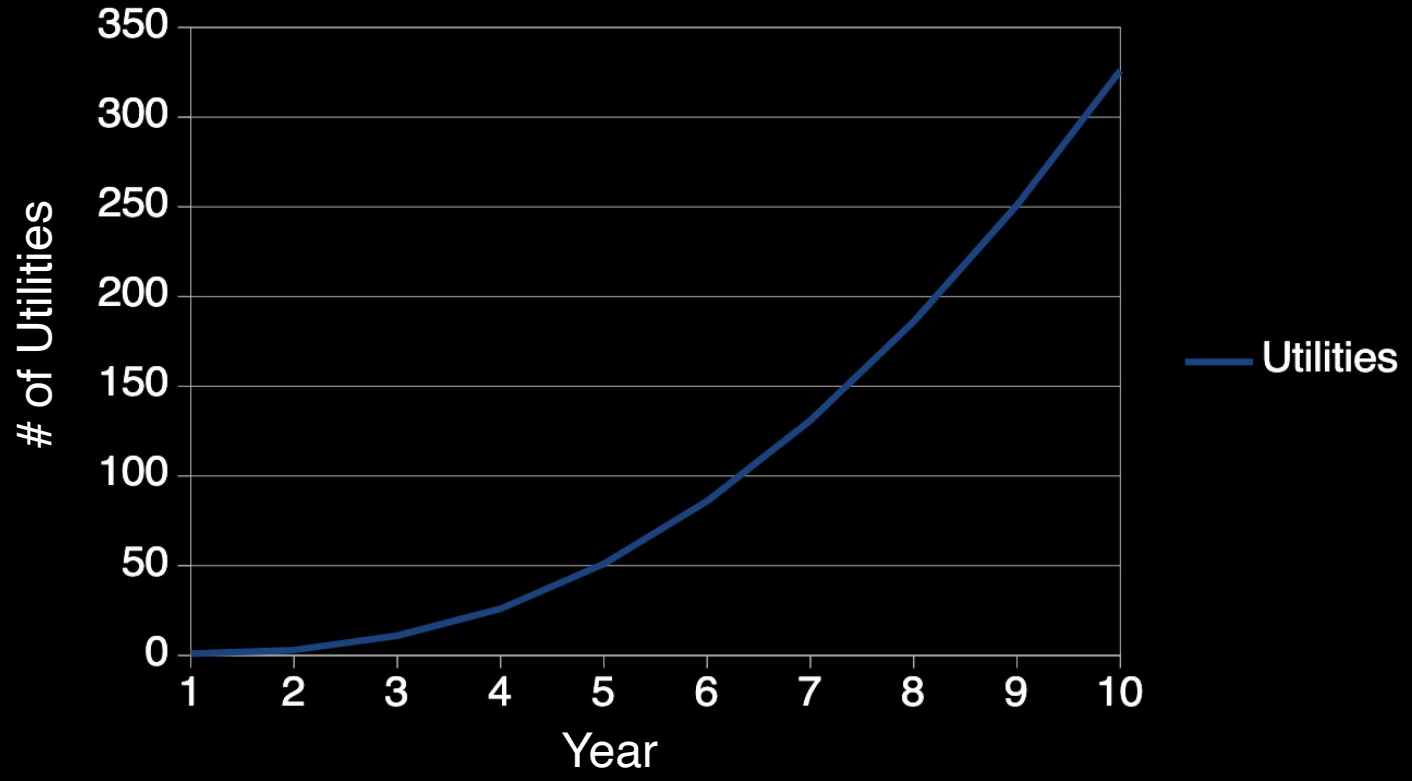
$48M ARR

Assumptions

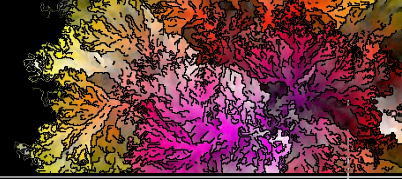
- $15k/substation
- 66 substations/utility

Appendix: Business Model

6x customers every 5 years



Appendix: Other Industries



Acoustic advances in one market apply to all markets

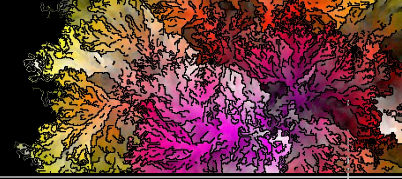
Wind turbines (**$355M TAM**)
- Predictive maintenance

Hydroelectric turbines (**$200M TAM**)
- Predictive maintenance

Commercial fishing (**$180M TAM**)
- Classify species of fish based on their sounds
- Minimize bycatch and increase fishing efficiency

Coffee roasting (**$3M TAM**)
- Identify when coffee beans begin to crack during roasting
- Difficult in loud industrial environments

Appendix: Market (Substations)

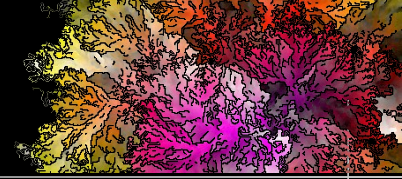


- 20% of O&M budget for federal hydroelectric operators is for substations
  - Substation O&M budget is **~$130k/substation/year**
    - Government price would be $5k/substation

- Assuming same ratio holds for private operators
  - Private operators have significantly more capital per substation

- Rural utilities as a bloc have an outsized representation of federal operators
  - Drives average price down
    - Rural: **$10k**/substation
    - Urban: **$20k**/substation

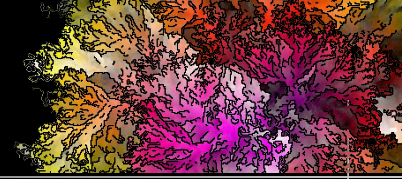
Appendix: Market (Wind)



- 2022: 71,000 wind turbines
- Average wind turbine costs $4.8M
  - 3.5 MW is average capacity
  - $1,391/kW is average cost/kW for on-shore wind
  - 3500 kW * $1,391 = $4.8M
- O&M budget is $40/kW/year → $140k/year
- Charge $5k/turbine

TAM: 71,000 turbines * $5k/turbine/year = $355M

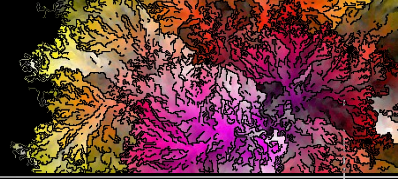
Appendix: Market (Hydroelectric)



- 2024: 250 billion kWh generated from hydroelectric dams
  - 28 million kW capacity
  - 10,000 turbines (@ 2800 kW/turbine)
- Each turbine ~$700k to buy
  - Assume Kaplan turbine, 8m pump head, 42 m^3/s
  - Based off of Norwegian hydro cost assessment report
- Charge $20k/turbine/year
  - 3% of cost

TAM: 10,000 turbines * $20k/turbine/year = $200M

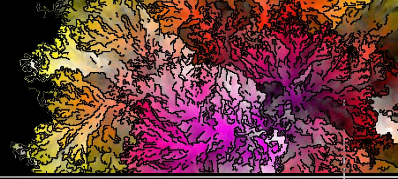
Appendix: Market (Fishing)



- 2023: 36,000 registered commercial fishing vessels in US
  - 8.5 billion lbs of catch in 1990
  - 9.8 billions lbs of catch in 2023
  - 31,000 registered vessels in 1990
    - 36,000 vessels in 2023
- Furuno Omni Sonar is most popular
  - $100k/vessel
- Charge $5k/year

TAM: 36,000 vessels * $5k/vessel = $180M

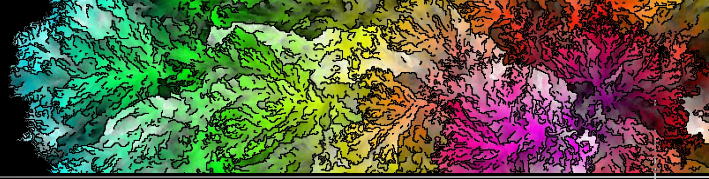
Appendix: Market (Coffee)



- 2025: 3,000 coffee roasters in the US
- Coffee roasters have declared that they want this
  - Local roaster said they would pay $1-2k
- Charge $1k/roaster

TAM: 3,000 roasters * $1k/roaster = $3M

Appendix: Competition



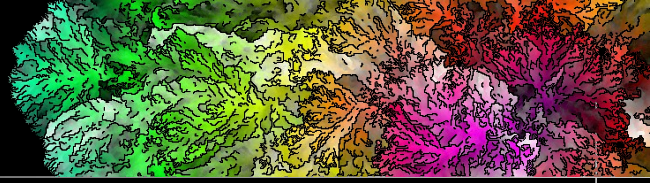
Vibration Analysis
- Tractian
- Betavib
- Extech
- Fluke

Distributed Acoustic Sensors
- Prisma Photonics
- OptaSense
- LineVision
- Silixa
- Luna
- Luma Tech

Ultrasound Sensors
- UE Systems
- Ludeca

Acoustic Sensors
- Mistras Group

Appendix: Vibration Analysis



Tractian
- Will not divulge pricing; believed to be dependent upon savings
- Good for bearing assessment
- Automated operation

Vaporware

Betavib
- $35,000 for the total system (+ $12,000/machine)
- Only does bearing assessment
- Automated operation

$$$

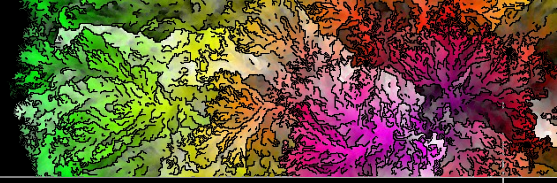
Extech VB450
- $749
- Manual operation

Limited operation

Fluke
- $15,000 for Fluke 810
- Fragile
- Requires extensive usage manual
- Manual operation

$$$; Limited operation

Appendix: Distributed Acoustics



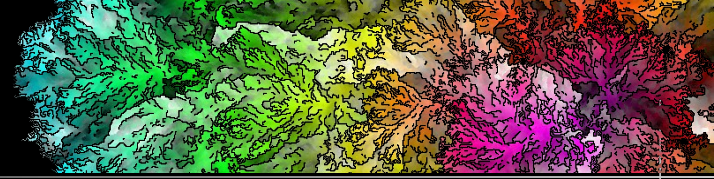
Distributed Acoustic Sensing (DAS)

- **$500k - $1M** to install
- Low frequency response (< 5 kHz)
- Best for perimeter security

$$$$$

Solves different problem

Appendix: Ultrasound



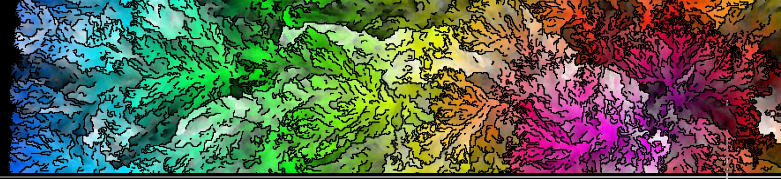
UE Systems
- > $15,000 per unit
- Limited analysis
- No data collection
- Manual usage

Mistras Group
- Monitors stray gassing and delamination
- No signature analysis
- Requires experienced operator

SDT 340
- $2,290 per unit
- Limited analysis
- No data collection

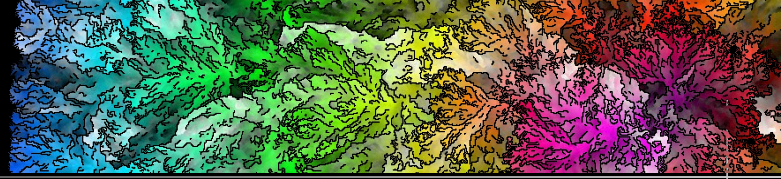
Manual operation
No signature analysis

Appendix: Budget

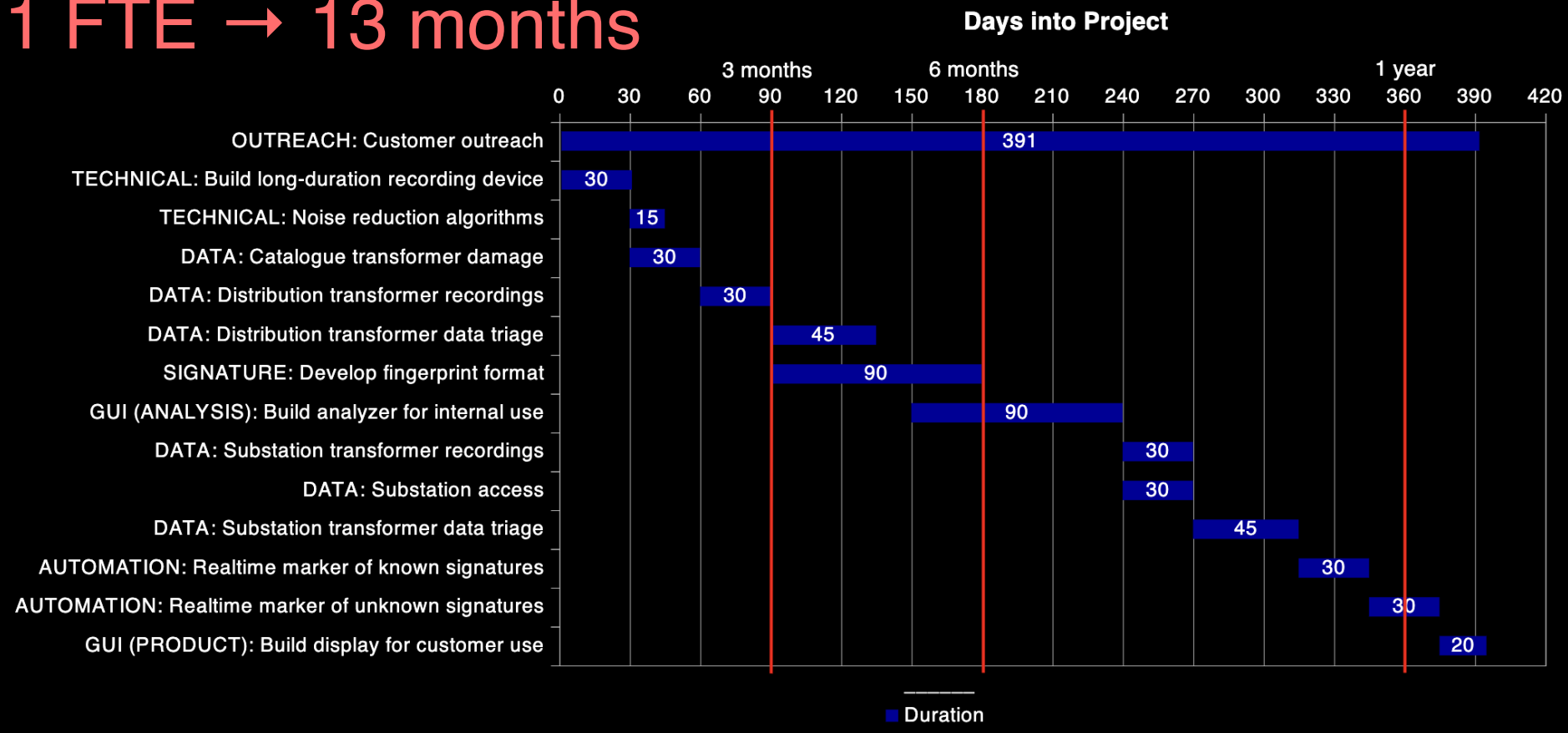


Effort	Item	Hours	Cost ($)
Outreach	Customer outreach	200	$40,000
Technical	Build long-duration recording device	120	$24,000
Technical	Noise reduction algorithms	40	$8,000
Data	Create catalogue of transformer damage	120	$24,000
Data	Distribution transformer recordings	120	$24,000
Data	Distribution transformer data triage	80	$16,000
Signature	Develop fingerprint format	360	$72,000
GUI (analysis)	Build analyzer for internal use	360	$72,000
Data	Substation access	-	$50,000
Data	Substation transformer recordings	120	$24,000
Data	Substation transformer data triage	80	$16,000
Automation	Realtime marker of known signatures	120	$24,000
Automation	Realtime marker of unknown signatures	120	$24,000
GUI (product)	Build display for customer use	80	$16,000
Data	500W transformers	-	$1,000
Cloud	AWS	-	$24,000
Consultants	Conferring with acoustic experts (50 hrs)	-	$10,000
Contingency	Contingency funding (10% for cost overruns)	-	$57,300
Legal	Patents and contracts (60 hrs)	-	$81,000
	Total	**1820 hrs**	**$415,000**

Appendix: Budget Timeline



1 FTE → 13 months



Appendix: Budget Timeline

3 FTEs → 5 months