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Design, Fabrication & Testing of Optimized Electrical & Acoustic Tuning in an Ultrasound Endoscope

BACKGROUND

Client Description: Dalhousie Ultrasound Lab
Group that designs ultrasound probes for brain imaging

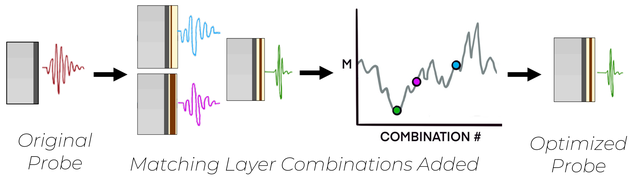
Client Focus: Optimization
Client is working on optimizing their probes in preparation for clinical testing. Probe accuracy is determined by the shape of the ultrasound pulse seen by the probe, which can be improved by adjusting ("tuning") the following:

1. **Matching Layers:** Copper & parylene added to probe tip
2. **Components for Tuning:** Electrical components added to probe circuitry to filter pulse

[1]

EXISTING TECHNOLOGY

Client has created a **program that mathematically models each probe** to predict how adding layers of copper & parylene of different thicknesses would affect pulse quality.

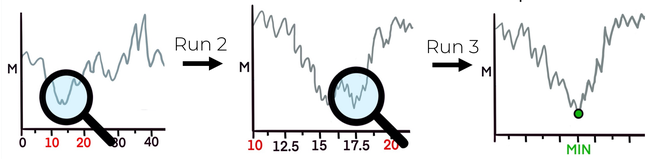


Original Probe — *Matching Layer Combinations Added* — *Optimized Probe*

The results of the tested combinations are consolidated in a **"M plot" that ranks the tuned pluses** from best to worst. The layer thicknesses at the min. M value are what are required to achieve optimal performance.

PROBLEMS

Program is **too slow to test all possible combinations**. Client must run multiple coarse searches centered around the best known combinations to "zoom" into optimal value.



Even with this method, it takes ~1 hour to obtain final results, and lab personnel **must manually initiate** each run.

Software Problems
- X Extremely slow run-time
- X Requires manual input
- X Program optimizes matching layers but not components

Hardware Problem
- X No space for components in circuitry

NEW DESIGN REQUIREMENTS

Software Needs
- ❑ Decrease run-time and/or human hours needed
- ❑ Update program to determine optimal tuning components to achieve target of 66% bandwidth across 20-40MHz range

Hardware Needs
- ❑ Make room for and add tuning components on "Breakout" PCB
- ❑ Reduce "Transmit" PCB from 8 to 4 layers

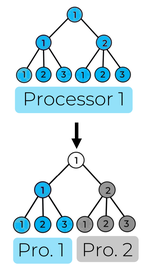
FIXING SPEED: SOFTWARE DESIGNS CONSIDERED

Alternative 1: Automated Iteration
Modify software to automatically identify most promising combinations & re-run optimization (rather than manually).

- ✓ Can build on existing code
- ✓ Eliminates need for human input
- X Minimal run-time improvement
- X Possible to miss some desirable combinations

NOT SELECTED

Alternative 2: Parallel Processing
Combination-testing divided between computer's multiple processors which work simultaneously to obtain results. Only one run is required.



- ✓ Drastic run-time improvement
- ✓ Evaluates all combinations
- ✓ Eliminates need for human input
- X Significant modifications to code

SELECTED

FINAL DESIGN

Software: Parallelizing
A portion of the program was re-written to make used of *parfor* loops – a *MATLAB* function that takes looped section of code and divides the iterations amongst multiple processors.

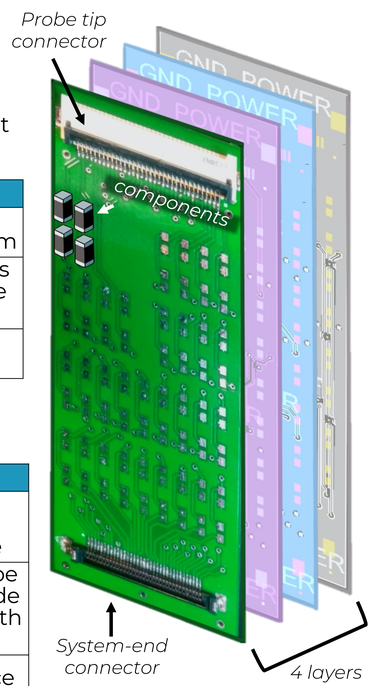
Software: Added Tuning Component Optimization
Expanded probe modeling software to predict how adding different component values/configurations would affect pulse quality.

Design Details	Rationale
Only test pairs of 2 components	• Satisfies limited hardware space • Fewer combinations = faster program
Only test standard, commercially-available component values	• No time wasted on infeasible options • Consistent hardware footprint (same PCB design can be re-used)
7 of 9 possible component configurations tested	• Eliminates configs. with poor tuning abilities according to literature

Hardware: PCB Re-Design

	Prior	After	Rationale
***Breakout* PCB:** Tuning Components	Don't fit	Components fit in series-shunt configuration	• Optimal config. according to modeling software
***Breakout* PCB:** Layers	2	4	• Components can be mounted on topside • Original board width retained
***Transmit* PCB:** Layers	8	4	• Cheaper to produce

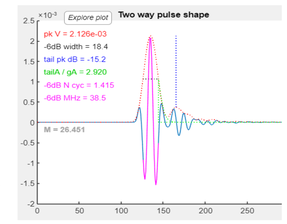
New "Breakout PCB" Design



RESULTS

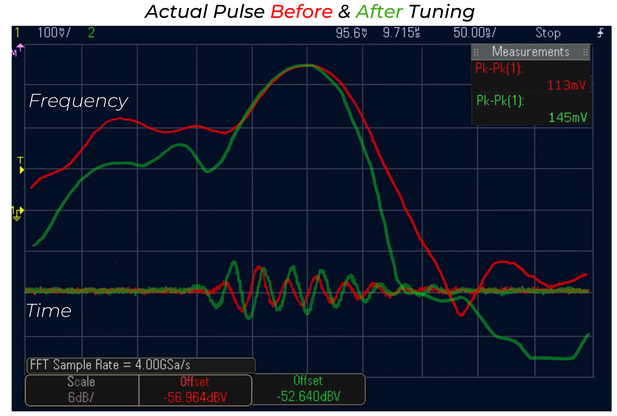
Efficiency
- ✓ Run-time decreased by 10%

Tuning Component Optimization
- ✓ Determined best tuning circuit configuration to be series-shunt inductors
- ✓ M-value decreased (improved) by up to 30%
- ✓ Increased sensitivity by 6dB
- ✓ Decreased tail noise by 6dB



Simulated tuned pulse

Actual Pulse Before & After Tuning



Freq. domain tuned pulse has sharper peak (bandwidth increase)
Time domain tuned pulse has higher amplitude (sensitivity increase)

Hardware
- ✓ Added tuning components to "Breakout" PCB
- ✓ Reduced "Transmit" PCB from 8 to 4 layers

RECOMMENDATIONS

Parallelization was only implemented for a portion of the program. For maximum run-time improvements, the **remaining test loops** should be **parallelized**. The team has provided the client with a detailed design report outlining code changes needed to achieve this. To further improve efficiency, remote processors (ex. Amazon Web Services) could be used for additional processing power.

REFERENCES

[1] Dalhousie Ultrasound Lab. (2018, February 28). Opportunities. Retrieved March 25, 2021, from https://dalhousieultrasound.com/opportunities/

[2] Nova Scotia Health Authority. (n.d.). Nova Scotia Health Authority Logos. Retrieved March 24, 2021, from http://www.nshealth.ca/files/nova-scotia-health-authority-logos