X-Band RF Waveform Engineering for Cavitation Favorability and Perfusion-Mediated Brain Thermal Recovery

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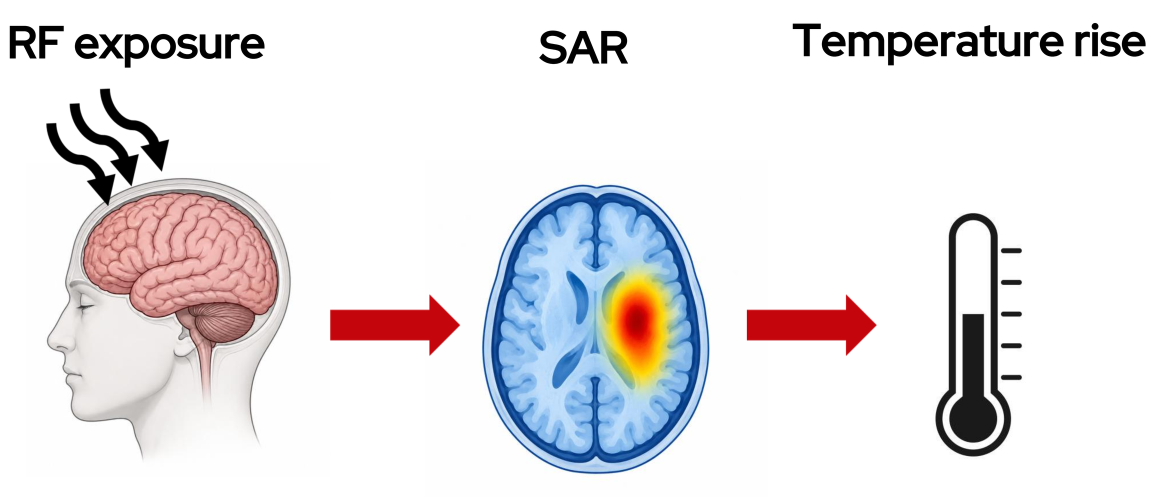
PANTHER

Background

Why thermoacoustic effects matter

- Short RF pulses deposit energy faster than thermal diffusion can occur.
- Rapid localized heating produces thermoelastic expansion and launches pressure waves.
- Pressure waves may create mechanical effects even when the average temperature increase is small.

Conventional RF assessment



Focuses mainly on heating metrics

Research gaps

- Most RF dosimetry focuses on thermal outcomes rather than mechanically generated pressure.
- The influence of RF pulse rise and fall times on pressure polarity is not well characterized.
- It is unclear whether blood perfusion significantly reduce temperature increase during short RF exposure

Introduction

- A sudden drop in static pressure leads to formation of small vapor-filled cavities in the liquid.
- Collapse of cavities generate shock waves may damage nearby surfaces.

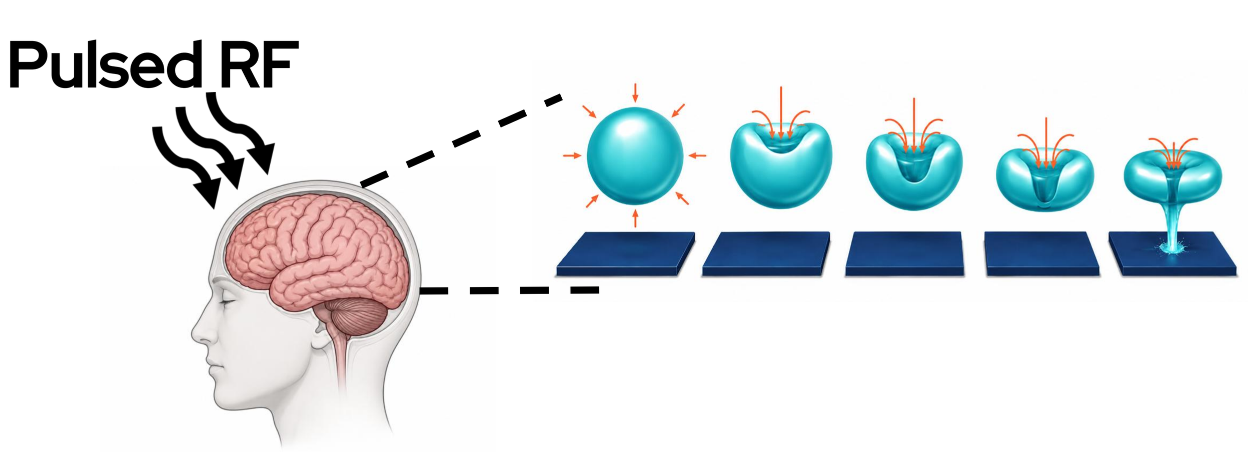


Fig 1 : Representation of RF induced cavitation in brain

Ways to create bubbles inside a liquid

- Pressure : Constant — Temperature ↑
- Temperature : Constant — Pressure ↓

Core idea

- A focused pulsed RF wave may induce cavitation by rapidly changing localized pressure of the fluid in the brain.

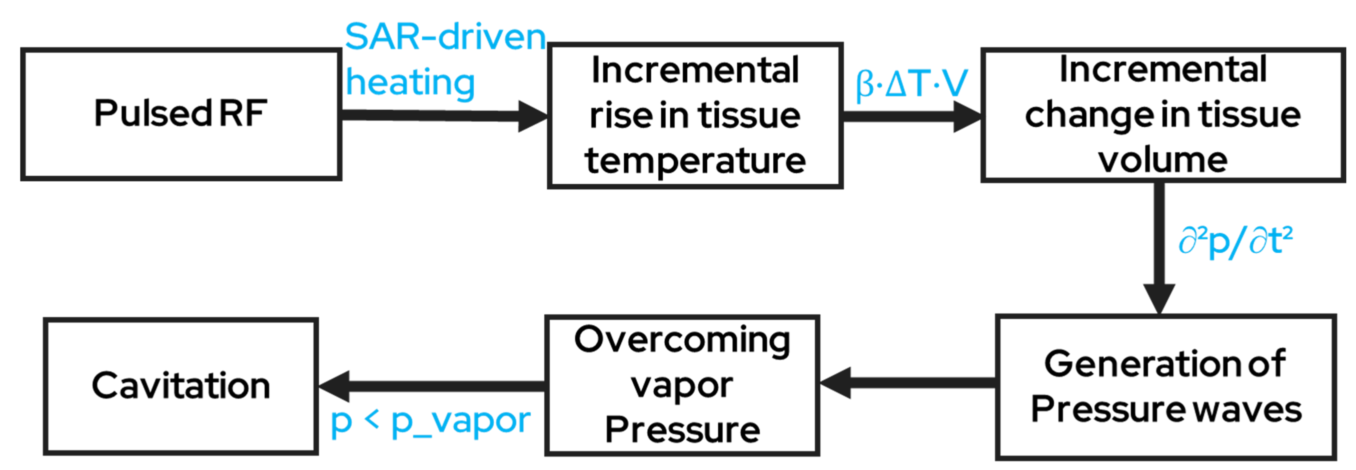


Fig 2 : Roadmap for RF pulsed induced cavitation

Cavitation study

Simulation setup:

- Excitation using circular horn lens antenna at 10.5 GHz.
- Peak power: 1 kW
- Water as test sample with radius = 4 cm, height = 3 cm.
- Test sample is divided into TVA and PA domains.
- Antenna and sample are separated by 3 cm.

Physics used:

1. Electromagnetics, frequency domain (EM)
2. Bioheat transfer
3. Thermoviscous acoustics domain (TVA)
4. Pressure acoustics domain (PA)

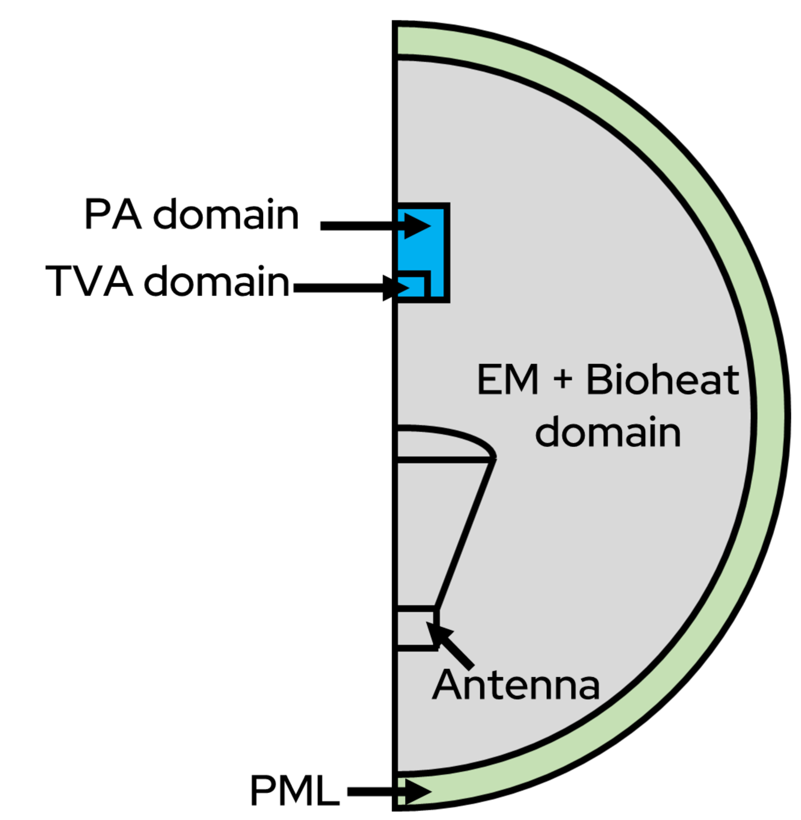


Fig 3 : Simulation setup for cavitation

Results:

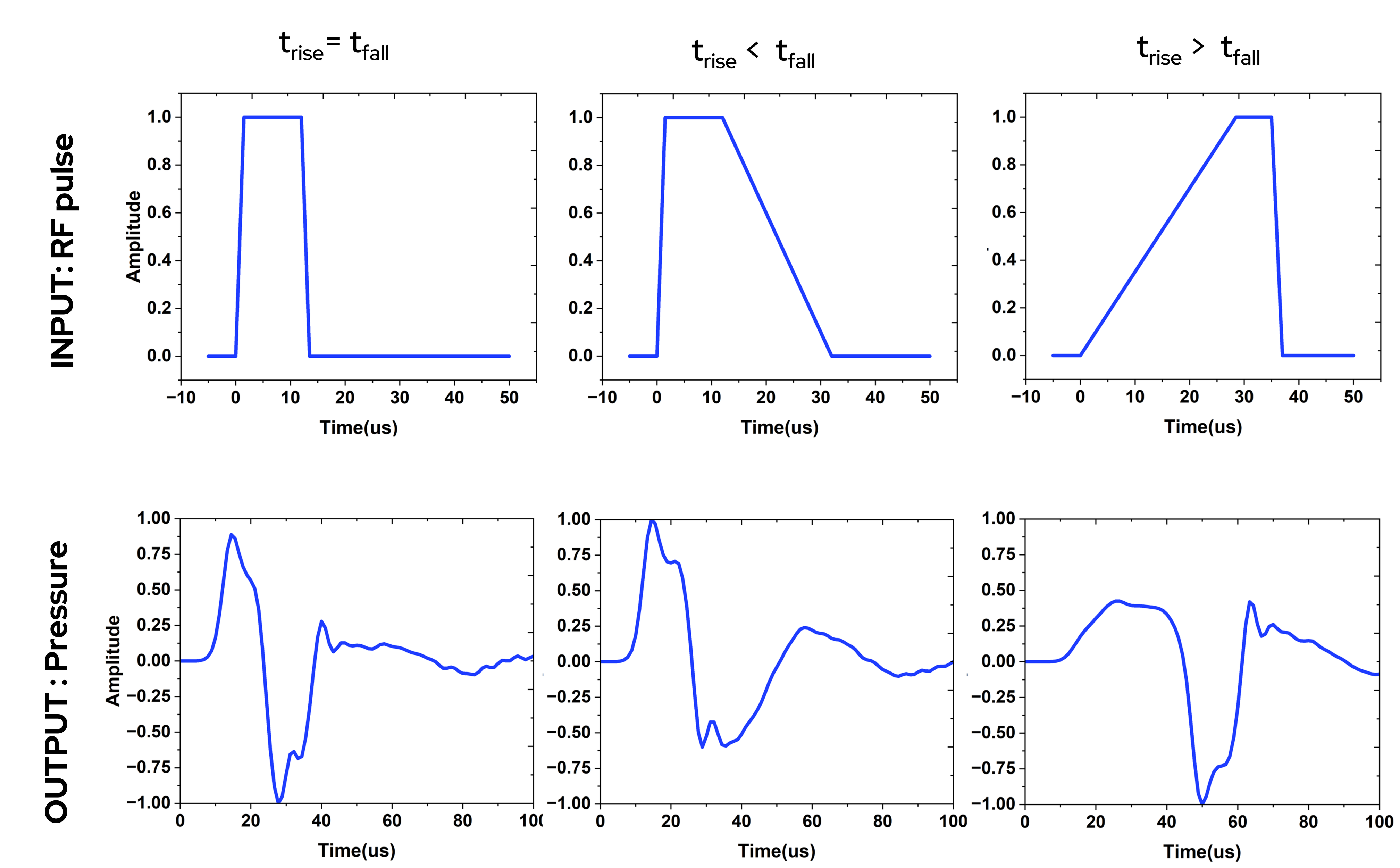


Fig 4 : Pressure induced in water due to different RF pulse excitations

- High fall time leads to compression dominant.
- High rise time leads to tension dominant; favorable for cavitation.

Perfusion study

Simulation setup:

- Head is modelled as water-filled ellipsoid.
- Continuous RF is on for 16 s and then turned off.
- 17 cm distance from antenna

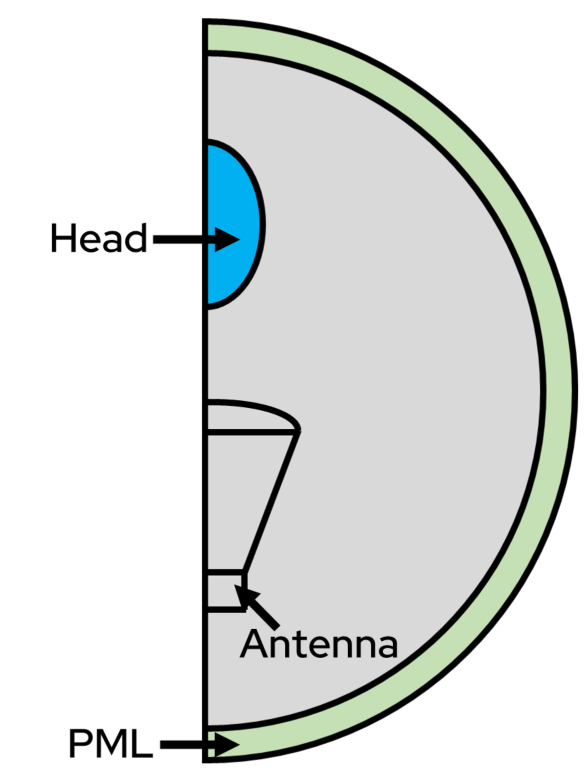


Fig 5 : Simulation setup for perfusion

Results:

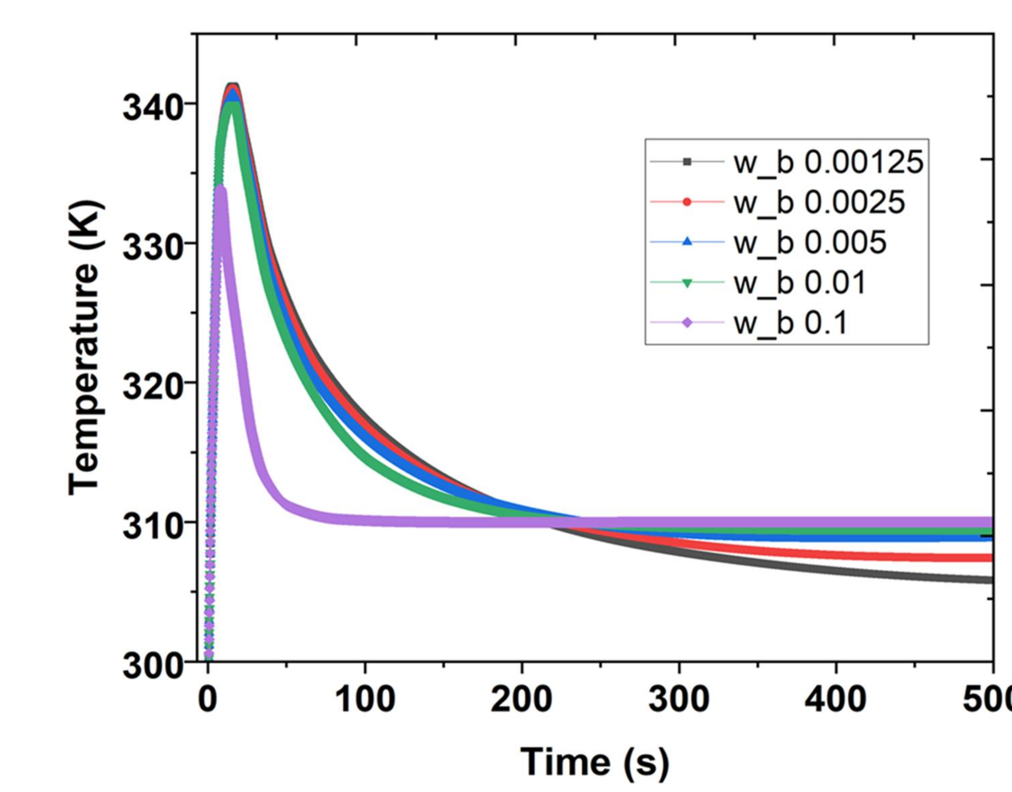


Fig 6 : Temperature plot of head under different perfusion rate

Conclusion

- Coupled EM-thermal-acoustic framework quantifies thermoacoustic pressure generation in tissue under pulsed X-band.
- High t_{rise} maximizes sustained negative pressure.
- Perfusion accelerates recovery but marginally affects peak thermal dose

Acknowledgement

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References

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