THE OHIO STATE UNIVERSITY

Lean Neural Networks for Real-time Embedded Spectral Notching Waveform Design

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Outline

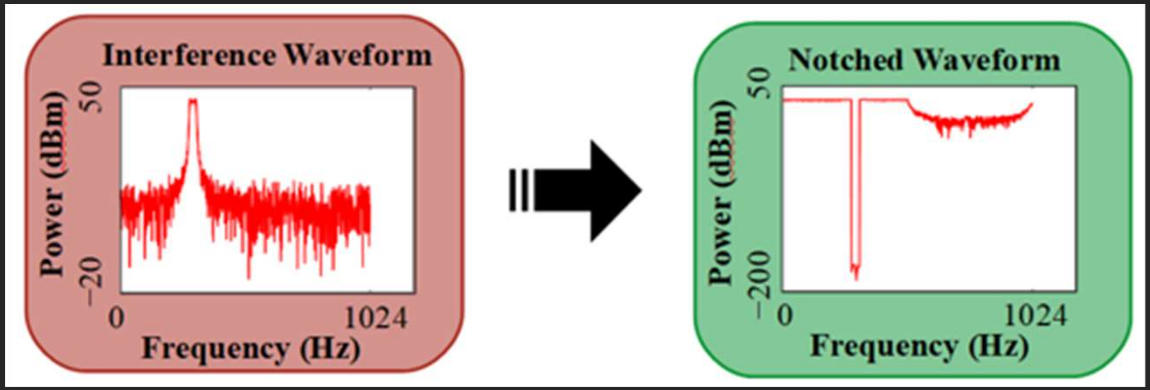
- Introduction
- Existing Solutions and their Limitations
- Our Solution
- Results
- Conclusion

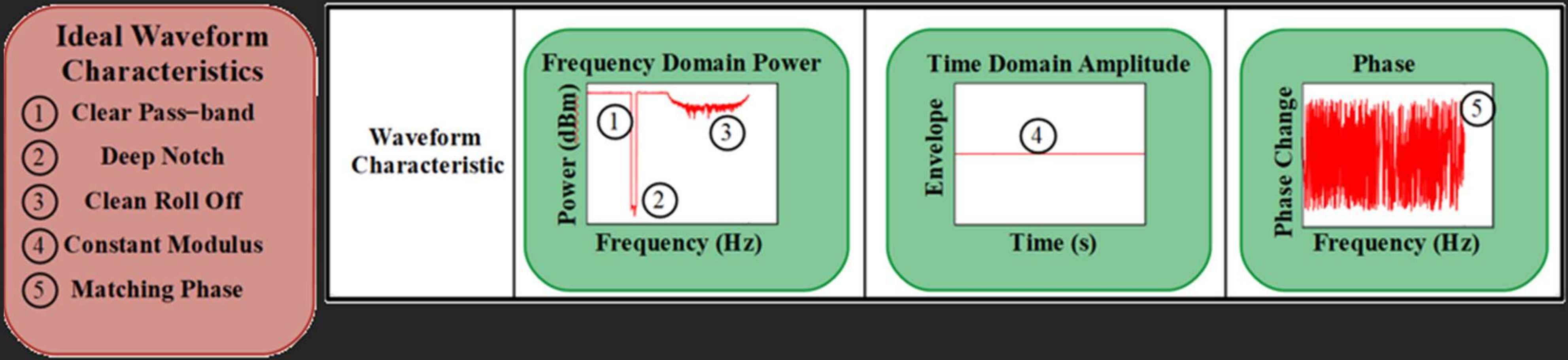
Increased Wireless Spectrum Interference

- 4G/5G Telecommunication Networks
- Mobile Sensors
- IoT Devices

Interference Mitigation - Spectral Notching

Avoid transmitting in saturated stop-band





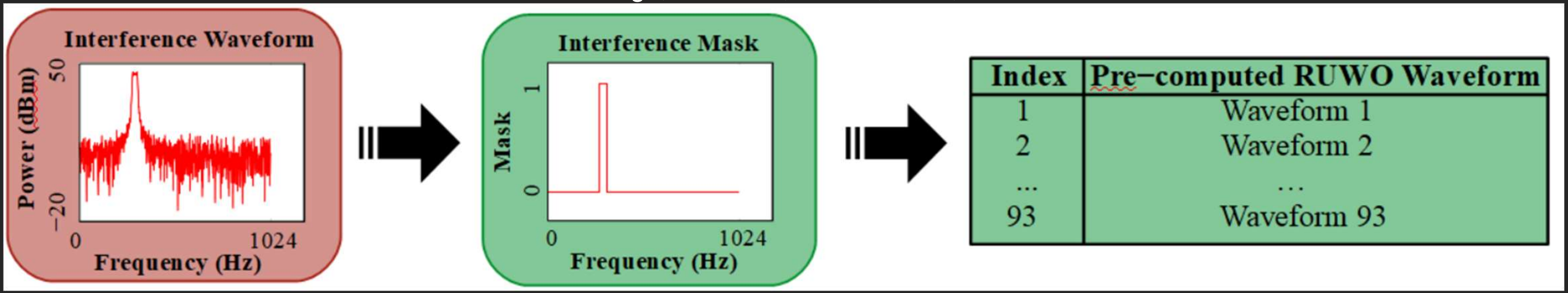
Selected Convex Optimization Algorithms

- Re-Iterative Uniform Weight Optimization Algorithm (RUWO)
- T. Higgins, T. Webster, and A. K. Shackelford, "Mitigating interference via spatial and spectral nulling," *IET Radar, Sonar & Navigation*, vol. 8, no. 2, pp. 84–93, 2014.
- Error Reduction Algorithm (ERA)
- J. R. Fienup, "Phase retrieval algorithms: a comparison," *Appl. Opt.*, vol. 21, pp. 2758–2769, Aug 1982.

Algorithm	Notch Depth (dBm)	Dell r720 2x Intel E5-2670, NVIDIA GT 1030, 144GB RAM Latency (ms)	Raspberry Pi 3B Broadcom BCM2837, 1GB RAM Latency (ms)
RUWO	**202.2**	1064.98 ± 10.94	453,965.43 ± 4131.61
ERA	31.9	**185.47 ± 3.87**	**1982.04 ± 29.27**

Neural Networks (NN)

- Superior non-linear function approximation when sufficiently trained
- Portable
- Validated in prior research (pre/post-processing)
- J. Boubin, A. M. Jones, and T. Bihl, "Neurowav: Toward realtime waveform design for vanets using neural networks," in *2019 IEEE Vehicular Networking Conference (VNC)*, pp. 1–4, 2019.
- P. Farr, A. M. Jones, T. Bihl, J. Boubin, and A. DeMange, "Waveform design implemented on neuromorphic hardware," in *2020 IEEE International Radar Conference (RADAR)*, pp. 934-939, 2020.
- A. Baietto, J. Boubin, P. Farr, T. J. Bihl, A. M. Jones, and C. Stewart, "Lean neural networks for autonomous radar waveform design," *Sensors*, vol. 22, no. 4, 2022.

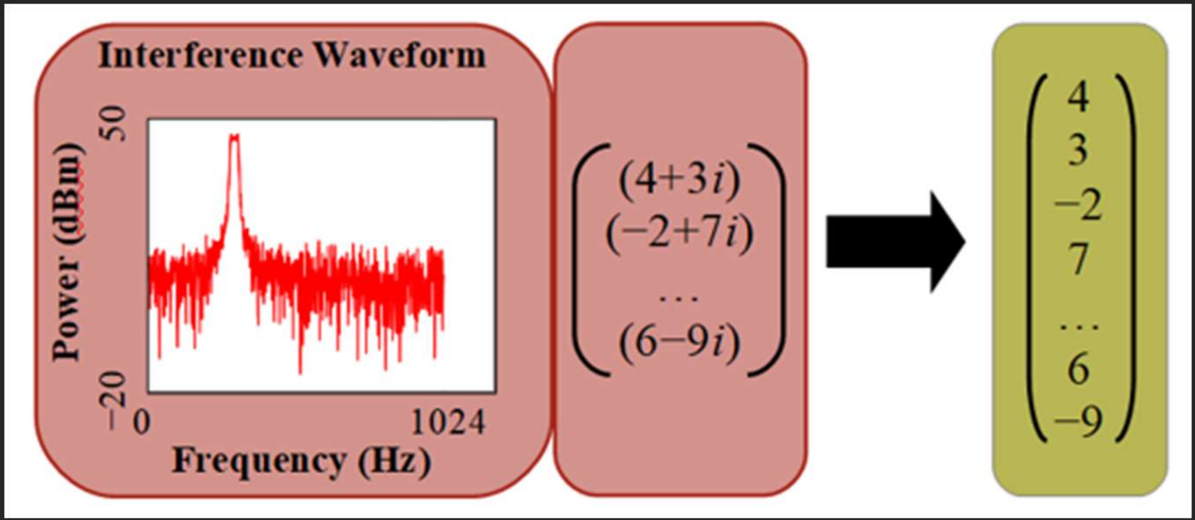


This Work

- End-to-end neural network model for spectral notching applied to 1024Hz radar waveforms
- Target embedded device constraints
- Use ubiquitous Tensorflow / Keras modeling

Tailored Loss Function

Popular loss functions, such as Mean Squared Error (MSE) rely on problem-agnostic coefficient vectors

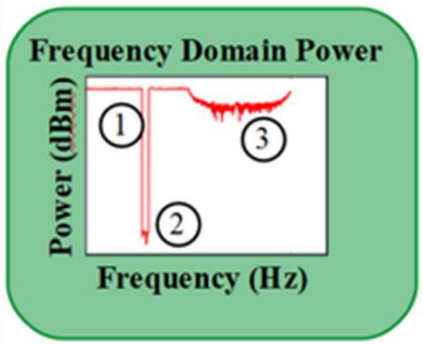
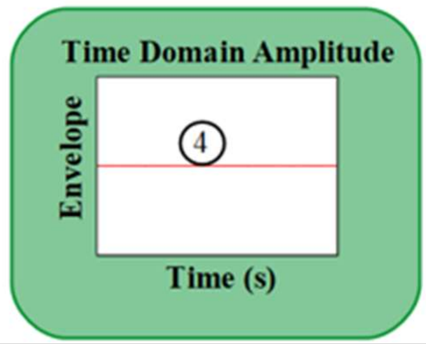
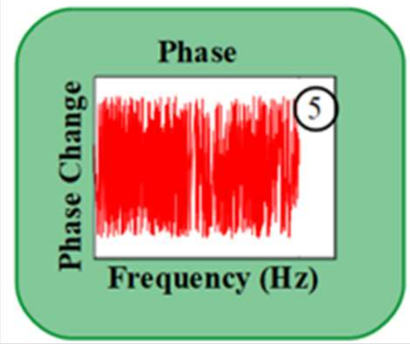


Tailored Loss Function

Incorporate desired waveform characteristics into neural network loss function

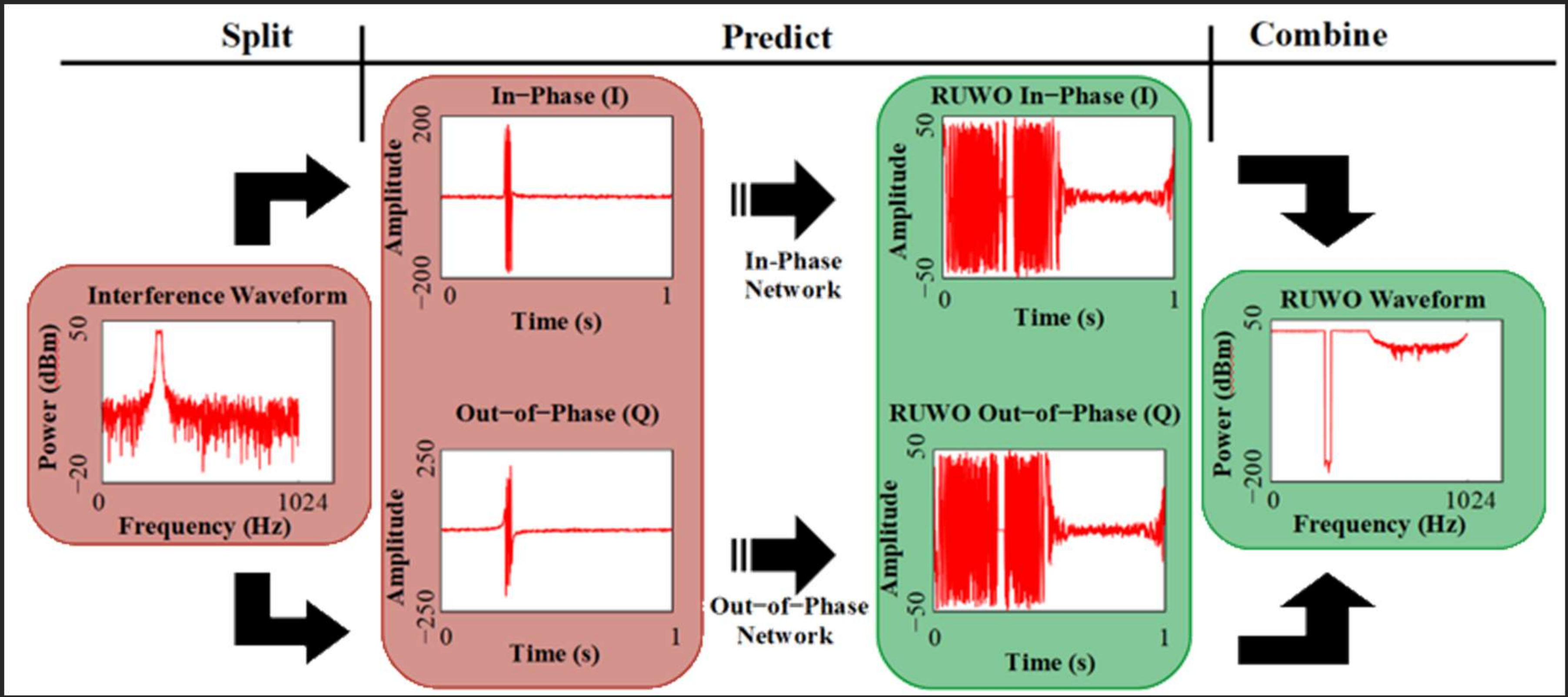
Ideal Waveform Characteristics

1. Clear Pass–band
2. Deep Notch
3. Clean Roll Off
4. Constant Modulus
5. Matching Phase

Waveform Characteristic			
Reflection in Loss Function	$\frac{1}{n}\sum_{i=1}^{n}(20*\log_{10}(FFT(\lvert z_i\rvert)) - 20*\log_{10}(FFT(\lvert\hat{z}_i\rvert)))^2$	$\frac{1}{n}\sum_{i=1}^{n}(IFFT(\lvert z_i\rvert) - IFFT(\lvert\hat{z}_i\rvert))^2$	$\frac{1}{n}\sum_{i=1}^{n}(\angle FFT(\lvert z_i\rvert) - \angle FFT(\lvert\hat{z}_i\rvert))^2$

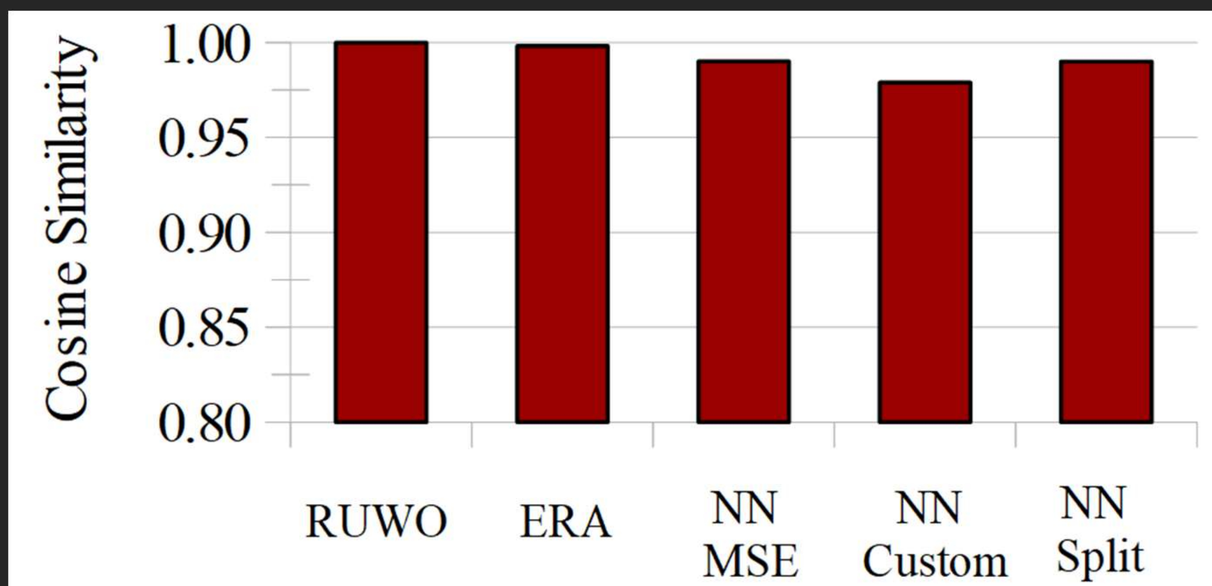
Tailored Network Architecture

Incorporate problem representation into the neural network structure



Results: Correctness

Neural networks capture algorithm performance within **2%** cosine similarity of RUWO



Notch Depth (dBm)	RUWO	ERA	NN MSE	NN Custom	NN Split
	202.2	31.9	28.5	22.3	29.8

Results: Latency and Energy

Almost **2000x** speedup on embedded devices over RUWO

Algorithm	Dell r720 2x Intel E5-2670, NVIDIA GT 1030, 144GB RAM		Raspberry Pi 3B Broadcom BCM2837, 1GB RAM	
	Latency (ms)	Energy (J)	Latency (ms)	Energy (J)
RUWO	1064.98 ± 10.94	261.3 ± 6.5	453,965.43 ± 4131.61	1510.5 ± 14.8
ERA	185.47 ± 3.87	45.5 ± 1.4	1982.04 ± 29.27	6.5 ± 0.1
NN MSE	23.19 ± 1.86	**3.7 ± 0.3**	**230.98 ± 2.74**	**0.6 ± 0.01**
NN Tailored Loss Function	**20.72 ± 0.44**	**3.7 ± 0.1**	233.92 ± 3.16	**0.6 ± 0.01**
NN Tailored Network Architecture	23.35 ± 0.29	4.1 ± 0.6	250.90 ± 0.63	0.7 ± 0.01

Conclusion

- Advanced neural network-backed waveform design
- Demonstrated importance of subject matter expertise for neural network construction
- Satisfactory notched waveforms on embedded devices with significant latency reduction

Questions?

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