

Non-Destructive Bond Wire Failure Detection in SiC Power Transistors Using Reflectometry Signals

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Introduction

- Bond wire degradation limits the reliability of SiC power transistors
- Electro-Optical Terahertz Pulse Reflectometry (EOTPR) enables non-destructive acquisition of degradation-related reflectometry signals, but extracting diagnostic information is challenging due to complex, device-specific reflections
- Proposal: physics-informed machine learning (ML) approach for robust bond wire state estimation

EOTPR Measurements

- 3 identical SiC MOSFET DUTs
- 22 bond wire degradation states
- 7 measurement pins
- EOTPR 4000 (6 ps rise time)

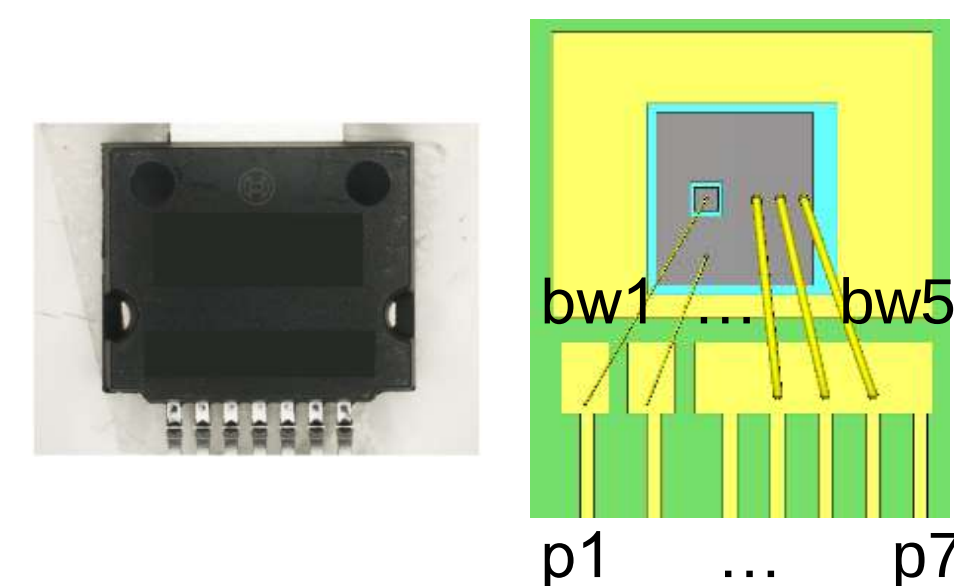


Fig. 1 DUT and schematic view of the opened device

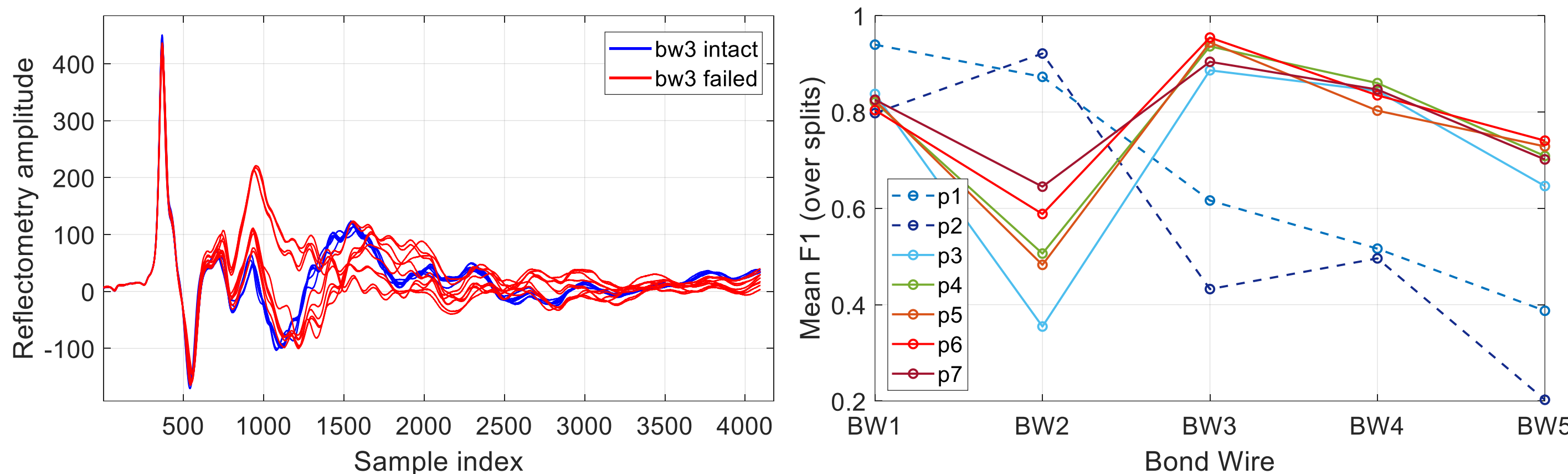


Fig. 2 EOTPR signals for samples with an intact (blue) and failed (red) bond wire 3

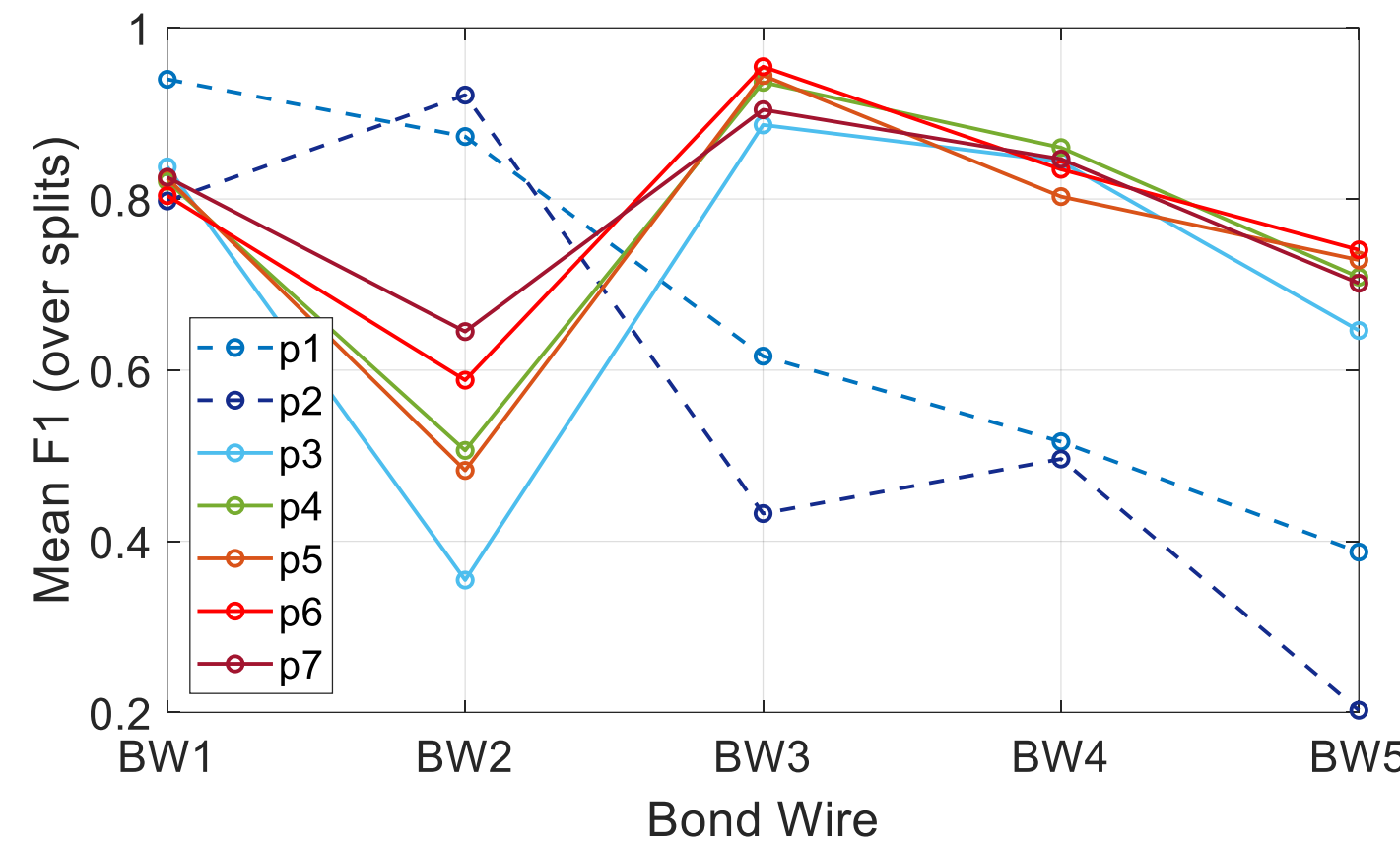


Fig. 3 Mean F1-score per bond wire across measurement pins

Signal Characteristics:

- Context-dependent:** Identical bond wire failures produce different EOTPR signatures depending on the remaining bond wire configuration (Fig.2)
- Pin-dependent:** Different measurement pins provide complementary diagnostic information (Fig.3)
- Distributed information:** Degradation information is distributed across the EOTPR signal, motivating global and local feature extraction (Fig.4)

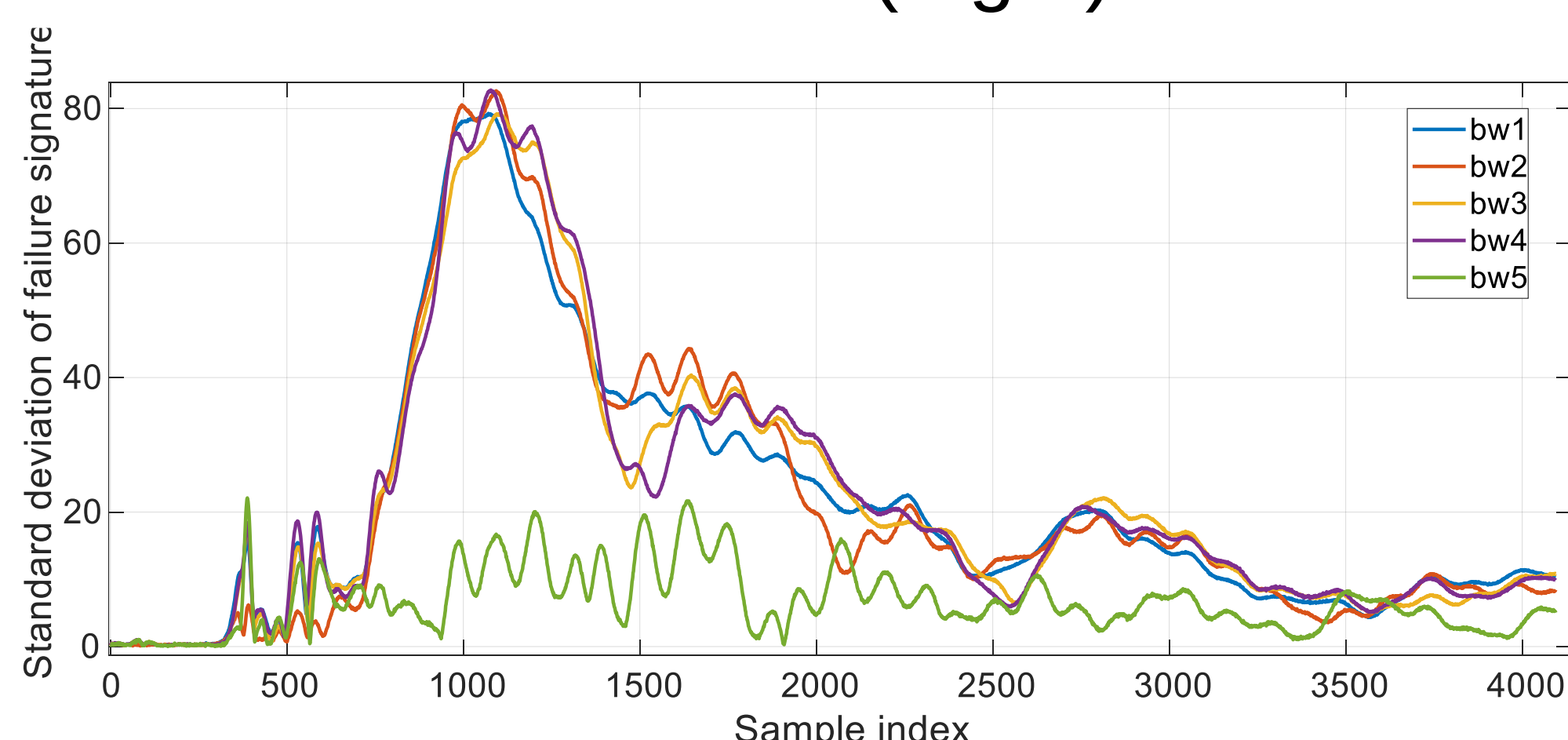


Fig. 4 Standard deviation of the failure signature for each bond wire (failure signature = signal – healthy reference)

Bond Wire State Classification

Leave-One-Device-Out (LODO): Models trained on DUT01 and DUT02 and evaluated on a previously unseen DUT03 to assess generalization across device-to-device variations

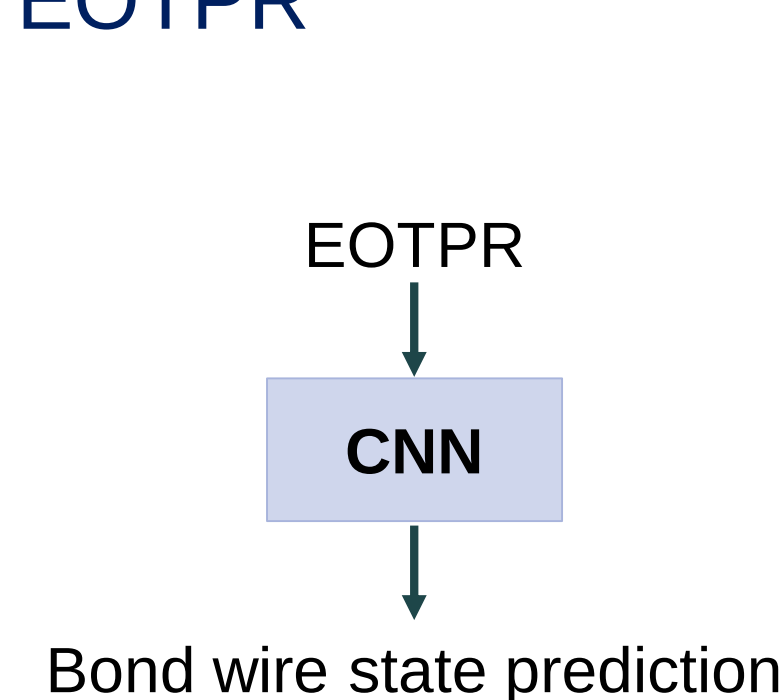
Input: EOTPR signals from one or multiple measurement pins (1P/2P/3P)

Output: Binary state prediction (intact/failed) for each bond wire (multi-label classification)

Compared approaches: End-to-end CNN and physics-informed feature-based (FeatWin) lightweight classifiers

CNN (1P/2P)

Automatic feature learning from EOTPR



Feature based (FeatWin-1P/2P/3P)

Physics-informed feature engineering

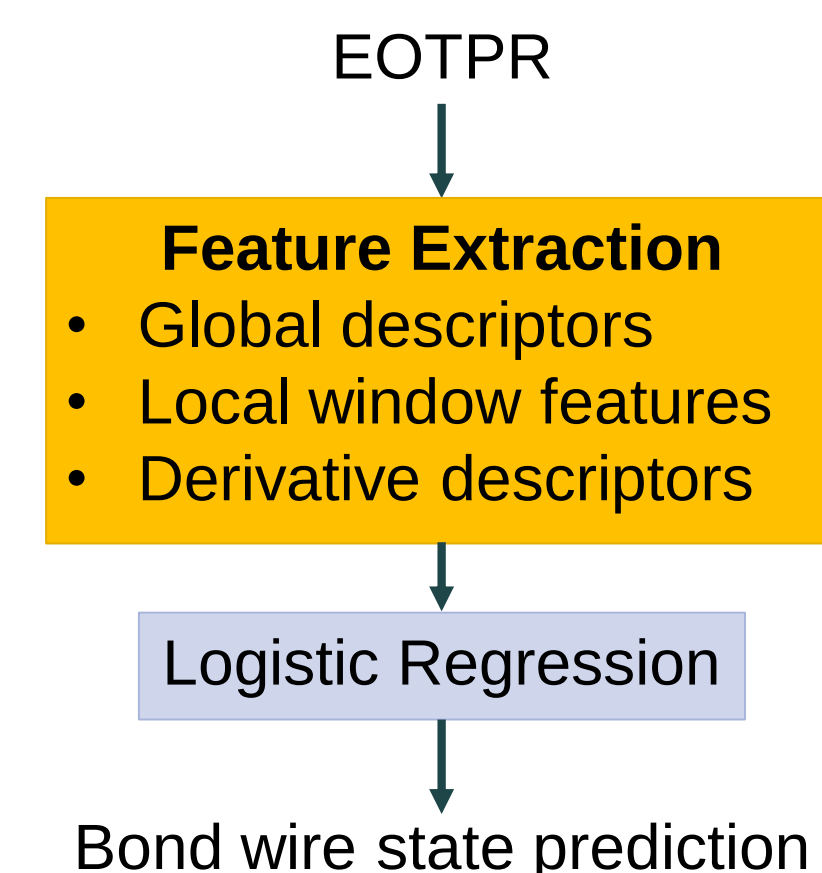


Table 1 Generalization Performance (mean±std) of Bond Wire State Estimation Models on an Unseen Device

Model	Pins	F1 source bond wires	F1 all bond wires	Accuracy
CNN-1P	6	0.780 ± 0.034	0.768 ± 0.029	0.774 ± 0.038
CNN-2P	6, 2	0.842 ± 0.035	0.888 ± 0.034	0.834 ± 0.034
FeatWin-1P	6	0.842 ± 0.078	0.801 ± 0.052	0.828 ± 0.085
FeatWin-2P	6, 2	0.882 ± 0.062	0.843 ± 0.046	0.865 ± 0.071
FeatWin-3P	6, 2, 4	0.882 ± 0.053	0.878 ± 0.047	0.863 ± 0.062
FeatWin-3P aggregated	6, 2, 4	0.893 ± 0.052	0.885 ± 0.047	0.879 ± 0.057

Conclusion

- Selecting informative signal regions and reflectometry features enables accurate bond wire state estimation with low model complexity
- Multi-pin signal fusion improves classification performance
- 88% accuracy achieved on an unseen device instance

Future Directions

- Optimized physics-informed feature descriptors
- Simulation-based data augmentation for improved generalization