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Geometry Scaling of Microwave Filters Using an Adaptive Homotopy Continuation Method

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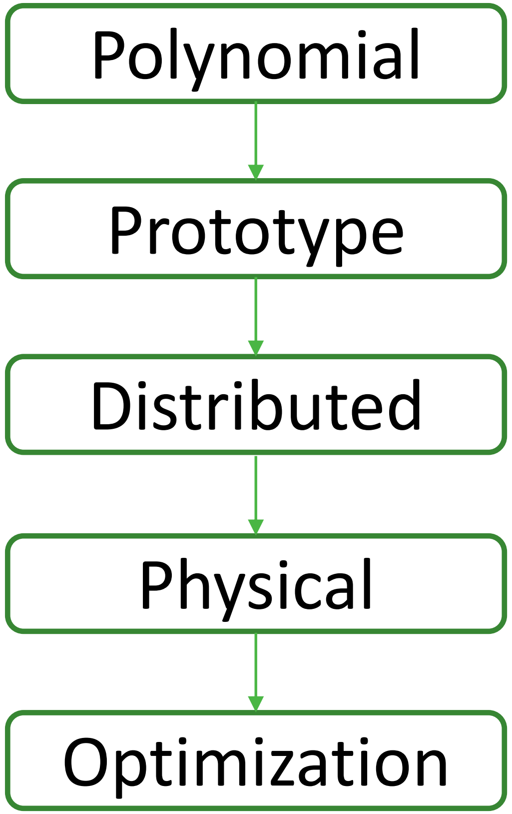
Outline

- Background
- Geometry scaling of Microwave Filters Using an Adaptive Homotopy Continuation Method
  - Adaptive Homotopy Continuation Method
  - Inverse Model Construction
- Experiment Results and Comparisons
- Conclusion

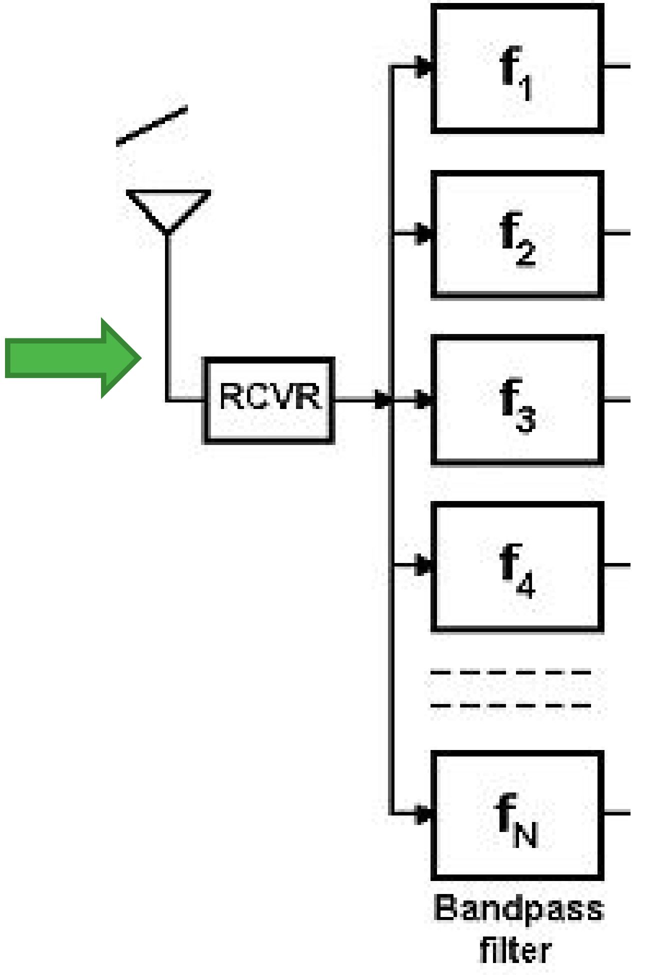
Background

- Microwave Filters
  - Components for passing and attenuating signals at specific frequency ranges
- The Filter Design Process
  - Follow several steps at different levels
  - The optimization is commonly based on full-wave electromagnetic (EM) simulation
    - Accounts for 90% of the total design time



Background

- Geometry Scaling
  - To redesign filters with the same structure for different required center frequencies and bandwidths
  - E.g., a multiplexing network with multiple channels
- Human effort
  - The synthesis technique for a single filter is well-established
  - “trial and error” to improve efficiency by skipping steps

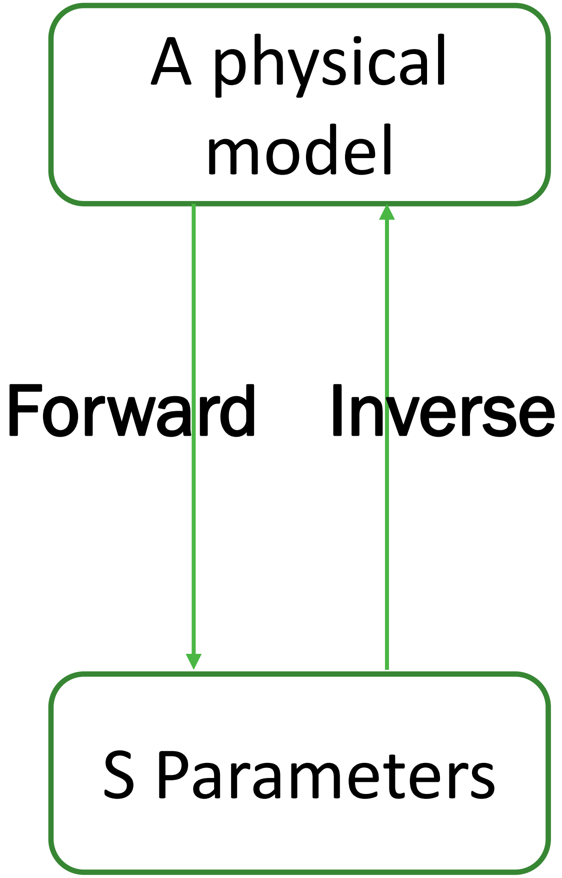


- Challenges:
  - Too much human participation
  - Non-linearity can result in failure
  - Low efficiency
  - Can not be reused

- Inverse model can be a promising solution

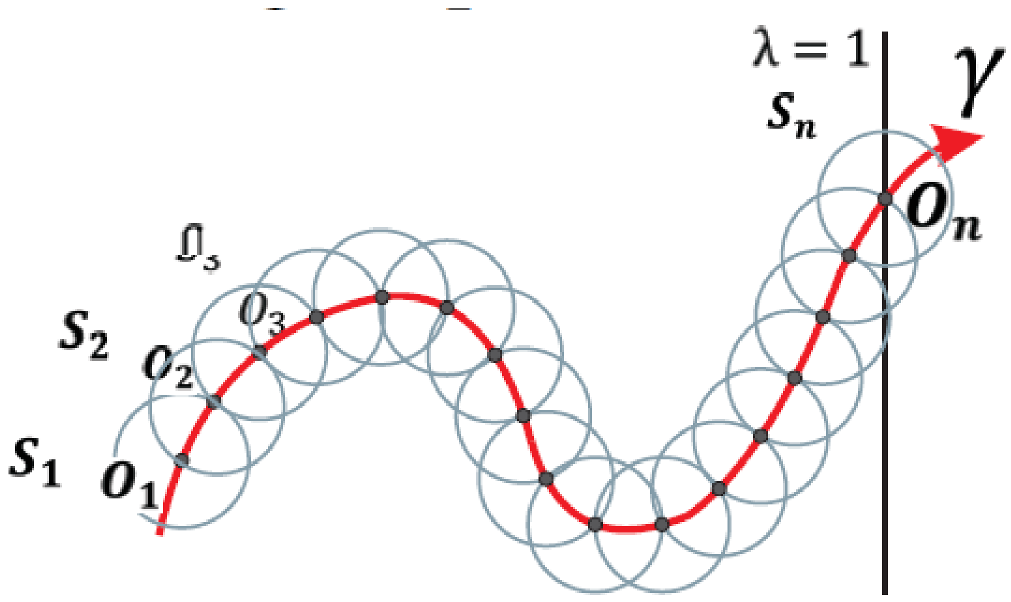
Background

- Inverse model
  - Output the physical parameters given the electrical parameters
- Why is the inverse model promising?
  - Be reused to directly give the filter's dimension without repetitive EM simulations
- How to train a reliable inverse model?
  - A high-quality database is needed
  - Homotopy Continuation (HC) can be applied



Background

- Homotopy Continuation (HC)
  - Divide a problem into a series of intermediate sub-problems
  - Each sub-problem is solved from its previous solution
    - A predictor followed by a corrector
- Why is HC applied?
  - More linear and easier to solve
  - The database is built by collecting all the intermediate solutions



An example of HC applications [1]

Adaptive HC Method

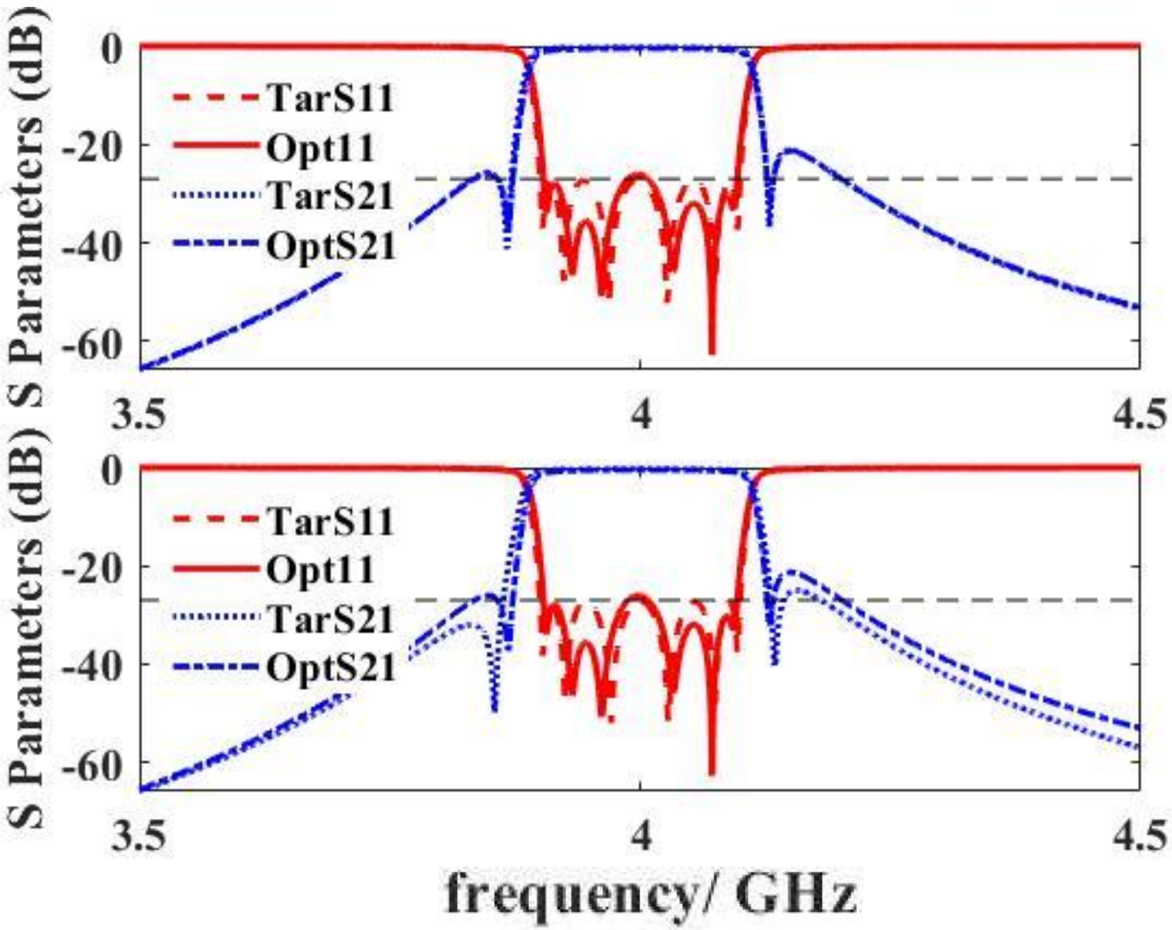
- 1. HC Step Considerations
  - Too large: fail to solve the next sub-problem
  - Too small: the computational cost increases
- Adaptive HC steps δ^i
  - Adjusted by the responses of physical parameters from the predictor

$$\delta^i = 2 * \delta^{i-1}, if\ C^{i-1} < \varepsilon$$
$$\delta^i = 0.5 * (\delta^{i-1} + \delta^{i-2}), if\ C^{i-1} \geq \varepsilon\ \&\ C^{i-2} < \varepsilon$$
$$\delta^i = \delta^{i-1}, if\ C^{i-1} \geq \varepsilon\ \&\ C^{i-2} > \varepsilon$$

- $BW^{i-1} = Predictor(x)$ is solved as $x = L^{i-1}$, then $BW^i = BW^{i-1} + \delta^i$
- C^{i-1} is the cost function of $Predictor(L^{i-1})$

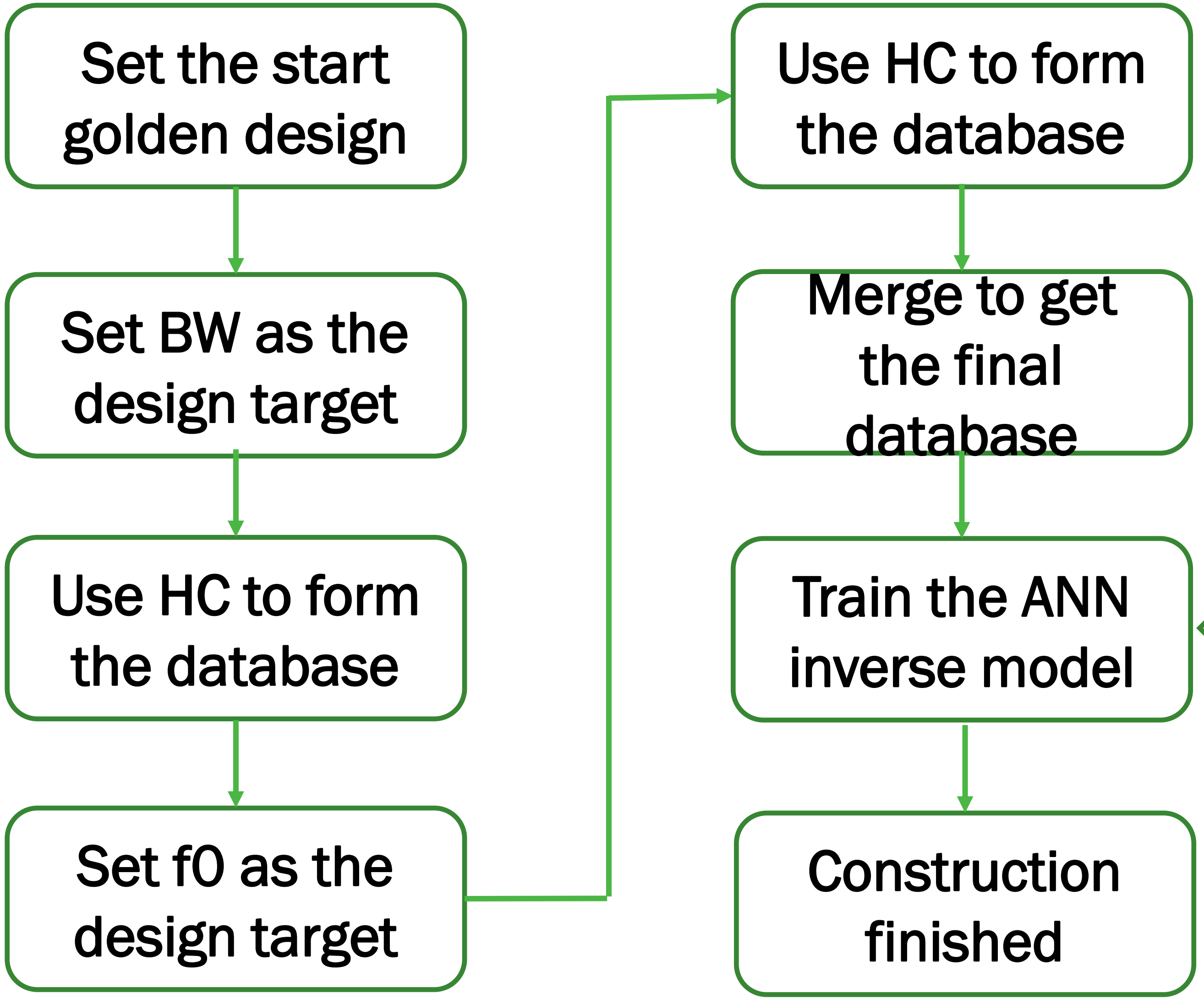
Adaptive HC Method

- 2. Inclusion of Transmission Zeros (TZs)
  - For the precise control of the response shape
  - Top figure: consider the shift of TZs
  - Bottom figure: the target normal TZS are the same as the golden design



Comparisons between target and optimal responses

Inverse Model Construction

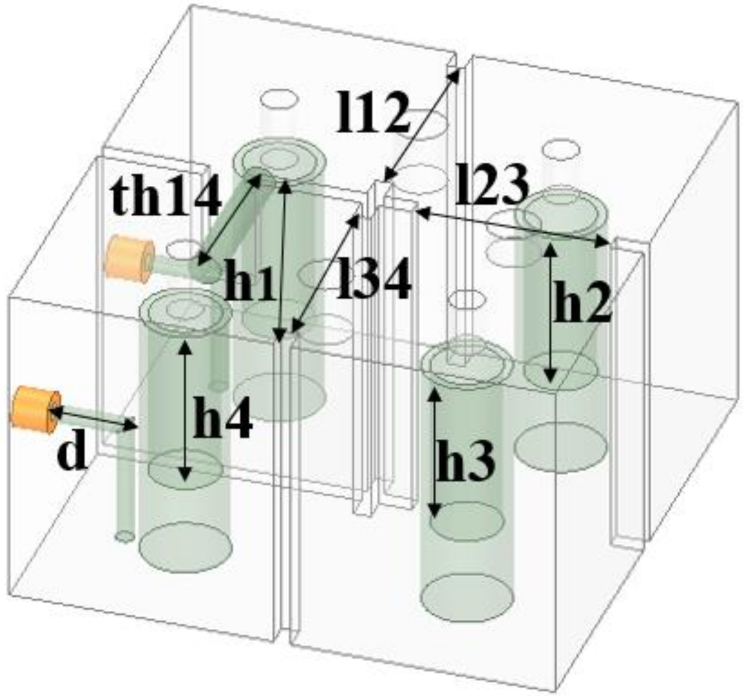


Why to chose ANN?

- Good at dealing with huge volume of data;
- Easy to build and train

Experiment Results

- Set up
  - A fourth-order coaxial resonator filter
  - 9 physical parameters
  - 2 TZs
  - Golden design at $BW = 3\%$, $f_0 = 1.95$ GHz

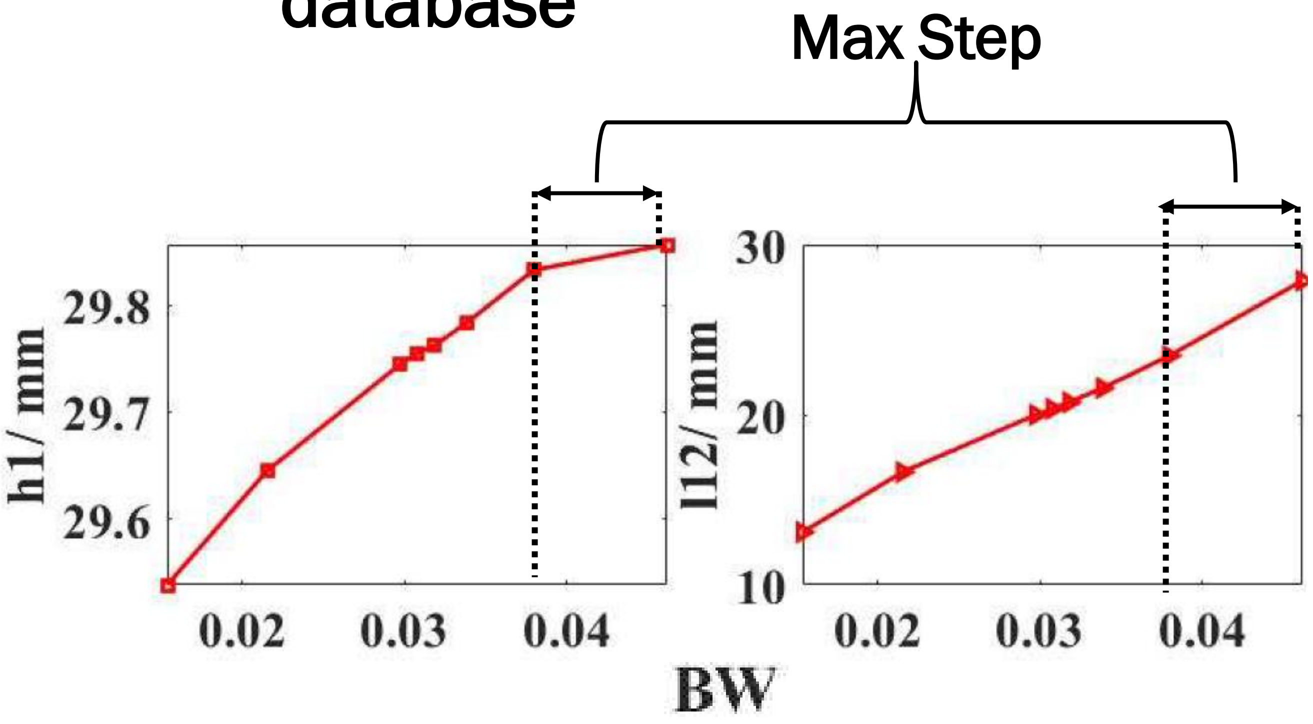


Desired BW and f0 → The well trained ANN → Target TZs

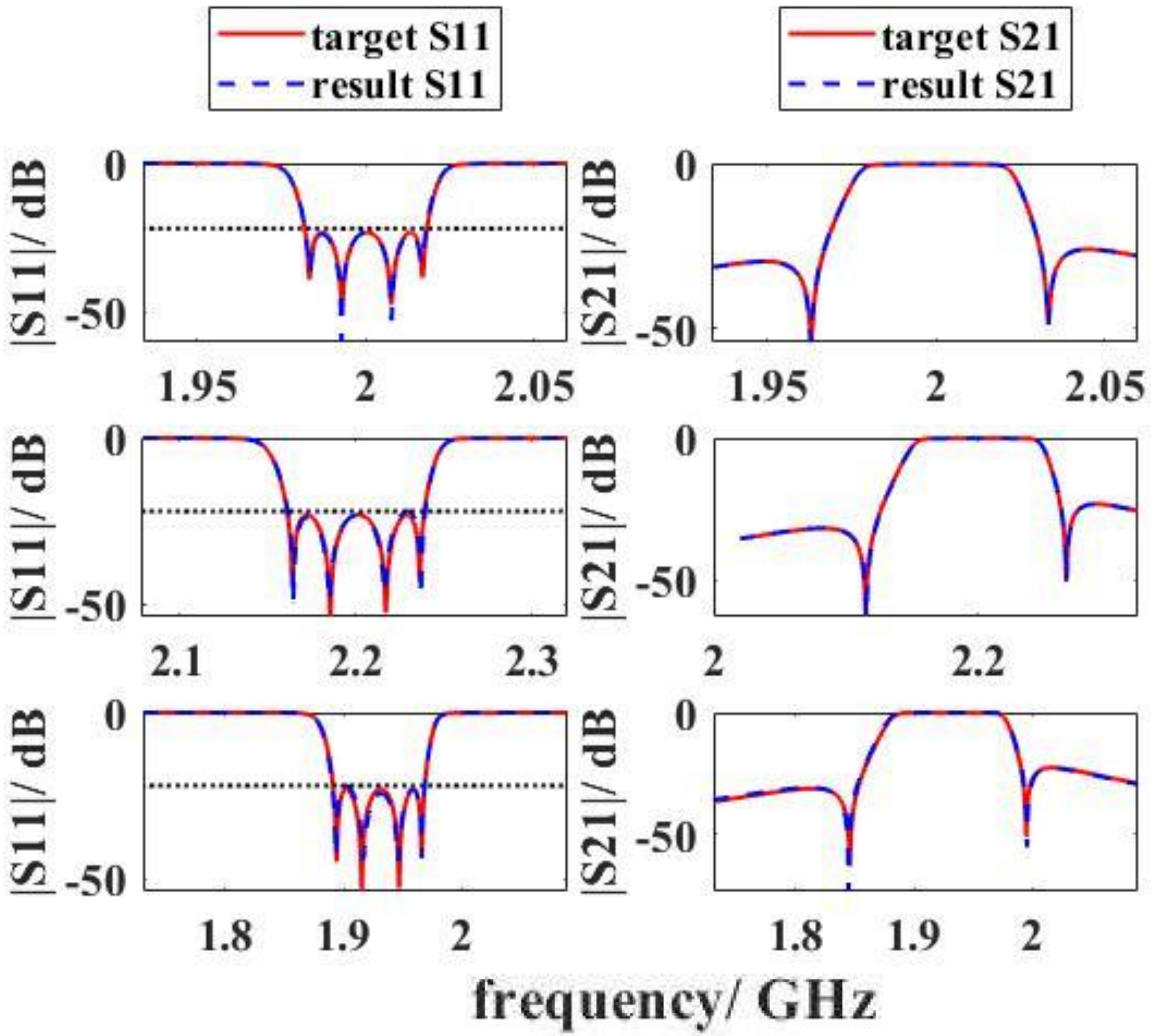
The well trained ANN → Physical parameters → Tune if necessary

Experiment Results

- Results
  - An 8×7 grid is formed as the database

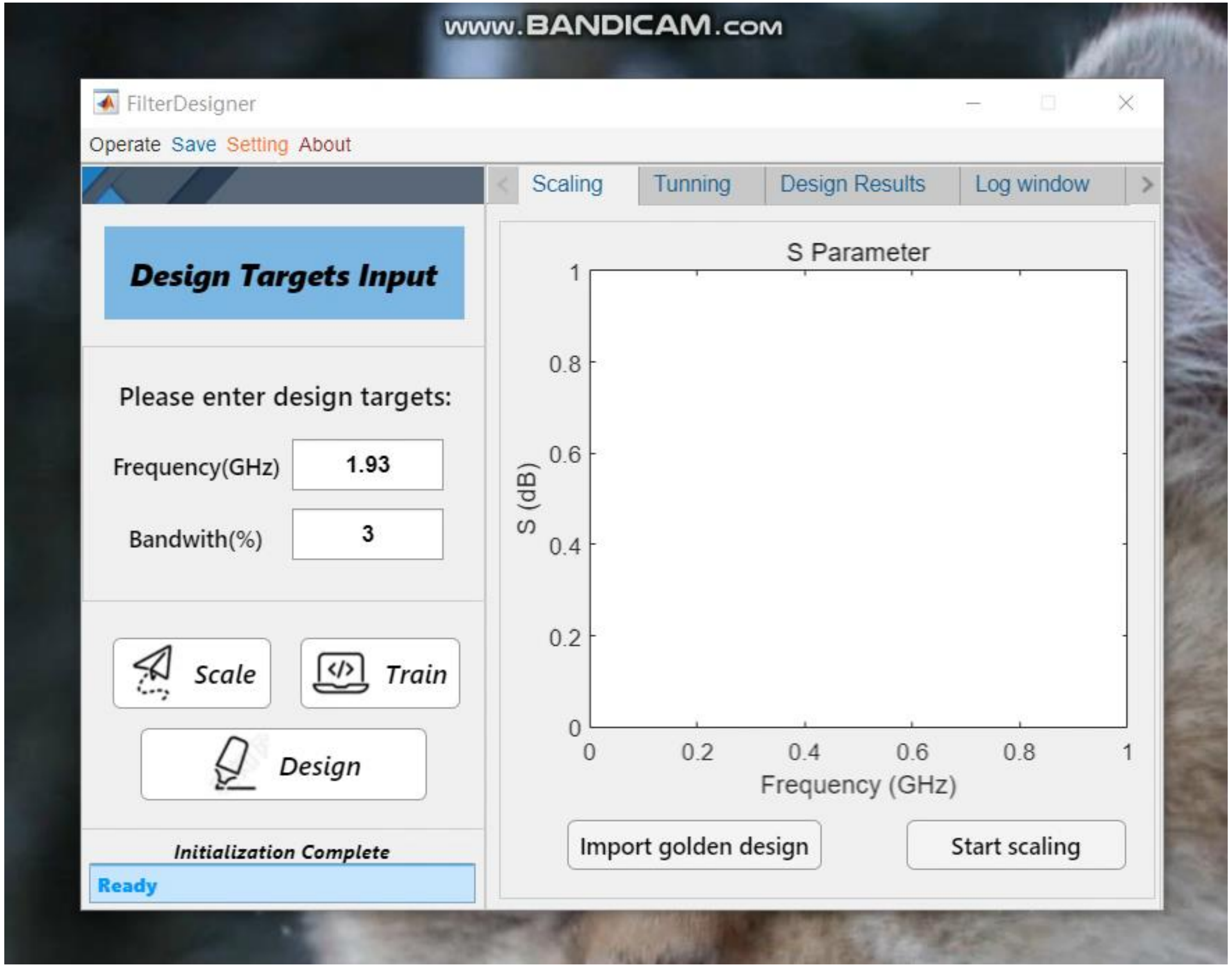


Some design variables vary with BW



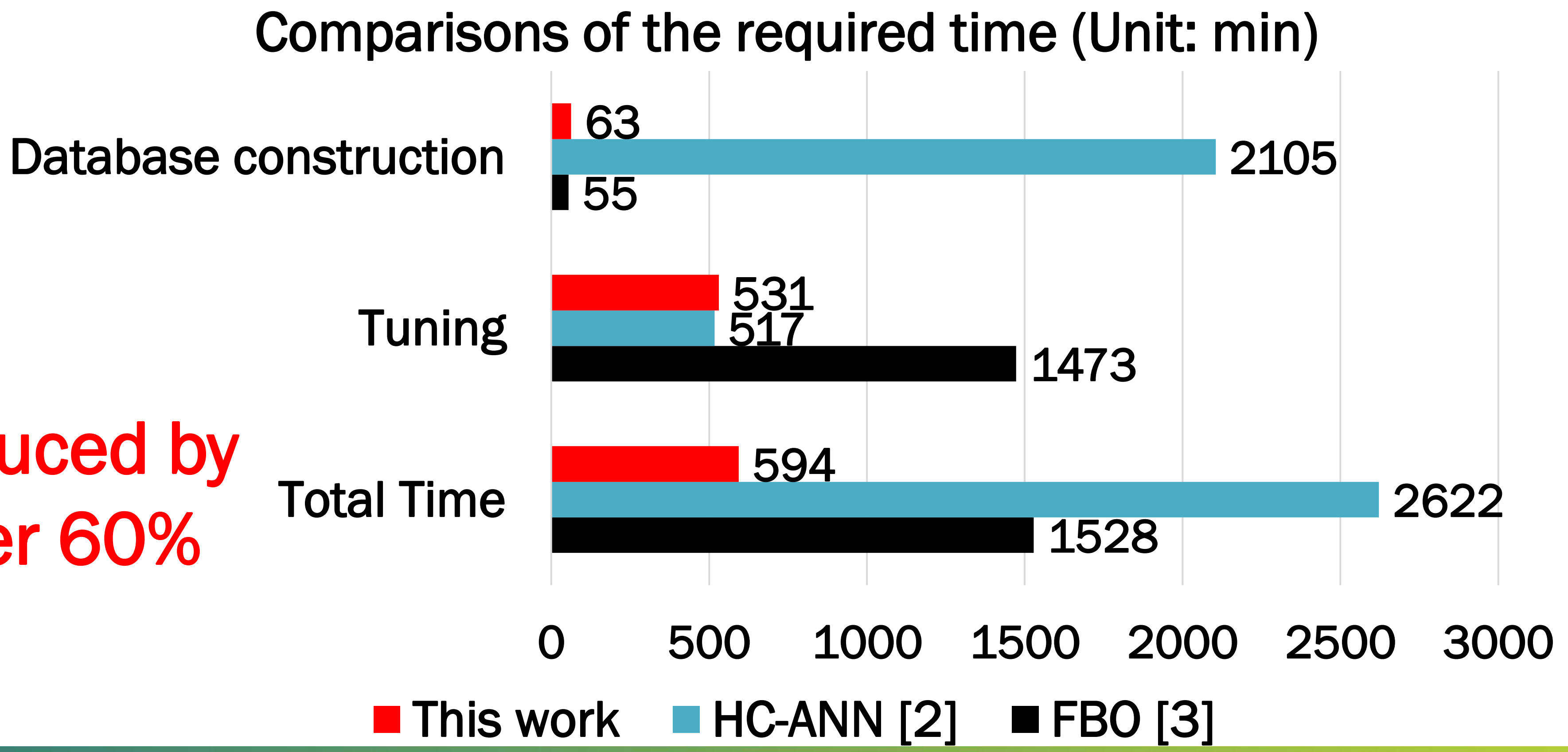
Three examples of geometry scaling

Experiment Results



Comparisons

- [2]: small steps; more cost on the database construction
- [3]: large steps; more cost on tunings



Reduced by over 60%

Conclusions

- To perform geometry scaling for multiple desired design specifications automatically and efficiently can be challenging
- Adaptive steps are embedded into HC
- TZs are included in the database
- To generalize this work to other types of filters and other design specifications besides the bandwidth and center frequency

Reference

- [1] G. Diaz-Arango, L. Hernandez-Martinez, A. Sarmiento-Reyes and H. Vazquez-Leal, "Fast and robust homotopy path planning method for mobile robotics," *2016 IEEE Intern. Symposium On Circuits and Systems (ISCAS),* Montreal, QC, Canada, 22-25 May. 2016.
- [2] C. Roy and K. Wu, "Homotopy optimization and ANN modeling of millimeter-wave SIW ciuciform coupler," *IEEE. Trans. Microw. Theory Techn*., vol. 70, no. 11, pp. 4751–4764, Nov. 2022.
- [3] S. Koziel and J.W.Bandler, "Low-cost dimension scaling and tuning of microwave filters using response features," *2016 IEEE MTT-S International Microwave Symposium (IMS),* San Francisco, CA, USA, 22-27 May. 2016.