Tuning Space Mapping: The State of the Art

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Tuning Space Mapping Approach

simultaneously achieves electromagnetics (EM) accuracy and circuit-design speed

based on the intuitive idea of "space mapping" and an EM-simulator-based tuning methodology

we review the state of the art of computer-based optimal tuning of microwave circuits

we explain the art of microwave design optimization through our "tuning space mapping" procedures

Tuning Space Mapping Procedures

involve three models

① fine model

② auxiliary fine model (fine model with tuning ports) of various distinct types (e.g., Type 1 and Type 0)

③ tuning models (auxiliary fine models augmented with tunable or tuning elements)

we implement these models utilizing commercial simulation software

Postproduction Tuning

computer-aided network tuning (*Pinel, 1971*)

design centering, tolerancing and tuning (*Bandler et al., 1976*)

postproduction tuning technique utilizing simulated sensitivities and response measurements (*Bandler et al., 1981*)

functional and integrated tuning approach (*Bandler and Salama, 1983, 1985*)

a scalar transmission-based tuning technique (*Zahirovic et al., 2010*)

tuning robot (*Yu and Tang, 2003*)

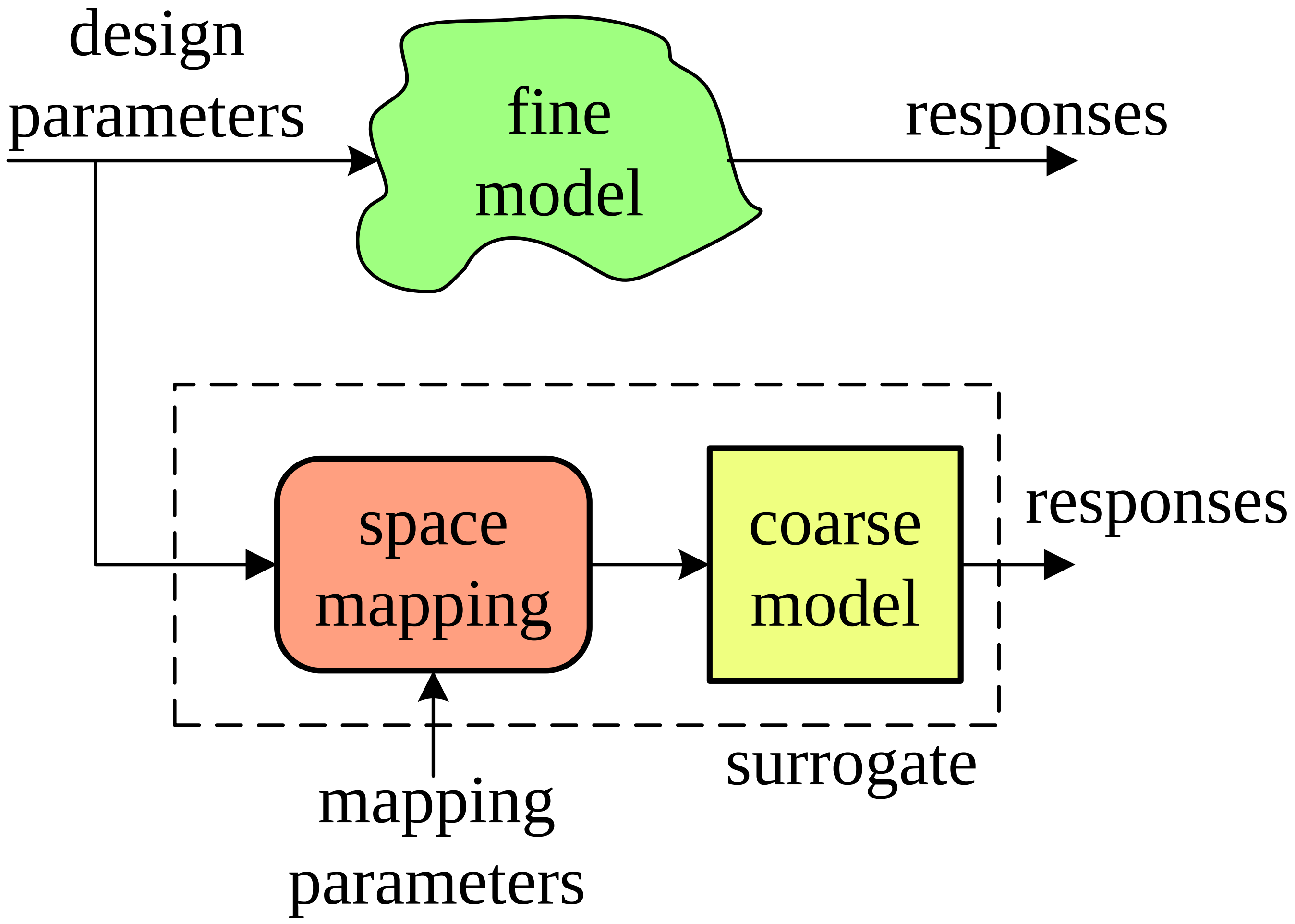
Electromagnetics-Simulator-Based Tuning

fast analysis and optimization of combline filters using tunable components in FEM simulator (*Swanson and Wenzel, 2001*)

design closure—companion modeling and tuning methods (*Rautio, 2006*)

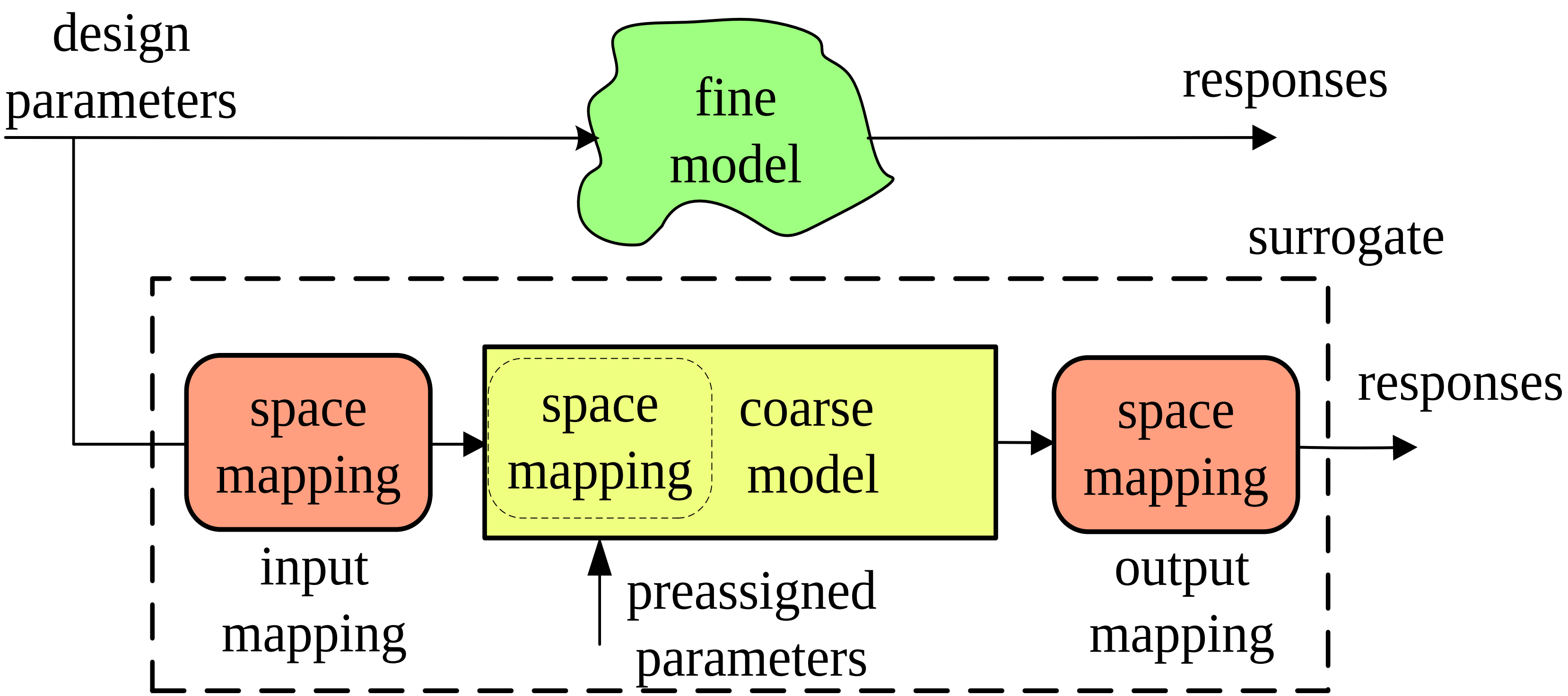
Space Mapping Concept

(*Bandler et al., 1994*-)



Implicit, Input and Output Space Mappings

(*Bandler et al., 2003*-)



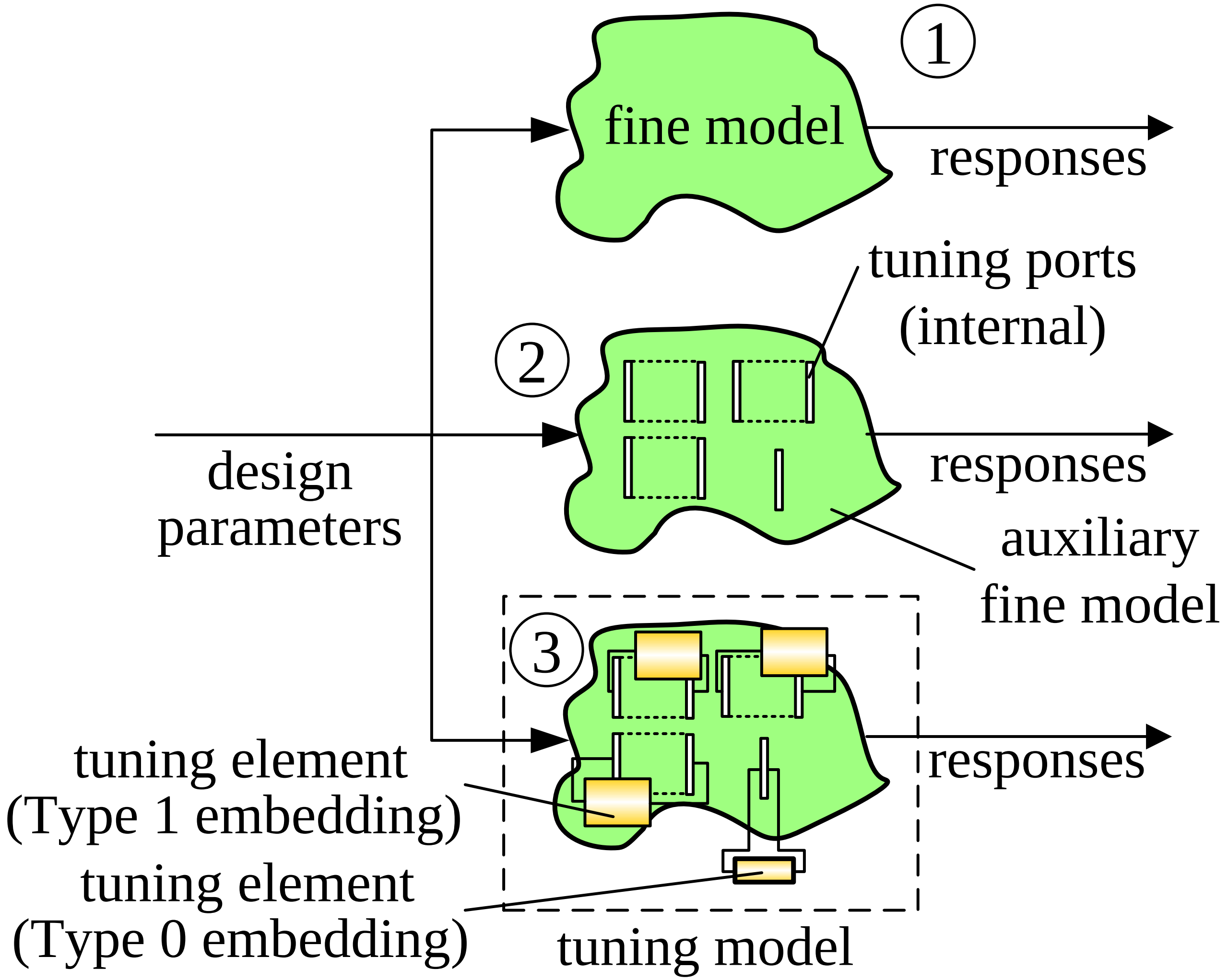
expert engineering knowledge helpful (few designable variables)

expertise helpful in "tuning the surrogate" (many possibilities, e.g., dielectric constant)

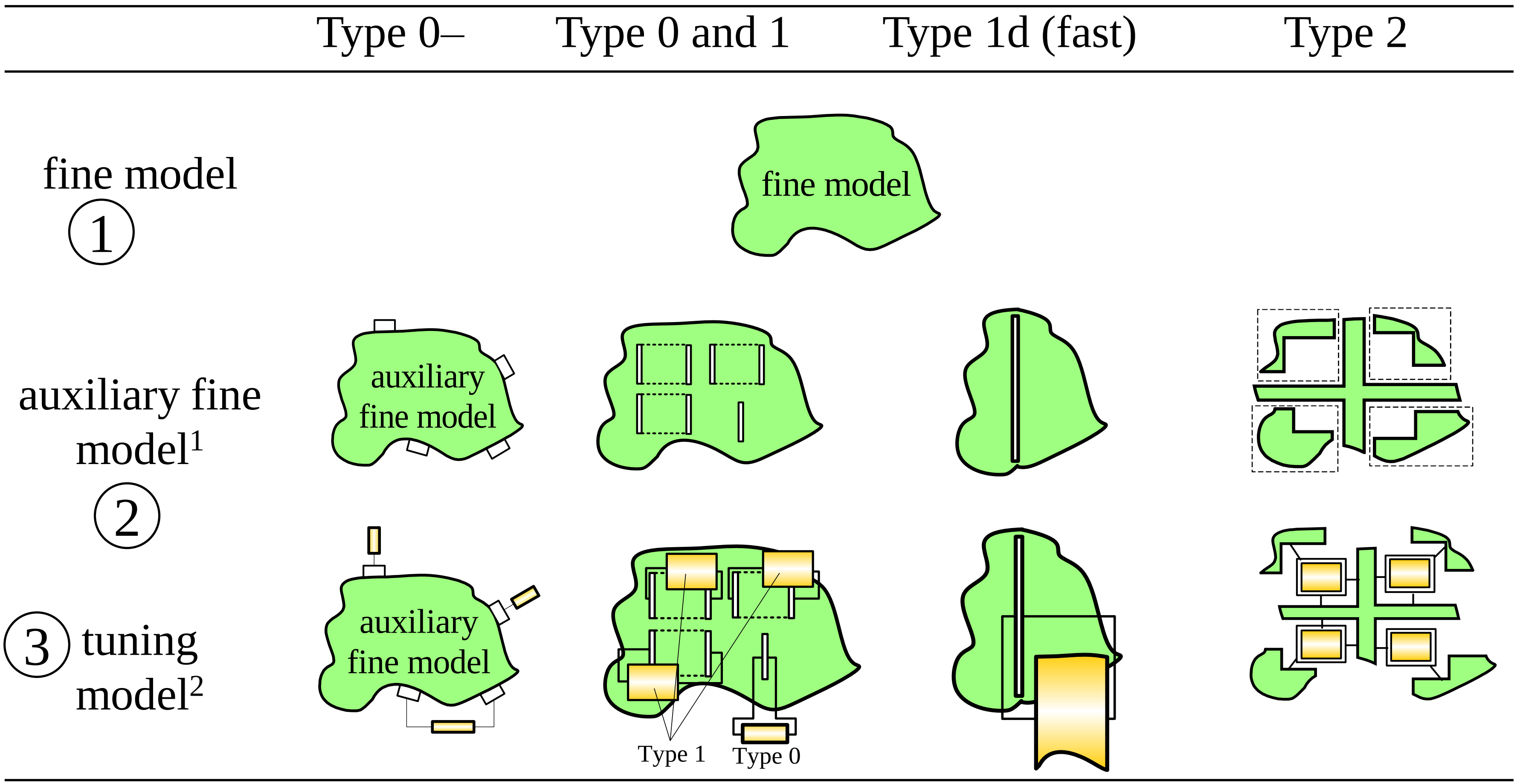
engineering expertise perhaps less necessary (many output variables)

Tuning Space Mapping (TSM): Type 0 and Type 1

(*Cheng et al., 2012*)



Tuning Space Mapping (TSM): Auxiliary Fine Model and Tuning Model (*Cheng et al., 2012*)

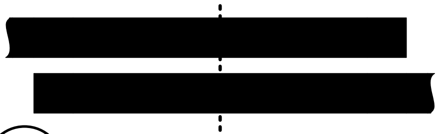


1. auxiliary fine model: fine model with tuning ports or split fine model components
2. tuning model: tuning components are added to the auxiliary fine model

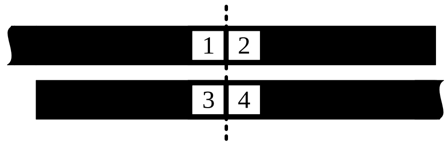
Tuning Space Mapping (TSM): Type 0 and Type 1

(*Cheng et al., 2012*)

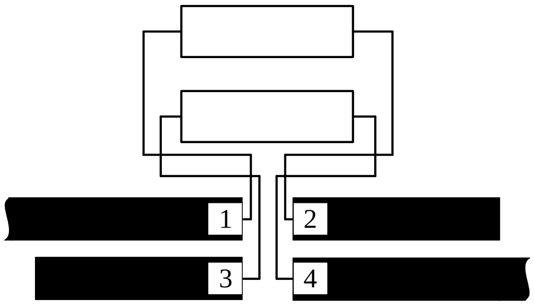
Type 0 tuning



① fine model



② auxiliary fine model

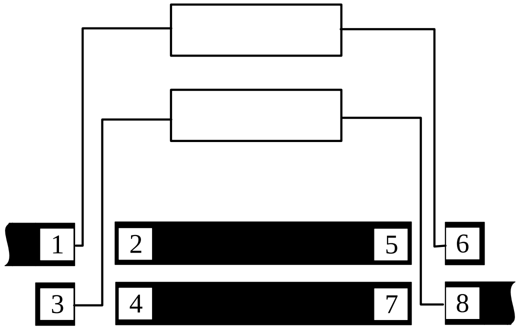


③ conceptual tuning model

Type 1 tuning

① fine model

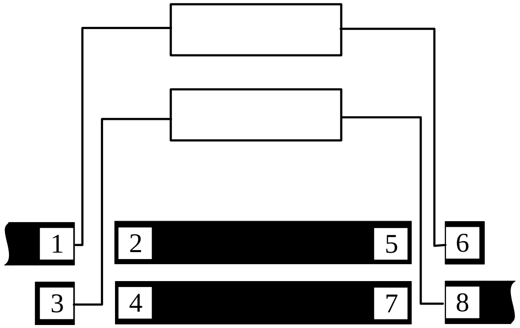
② auxiliary fine model



③ conceptual tuning model

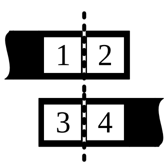
Tuning Space Mapping (TSM): Type 1 and Type 1d
(*Cheng et al., 2012*)

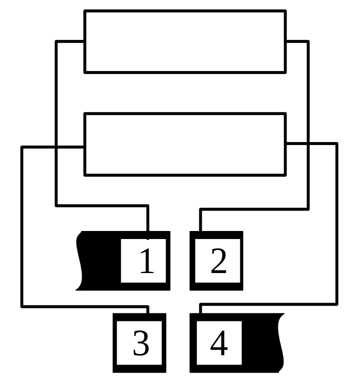
Type 1 tuning



① fine model ② auxiliary fine model ③ conceptual tuning model

Type 1d tuning

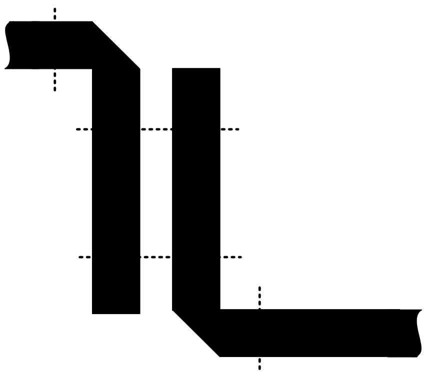


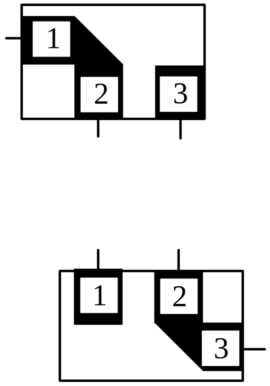


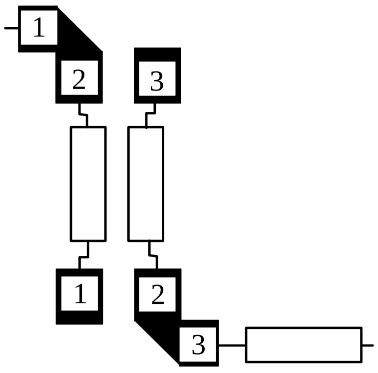
① fine model ② auxiliary fine model ③ conceptual tuning model

Tuning Space Mapping (TSM): Type 2
(*Cheng et al., 2012*)

Type 2 tuning







① fine model ② auxiliary fine model ③ conceptual tuning model

Tuning Space Mapping **Optimization** (*Cheng et al., 2012*)

the original optimization problem

$$\boldsymbol{x}^* \triangleq \arg \min_{\boldsymbol{x}} U(\boldsymbol{R}(\boldsymbol{x}))$$

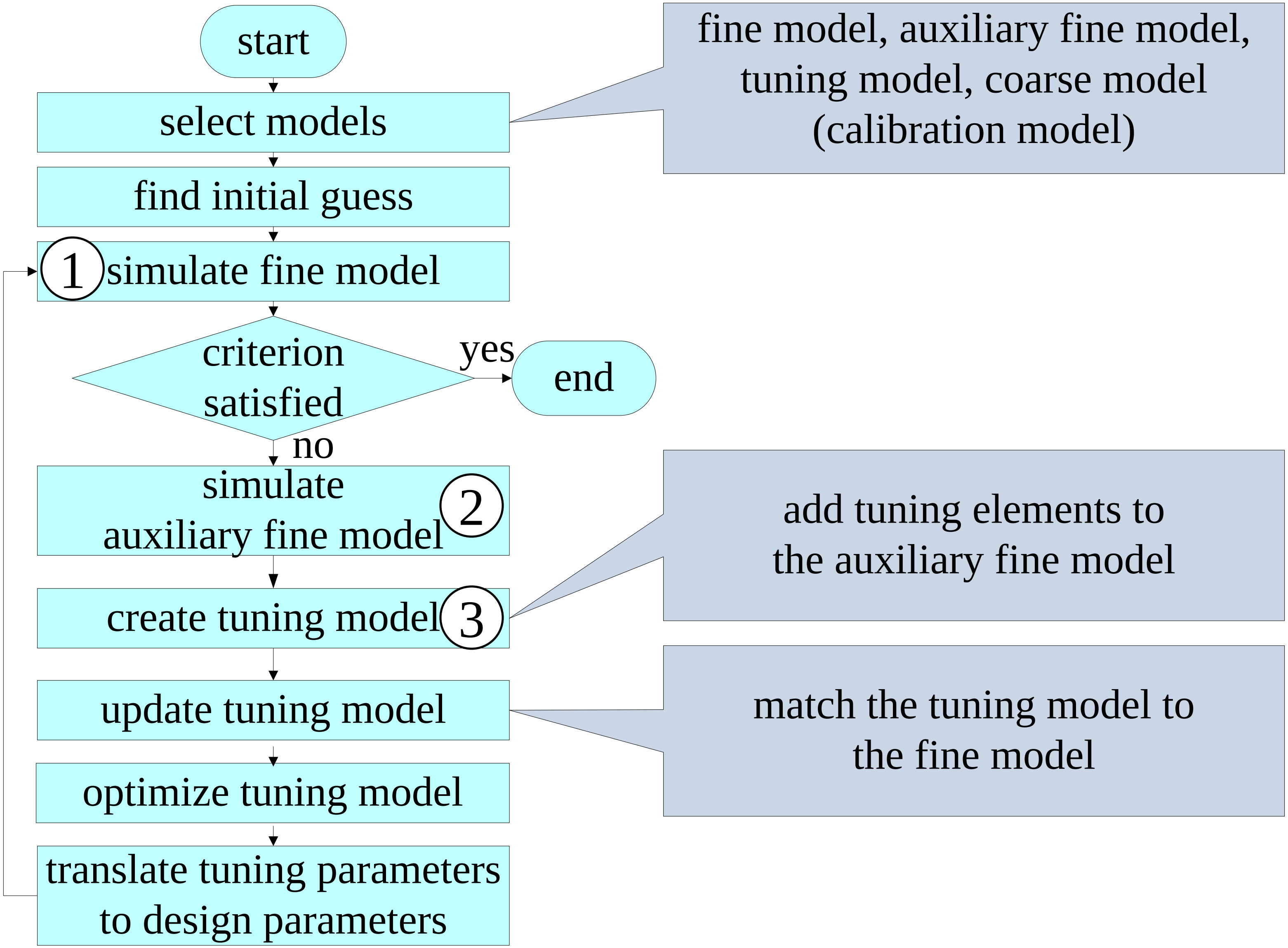
align tuning model with fine model

$$\boldsymbol{p}^{(i)} = \arg\min_{\boldsymbol{p}} \left\| \boldsymbol{R}_f(\boldsymbol{x}^{(i)}) - \boldsymbol{R}_t^{(i)}(\boldsymbol{t}^{(i)}, \boldsymbol{p}) \right\|$$

optimize tuning model

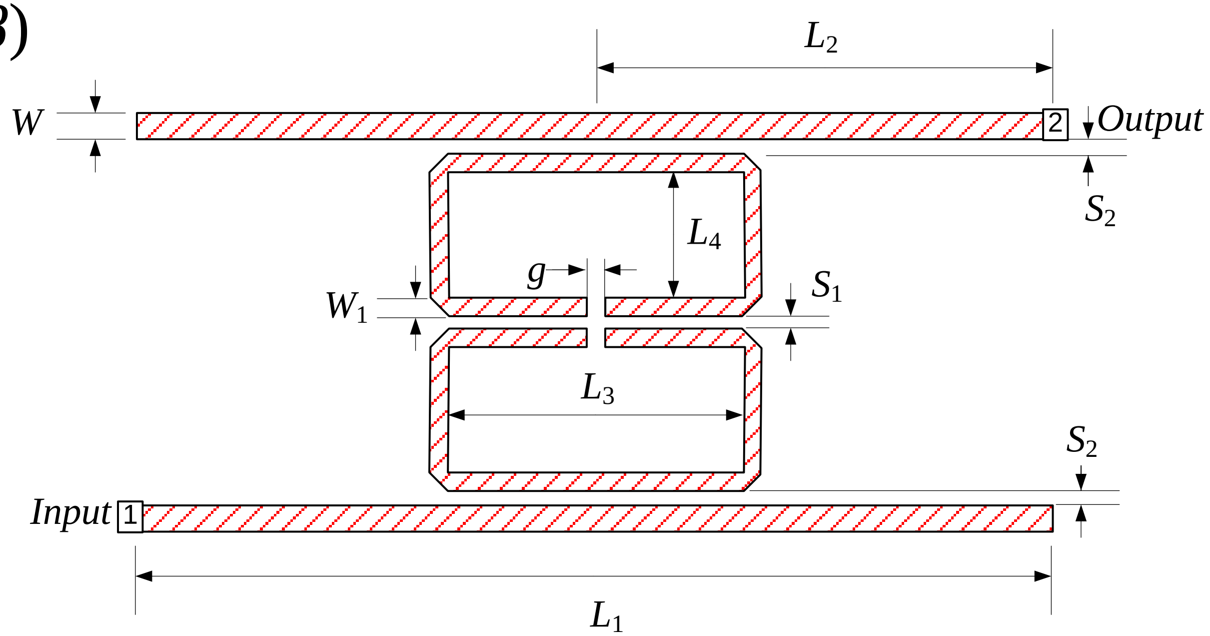
$$\boldsymbol{t}_{\text{opt}}^{(i)} = \arg\min_{\boldsymbol{t}} U\left(\boldsymbol{R}_t^{(i)}(\boldsymbol{t}, \boldsymbol{p}^{(i)})\right)$$

Tuning Space Mapping (TSM) Flowchart (*Cheng et al., 2012*)



Open-loop Ring Resonator Bandpass Filter

(*Koziel et al., 2008*)



design parameters:

$\boldsymbol{x} = [L_1\ \ L_2\ \ L_3\ \ L_4\ \ S_1\ \ S_2\ \ g]^T$ mm

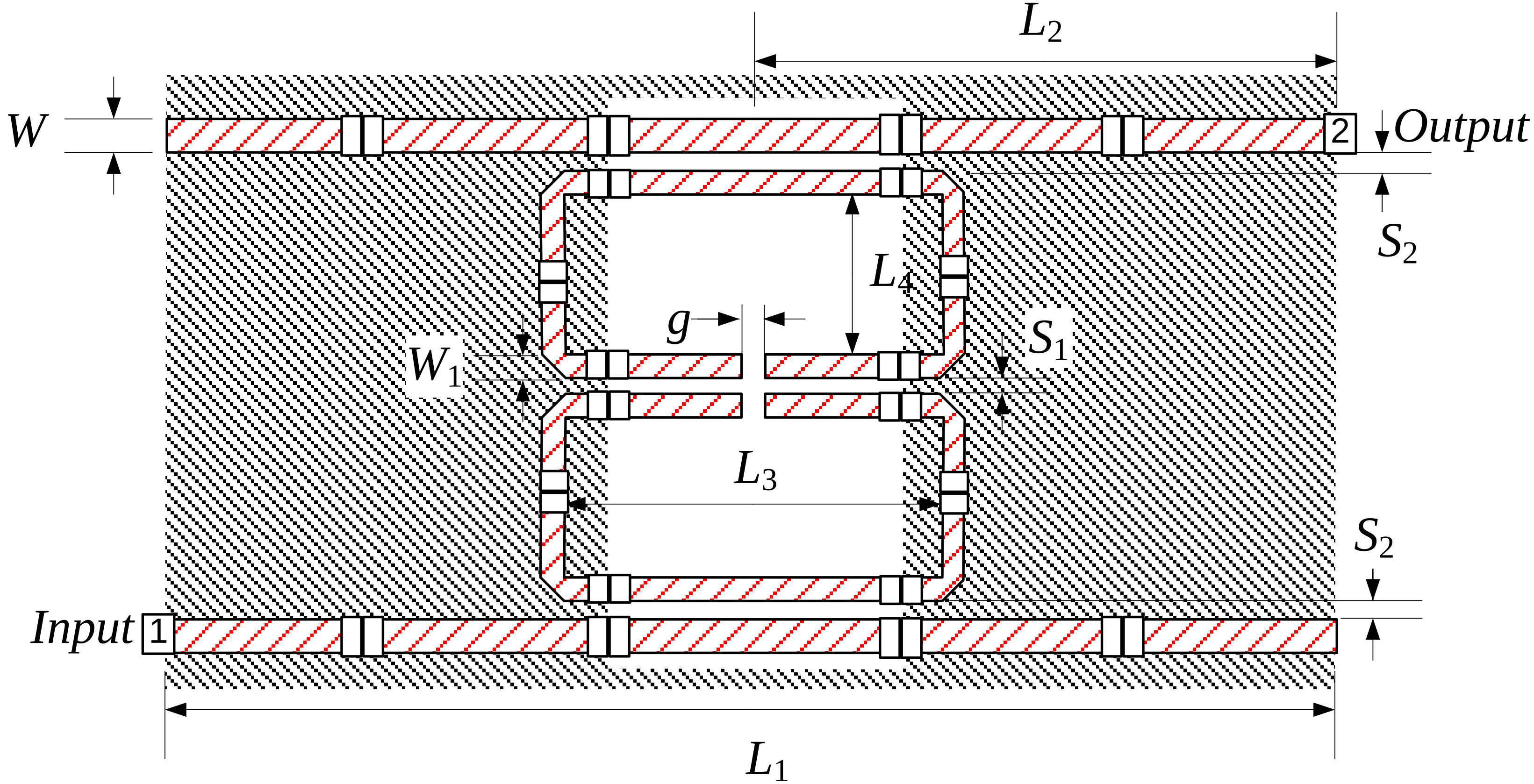
specifications:

$|S_{21}| \geq -3$ dB, 2.8-3.2 GHz

$|S_{21}| \leq -20$ dB, 1.5-2.5 GHz, 3.5-4.5 GHz

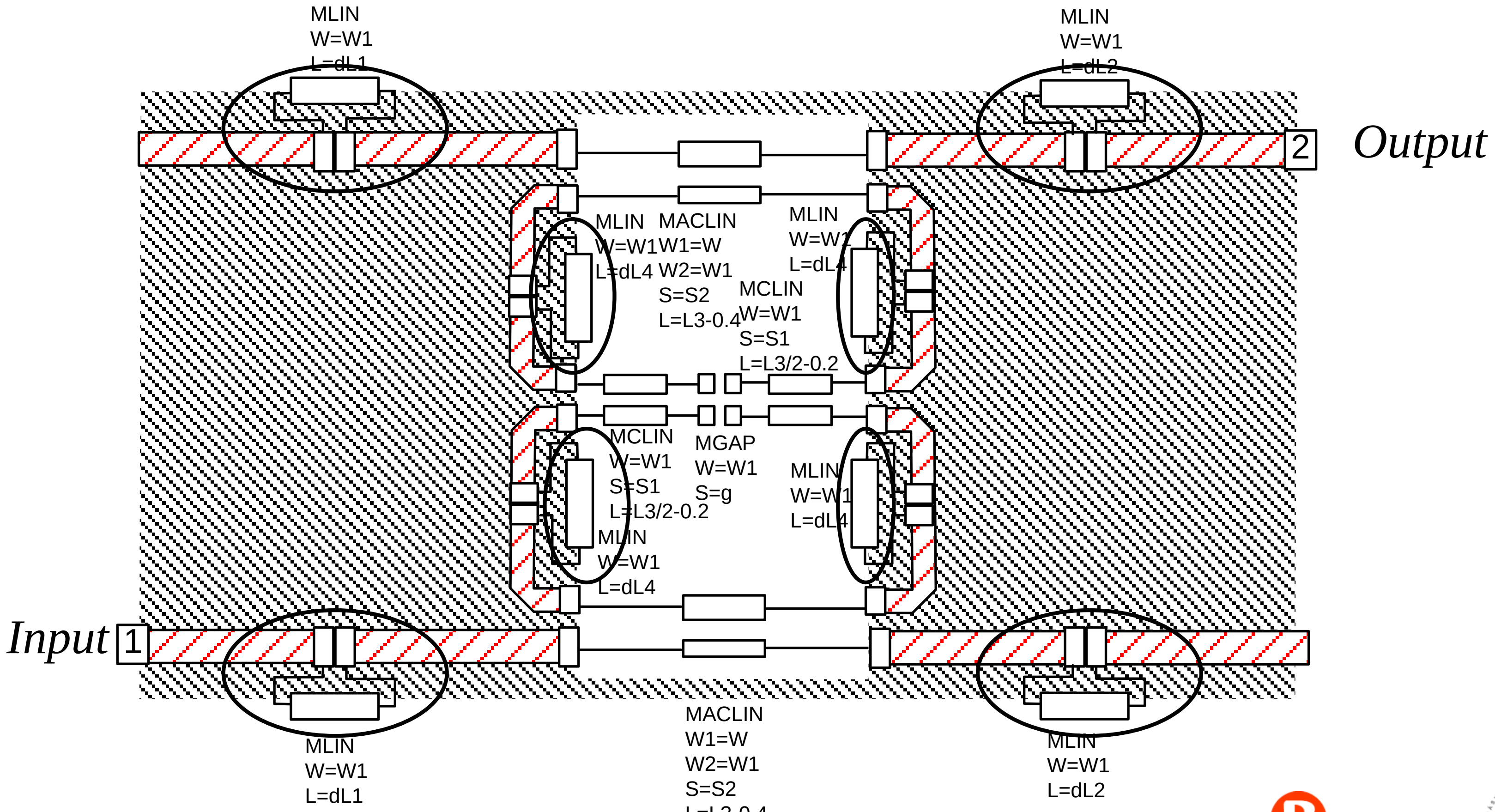
Open-loop Ring Resonator Bandpass Filter:
Types 1 and 0 Tuning Auxiliary Fine Model (*Cheng et al., 2010*)

Sonnet ***em*** model with internal (co-calibrated) ports:



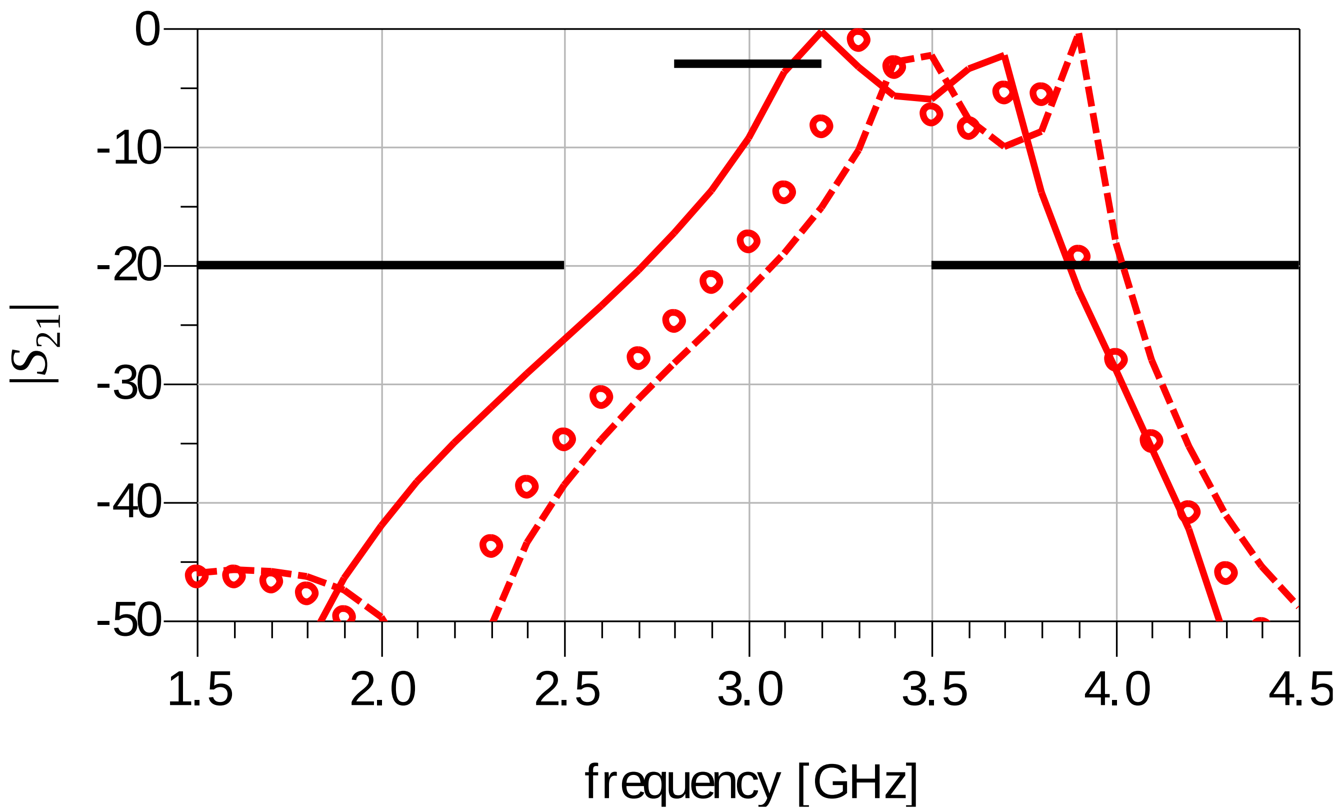
Open-loop Ring Resonator Bandpass Filter: Mixed Type 1 and Type 0 Tuning Model (*Cheng et al., 2010*)

Sonnet ***em*** tuning model with tuning elements
(Type 0 elements in circles)



Open-loop Ring Resonator Bandpass Filter:
Mixed Type 1 and Type 0 Tuning Model (*Cheng et al., 2010***)**

initial responses: tuning model (—), fine model (○),
fine model with co-calibrated ports (---)



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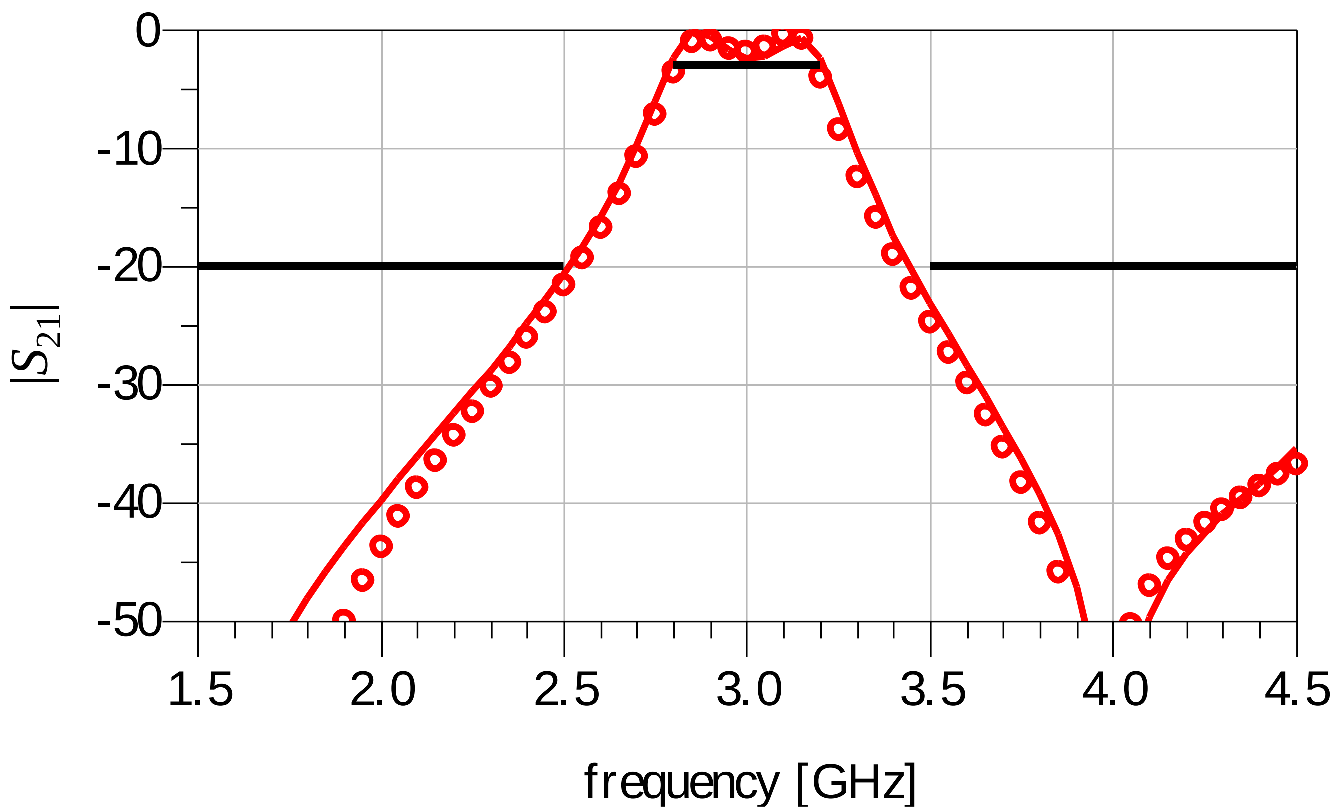
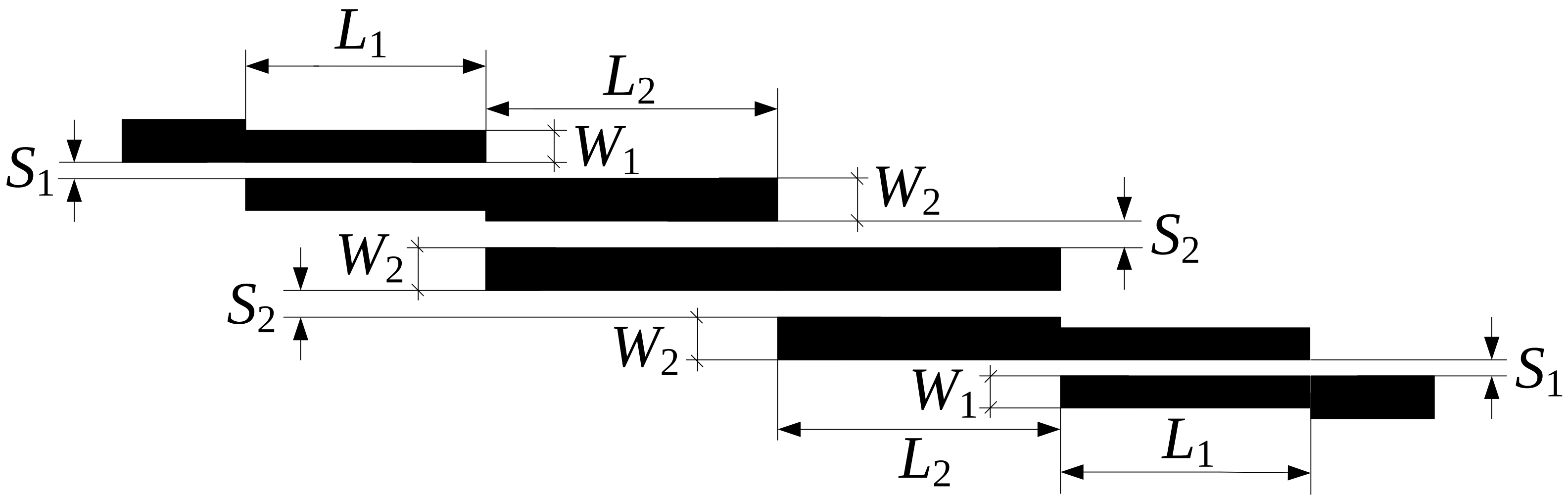
Open-loop Ring Resonator Bandpass Filter:
Mixed Type 1 and Type 0 Tuning Model (*Cheng et al., 2010*)

responses after two iterations: the tuning model (—), corresponding fine model (○)



Third-Order Chebyshev Filter (*Kuo et al., 2003*)

fine model (Sonnet ***em***)



design variables: $\boldsymbol{x} = [L_1\ L_2\ S_1\ S_2]^T$

design specifications:

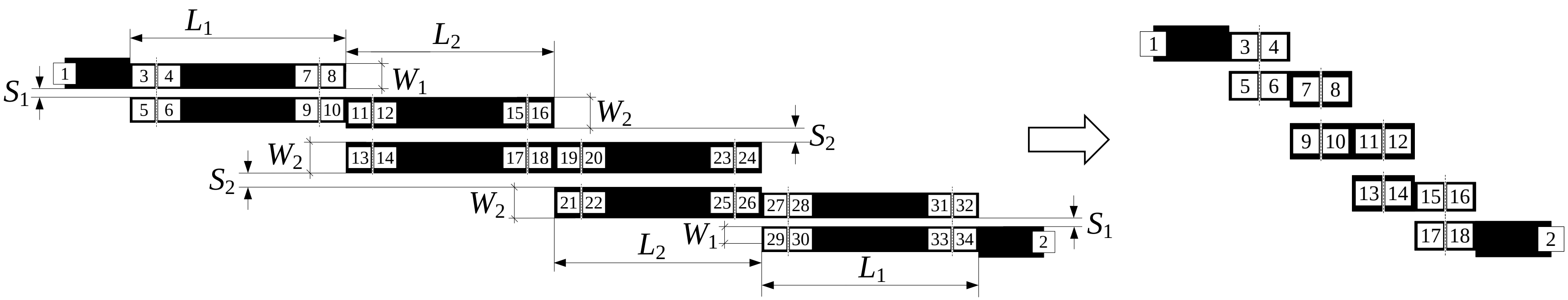
$|S_{21}| \geq -20$ dB, 1.0-1.6 GHz, 2.4-3.0 GHz

$|S_{21}| \leq -3$ dB, 1.8-2.2 GHz

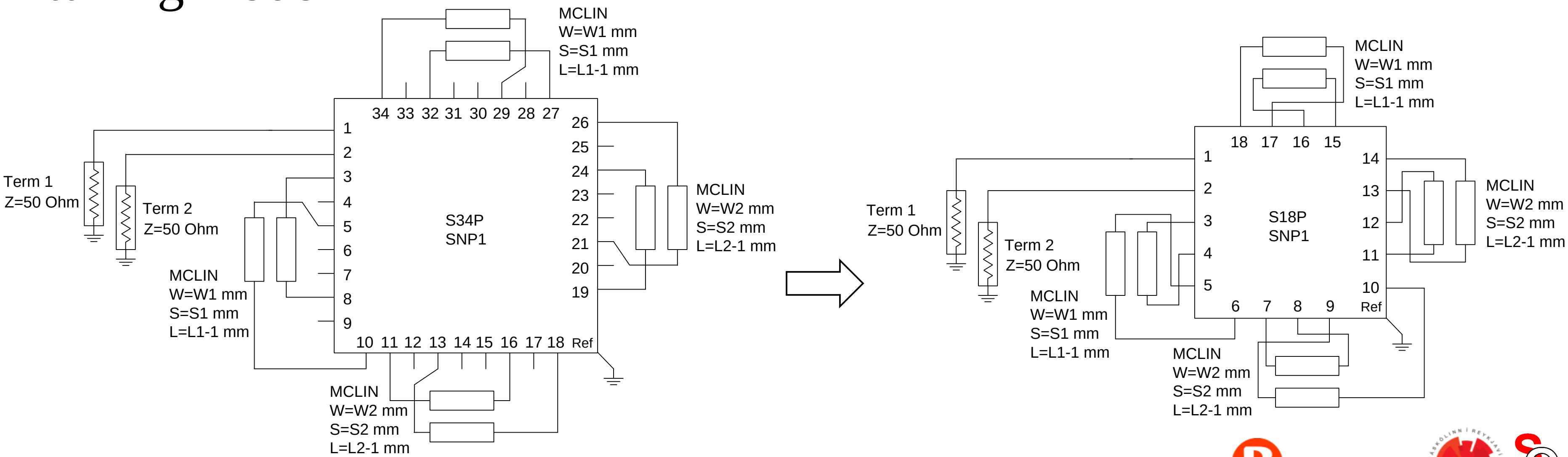
Third-Order Chebyshev Filter: Type 1d (Fast) Tuning

(*Koziel et al., 2010*)

auxiliary fine model

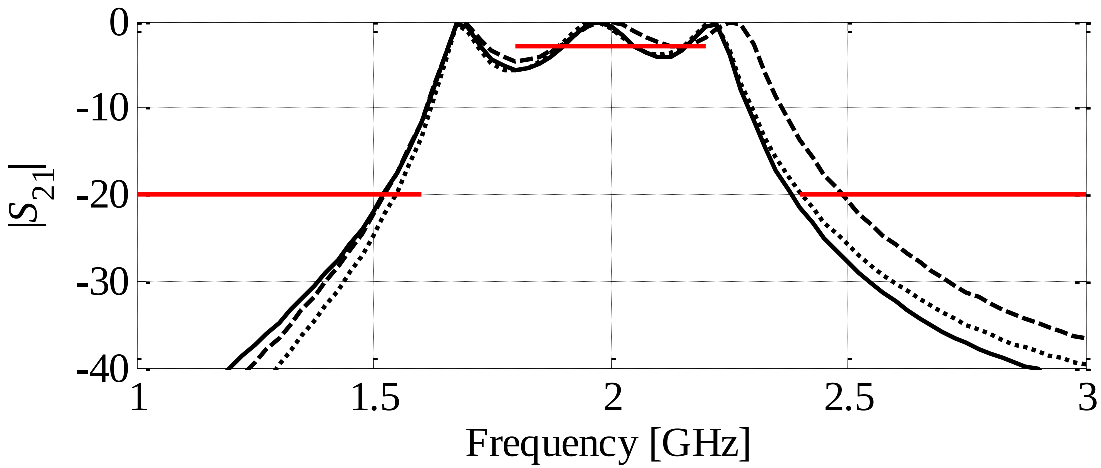


tuning model

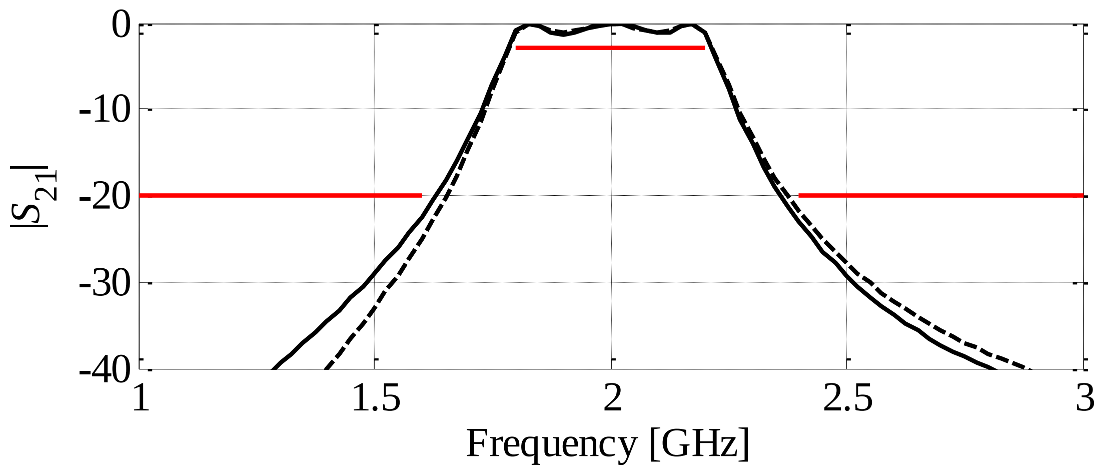


Third-Order Chebyshev Filter: Type 1d (Fast) Tuning

(*Koziel et al., 2010*)



initial fine model (—), tuning model (---), tuning model after the alignment procedure (…)

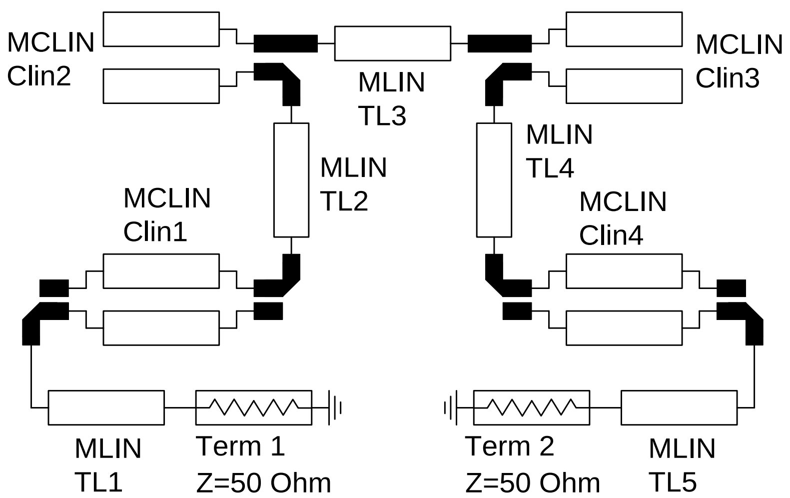


final model design (—), tuning model (---)

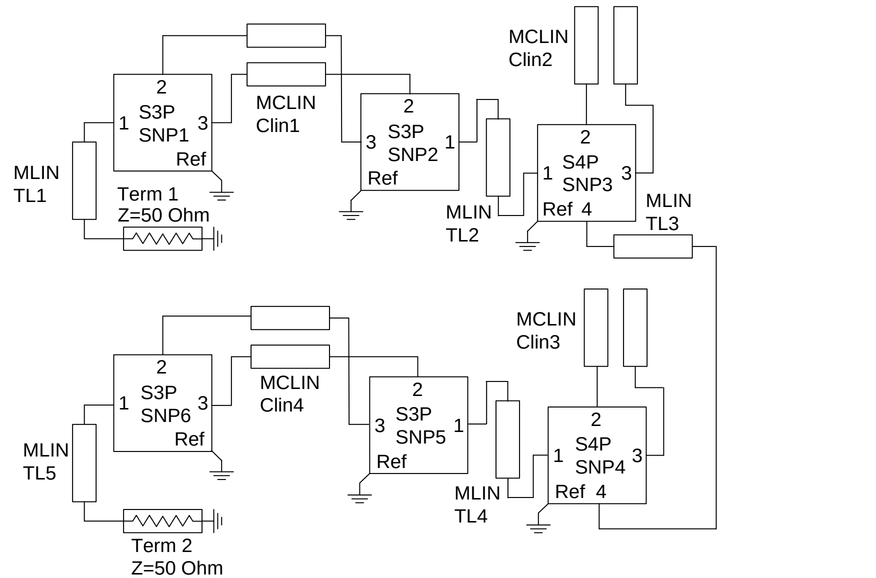
Coupled-line Bandpass Filter: Type 2 Tuning

(*Koziel and Bandler, 2011*)

conceptual tuning model

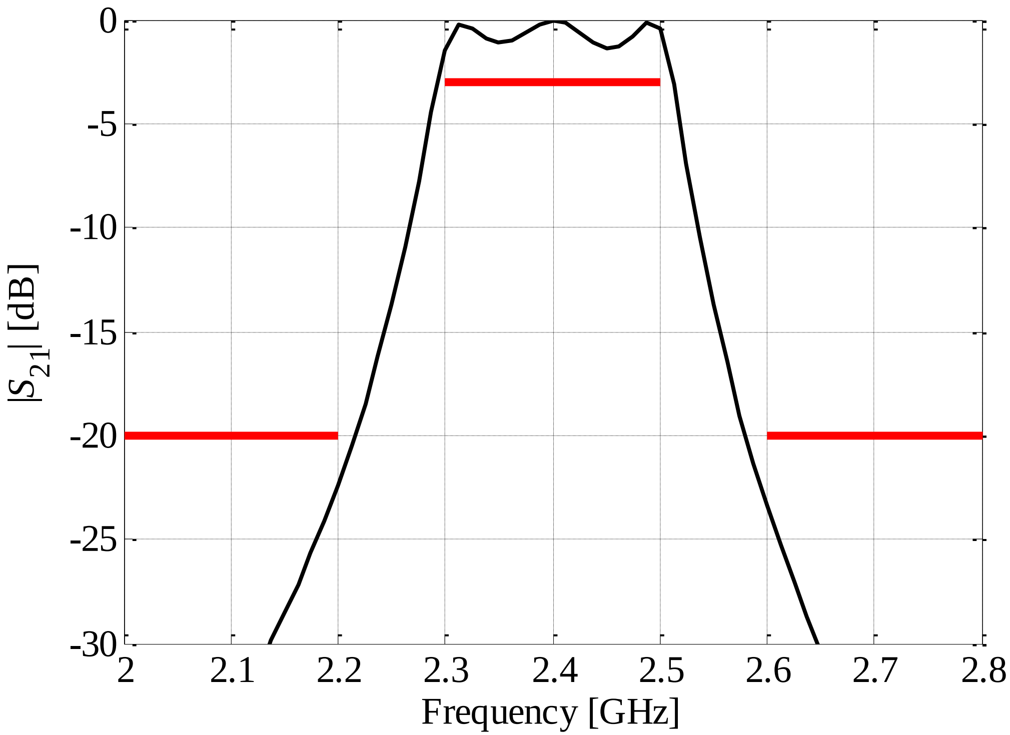


tuning model



Coupled-line Bandpass Filter: Type 2 Tuning
(*Koziel and Bandler, 2011*)

final fine model responses obtained in two iterations



Conclusions

review of tuning techniques

categorize and illustrate tuning space mapping procedures

tuning space mapping is generally robust because of misalignment compensation by

- physically valid tuning elements and
- subsequent parameter extraction procedures

considerations: the engineer’s knowledge, available software, difficulties in implementation, simulation costs

our aim: to help engineers understand the methodology and to inspire new implementations and applications

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