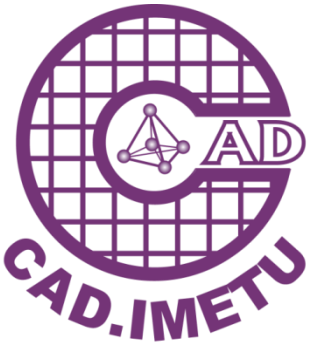

TACKLING CLOSE-TO-BAND PASSIVITY VIOLATIONS IN PASSIVE MACRO-MODELING

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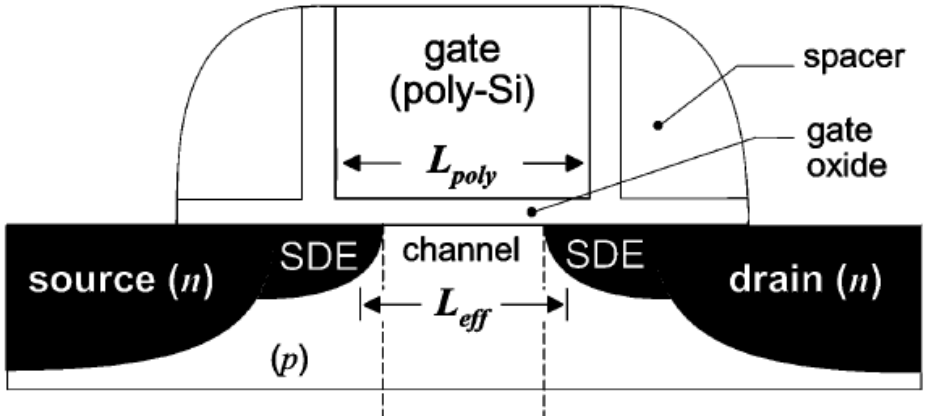
ASP-DAC 2014

Outline

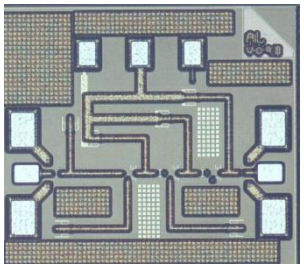
- Why passive modeling ?
- Difficulties encountered by traditional framework.
- The harm of large CTB violation and how we remove it.
- Experiment example.

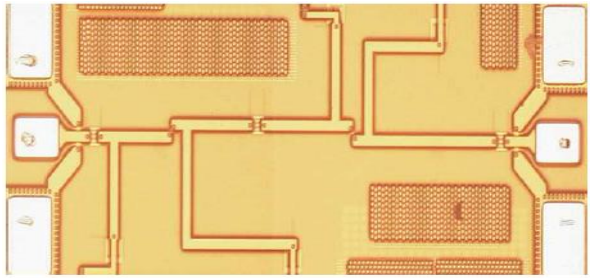
Active Device Modeling is Relatively "Easy", for Designers

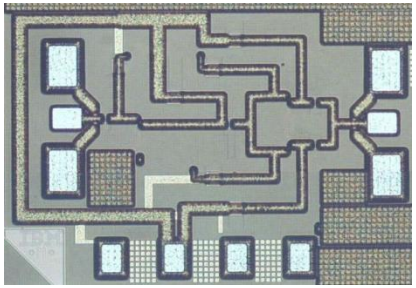


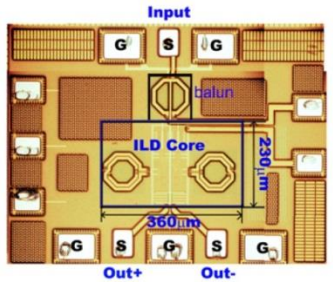
- Reasons
  - Active device modeling is in some sense simple, as the structure is fixed.
  - Modeling is mostly done in foundry, where there are a lot of modeling experts.

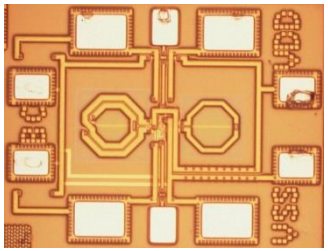
Passive Modeling is Much More Difficult

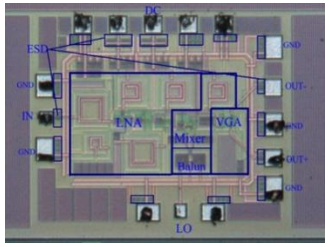


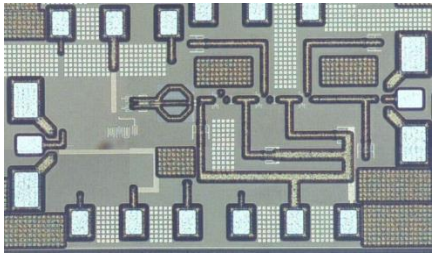


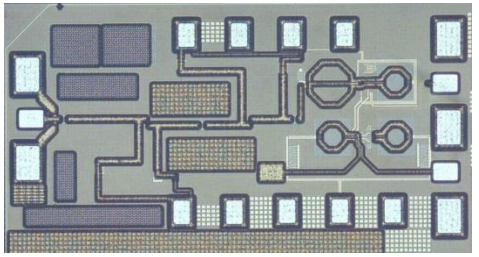






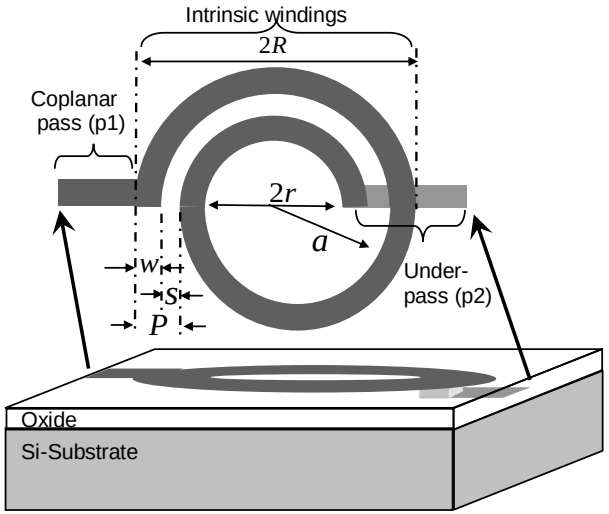


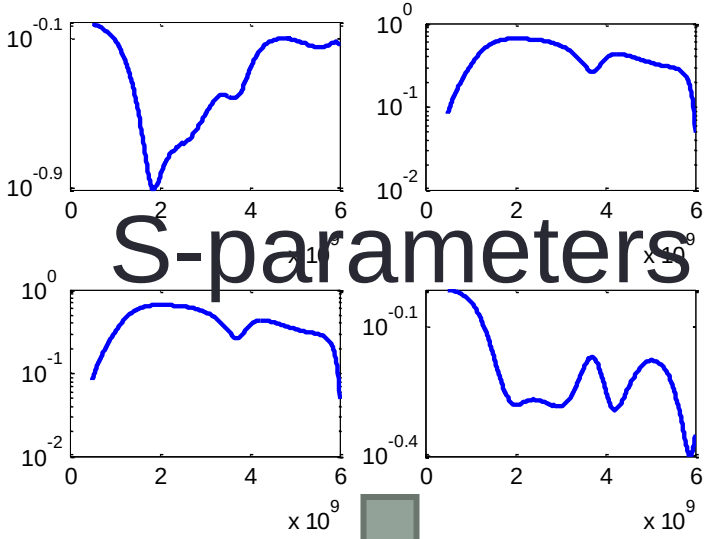


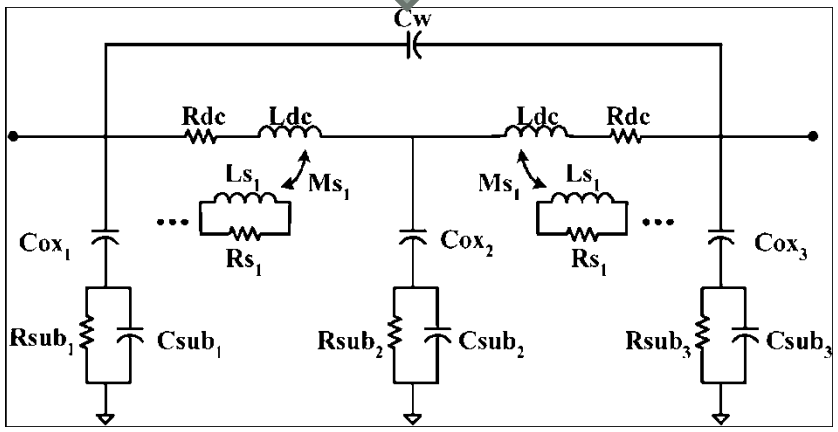


- Reasons
  - While passive elements are very different from each other(Balun/transformers, Transmission Lines, package).
  - Modeling need to be done by designers if the component is customized. Ordinary designers are not experts of modeling.

Equivalent Circuit Model

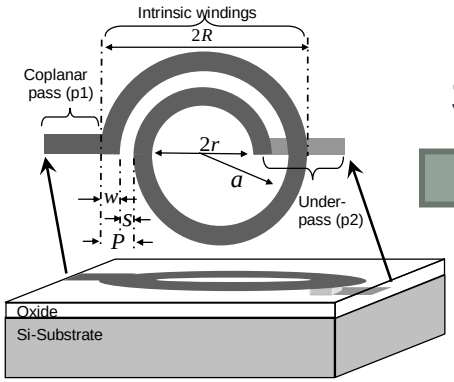




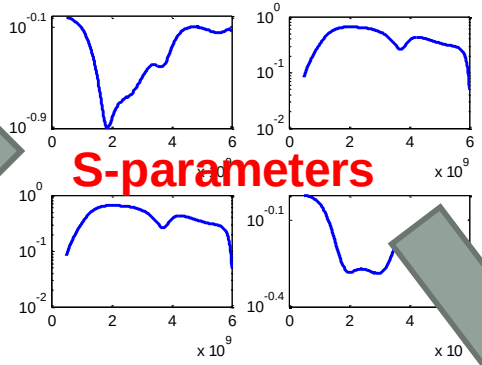


- **Compact modeling**
  - Develop a model with physical insight.
  - Do EM simulation to get S-parameters.
  - Extract model parameters (also requires physical insight).

State-Space Model

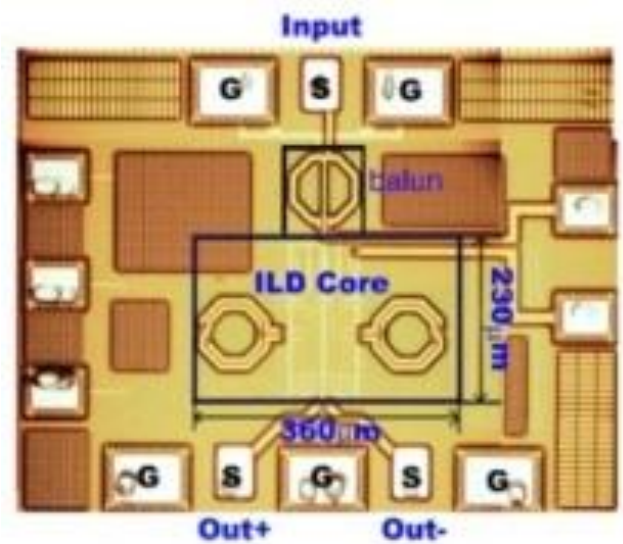


EM Simulation



S-parameters

$$\tilde{H}(s)$$



$$\dot{x} = Ax + Bu$$

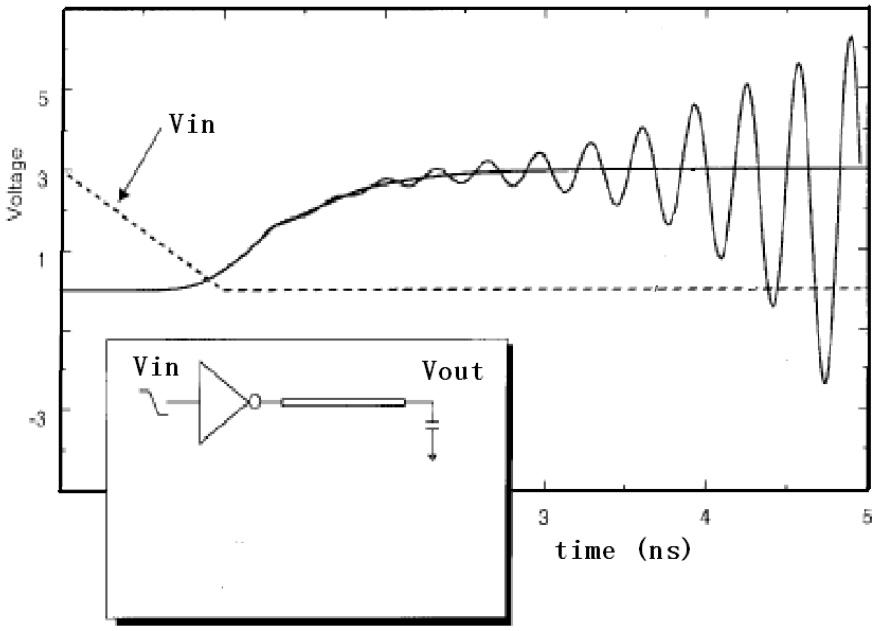
$$y = Cx + Du.$$

Passivity Conditions

- Passivity – the inability to generate energy.
- Non-passive model may cause convergence issue in simulation.
- Model generated for passive elements are required to be passive.

Passivity condition:

$$G(s) = H(s) + H^H(s) \geq 0, \quad s = j\omega$$



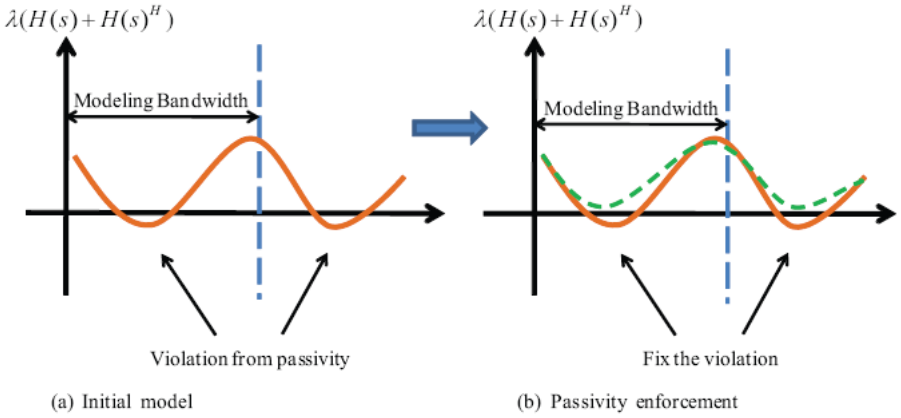
[Odabasioglu, 98]

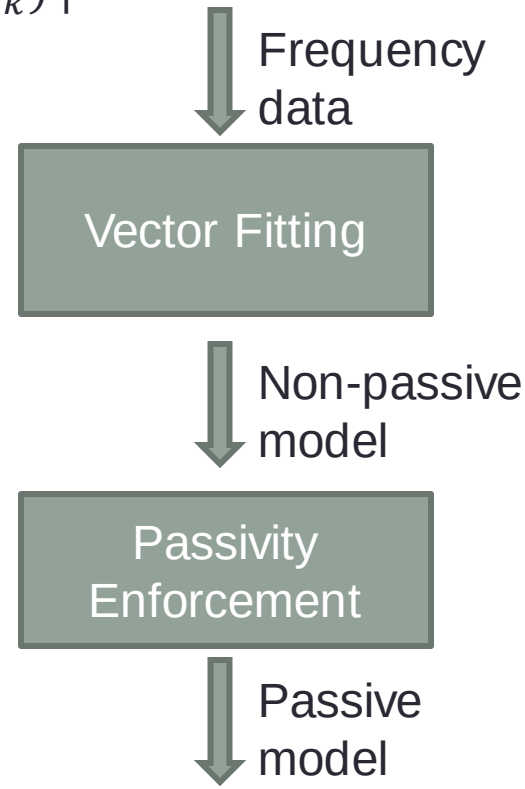
Traditional Framework

- Passivity-free Fitting
  - Minimize

$$Err = \sum_{k=1}^{N_0} |H_{origin}(s_k) - H(s_k)|^2$$

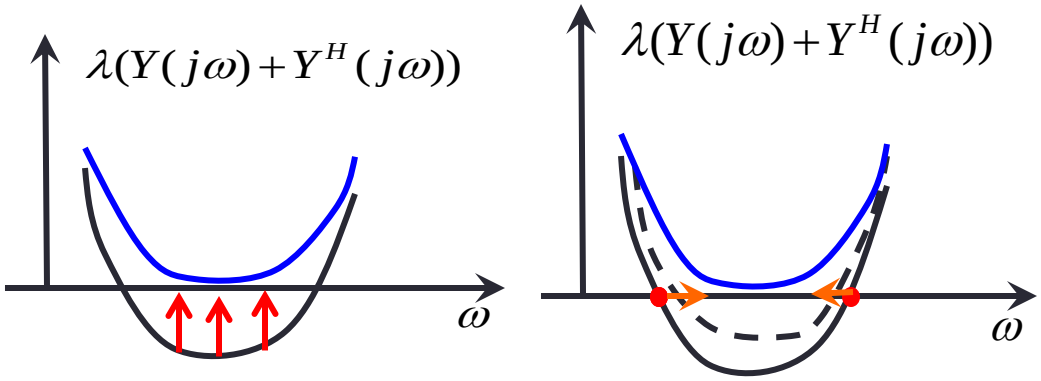
  - VF: Vector Fitting [B. Gustavsen]
- Iterative enforcement to fix the passivity
  - VF+LC+DAO
  - VF+LC+EPM+DAO
  - ……



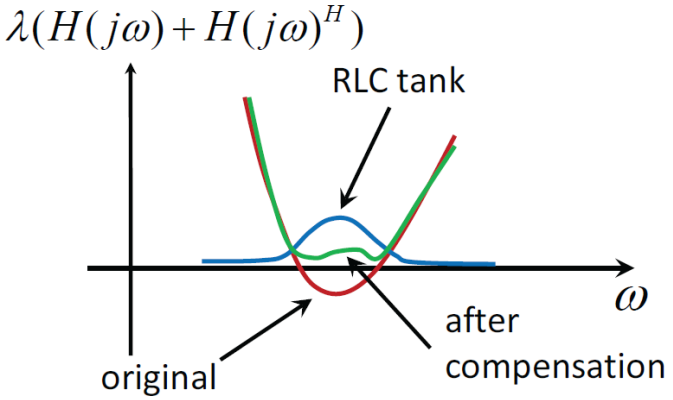


Existing Enforcement Methods

- Existing passivity enforcement methods
  - FRP: Frequency Residual Perturbation [Gustavsen, 08]
  - EPM: Eigenvalue Perturbation Method [Grivet,TCAS'04]
  - LC: Local Compensation [Wang, Ye, TMTT'12]



FRP, [Gustavsen, 08] EPM, [Grivet' 04, 06, 07]

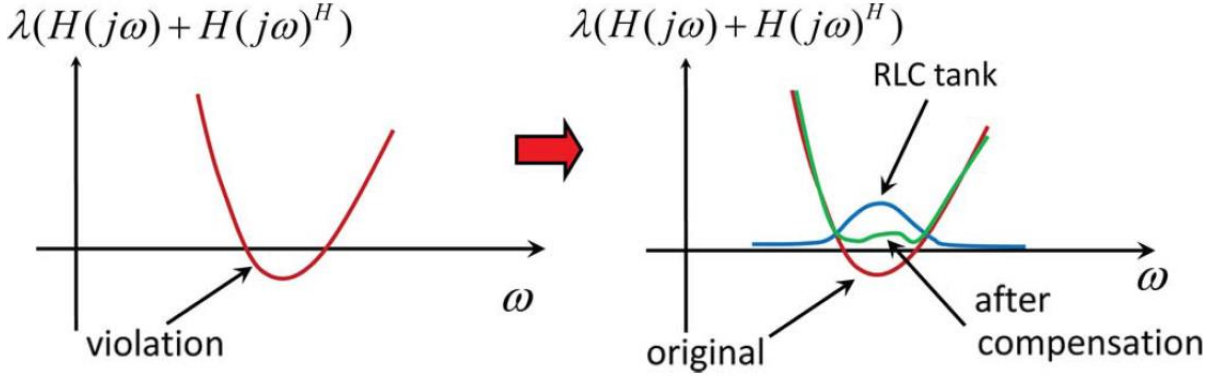


Tianshi Wang, Zuochang Ye, Robust Passive Macro-Model Generation with Local Compensation, IEEE T-MTT, 2012.

Principle of Local Compensation

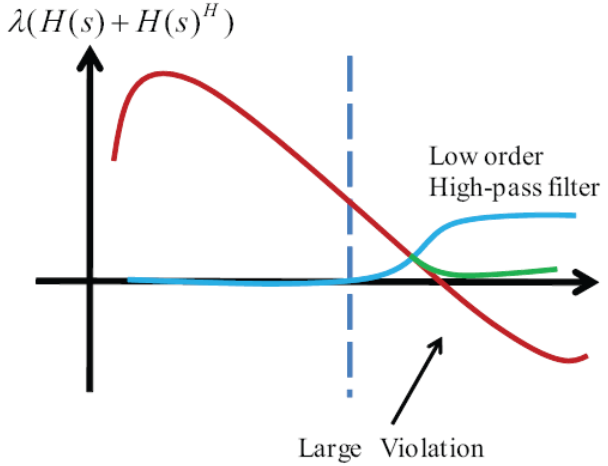
- LC identify and fix passivity violations individually and locally by adding poles and residuals to the system. Hence guarantees to converge. [T.Wang, Ye, TMTT'12]

- Generally speaking, in-band passivity violations are usually small provided that the original data is passive and the vector fitting is done properly.

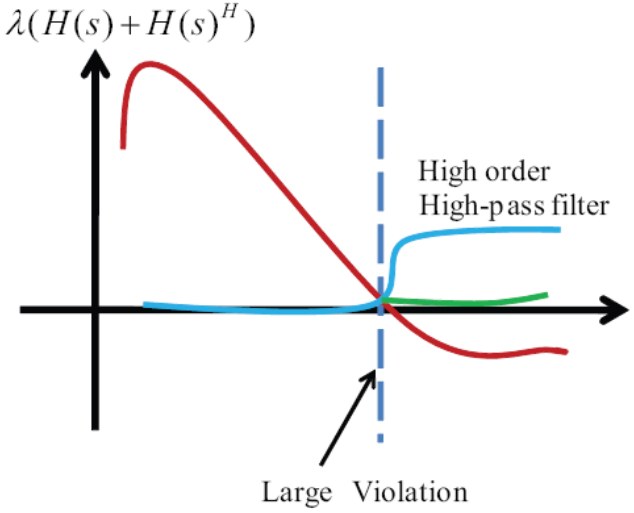


Close-to-Band Passivity Violation

- Will cause most existing passivity enforcement method fail to converge.
- LC employs high-pass passivity compensation for out-band violation, when facing large CTB violation, sharp-edge high-order filter is required.
- Unfortunately, it is not known so far how to implement a high order filter in local compensation method.



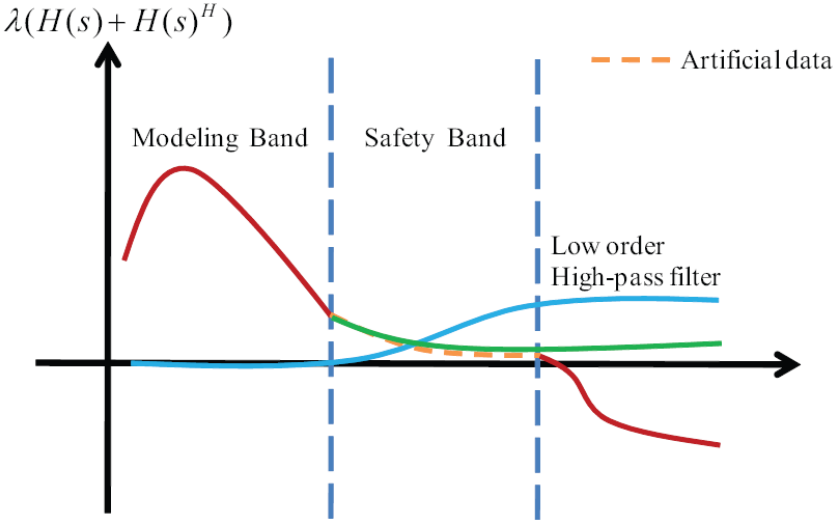
(a) Large violation far from modeling band



(b) Large violation close to modeling band

Passivity Data Extension

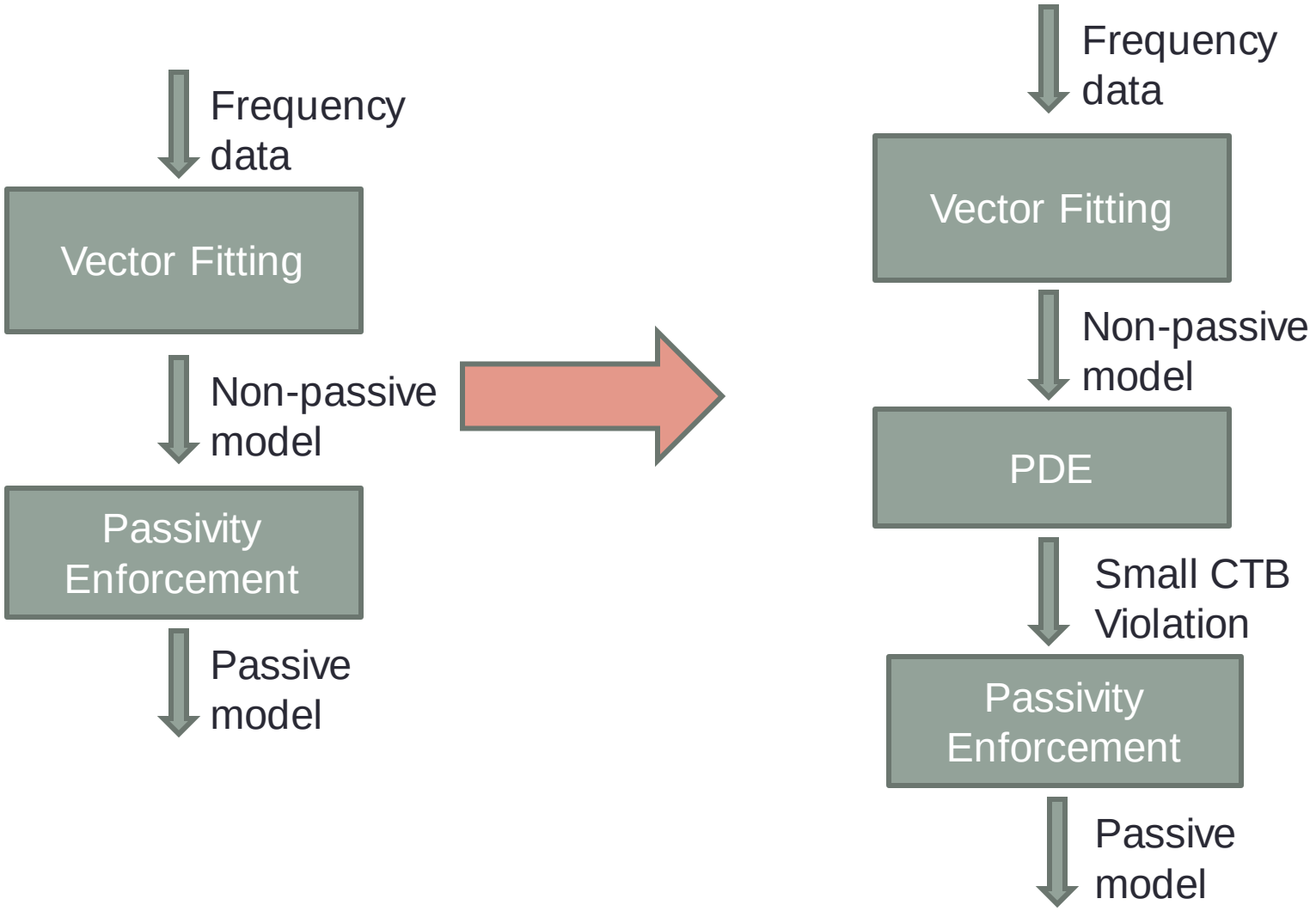
- Artificially create data points to extend the original data to a higher frequency, and use the augmented data to perform vector fitting.



- Splitting the frequency band into three parts:

$$0 \le f \le f_{max}, \text{ modeling band}$$
$$f_{max} < f \le f_{max} + BW_{safety}, \text{ safety band}$$
$$f_{max} + BW_{safety} < f < +\infty, \text{ far band}$$

Fixed Passive Modeling Framework



Data Needs to be Carefully Chosen

- Satisfy passivity condition.
- Guarantee in-band fitting accuracy.
- Discontinuity may affect the VF accuracy.

Formulate the Problem

- The data extension issue can be converted into an optimization problem.

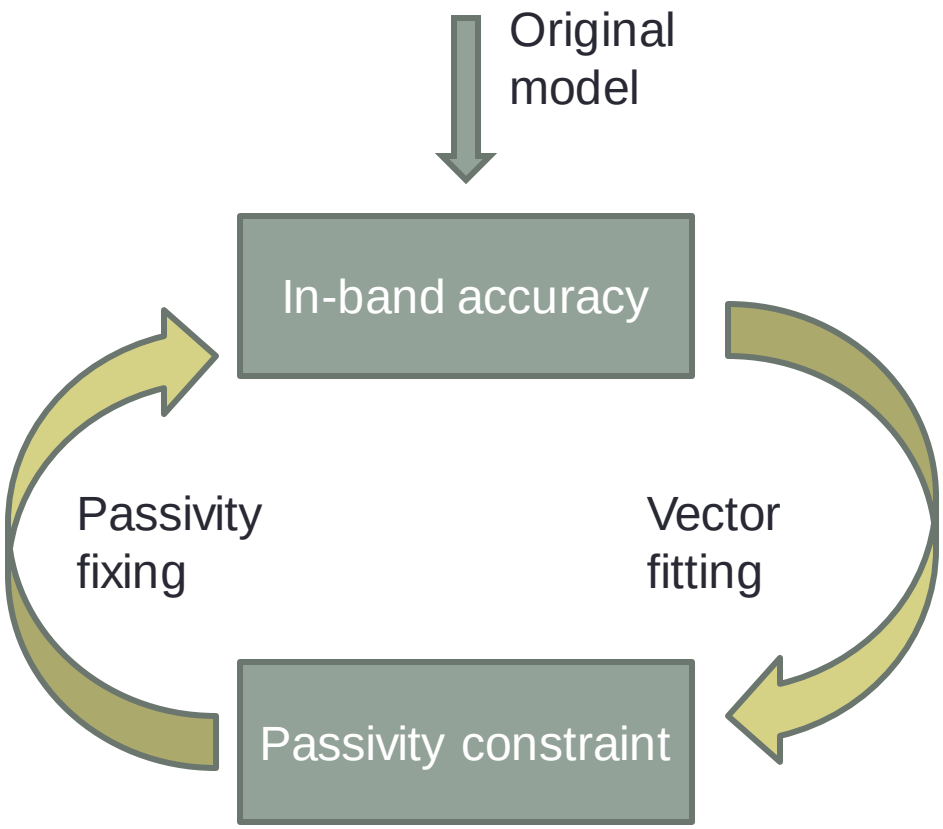
$$
\begin{aligned}
\text{Variable}: \quad & A, B, C, D \\
& \widetilde{H}(s_l),\ s_l = j2\pi f_l, f_l \text{ travel through} \\
& \text{safety band} \\
\text{Object}: \quad & \text{minimize} \sum_l |H(s_l) - \widetilde{H}(s_l)|^2, s_l \text{ is same} \\
& \text{as above} \\
\text{Constraint}: \quad & \widetilde{H}(s_l) + \widetilde{H}(s_l)^H \geq 0 \\
& Err < \delta_{max}
\end{aligned}
$$

A Greedy Strategy

- Iteratively apply VF and passivity fixing.

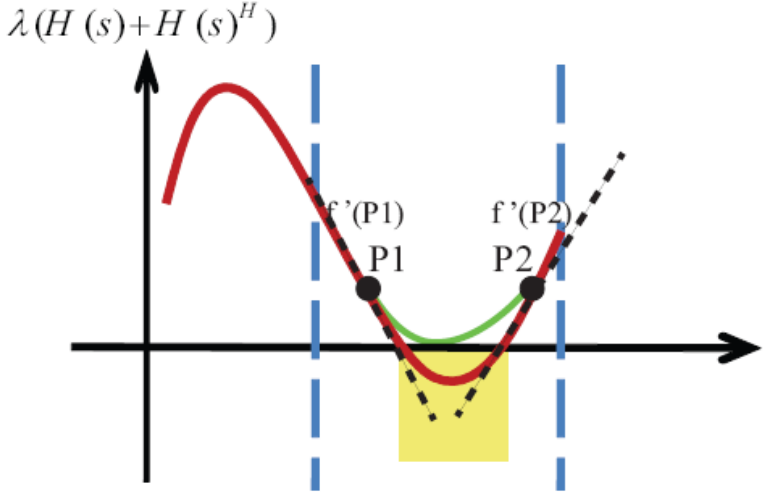
Algorithm 1 Framework of Frequency Data Extension

initialize A, B, C, D by fitting the modeling band;
r=0;
while $Err < \delta_{max}$ and $r < MaxRun$ **do**
  r=r+1;
  Step 1: Detect passivity violations of Model $\{A, B, C, D\}$ in safety band;
  Step 2:Find $\tilde{H}(s_l)$ which minimize sum $\sum_l |H(s_l) - \tilde{H}(s_l)|^2$ by fixing passivity violations in safety band;
  Step 3:Find $\{A_1, B_1, C_1, D_1\}$ which minimize sum $\sum_l |H_1(s_l) - \tilde{H}(s_l)|^2$ by fitting the extended dataset $\{H(s_k), \tilde{H}(s_l)\}$;
  $\{A, B, C, D\} := \{A_1, B_1, C_1, D_1\}$;
end while



Smooth Passivity Fixing

- Discontinuity will make VF perform poorly.



- Using a second-order rational function for fixing.

$$G_{fix}(s) = K\frac{s^2 + as + b}{s^2 + cs + d}$$

$$\mathrm{Re}(G_{fix}(j\omega)) = K\frac{\omega^4 + (ac - b - d)\omega^2 + ac}{(d - \omega^2)^2 + c^2\omega^2}$$

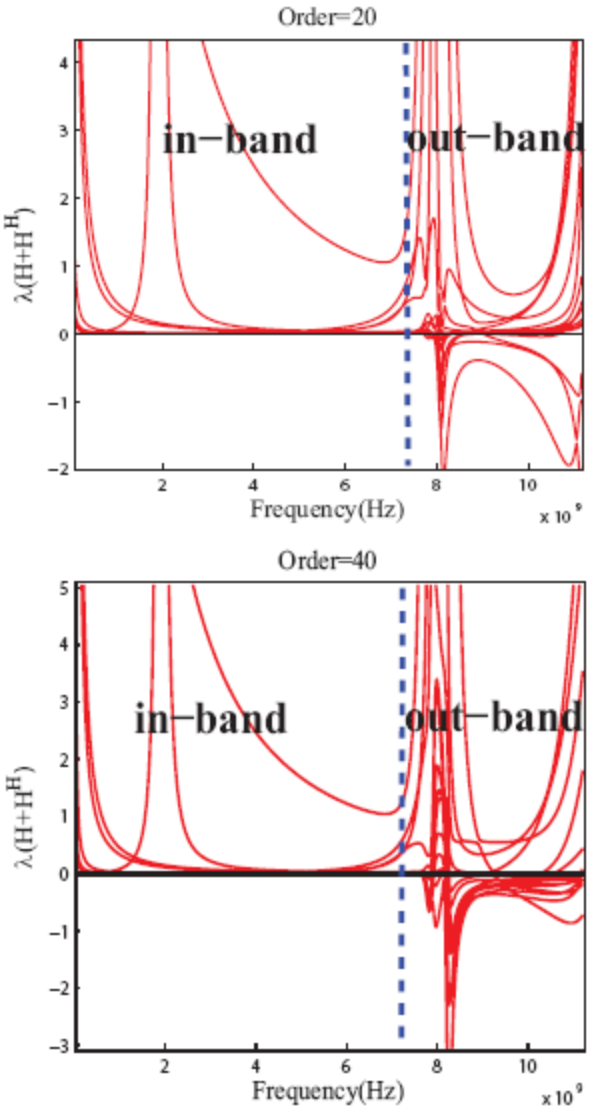
- When K is set to be positive, it is sufficient to set

$$\Delta = (ac - b - d)^2 - 4ac \leq 0$$

Experiment Examples

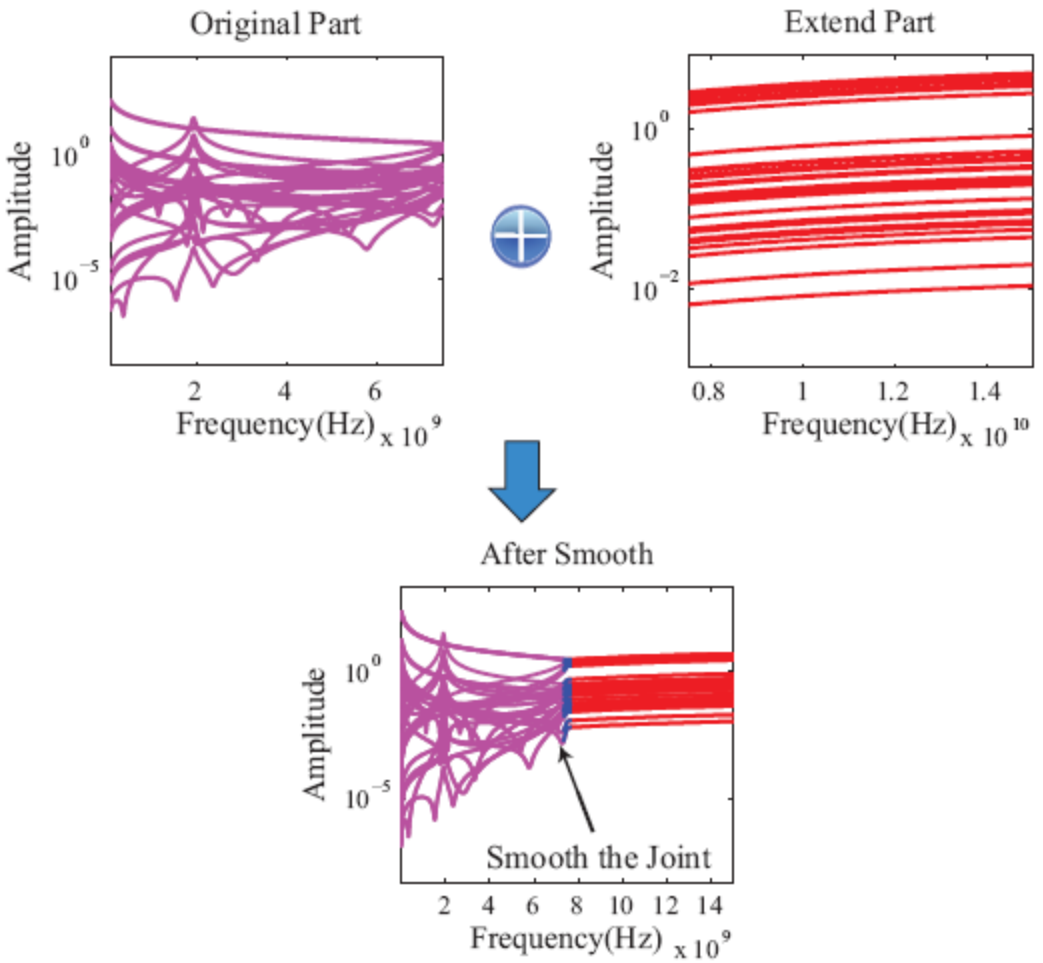
- Increasing VF order makes no help.
- Existing passivity enforcement methods failed when implemented in the traditional framework.

Methods	Iterations	Fitting Error
EPM	>40	
FRP	>40	
LC	26	Large Error



Experiment Examples

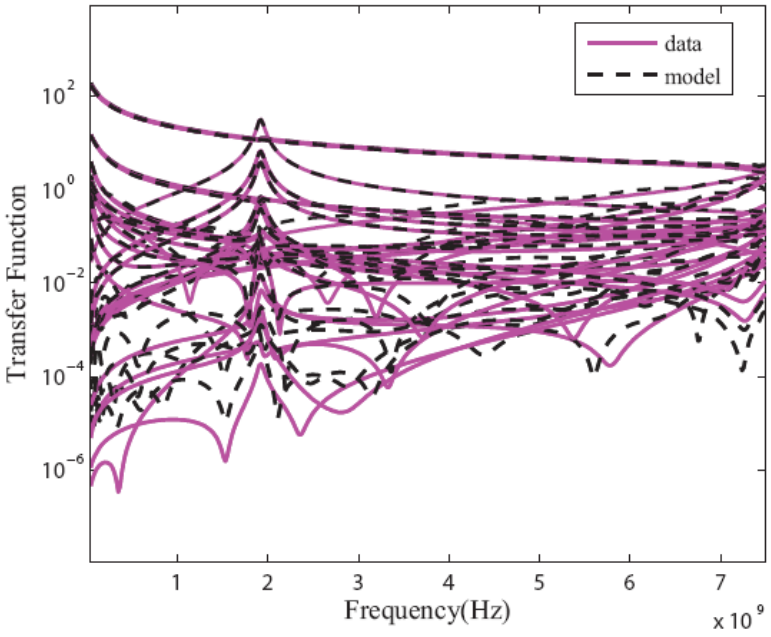
- Extended part must be carefully chosen.
- If we directly add an passivity part after the original data (to avoid discontinuity issue, the joint part is being smoothed with interpolation).



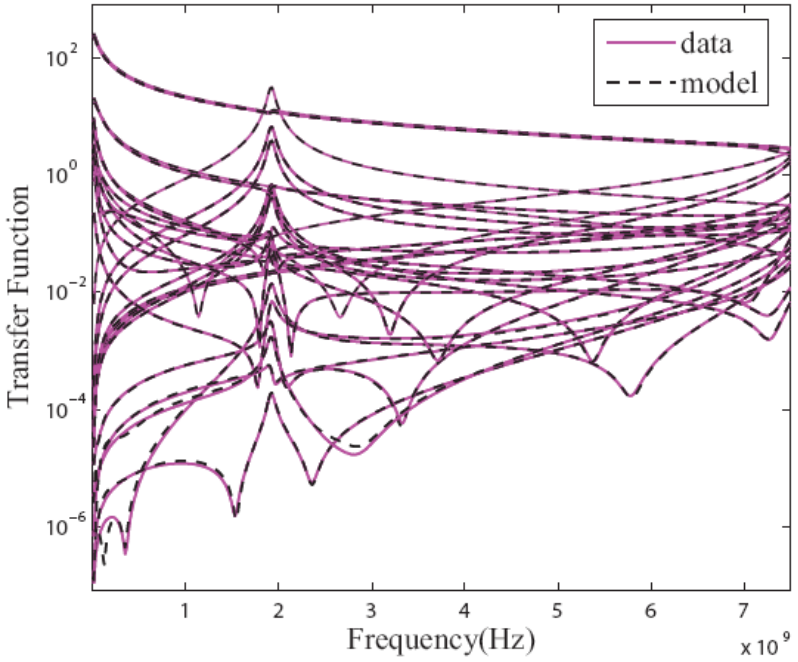
Experiment Examples

In-band fitting accuracy after data extension.

Extend with inappropriate part



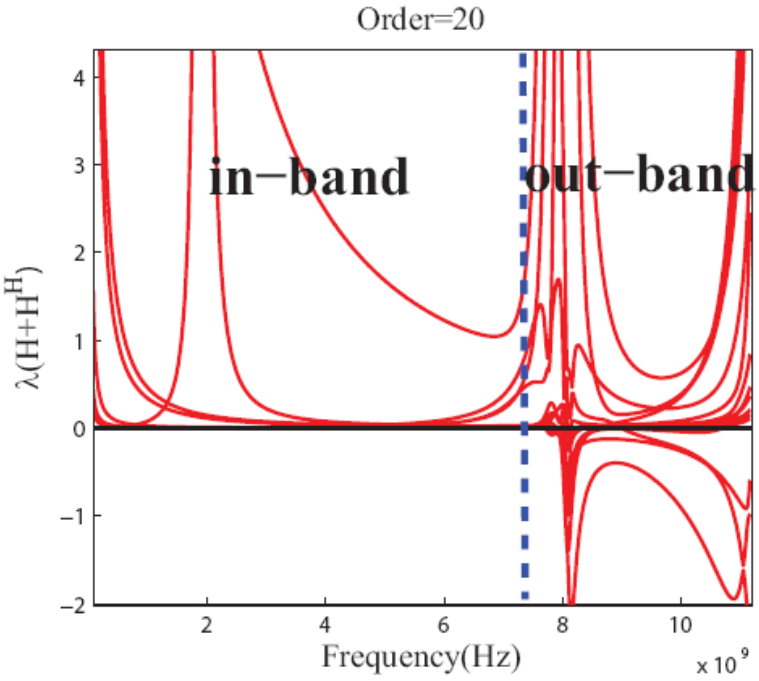
Extend with PDE method



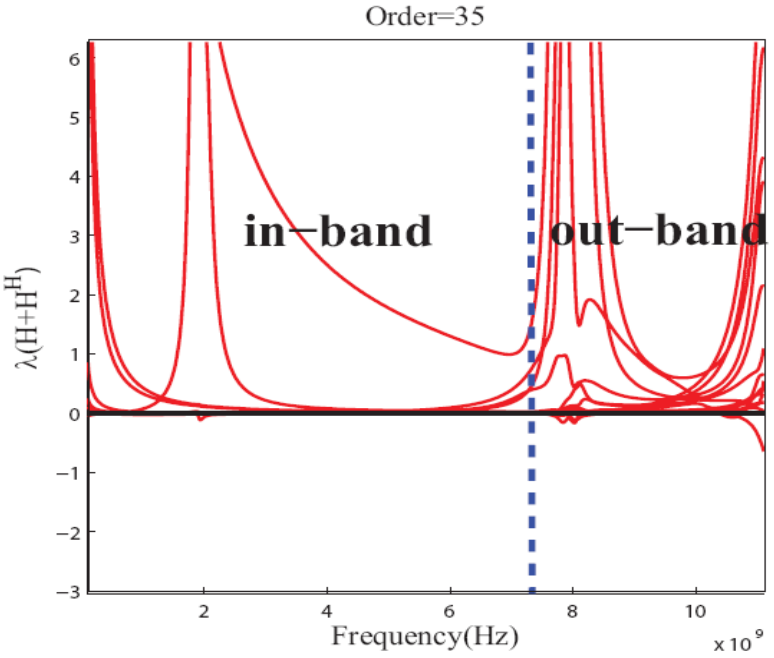
Experiment Examples

- Passivity extension help to reduce the CTB violation to about $\frac{1}{20}$ while simultaneously preserve in-band fitting accuracy.

Before

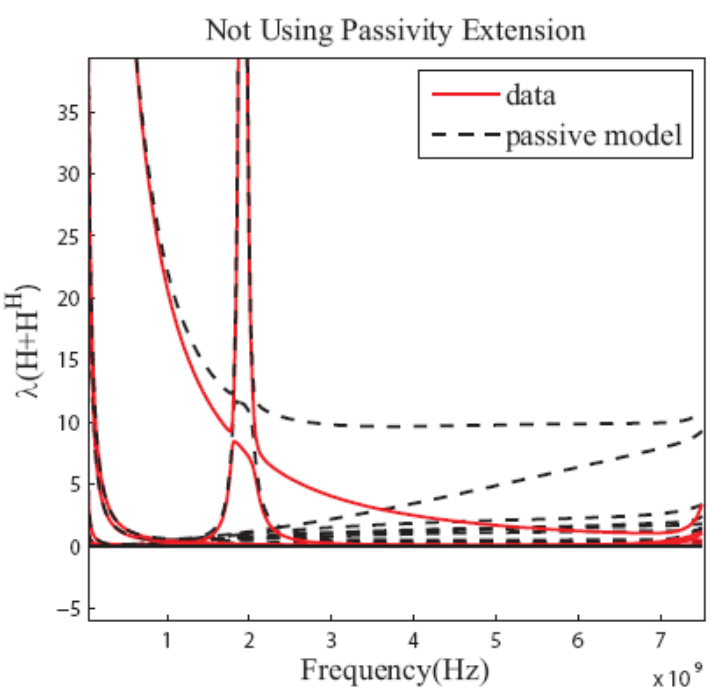


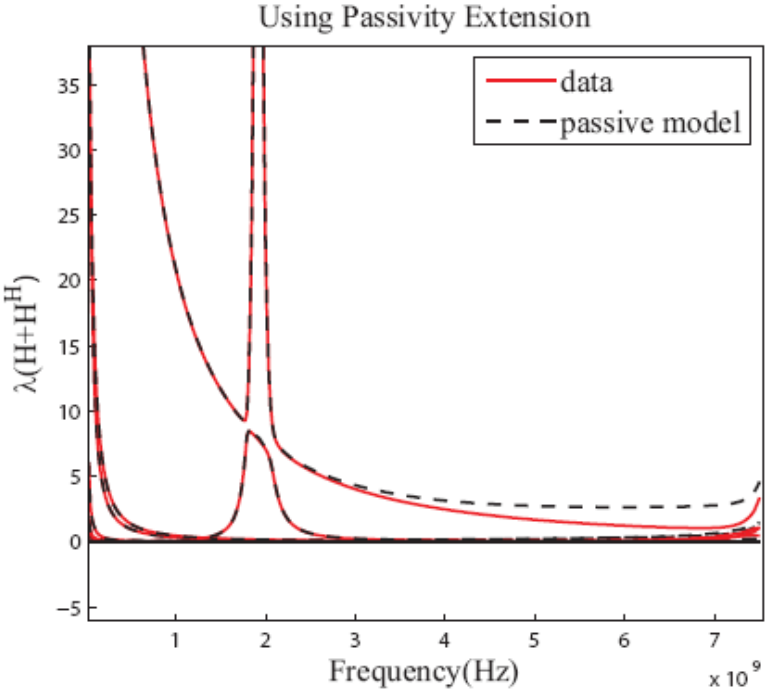
After



Experiment Examples

- Passivity enforcement method will benefit a lot from this reduction. Figure below shown LC implemented in both traditional framework and the fixed framework.





Experiment Examples

- Computation costs

- More enforcement runs mean more perturbation, thus larger fitting error.

Method	Iterations
LC with traditional framework	26 runs
LC+PDE	10 LC runs+4 VF runs

Conclusion

- Passive modeling is more difficult for designers.
- Traditional passivity modeling framework suffers from large CTB violation.
- PDE method can help remove large CTB violation issue.
- Existing method will benefit from the fixed framework.

Thank you!