TRL 校准技术

Table of Contents

一. 校准技术分类

校准技术有 SOLT, TRL/LM , Normalization, Enhanced Time domain Gating, T Matrix Deembedding

1. TRL 校准的优势和劣势

1) 优势

- THRU: Typically requires no characterization
- REFLECT: 不需要 characterization, 只需要大概相位信息判断是 Open 还是 Short, Needs to be the same for both ports
- LINES: Only require Zo & Zpd characterization
- Load: None involved

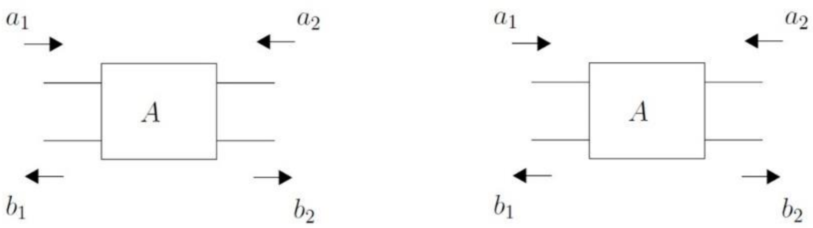
2) 劣势

- THRU: Lunch/receive must be same transmission line type (directly connectable)

- LINEs: need several lines across frequency, each line has numerical difficulty with some frequencies, low frequency LINEs becomes too long for practical implementation

二. S 矩阵和 T 矩阵

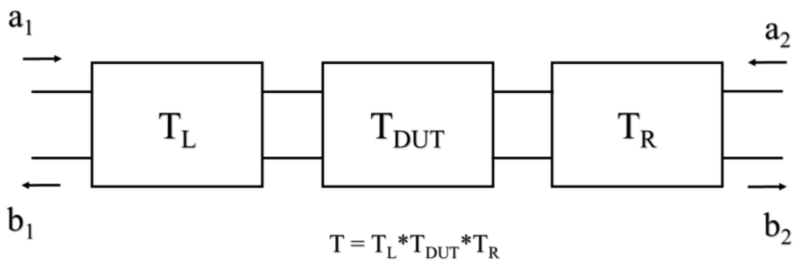
1. S 矩阵和 T 矩阵定义和关系



$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{1}$$

$$\begin{pmatrix} a_1 \\ b_1 \end{pmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \cdot \begin{pmatrix} b_2 \\ a_2 \end{pmatrix} \tag{2}$$

可以利用 T 矩阵的级联特性， 只需要求解出 T_L 和 T_R



S 矩阵和 T 矩阵的关系为

$$[T] = \begin{bmatrix} -\frac{1}{S_{21}} & -\frac{S_{22}}{S_{21}} \\ \frac{S_{11}}{S_{21}} & \frac{S_{21} \cdot S_{12} - S_{11} \cdot S_{22}}{S_{21}} \end{bmatrix} \tag{3}$$

$$[S] = \begin{bmatrix} -\frac{T_{21}}{T_{11}} & \frac{T_{11} \cdot T_{22} - T_{12} \cdot T_{21}}{T_{11}} \\ \frac{1}{T_{11}} & -\frac{T_{12}}{T_{11}} \end{bmatrix} \tag{4}$$

2. TRL 的 T 矩阵表达式

- THRU: totally known

$$[T_{THRU}^{Std}] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{5}$$

- REFLECT: unknown

$$Sgn(R\{\Gamma_{REFLECT}^{Std}\}) = \pm 1 \tag{6}$$

- LINE: partially known

$$[T_{LINE}^{Std}] = \begin{bmatrix} e^{-\gamma l} & 0 \\ 0 & e^{+\gamma l} \end{bmatrix} \tag{7}$$

三. 求解 T_{in} 和 T_{out} 矩阵

定义 DUT 左边和右边的 T 矩阵分别为

$$T_L = \begin{bmatrix} T_{11}^{l} & T_{12}^{l} \\ T_{21}^{l} & T_{22}^{l} \end{bmatrix} \qquad T_R = \begin{bmatrix} T_{11}^{r} & T_{12}^{r} \\ T_{21}^{r} & T_{22}^{r} \end{bmatrix}$$

1. THRU 等式

$$[T_{THRU}^{Meas}] = T_L \cdot [T_{THRU}^{Std}] \cdot T_R \tag{8}$$

结合（5），（8）可以变形为

$$[T_L]^{-1} \cdot [T_{THRU}^{Meas}] = T_R \tag{9}$$

定义新的标记符号T_L'为T_L的逆矩阵

$$[T_L^1] = [T_L]^{-1} = \begin{bmatrix} T_{11}^{l1} & T_{12}^{l1} \\ T_{21}^{l1} & T_{22}^{l1} \end{bmatrix} \tag{10}$$

通过（10），（9）可以变为

$$[T_L^1] \cdot [T_{THRU}^{Meas}] = T_R \tag{11}$$

2. LINE 等式

$$[T_{LINE}^{Meas}] = T_L \cdot [T_{LINE}^{Std}] \cdot T_R \tag{12}$$

（12）可以重写为

$$[T_L^1] \cdot [T_{LINE}^{Meas}] = [T_{LINE}^{Std}] \cdot T_R \tag{13}$$

$$[T_L^1] \cdot [T_{LINE}^{Meas}] = \begin{bmatrix} e^{-\gamma l} & 0 \\ 0 & e^{+\gamma l} \end{bmatrix} \cdot T_R \tag{14}$$

$$\begin{bmatrix} T_{11}^{l1} & T_{12}^{l1} \\ T_{21}^{l1} & T_{22}^{l1} \end{bmatrix} \cdot [T_{LINE}^{Meas}] = \begin{bmatrix} T_{11}^{r} \cdot e^{-\gamma l} & T_{12}^{r} \cdot e^{-\gamma l} \\ T_{21}^{r} \cdot e^{+\gamma l} & T_{22}^{r} \cdot e^{+\gamma l} \end{bmatrix} \tag{15}$$

通过（9）消去（15）中的T_L^1

$$\begin{bmatrix} T_{11}^{r} & T_{12}^{r} \\ T_{21}^{r} & T_{22}^{r} \end{bmatrix} \cdot [T_{THRU}^{Meas}]^{-1} \cdot [T_{LINE}^{Meas}] = \begin{bmatrix} T_{11}^{r} \cdot e^{-\gamma l} & T_{12}^{r} \cdot e^{-\gamma l} \\ T_{21}^{r} \cdot e^{+\gamma l} & T_{22}^{r} \cdot e^{+\gamma l} \end{bmatrix} \tag{16}$$

定义 M 矩阵

$$[M] = [T_{THRU}^{Meas}]^{-1} \cdot [T_{LINE}^{Meas}] \tag{17}$$

（16）等式可以变换为

$$\begin{bmatrix} T_{11}^{r} & T_{12}^{r} \\ T_{21}^{r} & T_{22}^{r} \end{bmatrix} \cdot [M] = \begin{bmatrix} T_{11}^{r} \cdot e^{-\gamma l} & T_{12}^{r} \cdot e^{-\gamma l} \\ T_{21}^{r} \cdot e^{+\gamma l} & T_{22}^{r} \cdot e^{+\gamma l} \end{bmatrix} \tag{18}$$

$$T_{11}^{r} \cdot M_{11} + T_{12}^{r} \cdot M_{21} = T_{11}^{r} \cdot e^{-\gamma l} \tag{19}$$

$$T_{11}^{r} \cdot M_{12} + T_{12}^{r} \cdot M_{22} = T_{12}^{r} \cdot e^{-\gamma l} \tag{20}$$

$$T_{21}^{r} \cdot M_{11} + T_{22}^{r} \cdot M_{21} = T_{21}^{r} \cdot e^{+\gamma l} \tag{21}$$

$$T_{21}^{r} \cdot M_{12} + T_{22}^{r} \cdot M_{22} = T_{22}^{r} \cdot e^{+\gamma l} \tag{22}$$

通过（20）可以求出

$$e^{-\gamma l} = \left(\frac{T_{11}^{r}}{T_{12}^{r}}\right) \cdot M_{12} + M_{22} \tag{23}$$

把（23）代入（19）得到

$$T_{11}^{r} \cdot M_{11} + T_{12}^{r} \cdot M_{21} = T_{11}^{r} \cdot \left[\left(\frac{T_{11}^{r}}{T_{12}^{r}}\right) \cdot M_{12} + M_{22}\right] \tag{24}$$

$$\left(\frac{T_{12}^{r}}{T_{11}^{r}}\right)^{2} \cdot M_{21} + \left(\frac{T_{12}^{r}}{T_{11}^{r}}\right) \cdot (M_{11} - M_{22}) - M_{12} = 0 \tag{25}$$

同理通过（21）（22）消去$e^{+\gamma l}$得到

$$\left(\frac{T_{22}^{r}}{T_{21}^{r}}\right)^{2} \cdot M_{21} + \left(\frac{T_{22}^{r}}{T_{21}^{r}}\right) \cdot (M_{11} - M_{22}) - M_{12} = 0 \tag{26}$$

观察（25）（26），发现$\frac{T_{12}^{r}}{T_{11}^{r}}$和$\frac{T_{22}^{r}}{T_{21}^{r}}$是（27）的两个解

$$X^{2} \cdot M_{21} + X \cdot (M_{11} - M_{22}) - M_{12} = 0 \tag{27}$$

通常有$\left|\frac{T_{12}^{r}}{T_{11}^{r}}\right| < \left|\frac{T_{22}^{r}}{T_{21}^{r}}\right|$

同样，结合（11）（14）消去T_R可以得到

$$[T_{L}^{1}] \cdot [T_{LINE}^{Meas}] = \begin{bmatrix} e^{-\gamma l} & 0 \\ 0 & e^{+\gamma l} \end{bmatrix} \cdot [T_{L}^{1}] \cdot [T_{THRU}^{Meas}] \tag{28}$$

定义 N 矩阵

$$[N] = [T_{LINE}^{Meas}] \cdot [T_{THRU}^{Meas}]^{-1} \tag{29}$$

（28）可以变换为

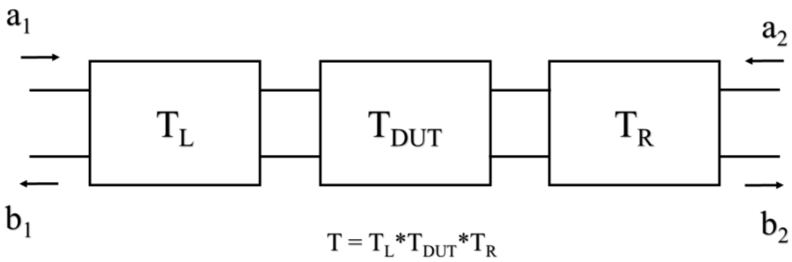
$$\begin{bmatrix} T_{11}^{l1} & T_{12}^{l1} \\ T_{21}^{l1} & T_{22}^{l1} \end{bmatrix} \cdot [N] = \begin{bmatrix} T_{11}^{l1} \cdot e^{-\gamma l} & T_{12}^{l1} \cdot e^{-\gamma l} \\ T_{21}^{l1} \cdot e^{+\gamma l} & T_{22}^{l1} \cdot e^{+\gamma l} \end{bmatrix} \tag{30}$$

展开（30），分别消去 $e^{-\gamma l}$ 和 $e^{+\gamma l}$ 可以得到

$$Y^2 \cdot N_{21} + Y \cdot (N_{11} - M_{22}) - N_{12} = 0 \tag{31}$$

两个解分别为$\frac{T_{12}^{l1}}{T_{11}^{l1}}$和$\frac{T_{22}^{l1}}{T_{21}^{l1}}$，通常有$\left|\frac{T_{12}^{l1}}{T_{11}^{l1}}\right| < \left|\frac{T_{22}^{l1}}{T_{21}^{l1}}\right|$

3. THRU 等式 II



$T = T_L * T_{DUT} * T_R$

$$\begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = [T_L] \cdot [T_R] \cdot \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} \tag{32}$$

$$\begin{bmatrix} T_{11}^{l1} & T_{12}^{l1} \\ T_{21}^{l1} & T_{22}^{l1} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} T_{11}^{r} & T_{12}^{r} \\ T_{21}^{r} & T_{22}^{r} \end{bmatrix} \cdot \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} \tag{33}$$

$$T_{11}^{l1} \cdot a_1 + T_{12}^{l1} \cdot b_1 = T_{11}^{r} \cdot b_2 + T_{12}^{r} \cdot a_2 \tag{34}$$

$$T_{21}^{l1} \cdot a_1 + T_{22}^{l1} \cdot b_1 = T_{21}^{r} \cdot b_2 + T_{22}^{r} \cdot a_2 \tag{35}$$

根据 S 参数的定义，$S_{11}^{Meas} = \frac{b_1}{a_1}|_{a_2=0}$　　$S_{21}^{Meas} = \frac{b_2}{a_1}|_{a_2=0}$ 可以令（34）中$a_2 = 0$

$$T_{11}^{l1} + T_{12}^{l1} \cdot \frac{b_1}{a_1} = T_{11}^{r} \cdot \frac{b_2}{a_1} \tag{36}$$

$$T_{11}^{l1} + T_{12}^{l1} \cdot S_{11}^{Meas} = T_{11}^{r} \cdot S_{21}^{Meas} \tag{37}$$

$$1 + \frac{T_{12}^{l1}}{T_{11}^{l1}} \cdot S_{11}^{Meas} = \frac{T_{11}^{r}}{T_{11}^{l1}} \cdot S_{21}^{Meas} \tag{38}$$

$$\frac{T_{11}^{r}}{T_{11}^{l1}} = \frac{1 + \frac{T_{12}^{l1}}{T_{11}^{l1}} \cdot S_{11}^{Meas}}{S_{21}^{Meas}} \tag{39}$$

同理，根据 S 参数定义，$S_{12}^{Meas} = \frac{b_1}{a_2}|_{a_1=0}$　　$S_{22}^{Meas} = \frac{b_2}{a_2}|_{a_1=0}$　可以令（35）中$a_1 = 0$

$$T_{22}^{l1} \cdot \frac{b_1}{a_2} = T_{21}^{r} \cdot \frac{b_2}{a_2} + T_{22}^{r} \tag{40}$$

$$T_{22}^{l1} \cdot S_{12}^{Meas} = T_{21}^{r} \cdot S_{22}^{Meas} + T_{22}^{r} \tag{41}$$

$$S_{12}^{Meas} = \frac{T_{21}^{r}}{T_{22}^{l1}} \cdot S_{22}^{Meas} + \frac{T_{22}^{r}}{T_{22}^{l1}} \tag{42}$$

$$\frac{T_{21}^{r}}{T_{22}^{l1}} = \frac{S_{12}^{Meas} - \frac{T_{22}^{r}}{T_{22}^{l1}}}{S_{22}^{Meas}} \tag{43}$$

根据（27），$\frac{T_{22}^{r}}{T_{21}^{r}}$已知，可以利用（44）恒等式带入（43）

$$\frac{T_{22}^{r}}{T_{22}^{l1}} = \frac{T_{21}^{r}}{T_{22}^{l1}} \cdot \frac{T_{22}^{r}}{T_{21}^{r}} \tag{44}$$

$$\frac{T_{21}^{r}}{T_{22}^{l1}} = \frac{S_{12}^{Meas}}{S_{22}^{Meas} + \frac{T_{22}^{r}}{T_{21}^{r}}} \tag{45}$$

4. REFLECT 等式

对于 REFLECT, 有（46）（47）等式成立

$$\begin{bmatrix} T_{11}^{l1} & T_{12}^{l1} \\ T_{21}^{l1} & T_{22}^{l1} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} b_2 \\ a_2 \end{bmatrix} \tag{46}$$

$$\frac{a_2}{b_2} = \Gamma_{REFLECT}^{Std} \tag{47}$$

（46）可以展开为

$$T_{11}^{l1} \cdot a_1 + T_{12}^{l1} \cdot b_1 = b_2 \tag{48}$$

$$T_{21}^{l1} \cdot a_1 + T_{22}^{l1} \cdot b_1 = a_2 \tag{49}$$

（49）式除以（48）式

$$\frac{T_{21}^{l1} \cdot a_1 + T_{22}^{l1} \cdot b_1}{T_{11}^{l1} \cdot a_1 + T_{12}^{l1} \cdot b_1} = \frac{T_{21}^{l1} + T_{22}^{l1} \cdot S_{11}^{Meas}}{T_{11}^{l1} + T_{12}^{l1} \cdot S_{11}^{Meas}} = \frac{a_2}{b_2} = \Gamma_{REFLECT}^{Std} \tag{50}$$

同样对于右边的矩阵$[T_R]$也有类似结论

$$\frac{T_{12}^{r} + T_{11}^{r} \cdot S_{22}^{Meas}}{T_{22}^{r} + T_{21}^{r} \cdot S_{22}^{Meas}} == \Gamma_{REFLECT}^{Std} \tag{51}$$

结合（50）（51）有

$$\frac{T_{21}^{l1} + T_{22}^{l1} \cdot S_{11}^{Meas}}{T_{11}^{l1} + T_{12}^{l1} \cdot S_{11}^{Meas}} = \frac{T_{12}^{r} + T_{11}^{r} \cdot S_{22}^{Meas}}{T_{22}^{r} + T_{21}^{r} \cdot S_{22}^{Meas}} \tag{52}$$

进一步

$$\frac{T_{21}^{l1}}{T_{11}^{l1}} \cdot \left(\frac{1 + \frac{T_{22}^{l1}}{T_{21}^{l1}} \cdot S_{11}^{Meas}}{1 + \frac{T_{12}^{l1}}{T_{11}^{l1}} \cdot S_{11}^{Meas}} \right) = \frac{T_{11}^{r}}{T_{21}^{r}} \cdot \left(\frac{\frac{T_{12}^{r}}{T_{11}^{r}} + S_{22}^{Meas}}{\frac{T_{22}^{r}}{T_{21}^{r}} + S_{22}^{Meas}} \right) \tag{53}$$

$$(T_{21}^{l1})^2 \cdot \left(\frac{T_{21}^{r}}{T_{22}^{l1}}\right) \cdot \left(\frac{T_{22}^{l1}}{T_{21}^{l1}}\right) = (T_{11}^{l1})^2 \cdot \left(\frac{T_{11}^{r}}{T_{11}^{l1}}\right) \cdot \frac{\left(\frac{\frac{T_{12}^{r}}{T_{11}^{r}} + S_{22}^{Meas}}{\frac{T_{22}^{r}}{T_{21}^{r}} + S_{22}^{Meas}} \right)}{\left(\frac{1 + \frac{T_{22}^{l1}}{T_{21}^{l1}} \cdot S_{11}^{Meas}}{1 + \frac{T_{12}^{l1}}{T_{11}^{l1}} \cdot S_{11}^{Meas}} \right)} \tag{54}$$

$$\left(\frac{T_{21}^{l1}}{T_{11}^{l1}}\right) = \pm\sqrt{\frac{\left(\frac{T_{11}^{r}}{T_{11}^{l1}}\right)\cdot\left(\frac{\frac{T_{12}^{r}}{T_{11}^{r}}+S_{22}^{Meas}}{\frac{T_{22}^{r}}{T_{21}^{r}}+S_{22}^{Meas}}\right)}{\left(\frac{T_{21}^{r}}{T_{22}^{l1}}\right)\cdot\left(\frac{T_{22}^{l1}}{T_{21}^{l1}}\right)\cdot\left(\frac{1+\frac{T_{22}^{l1}}{T_{21}^{l1}}\cdot S_{11}^{Meas}}{1+\frac{T_{12}^{l1}}{T_{11}^{l1}}\cdot S_{11}^{Meas}}\right)}} \tag{55}$$

（55）有两个解，但是我们可以根据$Sgn(R\{\Gamma_{REFLECT}^{Std}\}) = \pm 1$这个条件来筛选

$$\Gamma_{REFLECT}^{Std} = \frac{T_{21}^{l1}}{T_{11}^{l1}}\cdot\frac{1+\frac{T_{22}^{l1}}{T_{21}^{l1}}\cdot S_{11}^{Meas}}{1+\frac{T_{12}^{l1}}{T_{11}^{l1}}\cdot S_{11}^{Meas}} \tag{56}$$

其实通过（56）也可以直接求出$\frac{T_{21}^{l1}}{T_{11}^{l1}}$，但是由于$\Gamma_{REFLECT}^{Std}$比较难以准确确定，所以可以采用（55）公式求出，只需要假定两边的 REFLECT 结构都一样

5. 等式总结

- [M]矩阵：从公式（27）可以求出 $A = \frac{T_{12}^{r}}{T_{11}^{r}}$ 和$B = \frac{T_{22}^{r}}{T_{21}^{r}}$
- [N]矩阵：从公式（31）可以求出 $C = \frac{T_{12}^{l1}}{T_{11}^{l1}}$ 和 $D = \frac{T_{22}^{l1}}{T_{21}^{l1}}$
- THRU 等式：从公式（39）可以求出$E = \frac{T_{11}^{r}}{T_{11}^{l1}}$，从公式（45）可以求出$F = \frac{T_{21}^{r}}{T_{22}^{l1}}$
- REFLECT 等式：从公式（55）可以求出$G = \frac{T_{21}^{l1}}{T_{11}^{l1}}$

对于 De-embedding S 参数来说，上面的关系已经足够

$$[T_L]^{-1} = \begin{bmatrix} T_{11}^{l1} & T_{12}^{l1} \\ T_{21}^{l1} & T_{22}^{l1} \end{bmatrix} = T_{11}^{l1}\cdot\begin{bmatrix} 1 & \frac{T_{12}^{l1}}{T_{11}^{l1}} \\ \frac{T_{21}^{l1}}{T_{11}^{l1}} & \frac{T_{22}^{l1}}{T_{11}^{l1}} \end{bmatrix} = T_{11}^{l1}\cdot\begin{bmatrix} 1 & \frac{T_{12}^{l1}}{T_{11}^{l1}} \\ \frac{T_{21}^{l1}}{T_{11}^{l1}} & \frac{T_{21}^{l1}}{T_{11}^{l1}}\cdot\frac{T_{22}^{l1}}{T_{21}^{l1}} \end{bmatrix} = T_{11}^{l1}\cdot\begin{bmatrix} 1 & C \\ G & G\cdot D \end{bmatrix} \tag{57}$$

$$[T_R] = \begin{bmatrix} T_{11}^{r} & T_{12}^{r} \\ T_{21}^{r} & T_{22}^{r} \end{bmatrix} == T_{11}^{l1}\cdot\begin{bmatrix} \frac{T_{11}^{r}}{T_{11}^{l1}} & \frac{T_{11}^{r}}{T_{11}^{l1}}\cdot\frac{T_{12}^{r}}{T_{11}^{r}} \\ \frac{T_{22}^{l1}}{T_{21}^{l1}}\cdot\frac{T_{21}^{r}}{T_{22}^{l1}}\cdot\frac{T_{21}^{l1}}{T_{11}^{l1}} & \frac{T_{22}^{r}}{T_{21}^{r}}\cdot\frac{T_{22}^{l1}}{T_{21}^{l1}}\cdot\frac{T_{21}^{r}}{T_{22}^{l1}}\cdot\frac{T_{21}^{l1}}{T_{11}^{l1}} \end{bmatrix} = T_{11}^{l1}\cdot\begin{bmatrix} E & EA \\ DFG & BDFG \end{bmatrix} \tag{58}$$

对于

$$[T_{Meas}] = [T_L]\cdot[T_{DUT}]\cdot[T_R] \tag{59}$$

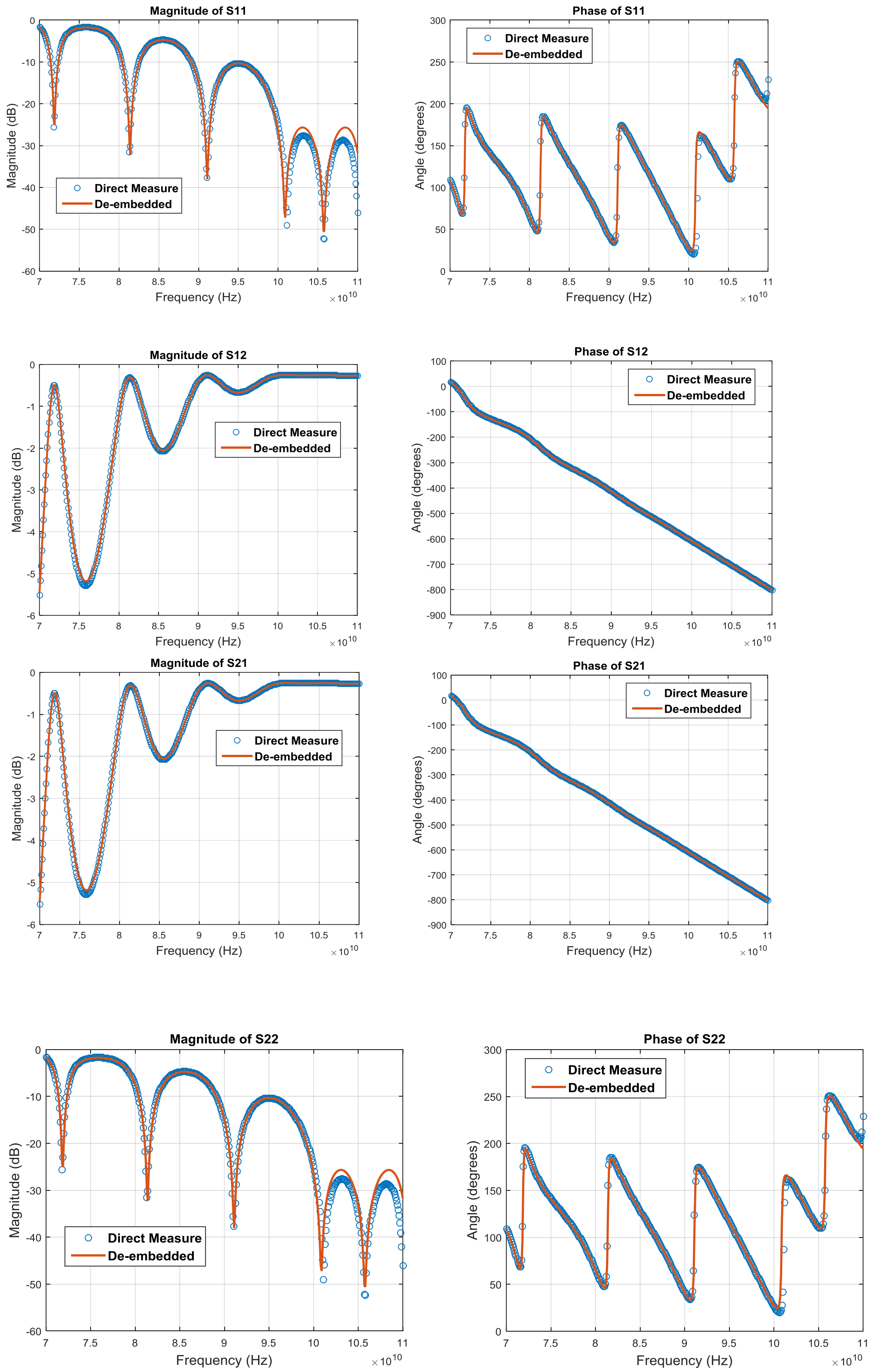
$$[T_{DUT}] = [T_L]^{-1}\cdot[T_{Meas}]\cdot[T_R]^{-1} = T_{11}^{l1}\cdot\begin{bmatrix} 1 & C \\ G & G\cdot D \end{bmatrix}\cdot[T_{Meas}]\cdot\frac{1}{T_{11}^{l1}}\cdot\begin{bmatrix} E & EA \\ DFG & BDFG \end{bmatrix}^{-1} \tag{60}$$

最后化简

$$[T_{DUT}] = \begin{bmatrix} 1 & C \\ G & G\cdot D \end{bmatrix}\cdot[T_{Meas}]\cdot\begin{bmatrix} E & EA \\ DFG & BDFG \end{bmatrix}^{-1} \tag{60}$$

四. Matlab 代码验证 TRL 理论

1. 理论验证图



2. 代码

D:\Dropbox\MatlabTest\TRL de-embedding\TRL_Calibration_v2.m

```
% The following is the scilab file to be translated into m file
%function varargout = uW_TRL_cal(s_thru, s_line, s_reflect,
REFLECT_STD)
```

```
clear
s_thru = 'C:\Users\e0012979\Google Drive\Huang Andong\S2P\Thru.s2p';
s_line = 'C:\Users\e0012979\Google Drive\Huang Andong\S2P\Line2.s2p';
%s_reflect = 'C:\Users\e0012979\Google Drive\Huang
Andong\S2P\Open.s2p';
s_reflect = 'C:\Users\e0012979\Google Drive\Huang
Andong\S2P\Short.s2p';
%REFLECT_STD = 'OPEN';
REFLECT_STD = 'SHORT';

% Read T/S-parameters Object
T_THRU = tparameters(s_thru);
T_LINE = tparameters(s_line);
S_REFLECT0 = sparameters(s_reflect);
S_REFLECT = S_REFLECT0.Parameters;

% Frequencies
freq = T_THRU.Frequencies;
Nf = length(freq);

% Read T-parameters
T_THRU_TP = T_THRU.Parameters;
T_LINE_TP = T_LINE.Parameters;

% Initialize T_IN and T_OUT
T_IN = zeros(size(T_THRU_TP));
T_OUT = T_IN;
K = [];
T_IN_INV = T_IN;


for m = 1:Nf

    % Reduce the redundent dimension
    T1 = squeeze(T_THRU_TP(:,:,m));
    T2 = squeeze(T_LINE_TP(:,:,m));

    % Compute the M and N matrix as defined in the doc
    INVT1 = inv(T1);
    M = INVT1*T2;
    N = T2*INVT1;

    % Equation to solve T12/T11, T22/T21 of the Tout matrix
    delta = (M(1,1) - M(2,2))^2 - 4*M(2,1)*(-M(1,2));
    X1 = ((M(2,2) - M(1,1)) - sqrt(delta))/(2*M(2,1));
    X2 = ((M(2,2) - M(1,1)) + sqrt(delta))/(2*M(2,1));
    Sol = [X1, X2];
    C1 = Sol(find(abs(Sol)==max(abs(Sol))));  % OUTPUT - T22/T21
    C2 = Sol(find(abs(Sol)==min(abs(Sol))));  % OUTPUT - T12/T11

    % Equation TRL N
    delta = (N(1,1) - N(2,2))^2 - 4*N(2,1)*(-N(1,2));
    X1 = ((N(2,2) - N(1,1)) - sqrt(delta))/(2*N(2,1));
    X2 = ((N(2,2) - N(1,1)) + sqrt(delta))/(2*N(2,1));
    Sol = [X1, X2];
    C3 = Sol(find(abs(Sol)==max(abs(Sol))));  % INPUT - D/C
    C4 = Sol(find(abs(Sol)==min(abs(Sol))));  % INPUT - B/A

    % Equation THRU FORWARD
```

```
    T_THRU_SP = t2s(T_THRU_TP); % Convert t-parameters to s-
parameters
    C5 = (1 + C4*T_THRU_SP(1,1,m))/(T_THRU_SP(2,1,m)); % T11/A

    % Equation THRU RESERVE
    C6 = (T_THRU_SP(1,2,m))/(T_THRU_SP(2,2,m) + C1);  % T21/D

    % Equation Reflect
    X_ = (S_REFLECT(2,2,m) + C2)/(S_REFLECT(2,2,m) + C1);
    Y_ = (1 + C3*S_REFLECT(1,1,m))/(1 + C4*S_REFLECT(1,1,m));
    sol = sqrt((C5*X_)/(Y_*C6*C3));

    A = 1; B = C4; C = sol; D = C3*C;
    GAMMA_STD = (C + D*S_REFLECT(1,1,m))/(A + B*S_REFLECT(1,1,m));
    if ((real(GAMMA_STD)>0) &&
strcmp(REFLECT_STD ,'SHORT')||((real(GAMMA_STD)<0) &&
strcmp(REFLECT_STD , 'OPEN')))
        sol = sol*(-1);
    end

    A = 1; B = C4; C = sol; D = C3*C;


 %   K = [K; sqrt(1/(A*D - B*C))];

    T_IN(:,:,m) = inv([A, B; C, D]);
    T_OUT(:,:,m) = [C5, C2*C5; C6*D, C1*C6*D];
    T_IN_INV(:,:,m) = [A, B; C,D];

end



%%
% % File path of the known s2p files, TF is the test fixture
Known_TF_path = 'C:\Users\e0012979\Google Drive\Huang
Andong\S2P\KNOWN__TEST_FIXTURE.s2p';
Known_path = 'C:\Users\e0012979\Google Drive\Huang
Andong\S2P\KNOWN.s2p';

% Import t-parameter object from the s2p file
Known_TF = tparameters(Known_TF_path);
% Import s-parameter object from the s2p file
Known = sparameters(Known_path); % Object

% Obtain the t/s-parameters from the t/s-p object
Known_TF_TP = Known_TF.Parameters;  % T-parameters
Caculated_Known_TP = zeros(size(Known_TF_TP)); % Initialization of
the Caculated known T-parameters



for m = 1:Nf
   % Caculated_Known_TP(:,:,m) =
inv(squeeze(T_IN(:,:,m)))*squeeze(Known_TF_TP(:,:,m))*inv(squeeze(T_O
UT(:,:,m)));
```

```
    Caculated_Known_TP(:,:,m) =
(squeeze(T_IN_INV(:,:,m)))*squeeze(Known_TF_TP(:,:,m))*inv(squeeze(T_
OUT(:,:,m)));
end

Calculated_Known_SP = t2s(Caculated_Known_TP);

Calculated_Known_SP_OBJ = Known;
Calculated_Known_SP_OBJ.Parameters = Calculated_Known_SP; % s-
parameter object

%Plot Calculated_Known_SP VS Known_SP

close all

for m = 1:2
    for n = 1:2
    a = figure;
    S_Known_MAG = rfplot(Known,m,n);
    hold on
    S_Cal_MAG = rfplot(Calculated_Known_SP_OBJ,m,n);
    title(sprintf('Magnitude of S%d%d',m,n),'FontSize',12)
    set(S_Known_MAG,'LineStyle','none','Marker','o','MarkerSize',6)
    set(S_Cal_MAG,'LineWidth',2)
    legend({'Direct Measure','De-embedded'},'FontSize',12,
'FontWeight','bold','Location','best')
    a.CurrentAxes.XLabel.FontSize = 13;
    a.CurrentAxes.YLabel.FontSize = 13;




    b=figure;
    S_Known_ANG = rfplot(Known,m,n,'angle');
    hold on
    S_Cal_ANG = rfplot(Calculated_Known_SP_OBJ,m,n, 'angle');
    title(sprintf('Phase of S%d%d',m,n),'FontSize',12)
    set(S_Known_ANG,'LineStyle','none','Marker','o','MarkerSize',6)
    set(S_Cal_ANG,'LineWidth',2)
    legend({'Direct Measure','De-embedded'},'FontSize',12,
'FontWeight','bold','Location','best')
    b.CurrentAxes.XLabel.FontSize = 13;
    b.CurrentAxes.YLabel.FontSize = 13;

    end
end
```