Studying the Forward-Reverse Method Through Simulations: II

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Description

This report studies a scenario not considered in earlier reports covering the Forward-Reverse Method (FRM)[1,2]. For the basics of the method and the nomenclature, please read those reports.

In practice, if the measurement port (the connector right at the VNA) is female, then the reversible test network needs to have male connectors. Therefore the standards measured at the VNA need to be male, while those measured at the end of the test network need to be female. Of course, if the VNA port is male, the opposite applies.

Using a gender adapter in some of the measurements seems like a viable way to require only one set of standards, but it does not solve the problem because the adapter would need to be characterized using accurately modeled standards. Following this path only makes the problem grow, requiring more measurements to solve for more variables.

The approach taken here is the cleanest possible. A set of standards of gender X is measured at the VNA, and another set of gender Y is measured at the end of the test network. Then, the FRM solves for the delay of both LOAD standards. It is assumed that the other parameters of the sets are known with enough accuracy.

The following plots show how well the delays can be recovered in realistic scenarios. The concern was how much covariance there could be between the two delays. As the plots show, and the conclusion stresses, in general the covariance is low and the precision is good.

[1] http://loco.lab.asu.edu/memos/edges_reports/report_20140630.pdf

[2] http://loco.lab.asu.edu/memos/edges_reports/report_20140707.pdf

Description

The settings of the nominal case are:

Simulation Parameter	Value	Comments
Number of repetitions	500	Sufficient repetitions for sampling parameter space
Frequency	1 GHz	The figure of merit is more sensitive as frequency increases
Delay of LOAD 1 (at VNA)	20 ps	
Delay of LOAD 2 (at test network)	30 ps	
Other parameters of standards	nominal	Nominal from Agilent
Se_{11}	$0, 0^\circ$	Perfect VNA calibration
$Se_{12}Se_{21}$	$1, 0^\circ$	Perfect VNA calibration
Se_{22}	$0, 0^\circ$	Perfect VNA calibration
St_{11}	$0.1, 45^\circ$	Close to optimal test network
$St_{12}St_{21}$	$0.8, 180^\circ$	Close to optimal test network
St_{22}	$0.9, 45^\circ$	Close to optimal test network
Measurement noise	1e-5	Approximate 1σ noise level for all loads in real and imaginary domains

The following figures present the results of simulations with nominal settings, compared to cases with other realistic settings.

Different Delay Values

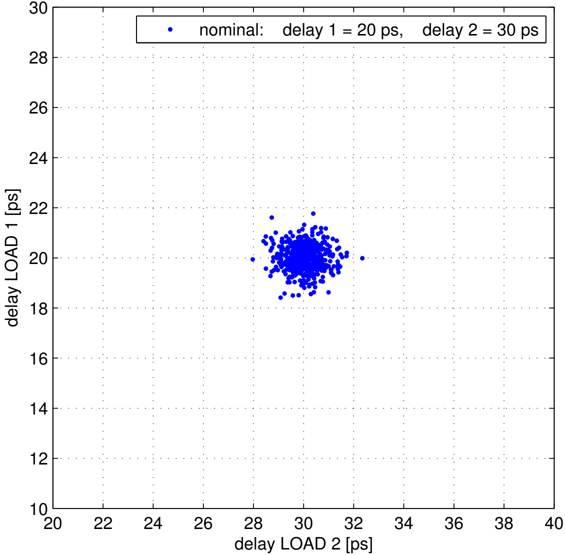

Figure : (1): The distribution of samples is very symmetrical, and the precision is better than $\pm$ 2 ps for both delays.

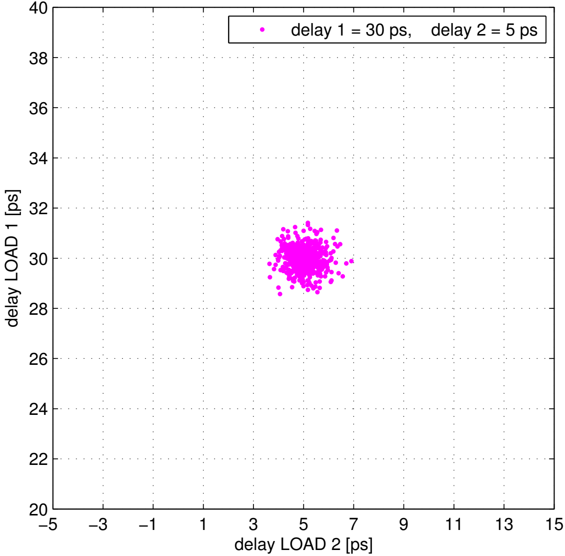

Figure : (2): Different values for the delays. Their distribution and precision are similar as those for the nominal case.

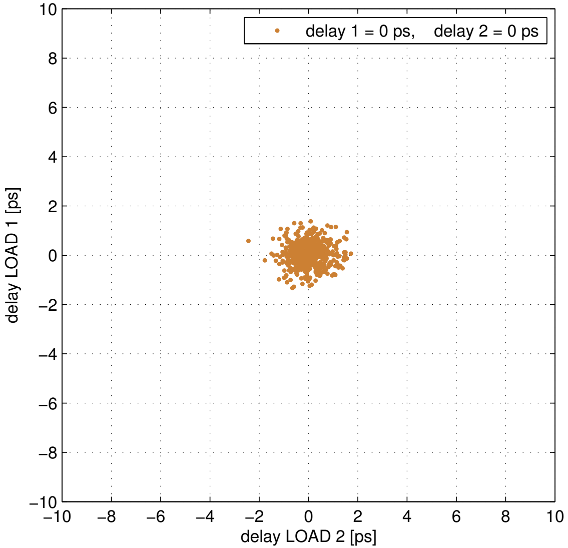

Figure : (3): Different values for the delays. Their distribution and precision are similar as those for the nominal case.

Effect of Load Resistance

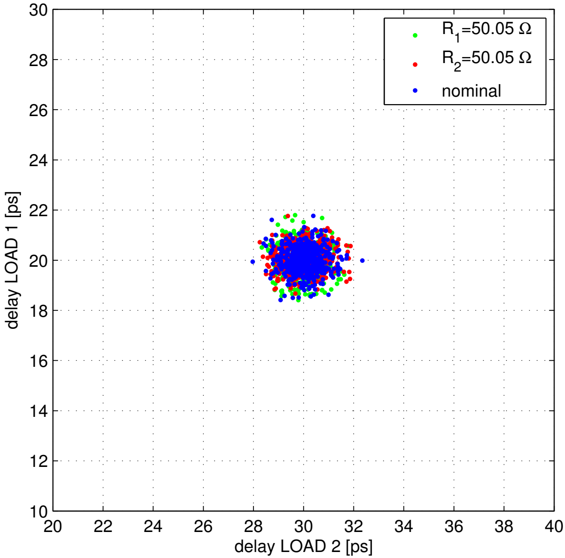

Figure : (4): The precision of the delays is not sensitive to the actual value of resistance of either LOAD.

Exploration of *Se*

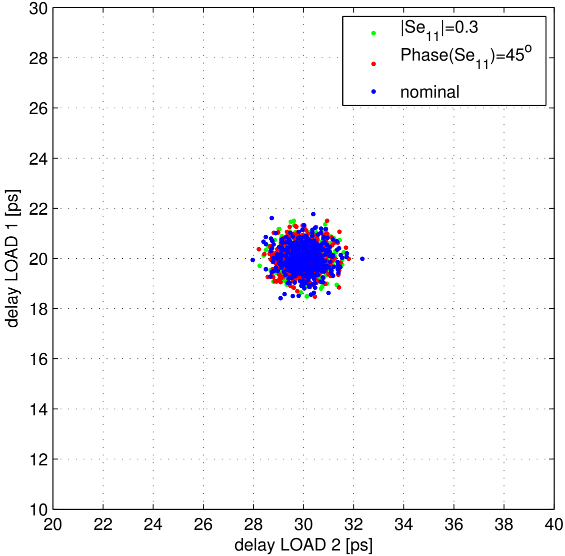

Figure : (5): The precision of the delays is not sensitive to reasonably imperfect values of Se_{11}.

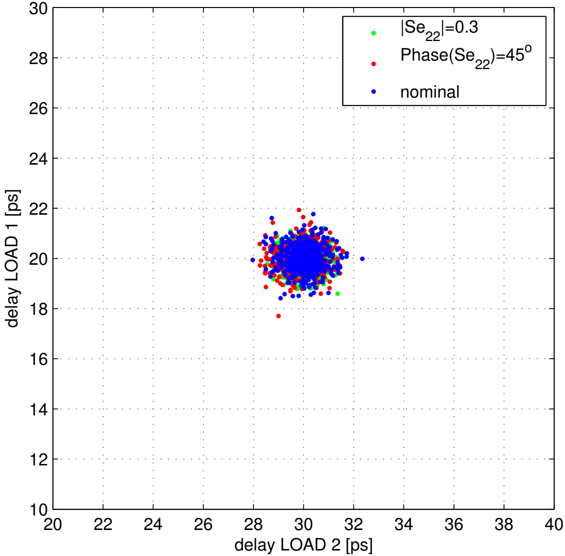

Figure : (6): The precision of the delays is not sensitive to reasonably imperfect values of Se_{22}.

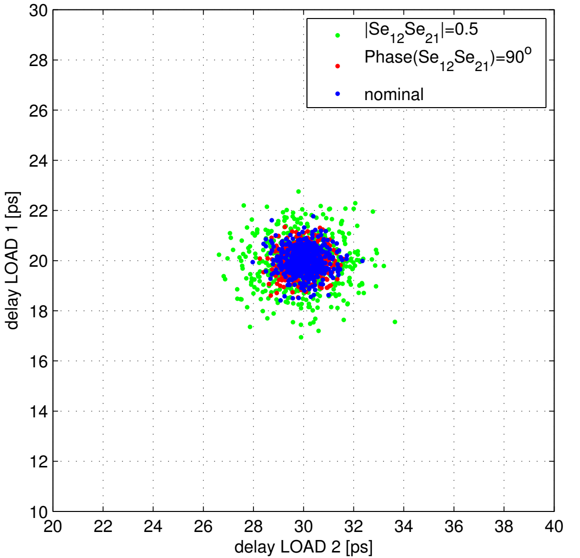

Figure : (7): The precision of the delays is sensitive to the magnitude of Se_{11}, but not to its phase. It is better to keep *Se* as close to perfect as possible by calibrating the VNA before the measurements.

Exploration of *St*

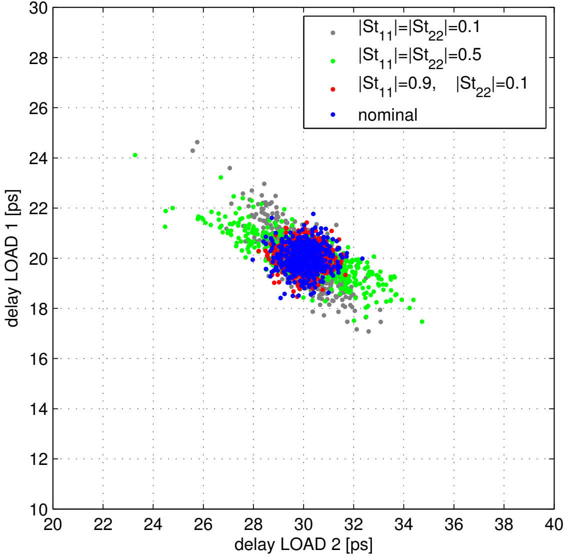

Figure : (8): The best precision and most symmetrical distribution is obtained when $|St_{11}|$ and $|St_{22}|$ are the furthest apart.

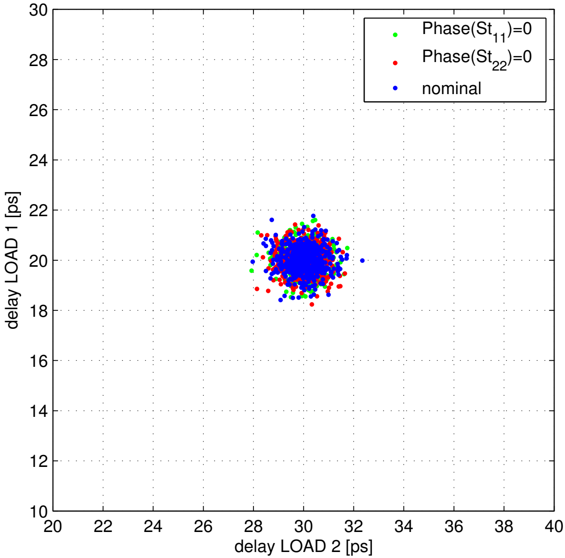

Figure : (9): The phases of St_{11} and St_{22} are not critical when optimizing the test network.

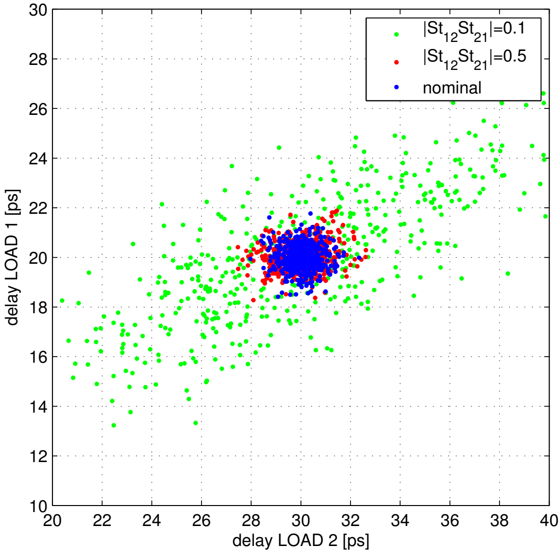

Figure : (10): The test network is optimized when the magnitude of $St_{12}St_{21}$ is as high as possible. In the plot, the nominal case is the best because $|St_{12}St_{21}|$=0.8.

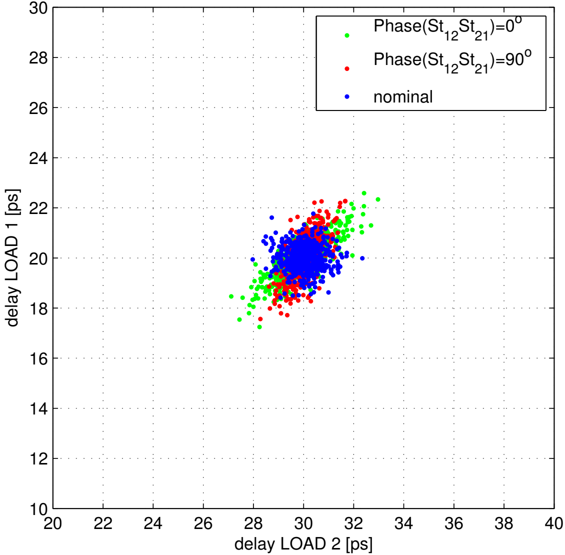

Figure : (11): As indicated by previous analyses, the best results are obtained when the phase of $St_{12}St_{21}$ is 180° (nominal in the plot).

Conclusion

- The most direct implementation of the FRM requires the use of standards of the two genders. I take advantage of this requirement and use this method to estimate the delay of both LOAD standards.
- The previous report in this series shows that there is a strong correlation between the loss and delay of the LOAD, even with only one set of standards. When considering two sets, the correlations and precisions are expected to degrade significantly, and for this reason only the delays have been considered as free parameters in this report.
- The simulations show that it is possible to estimate the LOAD delays with precision of $\pm$ 2 ps when using an appropriate test network, and assuming no systematic effects.
- The best test network has very different $|St_{11}|$ and $|St_{22}|$ (one close to 1 and the other close to 0). The magnitude of $St_{12}St_{21}$ has to be close to 1 and its phase close to 180°.