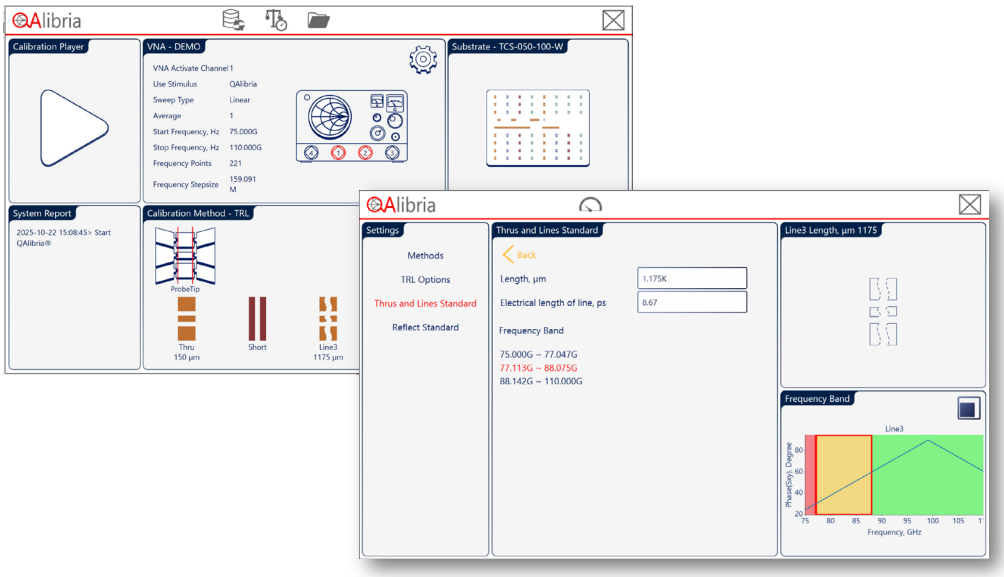
QAlibria® TRL Line Selection Tool



The TRL (Thru-Reflect-Line) calibration technique, originally introduced by Engen and Hoer in 1979 [1], is one of the most widely used vector network analyzer (VNA) calibration methods. It relies on three standards: a Thru connection, a Reflect (typically an open or short), and a Line with a known physical length.

For on-wafer measurements, these standards are typically implemented either on a commercially available calibration substrate (such as the AC2-2 or TCS-050-100-W from MPI Corporation [2, 3] or fabricated directly on the same wafer as the Device Under Test (DUT). The latter approach is generally preferred, as it significantly improves calibration accuracy at mmWave frequencies and under temperature-varying measurement conditions [4].

The distinctive advantage of the TRL method is that it eliminates the need for accurate modeling of the electrical characteristics of the calibration standards (such as impedance or reflection coefficient), making it an excellent choice for precise wafer-level calibration in the mmWave frequency range.

However, selecting the optimal TRL Line standard for a given frequency band is not always straightforward. The relative phase delay of the Line with respect to the Thru should remain between approximately 20° and 160° across the frequency range of interest. This requirement avoids phase ambiguity and ensures consistent calibration accuracy [5, 6].

Traditionally, engineers had to manually evaluate and compare the relative phase delay of each available transmission line, requiring multiple calculations to identify the optimal combination. This MPI application note introduces the QAlibria® TRL Line Selection Tool, which automates this process by performing all necessary calculations on the fly and visualizing valid Line-Thru combinations. With the help of the QAlibria® TRL Line Selection Tool, TRL calibration can be performed faster and more intuitively than ever, even by less-experienced users, while maintaining the highest calibration accuracy and confidence.

THE QAlibria® TRL LINE SELECTION TOOL

To access the tool from the dashboard of QAlibria®, click the gear icon in the relevant tab (highlighted in red on Figure 1) to open the calibration method setup. Note, that the frequency sweep needs to be set correctly before using the Line Selection Tool. In this application note we selected the W-band from 75 GHz to 110 GHz as an example.

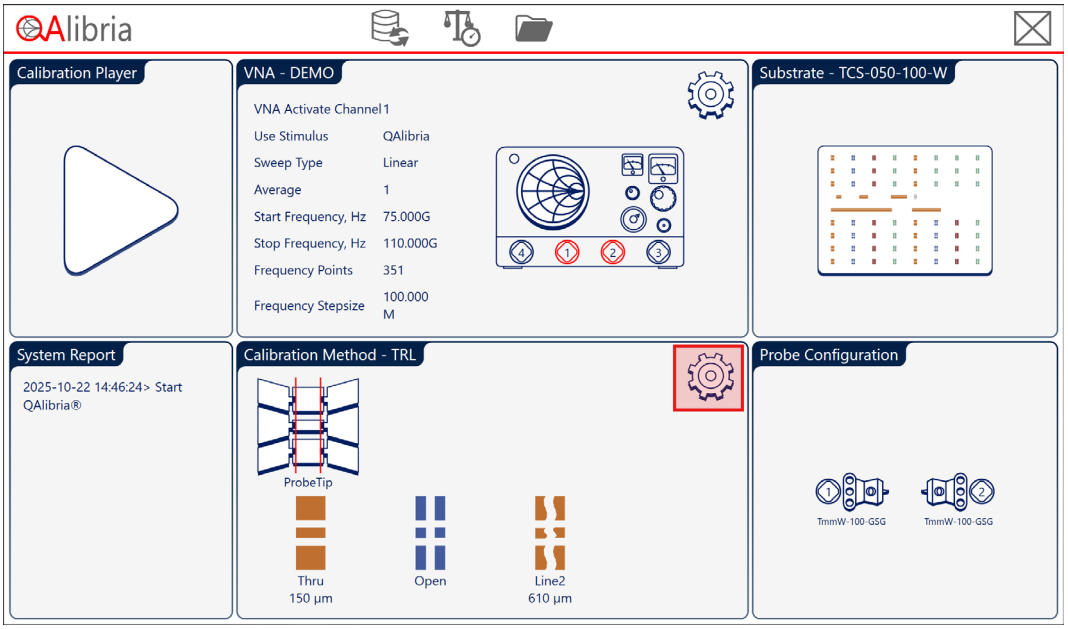


Figure 1: The dashboard of QAlibria® configured for the TRL calibration

As shown below in Figure 2, select the TRL method from the available options.

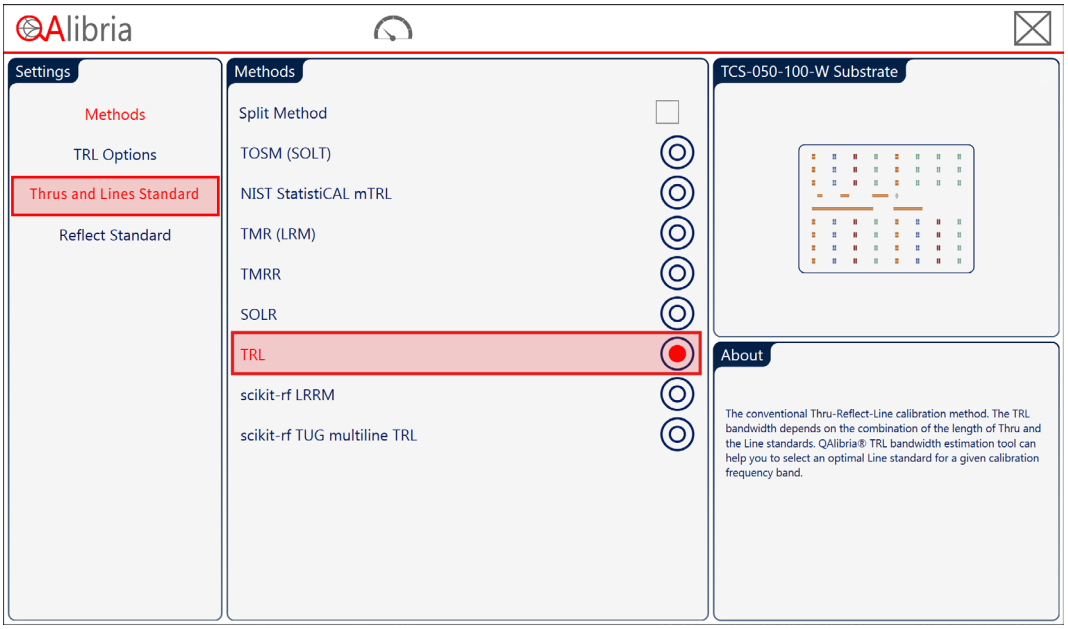


Figure 2: The page of calibration set up

When the TRL calibration method is enabled, the Line Selection Tool can be found under the Thrus and Lines Standard from the Settings tab (Figure 2 and Figure 3). The color bars next to the Line 1 through Line 5 in Figure 3 indicate that phase shift of each Line across the full frequency sweep, from low to high. The table below explains the color code used for the phase shift values. The red region should be minimized or avoided when choosing the Line standard.

Color	Line Standard Relative Phase Difference Compared to Thru	Recommendation
Red	-30° (+150°) to +30°	Avoid
Yellow	+30° to +60° and +120° to +150°	Acceptable
Green	+60° to +120°	Best

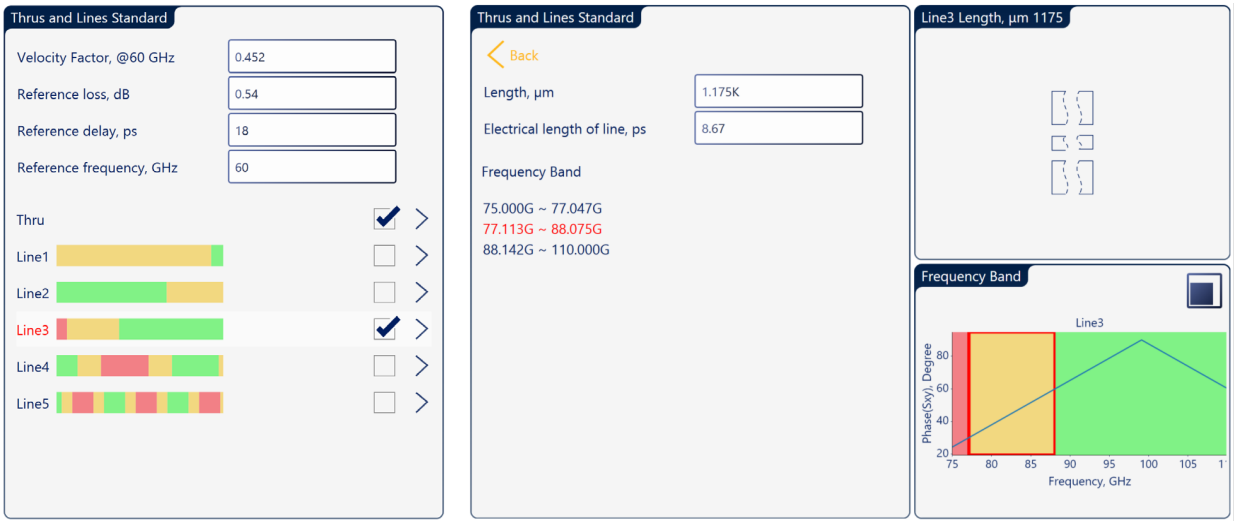


Figure 3: The tab of Thrus and Lines Standard (left) and the Frequency Band inspector for the Line 3 (right)

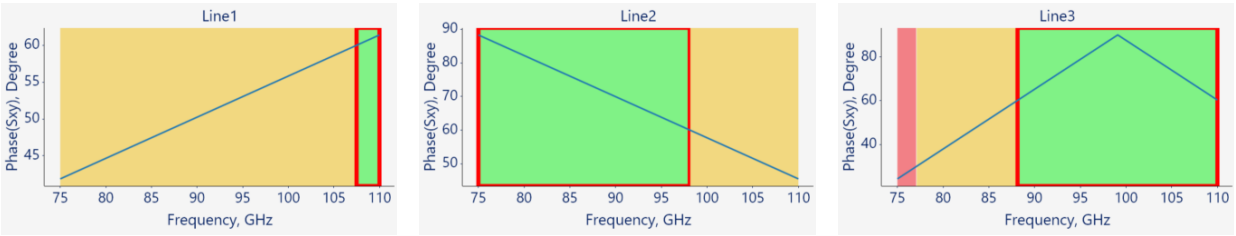


Figure 4: Phase delays computed for three lines: Line 1(left), Line 2 (middle) and Line 3 (right), respectively

Figure 4 (right) provides detailed frequency band information for Line 3 as an example. Line 3 shows a red region between 75 GHz and 77 GHz, but offers substantial green coverage from 88 GHz to 110 GHz. Therefore, Line 3 is unsuitable for calibrating a DUT operating near 77 GHz, e.g. as an automotive radar, yet highly advantageous for applications targeting the upper half of the W-band. In this example, both Line 1 and Line 2 meet the required phase condition (no red region) and can thus be selected as TRL Line standards. Note that the larger green region in the lower half of the frequency sweep for Line 2 indicates that Line 2 is the preferable choice when the frequency of interest lies in the first half of the W-band.

TRL ACCURACY VALIDATION

The following experiment demonstrates how the accuracy of the TRL-corrected data can be evaluated using the Line Selection Tool and MPI TCS-050-100-W calibration substrate. Designing of Experiment includes:

- **Calibration method:** TRL
- **VNA:** Anritsu VectorStar ME7838 70 kHz – 220 GHz single-sweep broadband system [7, 8]
- **Frequency range:** 0.1 GHz to 220 GHz
- **Probes:** TITAN™ T220MA-GSG0050 Probes in GSG configuration and pitch of 50 µm
- **Calibration Standards:** Thru (150 µm), Short, Line 3 (1175 µm)
- **DUT:** Line 2 (610 µm)

The experiment DUT is a matched transmission line with low insertion loss. The Line Selection Tool shows that Line 3 has three critical frequencies where the phase difference to the Thru approaches 0° or 180° (excluding the DC point). The background of Figure 5 shows the band colormap generated by the QAlibria® Line Selection Tool. Ignoring the low frequency peak near DC, the tool highlights three regions in red, around 60 GHz, 130 GHz, and 200 GHz, where the phase difference between Line 3 and the Thru nears either 0° or 180°. As a result, the TRL-corrected results will be inconsistent for these frequency bands.

The blue curve in Figure 5 shows the DUT TRL-corrected (Line 2) S21-parameter and has two peaks exceeding +10 dB: one peak around 130 GHz and the other peak around 200 GHz. The two peaks are also clearly visible at the dark green curve that shows DUT S11-parameter. Additionally, another abnormal peak of S11 can be found at around 60 GHz.

These peaks highlight the frequency points where TRL is ill-conditioned, as predicted by the Line Selection Tool.

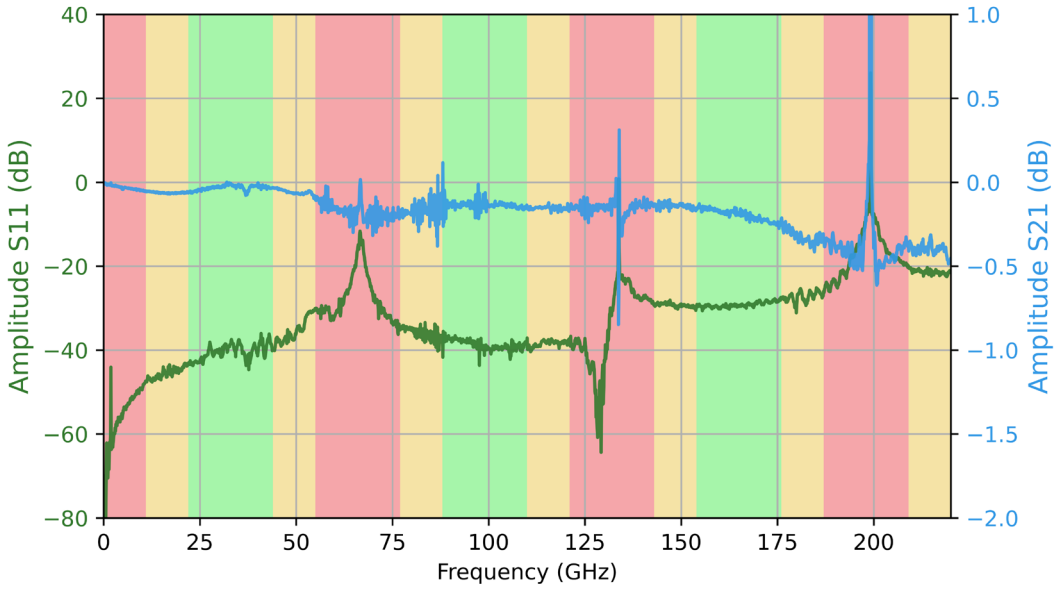


Figure 5: Error corrected S-parameters of the Line 2 standard using error terms from TRL with Line 3 and the Line standard

CONCLUSION

This application note introduced the fundamentals of TRL calibration and highlighted the importance of selecting appropriate Line standards to achieve accurate results. It also presented a dedicated tool that simplifies the Line selection process and supports the validation of TRL-calibrated measurements. By combining a clear methodology, intuitive operation, and graphical visualization of results, the QAlibria® TRL Line Selection Tool enables even less-experienced users to perform mmWave system calibration quickly, accurately, and with full confidence.

REFERENCES

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