Application Note

Automotive FPD-Link High-Temperature S-Parameter Measurement Guide

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Abstract

This document was translated from a simplified Chinese source. (ZHCAGC7)

S-parameters are important metrics for measuring the performance of high-speed signal channels, quantifying the reflection and transmission characteristics of links through parameters such as S_{11} and S_{21}. In the FPD-Link development process, S-parameters are used to assess the quality of PCB traces, connectors, and wiring assemblies and provide a basis for link margin analysis and system-level troubleshooting. Accurate measurement of S-parameters helps verify the system stability under harsh environmental conditions at high temperatures.

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1 Definition of S-Parameters

S-parameters characterize high-frequency networks based on the relationship between incident and scattered waves. The scattering relationship of a two-port network is expressed as $b_1 = S_{11}a_1 + S_{12}a_2$ and $b_2 = S_{21}a_1 + S_{22}a_2$. S_{11} and S_{22} are the complex reflection coefficients, and S_{21} and S_{12} are the forward and reverse transmission coefficients, respectively. The Log Mag S_{11} displayed on the instrument is typically $20\log_{10}|S_{11}|$ with a negative value, and the return loss RL = $-20\log_{10}|S_{11}|$ with a positive value. Therefore, $S_{11} < -10$ dB and RL > 10 dB indicate the same reflection condition.

- S_{11}: the complex reflection coefficient at port 1 when port 2 is terminated with a matched load; the return loss is $-20\log_{10}|S_{11}|$.
- S_{21}: the forward transmission coefficient from port 1 to port 2 when port 2 is terminated with a matched load; the insertion loss of a passive channel is typically $-20\log_{10}|S_{21}|$.
- S_{12}: the reverse transmission coefficient from port 2 to port 1 when port 1 is terminated with a matched load.
- S_{22}: the complex reflection coefficient of port 2 when port 1 is terminated with a matched load.

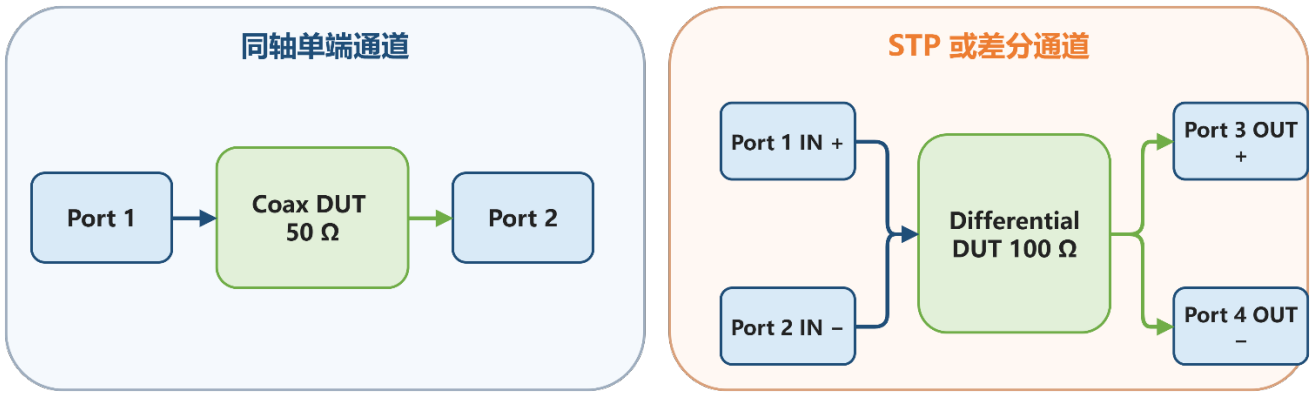


Figure 1-1. S-Parameter Measurement Topology

Table 1-1. Calibration of Different Test Channels for S-Parameters

Channel	Calibration	Test results
Coaxial single-ended	Full two-port calibration	S_{11}, S_{22}, S_{21}, and S_{12}
STP or differential PCB	Full multi-port calibration and conversion to mixed mode	Sdd, Scc, Sdc, and Scd
DUT with fixtures	Interface calibration plus fixture de-embedding	Raw and de-embedded data both saved

Note

In mixed-mode S-parameters, Sdd stands for Differential Input to Differential Output, Scc for Common-Mode Input to Common-Mode Output, Sdc for Common-Mode Input to Differential Output, and Scd stands for Differential Input to Common-Mode Output. The first letter in the subscript indicates the output mode, and the second letter indicates the input mode.

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2 Effects of Temperature

Temperature may change conductor resistivity, the dielectric's relative permittivity (Dk) and loss tangent (Df), mechanical dimensions, and connector contact conditions. Dk primarily affects signal propagation rate, electrical length, and characteristic impedance; Df characterizes dielectric loss and typically affects high-frequency insertion loss. Both are related to material, frequency, and temperature, and the direction and magnitude of their changes cannot be generalized. When conducting the analysis, prioritize the material supplier's data at the target frequency and temperature, and note down the board model, stack-up, copper thickness and roughness, cable dielectric, and connector materials.

Table 2-1. Effects of Various Factors on Test Results at Different Temperatures

Factor	Possible Observation	Verification Method
Variation in conductor resistivity and surface resistance	Variation in high-frequency insertion loss	Compare S_{21} to S_{12} and check consistency by repeating measurements
Change of Dk and Df over temperature	Phase delay, loss, and impedance variation	Combine material data, group delay, and TDR analysis
Thermal expansion of connectors or fixtures	Local reflection peaks and notches	TDR localization and temperature cycling test
Thermal drift of test cables	Phase or magnitude shift across the curve	Verification piece, temperature compensation, or calibration refresh

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3 Test System

A typical measurement link consists of a vector network analyzer (VNA), room-temperature connection cables, chamber feedthrough, high-temperature extension cables or fixtures, and a device under test (DUT). The VNA unit is usually kept at room temperature; the cables, connectors, calibration standards, and fixtures placed into the chamber must satisfy the target temperature requirements, and the cables should also satisfy the minimum bending radius requirements. The feedthrough must be insulated and the cables secured to reduce displacement and stress introduced by temperature cycling.

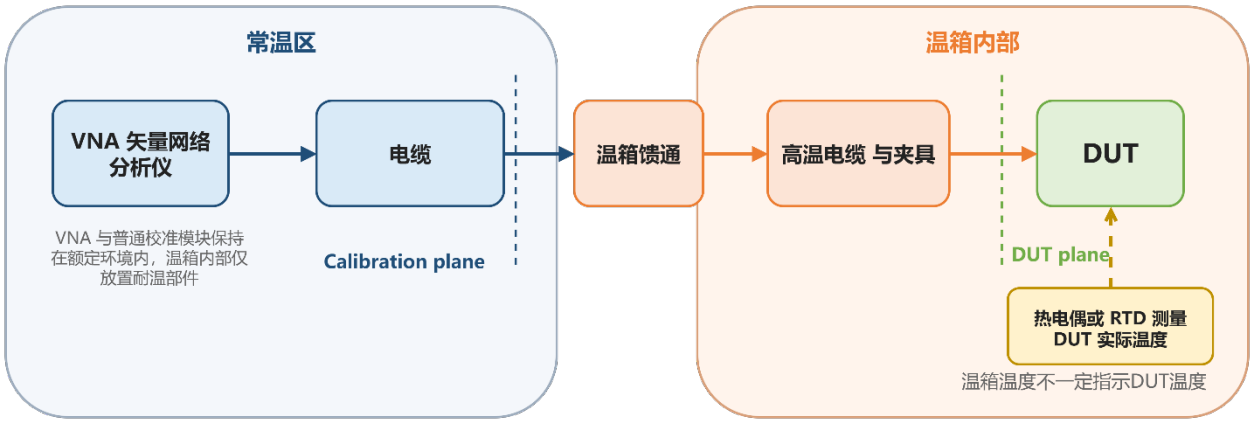


Figure 3-1. S-Parameter Test System

3.1 Test Instrumentation

- The port count, frequency range, dynamic range, and noise floor of the VNA should be aligned with the expected DUT loss and target uncertainty. The dynamic range should be selected based on the actual measurement headroom; 100dB is not a threshold for all conditions.
- For coaxial DUTs, a two-port VNA is typically used; for differential DUTs, a four-port VNA is recommended, or a switching system that has been validated and delivers required repeatability.
- Inside the chamber, temperature-resistant, low-loss, amplitude- and phase-stable test cables should be used. For cable performance, see manufacturer data or independent characterization results; do not refer to a single ppm indicator with no source and no applicable conditions.
- Mechanical calibration standards, ECal, CalPod, and high-temperature standards may only be used with a specific connector within their respective specified temperature, frequency, and power ranges. Normal ECal modules should not be placed directly into a chamber at 85°C or higher unless expressly permitted by the manufacturer.
- A calibrated thermocouple or RTD is used to measure the actual temperatures of the DUT and critical connectors. The air temperature in the chamber can be used for process monitoring, but it is not a substitute for DUT temperature.

3.2 Pre-measurement Preparation

3.2.1 Calibration and Fixture Handling

- Coaxial two-port DUT: Complete a full two-port calibration. Mechanical SOLT or ECal may be used; when the thru standard is not accurately characterized or cable routing is constrained, an applicable Unknown Thru method may be used.
- Differential four-port DUT: Complete a full multi-port calibration, verify the port pairing and polarity of differential pairs, and proceed with the conversion to mixed mode.
- Non-coaxial structures for which on-board calibration standards can be made: The Thru-Reflect-Line (TRL) calibration may be used. The geometry, impedance, line length, and valid frequency band of the standard should be compatible with the DUT interface and measurement frequency band.
- When the reference plane cannot reach the DUT directly: Complete calibration at an accessible interface and then de-embed using measured fixture data, 2x-Thru/AFR methods, or verified electromagnetic models. De-embedding methods, port mapping, model orientation, and valid frequency bands should be specified.

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Calibration and de-embedding: During the test, the calibration reference plane and the DUT reference plane should be identified. If a calibration standard covering the target temperature can be used at the DUT interface, establish the reference plane at the DUT port; if calibration is possible only outside the chamber or at the fixture inlet, de-embed using validated S-parameters of the fixture. Calibration removes errors caused by the VNA and test cables; de-embedding eliminates fixture errors introduced when calibration is not directly conducted at the DUT port.

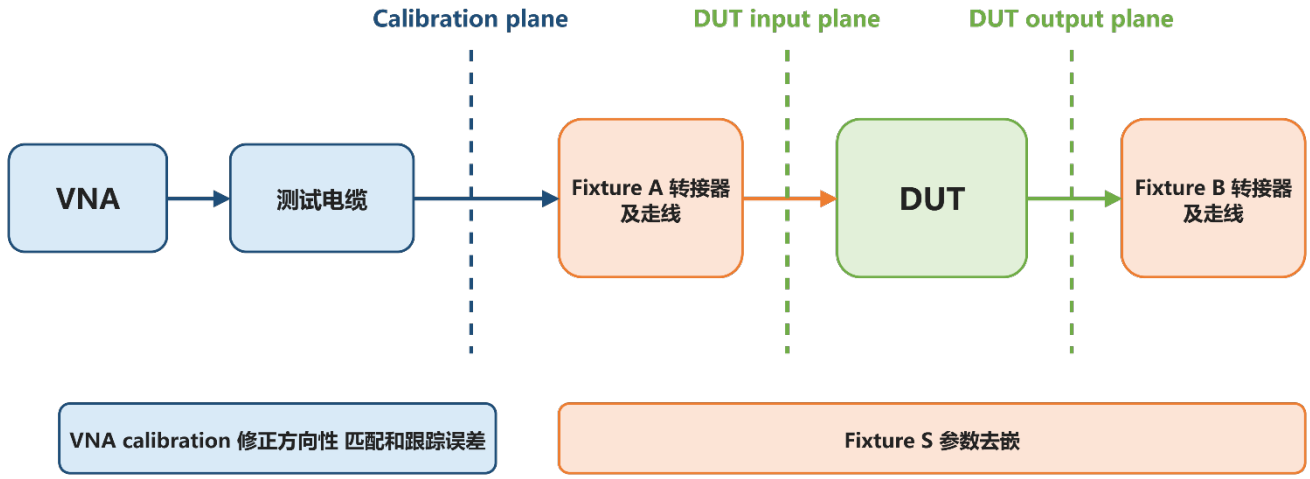


Figure 3-2. Calibration Reference Plane and Fixture De-embedding

3.2.2 Temperature Cycling and Thermal Stability Testing

A temperature plan typically contains room temperature and the maximum operating temperature specified for the product. The DUT and OEM specifications must be followed to select from −40°C, 85°C, 105°C, or 125°C.

Precondition the setup at the planned temperature extremes after each change to mounting or cable routing. After the chamber reaches its setpoint, continue waiting until both the measured DUT temperature and the S-parameter response have stabilized.

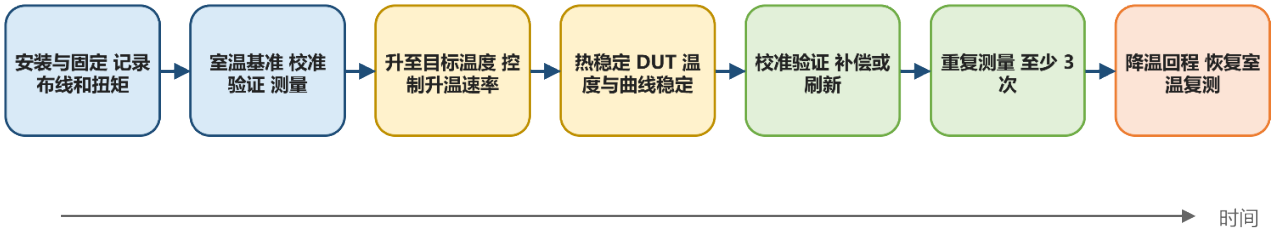


Figure 3-3. Temperature Cycling

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4 Measurement Procedure

1. Define the DUT scope, port definitions, differential pair polarity, and applicable channel specifications.
2. Set the start and stop frequency, point count, IFBW, port power, and averaging count for the VNA. Smoothing is disabled unless specified by the test plan. For TDR or time-domain transformation, synchronously set the window function, low-frequency extrapolation method, and equivalent rise time Tr; Tr should match the measurement bandwidth and be consistent at various temperature points.
3. Complete the connector cleaning, torque connection, and cable fixing, and take a photo of the test link.
4. Complete the full two- or multiple-port calibration and save the calibration status (calset).
5. Apply port extension or fixture de-embedding as planned;

   Use only corrected and validated data that covers the measurement frequency band, and save both the raw and corrected data.
6. Measure the stand-alone verification piece and confirm that the results fall within the pre-defined acceptance limits.
7. Mount the DUT, place the temperature sensors for the DUT and connector, and secure the cables.
8. Complete preconditioning and thermal stabilization per the temperature plan and perform validation, compensation, or calibration refreshes according to the drift control scheme.
9. Measure the DUT according to the repeatability schedule. It is typically recommended to complete at least three independent connections or repeated scans in the design verification phase; for differential DUTs, save the complete four-port single-ended data and mixed-mode data.
10. If the project requires the assessment of temperature hysteresis, complete the temperature rise and fall measurements and re-measure the reference point after returning to room temperature to check whether the results recover.

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5 Data Processing and Determination

The measurement frequency range should be defined based on the applicable FPD-Link Channel Specification and operating mode. Relevant channel specifications can be requested from the TI technical support team. The report should specify the part number, FPD-Link generation and operating rate, transmission medium (coaxial or STP), channel range, and the number, version, and date of the applicable specification.

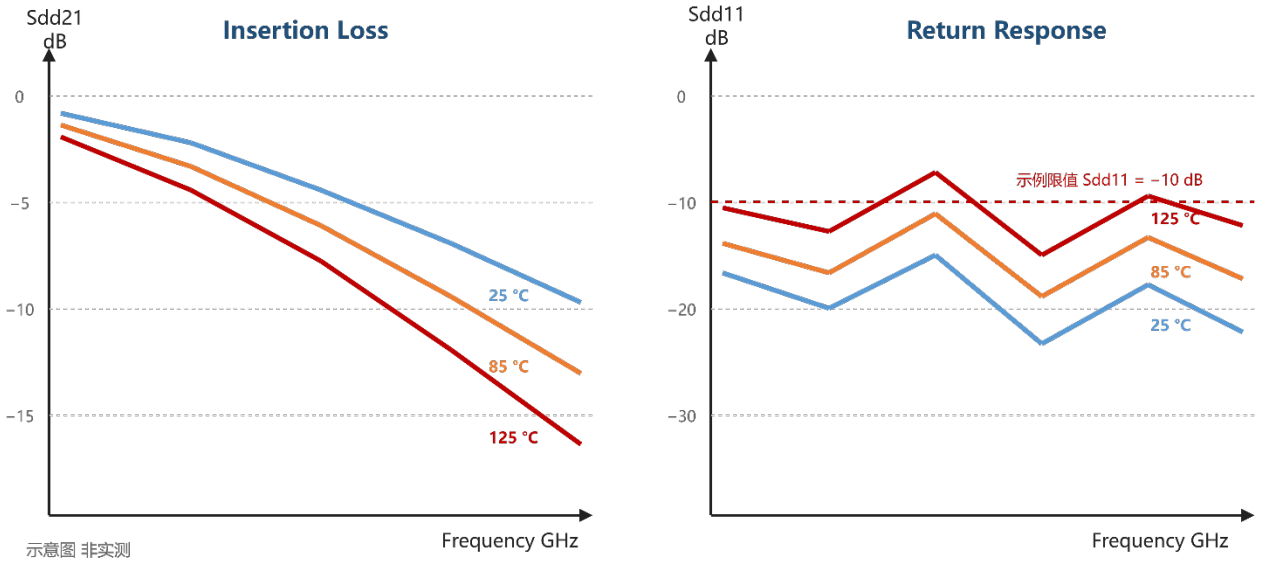


Figure 5-1. S-Parameter Diagram

5.1 Troubleshooting Procedures for Out-of-Range S-Parameters

As shown in Figure 5-2, the frequency domain reflection peak represents increased mismatch in a certain frequency band; in combination with TDR, it can be further determined that the impedance discontinuity is located at connectors, vias, cables, TVS diodes, or capacitors.

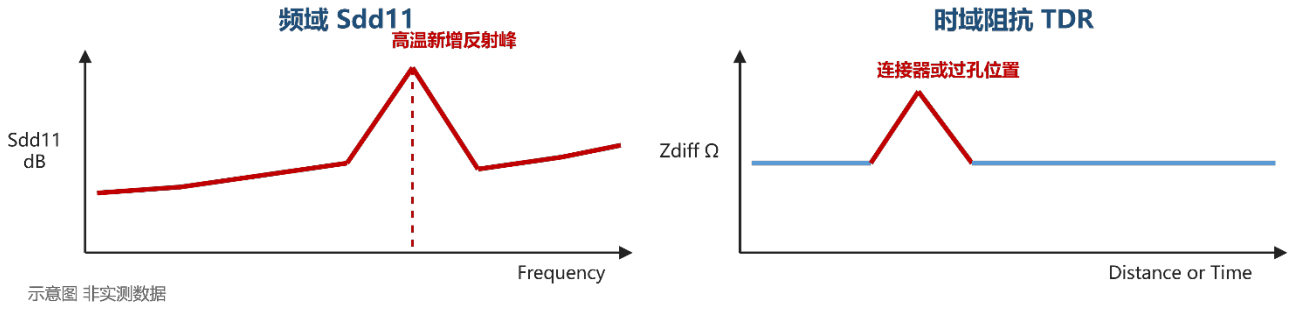


Figure 5-2. Schematic Diagram of Frequency-Domain Manifestations and TDR Localization of Abnormal Reflection

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6 Reference Documents

- Keysight Technologies, De-Embedding and Embedding S-Parameter Networks Using a Vector Network Analyzer, Application Note 5980-2784.
- Texas Instruments, 98x FPD-Link Channel Requirements, Version 1.2, 2025-04-17
- Texas Instruments, Detailed Explanation of S-Parameters and the FPD-Link Channel Specification

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