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Product Note No 2

Coaxial TRL Calibration Kits for Network Analyzers up to 40 GHz

This note describes the components and operation of the 7mm (GPC-7) and 2.9mm (K®) Thru - Reflect - Line (TRL) coaxial calibration kits of Focus Microwaves. These calibration kits cover a frequency range $(f_{max}-f_{min})/f_{min}$ of more than 40/1 using a single Delay Line standard.

Introduction

Automatic Vector Network Analyzers (VNA) are the most valuable and sophisticated tool for all measurement, design and test tasks from RF to millimetre wave frequencies. The accuracy of the VNA's has increased decisively since the introduction of synthesized sources and multi-detector configurations in the late 70's.

Several VNA calibration techniques have been developed and implemented for different measurement media such as coaxial, microstrip, on wafer and waveguide.
The simplest techniques use fixed Short - Open and 50 Ω standards, they in general are specified as 'economy kits'. The calibrations made using these kits are good up to about 6 GHz, depending on the analyzer used.
A more sophisticated method uses a Sliding Load standard to improve the 50 Ω position on the Smith Chart. These calibrations are acceptable up to 26 GHz.
Other techniques such as Short - Offset Short - Load or Line - Reflect - Match have also been used for waveguide or microstrip (on wafer) calibrations.
The most accurate calibrations, however, are generated by the 1979 [1] proposed TRL (Thru - Reflect - Line) calibration method. This is simply because the standards used can be made easier close to perfect specifications [2].

Focus Microwaves has developed coaxial TRL standards which provide state of the art calibrations of all commercially available Vector Network Analyzers, which include the TRL software option.

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Calibration Standards required by the TRL method

The Thru - Reflect - Line method requires three standards for complete calibration
- A **Thru** (with zero or non-zero length) connection
- A **Reflect** (best is Open or Short, needs to be known only within ±λ/4)
- A **Line** (Delay line with the same characteristic impedance as the Thru).

In all types of transmission media (coaxial, microstrip, waveguide) all three standards can be manufactured very easily to tight specifications:
- In microstrip only the width of the metallized line has to be accurate (for the Line), a simple microstrip open circuit represents a good and easy to make Reflect.
- In coaxial only the diameter and the ratio of the centre and external conductors of the Line extension need to be accurate. The coaxial parts of Focus' calibration kits are manufactured with a tolerance ±0.0001" (corresponds to a worst case error of -57dB).
Also an ideal short is easy to make in order to provide a good and repeatable Reflect.
The same is valid for waveguide components.

These are essentially the reasons why TRL provides the best calibrations for VNA's.

Further conditions to be fulfilled by the TRL standards concerning their size and form are presented and discussed elsewhere [2,3].

The TRL Calibration kits of Focus Microwaves

The TRL calibration kits of Focus Microwaves have been developed in order to make wide band coaxial calibrations using one of the following Network Analyzers:
Hewlett-Packard 8510-B and C, and 8720-C (1), Wiltron 360-A and B and 37000.

- The TRL-7mm calibration kit uses APC-7® connectors and covers the frequency range from 300 MHz to 18 GHz.

- The TRL-2.9mm calibration kit uses K® connectors and can be used to calibrate:
  - a Wiltron 360 or 37000 with K® connectors from 0.5 to 40 GHz.
  - a HP 8510-B/C or HP 8720-C with 3.5mm connectors from 0.5 to 26.5 GHz.
  - any of the analyzers with SMA connectors from about 0.3 to 18 GHz, as long as it has the TRL software option.

(1) The TRL calibration of the HP-8720-C Analyzer requires a 'perfect' attenuator to be connected to the opposite port during calibration to mask the effect of the mechanical switch. Since such a component does not really exist, the TRL calibrations of this analyzer are of restricted accuracy.

Components of the TRL Calibration Kits

The Focus Microwaves TRL calibration kits include the following standards

GPC-7-TRL-CV (figure 1)

- One 7mm direct short
- Two 50Ω loads
- One 50Ω line extension (Delay Line) including
    - One external conductor cylinder
    - One centre conductor extension
- One 10cm 50Ω airline (for verification)

GPC-2.9-TRL-CV (K®) (figure 2)

- One offset short (male)
- One offset short (female)
- Two 50Ω loads (1 male, 1 female)
- One set of adapters (two male-female, one female-female).
- One 50 Ω extension line including
    - One external conductor cylinder
    - Two centre conductor pins (one spare)
- One SMA or K® connector guide and fastener

Even though the TRL method does not require 50Ω loads, in the case of Network Analyzers these loads are used to terminate the cables during Isolation measurement (cross talking between the two channels). These loads are not used as reference standards and their quality is therefore not very important.

For users of the HP 8510-C network analyzers a 3½" floppy is available in DOS or LIF format including the Calkit's parameters.
For users of the Wiltron 360 this is not required because the Calkit's parameters can be introduced into the Analyzer in a straightforward manner.

Performance Verification of the TRL Calibrations

There is still confusion, among Engineers, concerning the term **Verification**.
In most cases the operator establishes a Thru connection at the calibration reference plane and verifies the transmission (S21) or connects a short on either port and verifies the reflection (S11 or S22).

As a matter of fact this test does not say much about the validity of the calibration, this is rather a **Repeatability** test, since both standards (Thru Line and Short) have already

been measured in the calibration procedure and cannot be used as Verification standards.
If the Analyzer **does not recognize** the standards when we measure them again then something is very wrong! If there is any problem recognizing the standards then you should verify the cables, the connectors and, if everything seems OK, repeat the calibration paying attention to **establish good mechanical connections** before any measurement action.

A quick and reliable **Verification** procedure can be limited in measuring, in addition to the above mentioned Direct Short (S11, S22) and Direct Transmission (S21) also

1- The **Ripple** δS11 and δS22 of an OFFSET SHORT at ports 1 and 2
2- The **Residual Reflection** S11 and S22 of the THRU LINE connection

Offset Short

To test an offset short use a low reflection 50Ω Airline (30dB or more return loss), normally supplied with the Calkit, connected to a Short. Set the S11 (or S22) display on LOG MAG and the SCALE to 0.1 dB/DIV. Using beadles airlines in general improve the quality of the test by eliminating additional causes of multiple reflections.

Graphs like figures 3 and 6 should be obtained on both ports. Both the HP and Wiltron Analyzers can be calibrated to generate maximum offset short ripple of less than 0.1 dB over the 0.3 to 40 GHz frequency range using TRL calkits. A careful calibration of the HP-8510-C can provide total peak to peak ripple of less than 0.05 dB.
This residual ripple is due to residual directivity and test port mismatch of the Analyzers and cannot be further improved by error corrections.

Thru Line

When testing a THRU Line then S12 and S21 are the least significant parameters to observe. Anyhow if there is any problem with S12 or S21 then the calibration is useless and should be discarded.
The RESIDUAL REFLECTION should be verified instead and should generate a return loss of 50 to 70 dB over the entire frequency range. Figures 5 and 8 show examples of such measurements over the 0.5 to 18 and 1 to 40 GHz ranges made using the GPC-7 and GPC-2.9 Calkits correspondingly.

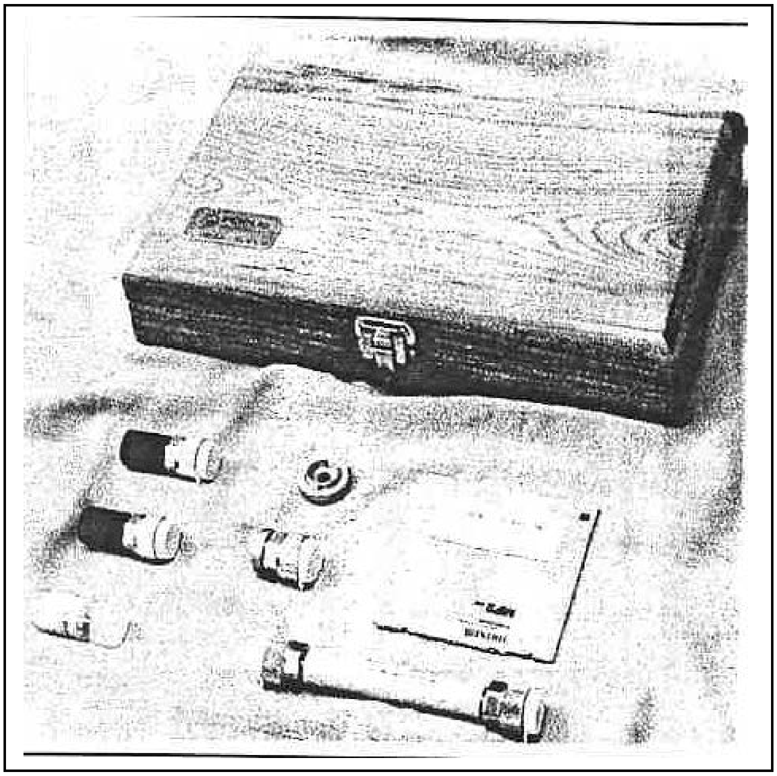

Figure 1
GPC-7 TRL Calibration kit

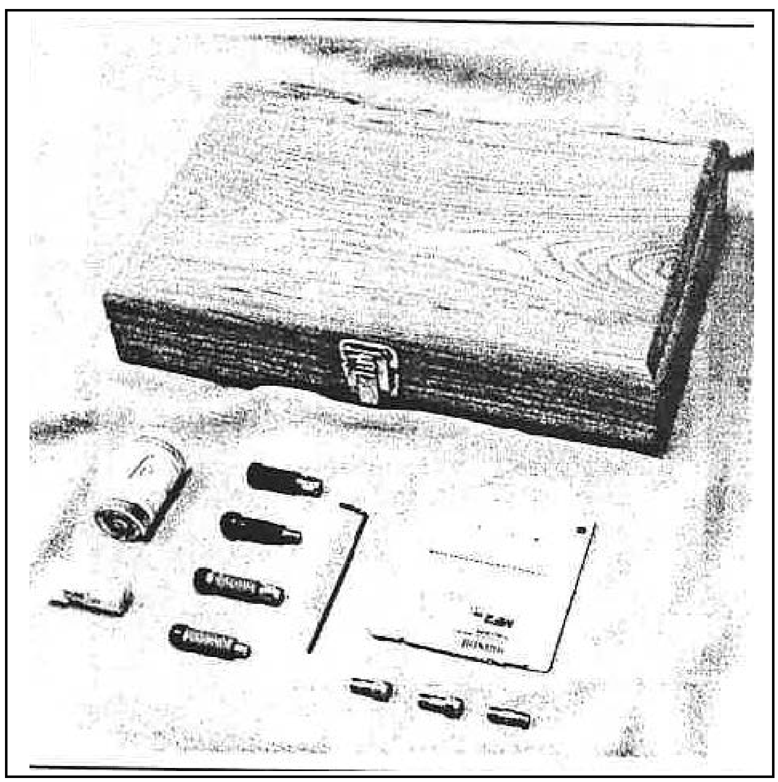

Figure 2
GPC-2.9 (K®) TRL
Calibration kit

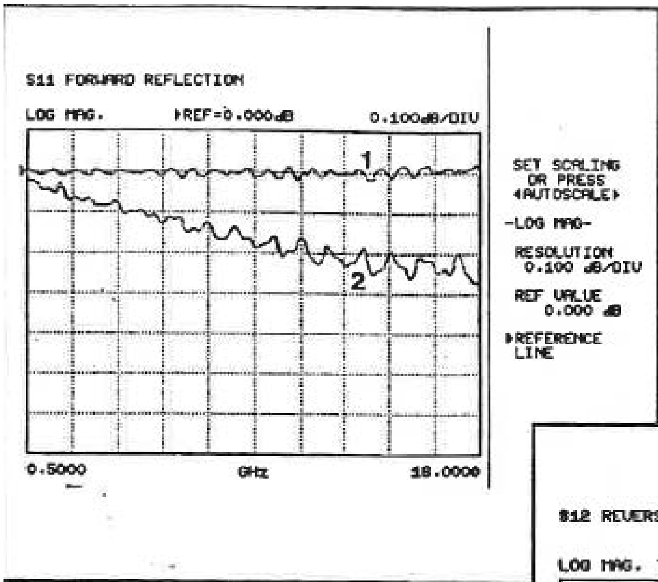

Figure 3
Short (1) and Offset Short (2)
Verification of GPC-7 kit

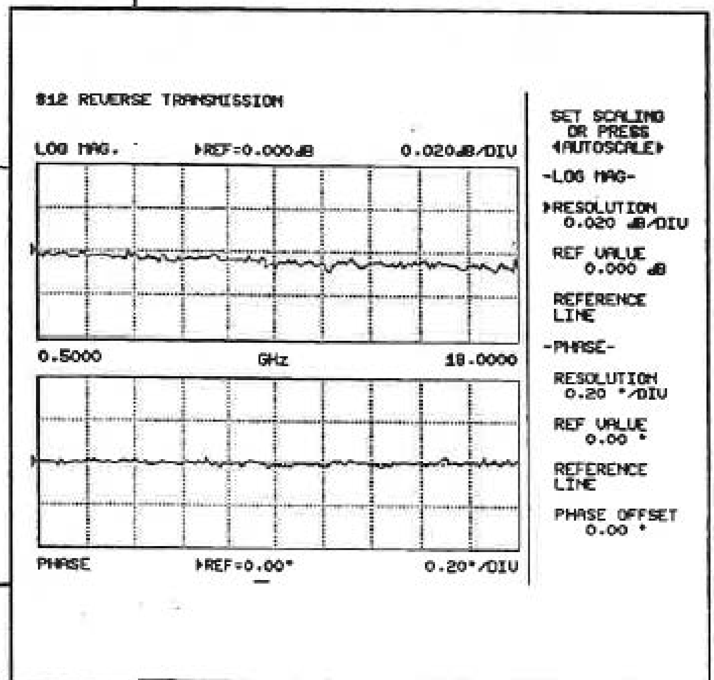

Figure 4
THRU Line Verification
of GPC-7 kit

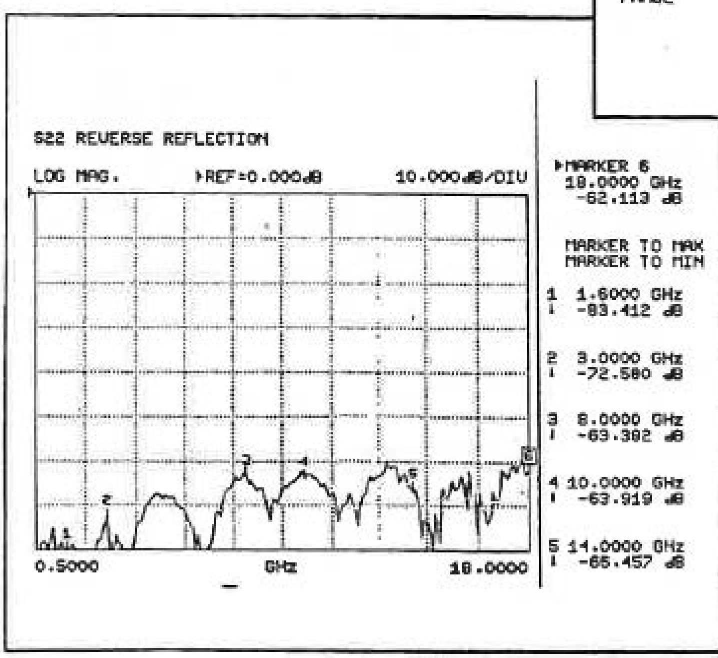

Figure 5
Residual Reflection
Verification of GPC-7 Kit

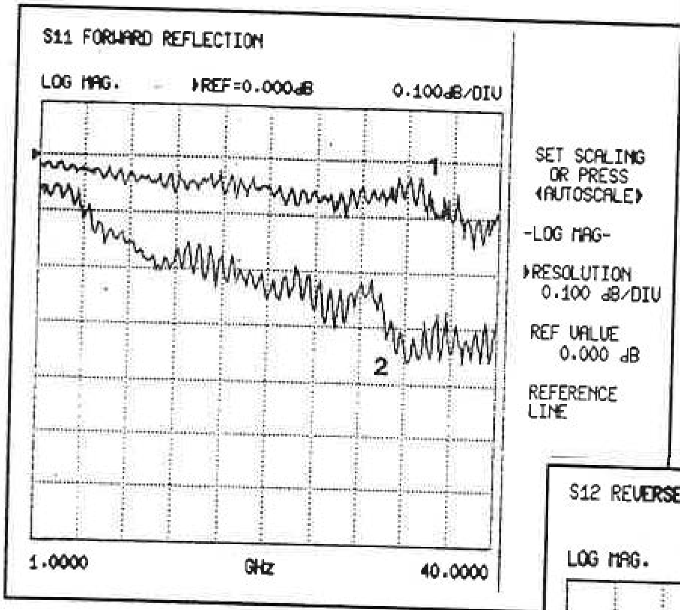

Figure 6
Short (1) and Offset Short (2)
Verification of GPC-2.9 kit

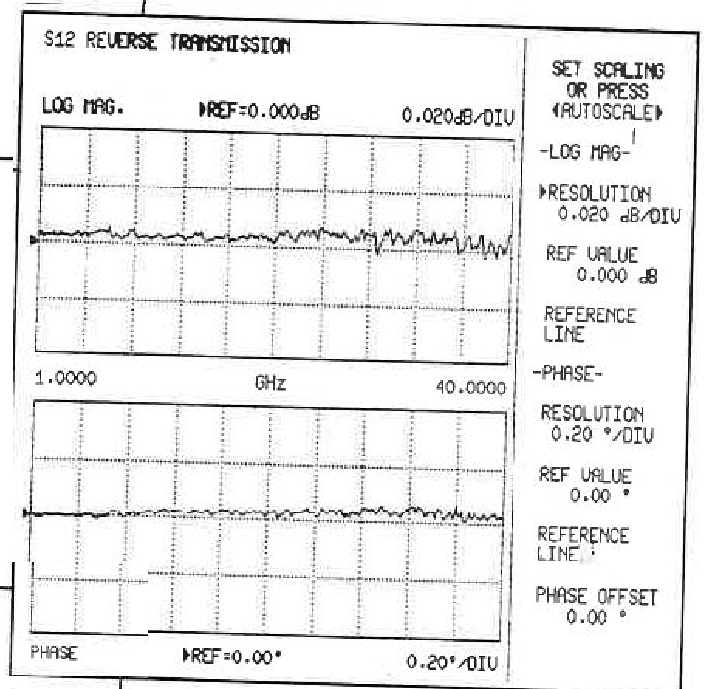

Figure 7
THRU Line Verification
of GPC-2.9 kit

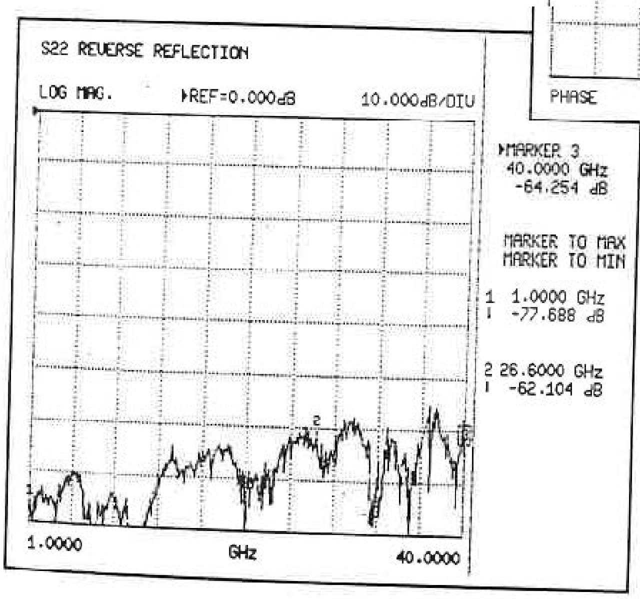

Figure 8
Residual Reflection
Verification of GPC-3.9 kit

References

[1] GF Engen and CA Hoer, "TRL: an improved technique for calibrating the dual six-port automatic network analyzer", IEEE MTT, December 1979.
[2] Calibration Techniques of Network Analyzers for Tuner Characterization, Application Note No 13, Focus Microwaves, May 1994.
[3] Product Note 8510-8, Hewlett Packard, October 1987.