TRL Calibration Kit:

- GPC-7/16-TRL-CV
- GPC-N-TRL-CV
- GPC-7-TRL-CV
- GPC-3.5-TRL-CV
- GPC-2.92-TRL-CV
- GPC-2.4-TRL-CV

Operation Manual

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1. Introduction

Vector Network Analyzer Calibration may be a difficult task, depending on the frequency range and even more so on the Calibration Method and the required Calibration standards used.

There is no universal rule as to which calibration standards are better since their practical realisation strongly depends on the transmission media used.

In general terms, a perfect load is more difficult to manufacture than a perfect short, but even this is media dependent.

We can summarise the standard's performance related to the media in Table 1.

Standard	Media		
	Coaxial	Microstrip	Waveguide
Open (O)	--	+	n/a
Short (S)	++	0	++
Load (L)	0	-	+
Sliding Load (SL)	+	n/a	0
Delay Line (DL)	++	++	++
Offset Short (OS)	++	0	++

Table 1: Manufacturability of perfect calibration standards
(++: Excellent, 0: Adequate, --: Poor, n/a: not available)

The calibration method itself should also be viewed in relation to the corresponding media, as well as to the dependence on the standards used.

The calibration methods themselves are sometimes based on assumptions about the standards used and their reproducibility that makes them quite critical to employ.

For example, manufacturing a perfect short circuit in waveguide in millimeterwave frequencies is very easy, but connecting it properly may not be easy. Depending on the standards used and the media, we give a global view of the different commercially available calibration methods in Table 2.

Calibration Method	Standards required	Media		
		Coaxial	Microstrip	Waveguide
Open, Short, Load	O, S, L	-	-	n/a
Sliding Load	O,S,L,SL	+	n/a	0
Short, Offset Load, Load	S,OS,L	+	0	0
Thru, Reflect, Line	DL,S or (O), L	++	+	++

Table 2: A global view of different calibration methods

The main conclusion from Tables 1 and 2 is that TRL (Transmission-Reflect-Line) is the most accurate and easy to employ method for all types of transmission media, including Coaxial, Microstrip (including Wafer) and Waveguide.
However, there is software required in the Network Analyzer system to permit TRL calibrations. Some of the cheaper Analyzers like HP8720 and HP8753 do not have this option. However, if they are used for frequencies below 5 GHz there is no problem. The problems arise beyond 5 GHz (HP8720).

The high end Vector Network Analyzers, however, (HP 8510B, HP 8510C and Wiltron 360 A and B) all include a TRL (Wiltron calls it LRL = Line-Reflect-Line) option.
The HP-8719C, HP-8720C, HP-8722A, HP-8753D include a modified TRL calibration capability (which HP calls TRL*). This TRL* allows calibration of the Network Analyzers

using Focus TRL calkits using two additional low VSWR 10 dB attenuators on the VNA ports. For further information on this subject, please refer to Product Note HP-8720-2. The TRL calibration kits of Focus Microwaves have been developed for making wideband coaxial calibrations using one of the above mentioned Network Analyzers.

- The TRL-7/16 calibration kit uses N connectors and can be used from .1 to 7.5 GHz.
- The TRL-N calibration kit uses N connectors and can be used from .4 to 12 GHz.
- The TRL-7mm calibration kit uses GPC-7 connectors and can be used from 500 MHz to 18 GHz.
- The TRL-3.5 mm calibration kit uses 3.5 mm connectors and can be used from 0.5 to 26.5 GHz.
- The TRL-2.92mm calibration kit uses K^{tm} connectors and can be used from 0.5 to 40 GHz.
- The TRL-2.4mm calibration kit uses 2.4mm connectors and can be used from 0.5 to 50 GHz.

K^{tm}: Trade Mark of Wiltron Company

2. The TRL Method

The Through-Reflect-Line (TRL) method was first proposed by Engen and Hoer in 1979. Since then it has been used and enhanced to improve bandwidth and included as a standard calibration method in HP and Wiltron Network Analyzers.

According to HP's product Note 8510-8 (1 Oct. 1987), the following conditions must be fulfilled by the TRL standards for a successful implementation.

TRL Standard	Requirements
REFLECT	1. Reflection coefficient Γ magnitude (optimally 1.0) need not be known. 2. Phase of Γ must be known within $\pm \lambda /4$ or $\pm 90°$. 3. Must be the same Γ on both ports. 4. May be used to set the reference plane if the phase response of the REFLECT is known and specified = 0.
THRU	5. If Non-Zero THRU is used the Reference Plane is set at the centre of the THRU. 6. If Zero THRU is used then the following assumptions are made: S11=S22=0 , S12=S21=1. 7. Characteristic impedance Z_0 of the THRU and Non-Zero LINE must be the same. 8. Attenuation of the THRU need not be known. 9. Insertion phase or electrical length must be specified if the THRU is used to set the reference plane
DELAY LINE	10. Z_0 of the LINE establishes the reference impedance after error correction is applied. 11. Insertion phase of the LINE must never be the same as that of the THRU (zero or non-zero length). 12. Optimal LINE length is 1/4 wavelength or 90° of insertion phase relative to the THRU at the centre frequency. 13. Useable bandwidth of a single THRU/LINE pair is 8:1 (frequency span/start frequency).

14. Multiple THRU/line pairs (Z_0 assumed identical) can be used to extend the bandwidth.
15. Attenuation of the LINE need not be known.
16. Insertion phase or electrical length need only be specified within λ /4 or ±90°.

In the case of coaxial calibrations, most of the above requirements can be easily met. The use of a coaxial short satisfies conditions 1 and 3.

In APC 7, the phase is 0 whereas in 7/16, N, 3.5mm, 2.9mm (K) and 2.4mm systems, the length of the offset short must be known within the λ/4 wavelength limit (Condition 2).

Conditions 5 and 6 are satisfied with any good coaxial through connection.

Conditions 7 implies some machining accuracy requirements for the non zero line. Since the characteristic impedance is given by $Z_o = (60/\sqrt{\varepsilon}) \ln D/d$ and $\varepsilon = 1$ (air), the overall precision is related to the accuracy of manufacturing of the 2 diameters D and d of the external and inner conductor of the coaxial line. For a simple structure like a centre conductor rod and an external conductor cylinder, high precision machining is easy within tolerances of ± 0.0002".

Conditions 8 and 9 are easily satisfied in the case of a coaxial line.

Conditions 13 is very pessimistic. The TRL calkits of Focus Microwaves yield fmax/fmin ratios beyond 40:1 (0.5 to 18 GHz, or 0.5 to 50 GHz), using only one pair of Through - Delay lines.

The limitation is at the high frequency end, where the phase of the delay line should not exceed 180°. This is feasible when the delay line is dimensioned λ/4 at the mid frequency band, as in our case.

Requirement 14 is therefore obsolete. The lack of a second delay line may create some phase errors in the calibration for very narrow bands (Example 0.5 - 2 GHz).

For those low frequencies, however, different calibration standards, such as Open-Short-Load can be used and yield, in general, satisfactory calibrations.

3. Components of the Calibration Kit

The Focus Microwaves TRL calibration kits include the following standards:

3.1 GPC 7/16-TRL-CV:

- Two offset shorts (1 male, 1 female): 8.5mm (28.4 psec.)
- Two 50Ω loads (1 male, 1 female)
- One 50Ω line extension (Delay Line): 1.27cm (42.3 psec.)
    - One external conductor cylinder
    - One center conductor extension
- One Connector Fastener
- One Adaptor 7/16 (Male) to APC-7
- One Adaptor 7/16 (Female) to APC-7

3.2 GPC N-TRL-CV:

- Two offset shorts (1 male, 1 female): 8.0mm (26.7 psec.)
- Two 50Ω loads (1 male, 1 female)
- One 50Ω line extension (Delay Line): 1.02 cm (34.0 psec.)
    - One external conductor cylinder
    - Ono center conductor extension
- One 50Ω Offset Short (for verification): 10 cm
- One Torque Wrench APC-7 (14 lbf-in)

3.3 GPC 7-TRL-CV:

- One 7mm direct short
- Two 50Ω loads
- One 50Ω line extension (Delay Line): 0.697 cm (23.2 psec.)
    - One external conductor cylinder

  - Ono center conductor extension
- One 50Ω Offset Short (for verification): 10 cm
- One Connector Fastener
- One Torque Wrench APC-7 (14 lbf-in)

3.4 GPC 3.5-TRL-CV:

- Two offset shorts (1 male, 1 female): 1.39 cm (46.7 psec.)
- Two 50Ω loads (1 male, 1 female)
- One set of adapters: 1.397 cm
  - two male-female
  - one female-female
- One 50 Ω extension line: 0.42 cm (14.2 psec.)
  - One external conductor cylinder
  - Two center conductor pins (one spare)
- One Connector Fastener
- One Torque Wrench 3.5mm (8 lbf-in)

3.5 GPC 2.92-TRL-CV:

- Two offset shorts (1 male, 1 female): 1.27 cm (42.3 psec.)
- Two 50Ω loads (1 male, 1 female)
- One set of adapters: 1.59 cm
  - two male-female
  - one female-female
- One 50 Ω extension line: 0.31 cm (10.5 psec.)
  - One external conductor cylinder
  - Two center conductor pins (one spare)
- One Connector Fastener
- One Center pin insert tool
- One Tweezer

- One Torque Wrench 3.5mm (8 lbf-in)
- One wrench 7/32”

3.6 GPC 2.4-TRL-CV:

- Two offset shorts (1 male, 1 female): 1.67 cm (56.0 psec.)
- Two 50Ω loads (1 male, 1 female)
- One set of adapters: 1.677 cm
  - two male-female
  - one female-female
- One 50 Ω extension line: 0.295 cm (9.88 psec.)
  - One external conductor cylinder
  - Two center conductor pins (one spare)
- One Connector Fastener
- One Center pin insert tool
- One Tweezer
- One Torque Wrench 2.4mm (8 lbf-in)
- One wrench 1/4”

For users of HP 8XXX family network analyzers, a 3½" floppy can be furnished in DOS or LIF format including the Calkit's parameters.

For users of Wiltron 360 this is not required because the Calkit's parameters can very easily be introduced into the Analyzer with a few keystrokes.

4. Load the Calkit Parameters

4.1 Network Analyzer: Wiltron 360

The parameters of the Calkits have to be entered before the beginning of the calibration procedure.

Wiltron 360 Steps:

```
- BEGIN CAL:
   - CHANGE CAL METHOD AND LINE TYPE:
      - CAL METHOD: LRL/LRM
      - TRANSMISSION LINE TYPE: COAXIAL
      - NEXT CAL STEP
         - INCLUDE ISOLATION
            - N DISCRETE FREQUENCIES (2 TO 501 POINTS):
               - CLEAR ALL
               - START:                          0.5 GHZ
               - INCREMENT:                      0.1 GHZ
               - NUMBER OF POINT:                100
               - FILL RANGE
               - FINISHED NEXT CAL STEP
                  - CHANGE LRL/LRM PARAMETERS
                     - NUMBER OF BANDS USED: ONE BAND
                     - LOCATION OF REF PLANE: MIDDLE OF LINE 1
                        - NEXT CAL STEP
                           - DEVICE 1 LINE 1 (REF):    0.0000mm
                           - DEVICE 2 LINE/MATCH:   DELAY LINE
                               GPC-7/16 = 1.27 cm   (42.30 psec.)
                               GPC-N    = 1.02 cm   (34.00 psec.)
                               GPC-7.0  = 0.6965 cm (23.23 psec.)
                               GPC-3.5  = 0.4267 cm (14.23 psec.)
                               GPC-2.92 = 0.3137 cm (10.46 psec.)
                               GPC-2.4  = 0.295 cm  (09.88 psec.)
                    - NEXT CAL STEP
                           - OFFSET LENGTH OR REFL DEVICE :
                               GPC-7/16 = 0.85 cm   (28.40 psec.)
                               GPC-N    = 0.80 cm   (26.70 psec.)
                               GPC-7.0  = 0.00 cm
                               GPC-3.5  = 1.397 cm  (46.67 psec.)
                               GPC-2.92 = 1.270 cm  (42.34 psec.)
                               GPC-2.4  = 1.677 cm  (56.02 psec.)
                           - TYPE OF REFLECTION: LESS THAN ZERO
                        - NEXT CAL STEP
-  START CAL
```

- After you terminate the parameter registration you can start with the calibration procedure (chapter 5).

4.2 HP-8510B/C

The parameters of the Calkits have to be entered before the beginning of the calibration procedure. Manual registration of calkit parameters is more complicated than with the Wiltron 360. If a floppy diskette with the calkit parameters is not available you have to proceed as follows:

```
- CAL
   - MORE
      - MODIFY 1
          OR
      - MODIFY 2

         - DEFINE STANDARD:     -- SHORT --
            - 1  X1
            - SHORT
               - L0:    0
               - L1:    0
               - L2=L3: 0
               - SPECIFY OFFSET
                  - OFFSET DELAY:
                     GPC-7/16 = 0.85 cm  (28.4 psec.)
                     GPC-N    = 0.8 cm   (26.7 psec.)
                     GPC-7.0  = 0 cm
                     GPC-3.5  = 1.397 cm (46.67 psec.)
                     GPC-2.92 = 1.270 cm (42.34 psec.)
                     GPC-2.4  = 1.677 cm (56.02 psec.)
                  - OFFSET LOSS:  0
                  - OFFSET Z0:   50
                  - MIN FREQ:   0.1 GHZ
                  - MAX FREQ:
                     GPC-7/16 = 7.5 GHz
                     GPC-N    = 12 GHz
                     GPC-7.0  = 20 GHz
                     GPC-3.5  = 30 GHz
                     GPC-2.92 = 40 GHz
                     GPC-2.4  = 50 GHz
                  - COAXIAL
                  - STD OFFSET DONE
               - LABEL STD
                 - BACKSPACE (IF NECESSARY)
                 - S H O R T
                 - DONE
               - STD DONE
```

- **DEFINE STANDARD**: -- LOAD --
  - **2 X1**
  - **LOAD**
    - **FIXED**
    - **SPECIFY OFFSET**
      - OFFSET DELAY: **0**
      - OFFSET LOSS: **0**
      - OFFSET Z0: **50**
      - MIN FREQ: **0.1 GHZ**
      - MAX FREQ:
        GPC-7/16 = **7.5 GHz**
        GPC-N = **12 GHz**
        GPC-7.0 = **20 GHz**
        GPC-3.5 = **30 GHz**
        GPC-2.92 = **40 GHz**
        GPC-2.4 = **50 GHz**
      - **COAXIAL**
      - **STD OFFSET DONE**
    - **LABEL STD**
      - **BACKSPACE** (IF NECESSARY)
      - **L O A D**
      - **DONE**
    - **STD DONE**

- **DEFINE STANDARD**: -- THRU --
  - **3 X1**
  - **DELAY/THRU**
    - **SPECIFY OFFSET**
      - OFFSET DELAY: **0**
      - OFFSET LOSS: **0**
      - OFFSET Z0: **50**
      - MIN FREQ: **0.5 GHZ**
      - MAX FREQ:
        GPC-7/16 = **7.5 GHz**
        GPC-N = **12 GHz**
        GPC-7.0 = **20 GHz**
        GPC-3.5 = **30 GHz**
        GPC-2.92 = **40 GHz**
        GPC-2.4 = **50 GHz**
      - **COAXIAL**
      - **STD OFFSET DONE**
    - **LABEL STD**
      - **BACKSPACE** (IF NECESSARY)
      - **T H R U**
      - **DONE**
    - **STD DONE**

```
- DEFINE STANDARD:        -- DELAY --
   - 4  X1
   - DELAY/THRU
      - SPECIFY OFFSET
         - OFFSET DELAY:
              GPC-7/16 = 1.27 cm   (42.30 psec.)
              GPC-N    = 1.02 cm   (34.00 psec.)
              GPC-7.0  = 0.6965 cm (23.23 psec.)
              GPC-3.5  = 0.4267 cm (14.23 psec.)
              GPC-2.92 = 0.3137 cm (10.46 psec.)
              GPC-2.4  = 0.295 cm  (09.88 psec.)
         - OFFSET LOSS:  0
         - OFFSET Z0:   50
         - MIN FREQ:   0.5 GHZ
         - MAX FREQ:
              GPC-7/16 = 7.5 GHz
              GPC-N    = 12 GHz
              GPC-7.0  = 20 GHz
              GPC-3.5  = 30 GHz
              GPC-2.92 = 40 GHz
              GPC-2.4  = 50 GHz
         - COAXIAL
         - STD OFFSET DONE
      - LABEL STD
        - BACKSPACE (IF NECESSARY)
        - D E L A Y
        - DONE
      - STD DONE


- SPECIFY CLASS
   - MORE
      - MORE
         - TRL THRU:  3  X1
         - TRL LINE:  4  X1
         - TRL SHORT: 1  X1
         - ADAPTER:   2  X1
      - CLASS DONE
   - TRL OPTION
      - CAL:  Z0
      - LINE: Z0
      - SET REF: THRU
      - LOWBAND FREQ: 0 GHZ
   - TRL OPTION DEFINED
- LABEL CLASS
   - MORE
      - MORE
         - TRL THRU: THRU
         - TRL LINE: DELAY
         - TRL SHORT: SHORT
```

- **CLASS DONE**
- **LABEL CLASS DONE**

- **LABEL KIT**
  - **BACKSPACE** (IF NECESSARY)
  - **F M I - G P C** ...
  - **DONE**

- **KIT DONE**

The parameters of the calkit can then be saved on disk for easier retrieval.

- **TAPE/DISC**
  - **STORE**
    - **CALKIT 1-2**
      - **1**
        OR
      - **2**
        - **CAL FILE**
          - **FILE 1 .. 8**

4.3 HP-8753D/E

The parameters of the Calkits have to be entered before the beginning of the calibration procedure.

```
- CAL
   - CALKIT []
      - USER KIT
      - MORE
         - MODIFY []
           - DEFINE STANDARD:     -- SHORT --
              - 1  X1
              - SHORT
                 - SPECIFY OFFSET
                    - OFFSET DELAY:
                       GPC-7/16 = 0.85 cm  (28.4 psec.)
                       GPC-N    = 0.8 cm   (26.7 psec.)
                       GPC-7.0  = 0 cm
                       GPC-3.5  = 1.397 cm (46.67 psec.)
                       GPC-2.92 = 1.270 cm (42.34 psec.)
                       GPC-2.4  = 1.677 cm (56.02 psec.)
                    - OFFSET LOSS:  0
                    - OFFSET Z0:   50
                    - MIN FREQ:   0.1 GHZ
                    - MAX FREQ:
                       GPC-7/16 = 7.5 GHz
                       GPC-N    = 12 GHz
                       GPC-7.0  = 20 GHz
                       GPC-3.5  = 30 GHz
                       GPC-2.92 = 40 GHz
                       GPC-2.4  = 50 GHz
                    - COAXIAL
                    - STD OFFSET DONE
                 - LABEL STD
                    - BACKSPACE (IF NECESSARY)
                    - S H O R T
                    - DONE
                 - STD DONE

           - DEFINE STANDARD:      -- LOAD --
              - 2  X1
              - LOAD
                 - FIXED
                 - SPECIFY OFFSET
                    - OFFSET DELAY: 0
                    - OFFSET LOSS:  0
                    - OFFSET Z0:   50
                    - MIN FREQ:   0.1 GHZ
                    - MAX FREQ:
```

GPC-7/16 = **7.5 GHz**
GPC-N = **12 GHz**
GPC-7.0 = **20 GHz**
GPC-3.5 = **30 GHz**
GPC-2.92 = **40 GHz**
GPC-2.4 = **50 GHz**

- **COAXIAL**
- **STD OFFSET DONE**
- **LABEL STD**
  - **BACKSPACE** (IF NECESSARY)
  - **L O A D**
  - **DONE**
- **STD DONE**

- **DEFINE STANDARD**: -- THRU --
  - **3 X1**
  - **DELAY/THRU**
    - **SPECIFY OFFSET**
      - OFFSET DELAY: **0**
      - OFFSET LOSS: **0**
      - OFFSET Z0: **50**
      - MIN FREQ: **0.5 GHZ**
      - MAX FREQ:
        GPC-7/16 = **7.5 GHz**
        GPC-N = **12 GHz**
        GPC-7.0 = **20 GHz**
        GPC-3.5 = **30 GHz**
        GPC-2.92 = **40 GHz**
        GPC-2.4 = **50 GHz**
      - **COAXIAL**
      - **STD OFFSET DONE**
    - **LABEL STD**
      - **BACKSPACE** (IF NECESSARY)
      - **T H R U**
      - **DONE**
    - **STD DONE**

- **DEFINE STANDARD**: -- DELAY --
  - **4 X1**
  - **DELAY/THRU**
    - **SPECIFY OFFSET**
      - OFFSET DELAY:
        GPC-7/16 = **1.27 cm** (42.30 psec.)
        GPC-N = **1.02 cm** (34.00 psec.)
        GPC-7.0 = **0.6965 cm** (23.23 psec.)
        GPC-3.5 = **0.4267 cm** (14.23 psec.)
        GPC-2.92 = **0.3137 cm** (10.46 psec.)
        GPC-2.4 **= 0.295 cm** (09.88 psec.)
      - OFFSET LOSS: **0**
      - OFFSET Z0: **50**
      - MIN FREQ: **0.1 GHZ**

```
              - MAX FREQ:
                 GPC-7/16 = 7.5 GHz
                 GPC-N    = 12 GHz
                 GPC-7.0  = 20 GHz
                 GPC-3.5  = 30 GHz
                 GPC-2.92 = 40 GHz
                 GPC-2.4  = 50 GHz
              - COAXIAL
              - STD OFFSET DONE
           - LABEL STD
              - BACKSPACE (IF NECESSARY)
              - D E L A Y
              - DONE
           - STD DONE

   - SPECIFY CLASS
           - SPECIFY
              - S11A    (Reflect Forward Match)
                - 1 X1       -- SHORT --
              - S11B    (Line Forward Match)
                - 4 X1       -- DELAY --
              - S11C    (Line Forward Transmission)
                - 4 X1       -- DELAY --

           - SPECIFY
              - S22A    (Reflect Reverse Match)
                - 1 X1       -- SHORT --
              - S22B    (Line Reverse Match)
                - 4 X1       -- DELAY --
              - S22C    (Line Reverse Transmission)
                - 4 X1       -- DELAY --

           - MORE
              - SPECIFY
                - FWD. TRANS.
                   - 3 X1    -- THRU --
                - REV. TRANS.
                   - 3 X1    -- THRU --
                - FWD. MATCH
                   - 3 X1    -- THRU --
                - REV. MATCH
                   - 3 X1    -- THRU --
                - RESPONSE
                   - 3 X1    -- THRU --
                - RESPONSE AND ISOLATION
                   - 3 X1    -- THRU --
              - CLASS DONE
           - CLASS DONE

   - LABEL CLASS
           - LABEL
```

- **S11A** (Reflect Forward Match)
  - **S H O R T**
- **S11B** (Line Forward Match)
  - **D E L A Y**
- **S11C** (Line Forward Transmission)
  - **D E L A Y**

- **LABEL**
  - **S22A** (Reflect Reverse Match)
    - **S H O R T**
  - **S22B** (Line Reverse Match)
    - **D E L A Y**
  - **S22C** (Line Reverse Transmission)
    - **D E L A Y**

- **MORE**
  - LABEL
    - **FWD. TRANS.**
      - **T H R U**
    - **REV. TRANS.**
      - **T H R U**
    - **FWD. MATCH**
      - **T H R U**
    - **RESPONSE**
      - **T H R U**
    - **RESPONSE AND ISOLATION**
      - **T H R U**

  - **LABEL DONE**
- **LABEL DONE**

- **LABEL KIT**
  - **BACKSPACE** (IF NECESSARY)
  - **F M I - G P C** ...
  - **DONE**

- **KIT DONE**

5. Calibration Procedure

5.1 Introduction

The TRL calibration is among the simplest and fastest ones to employ. This is due to the simplicity of the standards used. There are only 2 areas where some attention should be paid.

1. Never Overtorque the connectors, use the torque wrench.
2. Carefully align the center conductor of the delay line.

In the case of Wiltron 360A, the standards have to be introduced in a given sequence, which does not permit repetition of a previous operation.

The HP analyzers and the Wiltron 360B permit any sequence of applications of the standards. Some users omit to include isolation measurement in the calibration procedure. This is acceptable only for frequencies below 3 GHz. For calibrations beyond 3 GHz, isolation measurements should be included systematically.

The following section explains the procedure for introducing the different standards in the measurement system and, in particular, the delay line standards in 7/16, N, 7, 3.5, 2.92 and 2.4 mm, which are the only delicate operations of the Focus Microwaves calibration procedure.

5.2.1 TRL *

TRL* is a modified TRL calibration used with HP-8719C, HP-8720C, HP-8722A, HP-8753D. Because this VNA uses only three detectors, the effective source match and load match effects are not fully error-corrected. Two low VSWR must be placed on the VNA cables at the reference plane connectors. With the attenuators in place, the effective port match of the system is improved.

5.2 GPC-7 Calibration

5.2.1 Throughline

Throughline connection consists of aligning and fastening the GPC-7 connectors of the cable together.

A problem may sometimes arise if the inner threads of the GPC 7 connector touch each other. In order to avoid this problem, always turn one threaded ring fully inside, and the other fully outside, of the GPC-7 connector.

When fastening the connectors, use your hands or a dynamometric torque wrench. Do not overtorque them.

After the connection is established, take a minute to make sure it is a mechanically solid one and, by looking at the Analyzer's response, make sure there is no change when you try to move the connectors and the cables joined to them.

If you see any change in the Analyzer's trace you have to re-establish the connection and re-start. If the problem persists, you have to verify the cables. There is no point in continuing a calibration if the system has mechanical instability.

5.2.2 Delay Line Assembly Procedure

The Delay Line of Focus Microwaves consists of a pair of components assembled between the 2 GPC-7 connectors at the end of the measurement cables. The patented, special design permits perfect alignment without any additional components.

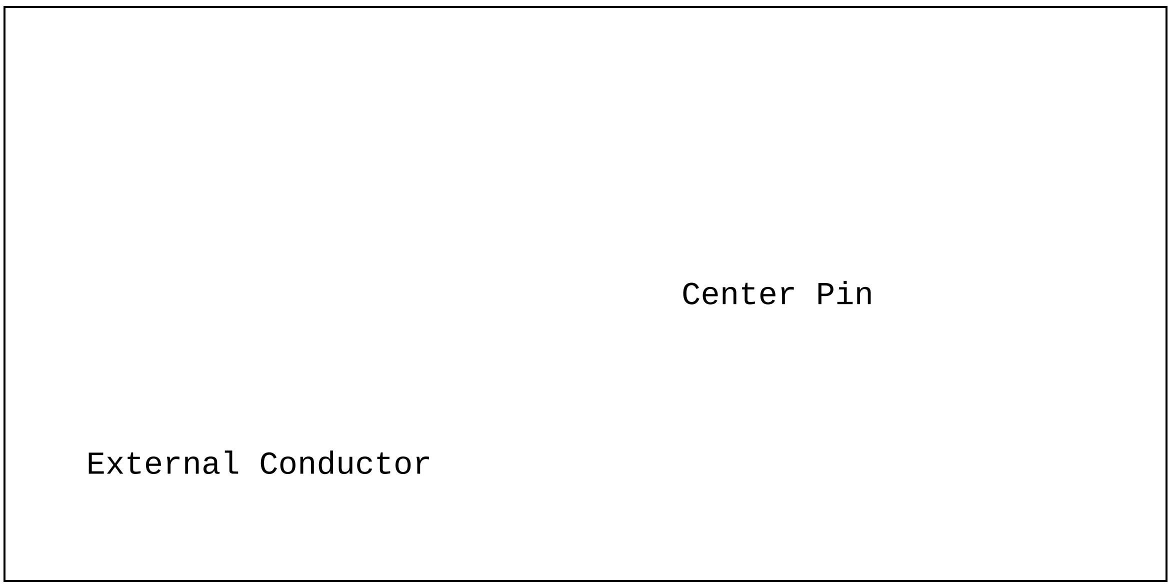

Figure 1: GPC-7 Delay Line Components

In order to insert and properly align the Delay Line components, you proceed as follows:

1. Turn the threaded ring on both GPC 7 connectors of the measurement cables fully inside.

2. Mount the external conductor on the left GPC 7 connector (Figure 2).

3. Insert the center pin in the left GPC-7 connector central conductor (Figure 2). The pin will hang slightly downwards.

Figure 2: Assembly of External Conductor and Center Pin

4. Approach the right GPC-7 connector under angle and make sure the mobile center pin is well placed in the central conductor of the right GPC-7 connector (Figure 3).

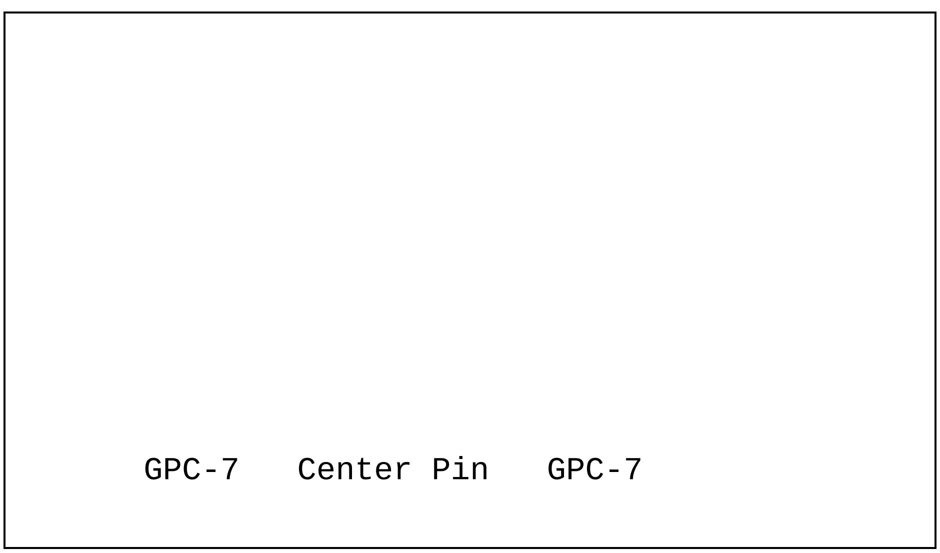

Figure 3: Final assembly of Delay Line

It is very important not to miss the center conductor of the right GPC-7 connector. You should always observe the trace of the network analyzer while you manipulate the pin. If you see anomalous transmission, such as resonance or excessive loss, DO NOT FASTEN the 2 GPC-7 connectors. You may damage the center connector. In this case, you reopen the assembly and restart positioning the pin in the left GPC-7 connectors and approach both connectors carefully.

5.2.2 Shorts

Connecting the SHORT on port 1 and port 2 is, in general, a simple task, as long as you pay attention not to overtorque them. After finishing, make sure (by moving the assembly) that the Analyzer's response stays constant.

5.2.3 The 50 Ohm Loads

Connect the two 50Ω LOADS on ports 1 and 2 simultaneously to measure isolation. Again you should follow the rules for mounting GPC-7 connectors.
The two Loads have about 30 dB Return Loss, which is fully sufficient for isolation measurements; however, these Loads should not be used as 50Ω reference standards.
Once you have established reliable connection for each standard, you can proceed to the measurement by pressing the corresponding Softkeys on the Analyzer.

5.3 GPC 7/16, GPC-N, GPC-2.4, GPC-2.92, GPC-3.5 Calibration

5.3.1 Preparation

The 2.4, 2.92 and 3.5 mm connectors, like N, 7/16 and SMA are not hermaphrodite like the GPC-7.

In order to make proper calibrations, you have to first decide on the connector sex you need on each side of your device under test.

The 2.4, 2.92, 3.5 mm, N and 7/16 TRL calkits of Focus Microwaves is basically designed to permit wideband calibrations for insertable components.

These are components with one male and one female connector.

The adapters included in the kit (3.5, 2.92 and 2.4 mm) permit you to switch over to another connector sex, after the calibration, by replacing a female/female adapter with a male/female one. This, in combination with the cable adapters should satisfy all particular requirements.

The following chapter is based on the assumption that you are calibrating a setup with one male and one female connector. This is also the best arrangement to establish a reliable Throughline connection.

5.3.2. Throughline

The Throughline is connected in a usual manner. In order to avoid premature performance deterioration, you should never turn the center pin of a male connector in the female receptible. Only the external hexagonal nut of the connector should turn.

Also be very careful when you first insert male and female connectors into each other not to miss the female part. For 2.4 and 2.92 mm connectors this is destructive.

Once you have established the Throughline connection, verify the trace of the Analyzer and try to move the cables and the connection. If the trace changes, you should get better cables and not continue with the calibration.

5.3.3 Delay Line Assembly Procedure

The 2.4, 2.92 and 3.5 mm, N, and 7/16 Delay Lines include 3 parts:

1. The external conductor cylinder.
2. The center conductor extension pin.
3. The connector fastener.

Assembly of the Delay Line has to be made exactly according to the following procedure:

1. Insert the center pin's male side into the center pin of the female connector (Figure 4a). You can use either your fingers on the plastified edge of a pair of pliers and push the center pin to the step to avoid any gap (Figure 4b).

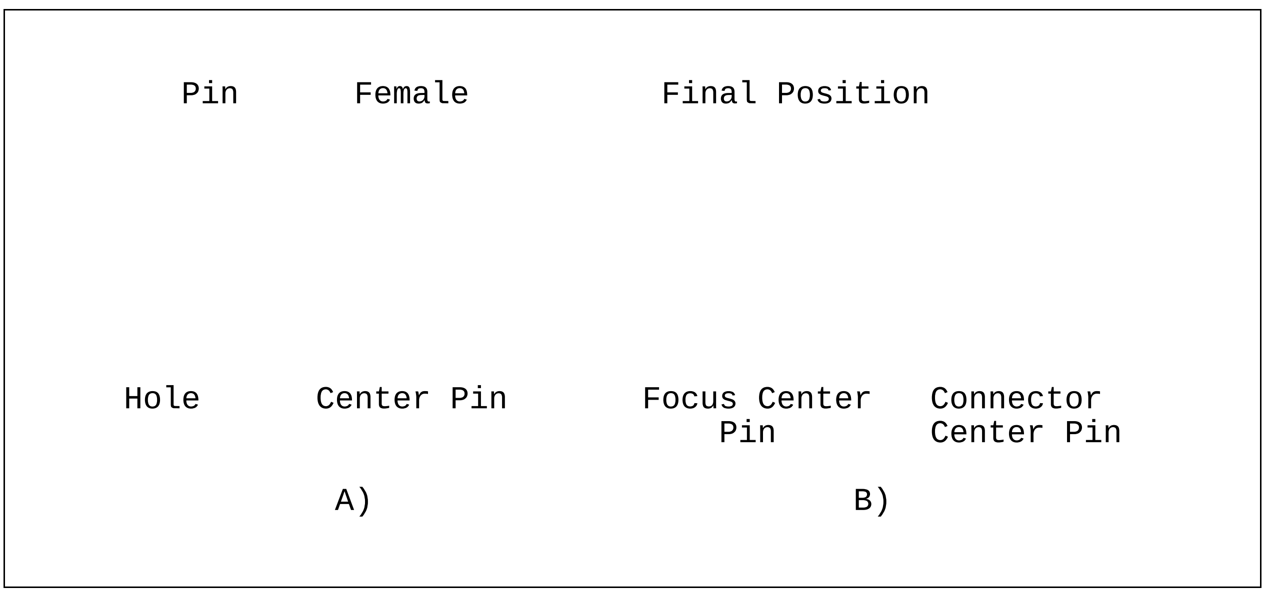

Figure 4: Delay Line inside the female connector

2. Insert the external conductor of the Delay Line in the cavity of the female connector, sliding it over the already positioned center pin (Figure 5).

2. Slide the connector fastener over the male connector of the other measurement cable up to the end (Figure 6) and fasten the 2 Allen screws until their heads touch the external surface of the fastener.

Center Pin Female Connector

Outer Conductor
Cylinder

Figure 5: Delay Line external conductor

The 2 Allen screws are not supposed to touch the hexagonal body of the male connectors but reach behind it, so the fastener can turn freely. A simple check for this is the final sitting of their heads on the fastener as described above. These Allen screws should normally be screwed using the fingers, not an Allen key (Figure 6).

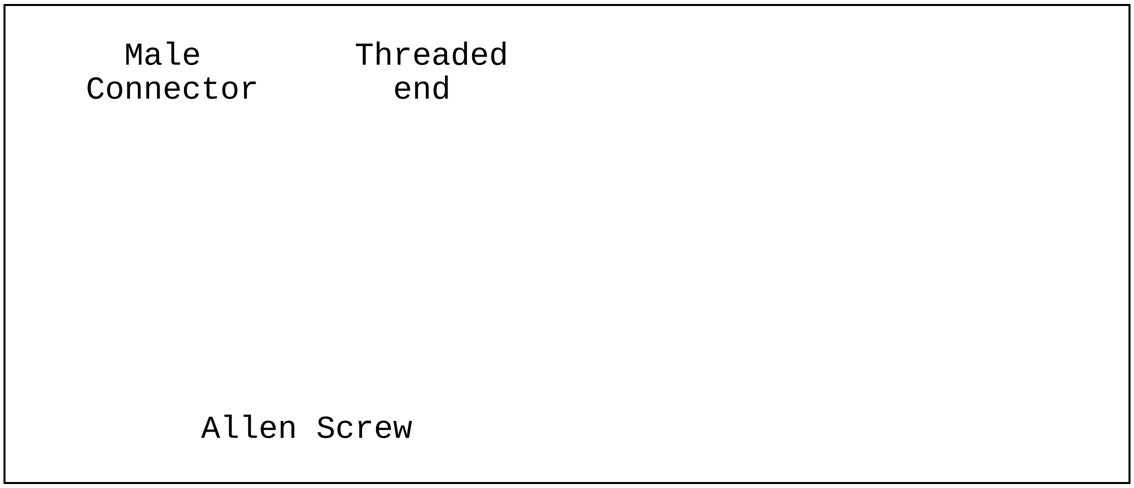

Figure 6: Assembly of the Connector Fastener

4. Carefully align the female side, with the Delay Line and Center Pin already mounted, with the male connector side, covered actually by the connector fastener, and screw the male part over the female part trying not to bend the setup. The center pin of the male side is conical and will enter, if the female side has been properly aligned, right in the hole of the Focus center pin (Figure 4a). As you proceed to screw the fastener over the female thread, it is recommended to <u>observe the trace</u> on the Analyzer and make sure that a correct flat transmission response is established as you proceed with tightening the connection. When you finish tightening the connector fastener over the female part (use only hand force, no tools), you should again perform the rigidity test, moving the junction with the cables, and make sure there is no change in the Analyzer's trace. Once the connection is established, you can proceed with the measurement.

   <u>ATTENTION:</u> If you do not see the Analyzer's trace stabilize flat as you tighten the fastener over the female part, or you think you have to unscrew the fastener and start again, then please proceed as follows: <u>UNSCREW THE FASTENER FULLY</u> and take it off (it will normally also pull the center pin out) and start the assembly procedure from the beginning (step 1). You can also pull out the pin from the male connector using a plastified edge of pliers and insert it again into the female side before

you re-start the procedure.

UNDER NO CIRCUMSTANCES SHOULD YOU SCREW THE FASTENER BACK AND FORTH !! It is almost certain that if you do this, the second time you tighten, the male pin will miss and damage the female connector. In this case the connector needs replacement.

To REMOVE the Delay Line unscrew the connector fastener carefully, disassemble the fastener and remove the center pin using the plastified edge of pliers, paying attention not to bend it. You may also use the tweezer to remove the external conductor cylinder from the female side of the assembly.

5.3.4 Shorts

The Calkit contains two offset short circuits, one male and one female. They have to be connected either using hand force or a dynamometric wrench, always paying attention not to turn the center conductors into each other.

5.3.5 50 Ohm Loads

The Calkit contains two 50 Ohm terminations, one male and one female. The two Loads have to be connected using the same procedure as the Shorts, for Isolation measurements.

After the calibration is terminated you can proceed to the verification and/or save the caldata in a CALSET (HP Analyzers) or a file (to be named) on the floppy diskette (Wiltron 360).

6. Calibration Verification

6.1 Introduction

There is some confusion, among engineers, concerning the term Verification. In most cases, the operator connects both connectors 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 "reproducibility" test, since both standards (Throughline and Short) have already been used in the calibration procedure and we "told" the Analyzer: "this is a Short" or "this is a Through" by pressing the corresponding Softkeys during the calibration. So the Analyzer should recognise the standards when we measure them again except if something is very wrong! If you have any problem recognising 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 you measure.
A more reliable verification procedure consists of measuring:

1. An OFFSET SHORT.
2. The Residual Reflection of the THROUGHLINE.

It is also recommended to verify the phase of the reflection on the Polar chart.
With the VNA port opened, the reflection should be close from 0 degree. It is normal to have the phase moving toward –45 degree, from the fringing effect of the connector, when the frequency increase .

With the VNA port connected with a Short, the reflection should be close from 180 degree. For APC-7 the reflection should be exactly at 180 degree for all frequencies because the short is exactly at the VNA reference plane. For all the others calkits, the short has an offset with the VNA reference plane. Never add an electrical delay on any of the 4 S-parameters values. Before start the calibration, be sure the 4 channels have the electrical delay at 0sec.

6.2 Offset Short

6.2.1 GPC-7/16

To generate an offset short, use the 40cm Airline connected to a Short. Set the S11 (or S22) display on LOG AMPLITUDE and set the SCALE to 0.1dB/DIV. You should observe on both ports graphs like Figure 7.

Figure 7: GPC-7/16 test: 1-Direct Short, 2- Offset Short (40 cm)

6.2.2 GPC-N

To generate an offset short, use the 10cm Airline supplied with the Calkit connected to a Short. Set the S11 (or S22) display on LOG AMPLITUDE and set the SCALE to 0.1dB/DIV. You should observe on both ports graphs like Figure 8.

Figure 8: GPC-N test: 1-Direct Short, 2- Offset Short (10 cm)

6.2.3 GPC-7

To generate an offset short, use the 10cm Airline supplied with the Calkit connected to a Short. Set the S11 (or S22) display on LOG AMPLITUDE and set the SCALE to 0.1dB/DIV. You should observe on both ports graphs like Figure 9.

Figure 9: GPC-7 test: 1-Direct Short, 2- Offset Short (10 cm)

Both the HP and Wiltron Analyzers can be calibrated to generate offset short ripple of less than 0.1dB over the 0.5 to 18GHz frequency range. A careful calibration of the HP-8510-C can provide a ripple of 0.05dB.

This residual ripple is due to internal directivity of the Analyzers and cannot be improved.

6.2.4 GPC-3.5

To generate an offset short, we use one 3.5 mm Precision Airline (not included in the Calkit) and the corresponding short on each port of the Analyzer. Set the S11 display to LOG MAGNITUDE and the SCALE to 0.1dB/DIV. You should be able to generate plots like the one of Figure 10. The ripple of the trace is comparable to the GPC-7 values, but deteriorates slightly beyond 18GHz. All this again is due to the internal Source match of the Analyzer.

Figure 10: GPC-3.5 test: 1-Direct Short, 2- Offset Short (4.3 cm)

6.2.5 GPC-2.92

To generate an offset short use one of the supplied male to female adapters and the corresponding short on each port of the Analyzer. Set the S11 display to LOG MAGNITUDE and the SCALE to 0.1dB/DIV. You should be able to generate plots like the one of Figure 11. The ripple of the trace is comparable to the GPC-7 values, but deteriorates slightly beyond 18GHz. All this again is due to the internal Source match of the Analyzer.

Figure 11: GPC-2.92 test: 1-Direct Short, 2- Offset Short (1.6 cm)

6.2.6 GPC-2.4

To generate an offset short use one of the supplied male to female adapters and the corresponding short on each port of the Analyzer. Set the S11 display to LOG MAGNITUDE and the SCALE to 0.2dB/DIV. You should be able to generate plots like the one of Figure 12. The ripple of the trace is comparable to the GPC-7 values, but deteriorates slightly \beyond 26GHz. All this again is due to the internal Source match of the Analyzer.

Figure 12: GPC-2.4 test: 1-Direct Short, 2- Offset Short (1.6 cm)

6.3 Throughline

When testing a Throughline, S12(S21) is the least significant parameter to observe. If there is any problem with S12(S21), the calibration is useless and should be discarded. You have to verify the RESIDUAL REFLECTION. You should get residual return loss of 50 to 70 dB over the entire frequency range.

6.3.1 GPC-7/16

Figure 13: GPC-7/16 test: Thru Line Return Loss

6.3.2 GPC-N

Figure 14: GPC-N test: Thru Line Return Loss

6.3.3 GPC-7

Figure 15: GPC-7 test: Thru Line Return Loss

6.3.4 GPC-3.5

Figure 16: GPC-3.5 test: Thru Line Return Loss

6.3.5 GPC-2.92

Figure 17: GPC-2.92 test: Thru Line Return Loss

6.3.6 GPC-2.4

Figure 18: GPC-2.4 test: Thru Line Return Loss

TEST RESULTS

CALKIT:

TEST FREQUENCY:

S/N:

DATE:

TESTED BY:

7. Test Results of Calkit: ______________________ S/N: