MICROWAVE TEST FIXTURE CHARACTERIZATION

DE-EMBEDDING TECHNIQUES MANUAL

BY

RHONDA FRANKLIN

in Fulfillment of

DIRECTED STUDY REQUIREMENTS

for

Winter 1990

DR. P.B. KATEHI

CONTENTS

INTRODUCTION

Measurements of the microwave circuits require the very good connections at the interfaces of both the circuit to test fixture and test fixture to Network Analyzer (NA). The measurements of the test connections, however, require the movement of the Network Analyzer reference plane. When performing a standard 7mm calibration of the HP8510, the reference plane for measurements will be the boundary of the coaxial cables. Once the device under test (DUT) is connected to the HP8510 NA, it is important to get good coupling to the I/O ports of the NA. Thus, the reference plane of the network analyzer must be moved to the edge of the circuit. This difference in reference planes is due to the transition launcher.

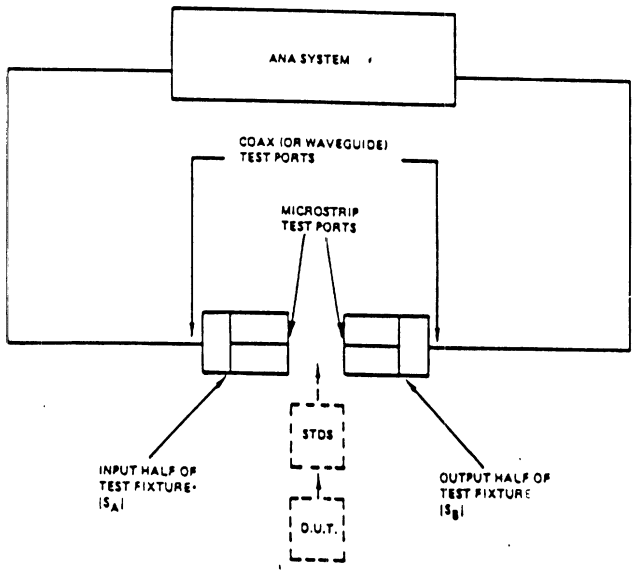


Figure A. Microstrip Test fixture approach for de-embedding. (Figure by L.P. Dunleavy [2], permission of author)

Test fixtures connect the NA and the DUT using inside connections through the launcher-transitions. However, the calibrated NA cannot distinguish between the scattering matrix of the fixture containing the DUT as a whole and the DUT and the test fixture separately.

By de-embedding, the scattering parameters of the DUT can be found from the overall data. To do this, the test fixture must be

characterized to determine the s-parameters separately, called unterminating. [4]

The calibration procedure allows the modelling of the system errors by measuring known standards. In de-embedding, the networks representing the launcher-transisiton between the NA and DUT are assumed and known standards are measured in the place of the DUT. These measurements will allow the reference plane at the interface to be moved to the interface of the DUT through de-embedding.

There are two types of de-embedding techniques. First, two tier requires the NA to be calibrated using its own standards. The test fixture is characterized using the calibration standards of the DUT. Secondly, a single overall calibration at the DUT interface is performed using the calibration standards of the DUT known as one-tier de-embedding.

The de-embedding one tier is more accurate since propagation of measurements errors are reduced. An additional advantage to one-tier is the NA's ability to provide the de-embedded device s-parameters without more data processing. Lastly, it is also possible to display directly de-embedded data through the graphical representation of measurements. However, for repeatability purposes and contact life, two-tier is more favorable.

This manual will present both the one-tier and two-tier de-embedding techniques. The one-tier technique has the advantage of being displayed on the HP8510. However, the data can only be displayed for one data point for the DUT. The two-tier de-embedding technique requires three procedures: 1) the data transfer of the standard measurements, 2) fixture characterization and 3) the device under test de-embedding. However this method cannot be displayed graphically as easily.

Since the circuits being measured require microstrip measurements, TSD (Thru, Short, Delay Method) will be used. This method requires the measurement of a thru, short and delay lines to characterize the test fixture.

Once the fixture is characterized, the DUT will be de-embedded after measuring . Lastly, the errors will be extracted as a result of

the fixture characterization. Below is a flow chart of the basic de-embedding process. [2]

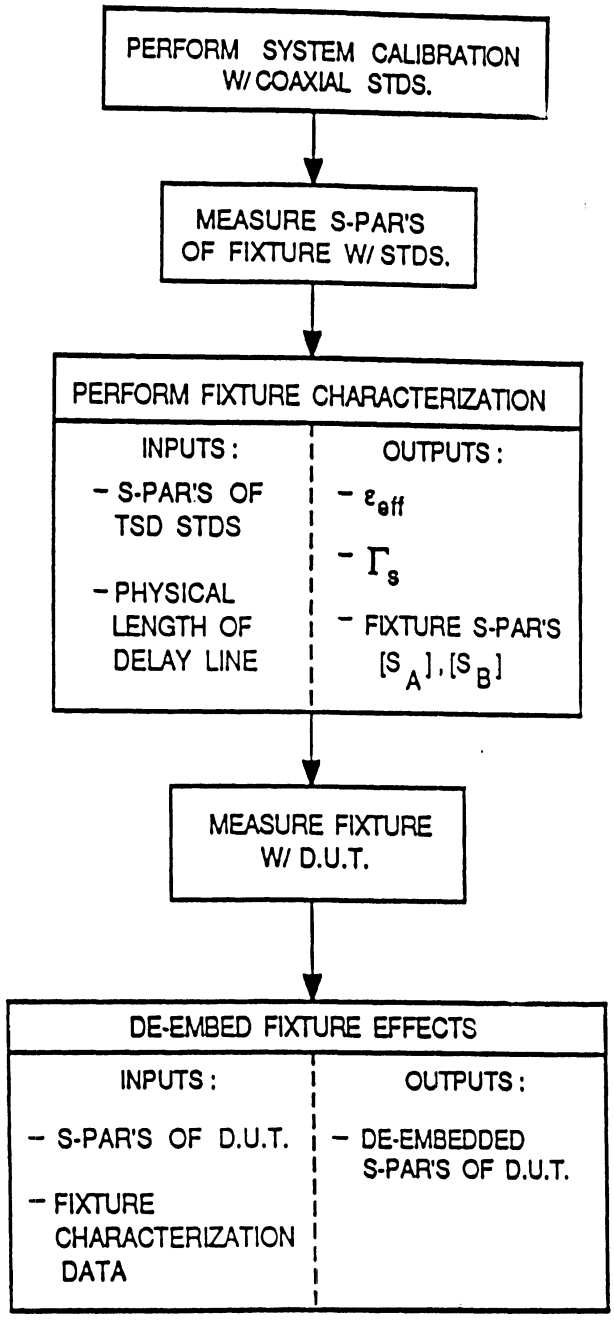


Figure B: Procedures for measurements and de-embedding.

SECTION I

GENERAL INFORMATION

EQUIPMENT LIST:

1 8510B Network Analyzer
- 1 7mm Calibration Kit
- 1 7mm Coaxial Cable Set

1 Test Fixture with
- 1 Small Holder
- 1 Medium Holder
- 1 Large Holder

1 Calibration Kit for Test Fixture
Standards:
- 1 Thru line (shortest delay line)
- 1 Medium line
- 1 Long line
- 1 Open Line

ONE-TIER DE-EMBEDDING:

1 Certified Data Cartridge with TRL Calibration Set

TWO-TIER DE-EMBEDDING:

3 Basic Programs
- 1. BAS–UNO: used for fixture characterization
- 1 RET2: used for data acquistion
- 1 BAS_SPAR1: used for de-bedding the DUT

1 Device Under Test , DUT (i.e. 2R microstrip filter)

PROCEDURES:

GENERAL OUTLINE:

1. BEFORE BEGINNING, MAKE SURE THE ABOVE ITEMS IN THE EQUIPMENT LIST ARE AVAILBLE.

2 **<PRESET>** the 8510 [green button]

3. Under the STIMULUS MENU, **<SET>** the [START] and [STOP] frequencies.

   a. For the 2-tier measurements, the Start frequency=2 GHz and the Stop frequency =18 GHz.

   b. For the 1-tier measurements the Start and Stop frequencies can be set in the range of the Network Analyzer.

4. To begin the calibration sequence, this presentation will be in the following order:

   1. 7mm Calibration of the HP 8510B Network Analyzer
   2. One-Tier De-embedding Technique
   3. Two-Tier De-embedding Technique

5. BEFORE proceeding to the calibration techniques, make sure the following calibration sets (cal sets) are loaded onto the HP 8510B: 7mm Cal Set and TRL Cal Set.

LOADING CAL SETS ONTO THE HP 8510B

1. **<CHECK>** the cal settings by using the [CAL] key. If both settings are correct, proceed to the calibration techniques. Otherwise, proceed to step 2.

2. **<LOAD>** the TRL measurements onto the NA. To do this, **<INSERT>** the Data Cartridge into the tape drive.
   a. **<PRESS>** [TAPE] key

   b. **<PRESS>** [DIRECTORY] to see a listing of the various calibration settings. See Directory Listing Below.

DIRECTORY LISTING ON DATA CARTRIDGE

File 1	7mm A.1
File 2	3.5 mm A.1
File 3	K-Conn
File 4	TRL CAL *
File 5	TRLB (This was added in the solid state lab downstairs.)

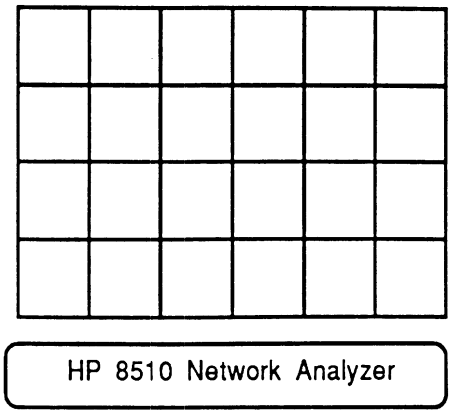
   c. **<PRESS>** [CAL KIT 1-2] : This will allow the loading of the calibration set into the cal kit.
      1. **<PRESS>** [*1]
         a. **<PRESS>** [File 1]

      2. **<PRESS>** [*2]
         a. **<PRESS>** [File 4]

   The procedures in c. allow the calibration kits to be loaded into the correct set. If one of the cal kits is already on the 8510B omit that step and load the proper kit.

   d. To check the settings, hit the [CAL] key and the display should show:

SCREEN:



CAL1 (7mm*)
CAL2 (TRL CAL*)

SECTION II

CALIBRATION TECHNIQUES

7mm CALIBRATION OF THE HP 8510 NETWORK ANALYZER

PART A.

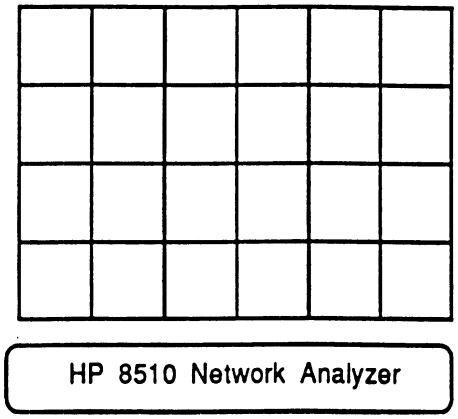
A 1 To begin, <**CONNECT**> the 7mm Coaxial Cables to Ports 1 and 2 of the HP 8510 Network Analyzer.

A2. Using the [CAL] key, <**SELECT**> [CAL1] key for the 7mm calibration set.

If the user is familiar with the procedures for 7mm calibration proceed to De-embedding techniques when complete. The 7mm calibration is not necessary for the one tier de-embedding techniques, however it does provide a comparison between the de-embedded measurements and the uncalibrated (embedded) measurements.

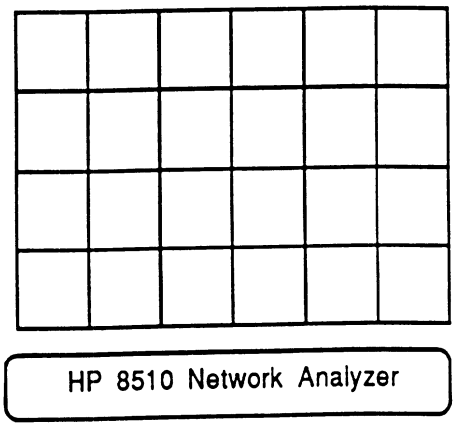
PART B.

SCREEN:



B-I. <**SELECT**> [Full 2port]

SCREEN:

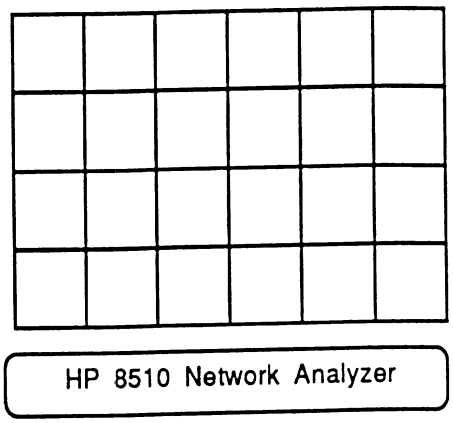


Reflection
Transmission
Isolation

Full 2 Port done

B1. **<SELECT>** [refletion]

SCREEN:



S11
Open
Short
Load

S22
Open
Short
Load

Reflection done

a. Using the 7mm Calibration Kit, perform Open and Short measurements by **<CONNECTING>** the Open standard then the Short Standard to Ports 1 and 2.

b. For Loads **<CONNECT** >the 50 ohm and proceed with the following.

1. For low frequencies, use the lowband measurements with the 50 ohm load.

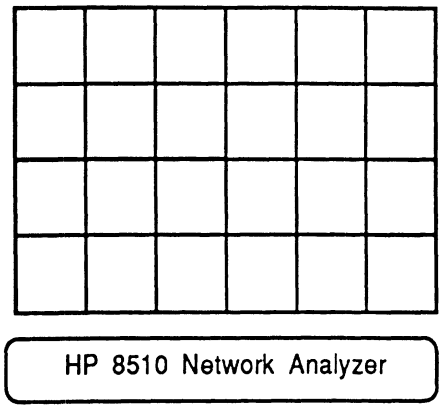
2. For wide frequency ranges, use the broadband measurement with the 50 ohm load. For a more accurate calibration also use the sliding load. See the HP 8510 Manual for instructions on using the Sliding Load.

c. In the above measurements, using a torque wrench will also increase the accuracy of the measurements and reduce the error introduced due to connector leakage.

d. When complete, <PRESS> [Reflection done].

B2. **<SELECT>** [transmission]

SCREEN:



Fwd. Transmission
Fwd. Match Thru
Rev. Transmission
Rev. Match Thru

Transmission done

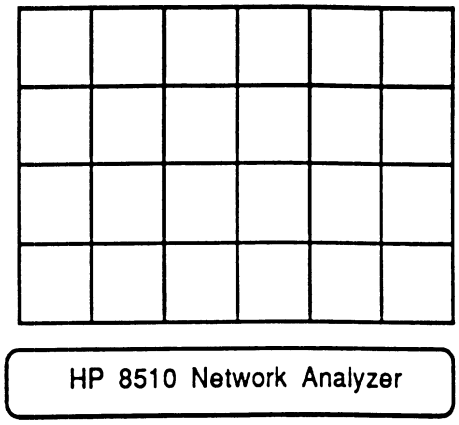
a. **<CONNECT>** the cables for Ports 1 and 2.

b. **<PRESS>** [Fwd. Transmission]
[Fwd. Match Thru]
[Rev. Transmission]
[Rev. Match Thru]

c. When complete, **<PRESS>** [Transmission done]

B3. **<SELECT>** [Isolation]

SCREEN:



Omit isolation

Isolation done

a. **<PRESS>** [omit isolation]

b. **<PRESS>** [Isolation done]

c. If Isolation is necessary, see the HP 8510 Manual for further instructions.

B4. Returning to the Full 2 Port screen, **<PRESS>** [Save 2-Port Cal]. The calibration can be saved in any of the open sets.
Aside: Sometimes the calibrations sets are full, so the NA will indicate to delete some of the old settings. It is good practice to do this procedure before beginning calibrations.

B5. The calibration can be checked by putting on various loads standards. To check S11, connect the 50 ohm line. It should show at least -20 dB insertion loss. The open circuit or short circuit should show a |S11| of zero, and phase of S11 at +/- 180 degrees.

B6. This is the end of the 7mm Calibration.

B7. The circuit can be measured to obtain em-bedded data.

ONE TIER DE-EMBEDDING TECHNIQUE

PART A:

IMPORTANT: FOR THE MOST ACCURATE AND RELIABLE MEASUREMENTS, A MICROSCOPE SHOULD ALWAYS BE USED TO ENSURE GOOD CONNECTIONS FOR CALIBRATING THE FIXTURE CHARACTERIZATION. THIS IS **ABSOLUTELY NECESSARY** TO AVOID DAMAGE TO THE LAUNCHERS & MICROSTRIP CONDUCTOR. (See the figure below.)

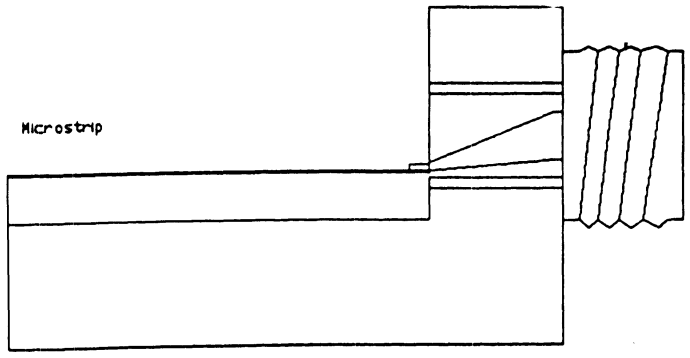
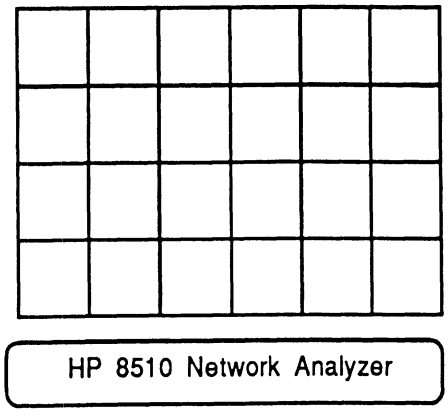


Figure1. Continuous taper transmission (taper from Eisenhart [ ]); at the end of the transition.

A1. Under the [CAL] menu, <**PRESS**> [CAL2 TRL CAL*]

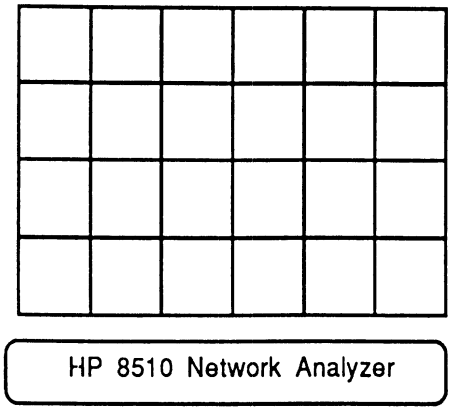
SCREEN:



CAL1 (7mm*)
CAL2 (TRL CAL*)

A2. <PRESS> [TRL 2 Port]

SCREEN:



THRU
THRU

S11 RELECT
OPEN

S22 REFLECT
OPEN

ISOLATION

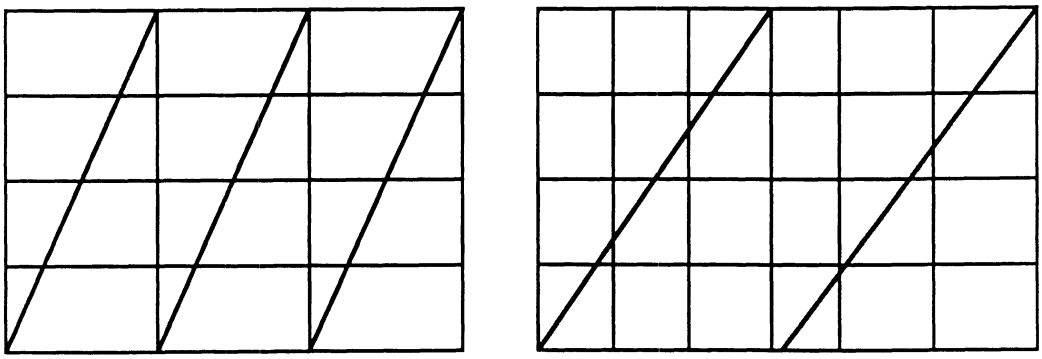
LINES
LINES

LOWBAND
REFLECTION

A3. From this point on the following fixture holders and standards are required for the characterization of the test fixture.

Fixture Holders:	Standards:
1. small	1. thru line open line
2. medium	2. med. line
3. large	3. long line

A4. When making a connection, always check the phase terms. Depending on the frequency range and length of standards, the variation in the number of slopes per division should be noticeable before and after the connection is established. As an example (see below) a good connection has about 1 slope per horizontal division whereas a bad connection is about 1 slope per 3 horizontal divisions.



Good Connection

Bad Connection

PART B:

B1. Thru menu
<CONNECT> Thru line to Port 1 and 2.
<PRESS> [thru]

B2. Open Menu
a. **<CONNECT>** Open standard to Port 1
<PRESS.> [S11 Reflect Open]

b. **<CONNECT>** Open standard to Port 2.
<PRESS> [S22 Reflect Open]

The connectors are labeled IN and OUT. Always connect the IN connector to Port 1 and the Out connector to Port 2.

B3. Lines Menu: **<PRESS>** [Lines]
a. **<CONNECT>** Medium line standard to Ports 1 and 2.
<PRESS> [Med. line]

b. **<CONNECT>** Long line standard to Ports 1 and 2.
<PRESS> [Long line]

c. When complete, **<PRESS>** [Lines Done]

B4. **<PRESS>** [Isolation]
   a. **<PRESS>** [Omit Isolation]
   b. **<PRESS>** [Isolation done]

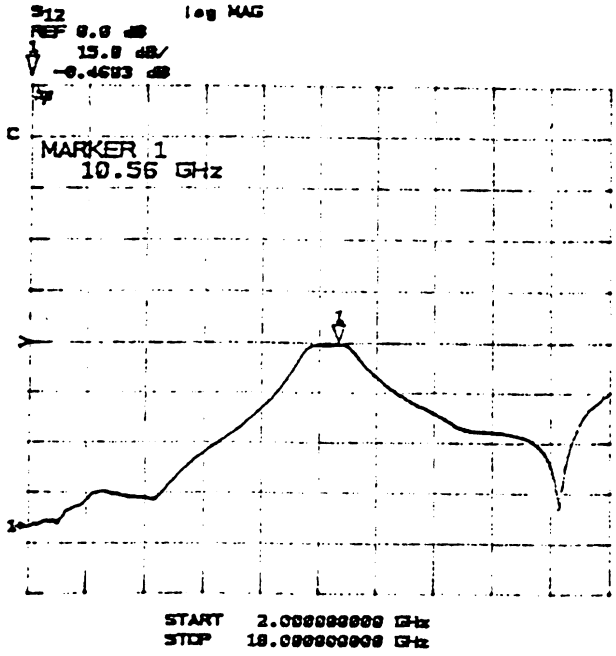
B5. **<PRESS>** [Save TRL 2-Port]
This calibration can be saved in any of the open calibrations sets.

B6. Once the calibration is saved, the HP 8510B will automatically turn the calibration on.

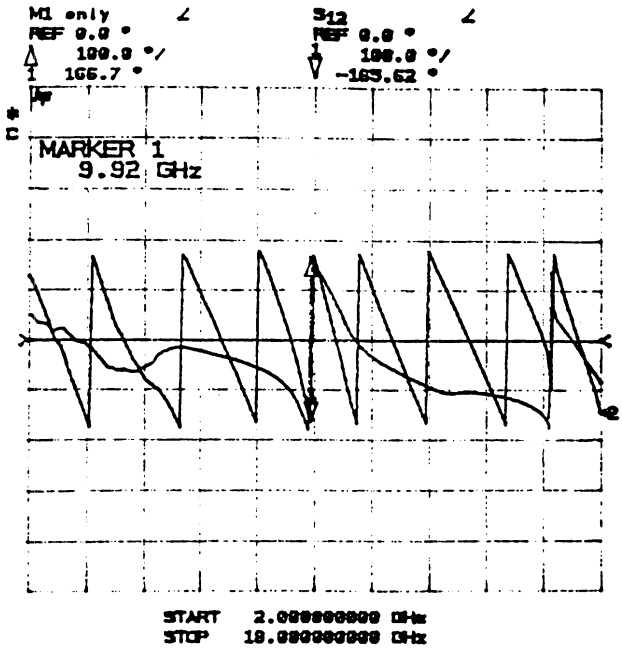
B7. Now connect the device under test.

To compare the de-embedded measurements with the embedded measurements, choose the cal set storage number and that calibration will be loaded to the network analyzer.

A comparison of the phase terms between the embedded and de-embedded fixture will show the most significant difference. As the test fixture is de-embedded, the phase term should become more flat. Also the magnitude of the s-parameters will show a slight decrease when the errors due to the fixture are calibrated out. of the system. See the example of a 2 Resonator filter below.



De-embedded magnitude measurements



De-embedded phase measurements

(The flatter response is the de-embeded measurement while the other phase is the nonde-embedded measurement.)

TWO TIER DE-EMBEDDING TECHNIQUES

INTRODUCTION:

The following set of instructions will be using the HP9000 workstations. The directions will include command instructions , <COMMANDS>, the USER'S KEY RESPONSE, [KEY RESPONSE], and the computer response "< >".

PART I:

1. Perform a standard 7mm Calibration on the HP8510 Network Analyzer. Set the Number of Points to 51 or 101 on the HP8510 and in the program RET101. The RET101 program has 101 points stored initially.

2. Connect the HP8510 to the HP computer workstation using the external HPIB bus inside the HP8510.

PART II: RET101 OR RET2 WILL PERFORM THE DATA TRANSFER BETWEEN THE HP8510 AND THE HP COMPUTER.

1. On the HP computer, Run Program **RET101** or **RET2(101)**

2 <**CONNECT**> the **THRU** line

THE COMPUTER PROMPTS ARE:

2-1. "<Header(Title, Date, Etc.)>", [CONTINUE]

2-2. "<Press to Continue>"

2-3. "<Select S-Parameters to store>" all or [K3] key

example: [restart] [S11 only] [S22 only] [all]

2-4. "<Filename?>"

2-5. "<Pause and rerun program for next Data Transfer>"

3. Measure the medium standard.
   3a. **<CONNECT>** **MEDIUM** line
   Repeat procedures 2-1 thru 2-5.

4. Measure the long standard.
   4a. **<CONNECT>** **LONG** line
   Repeat procedures 2-1 thru 2-5.

5. Measure the S11 open standard.
   5a. **<CONNECT>** **OPEN** line to Port 1 for S11.
   Repeat procedures 2-1 thru 2-5.

6. Measure the S22 open standard.
   6a. **<CONNECT>** **OPEN** line to Port 2 for S22.
   Repeat procedures 2-1 thru 2-5.

7. Measure the device under test DUT. This measurement is without de-embedding of the test fixture.

   7a. **<CONNECT>** Device Under Test
   Repeat procedures 2-1 thru 2-5.

PART III: BAS_UNO1 CHARACTERIZES THE TEST FIXTURE.

1. **<LOAD> TYPE:** " BAS_UNO1:INTERNAL,4,1"
   (the left 5-1/2" drive) and **<RUN>**.

2. "< Output to screen (1) or Printer (0)? >" Choose (1) unless printing the data.

3. "< Enter file for SHORT LINE? >" {filename} **<RETURN>**

4. "< Enter file for MED LINE? >" {filename} **<RETURN>**

5. "< Enter file for LONG LINE? >" {filename} **<RETURN>**

6. "< Enter file for OPEN STD PORT 1? >" {filename} **<RETURN>**

7. "< Enter file for OPEN STD PORT 2? >" {filename} **<RETURN>**

8. The next prompt shown should say "Working on Gamma".

9. S11[A], S11[B], S22[A], S22[B] are calculated.

10. The computer screen will say the following after the files have been entered: " LAST FILE ENTERED WAS " {filename}.

11. "Write the Data to Disk" {filename}

12. " Store data in ASCII <A> OR BDAT<B>? " **<CHOOSE B>**

13. " That's all folks. " THIS THE LAST LINE OF THE PROGRAM.

PART IV: BAS_SPAR1 performing de-embedding of the DUT.

1. **<LOAD>** TYPE: "BAS_SPAR1:INTERNAL,4,1", then, **<RUN>**

2. **<PRESS>** [Continue] whenever interrupted.

3. "File name" : {filename}

4. Select the Desired operation.

   PRINT PRINT SCREEN
   GET FILE PROGRAM INFO

5. " DB/PHASE" : [K2] Key
   This tell the computer the form of the output.

6. Print about 50 points.

7. **<EXTRACT>** De-embed **<RETURN>**

8. <FIXTURE CHARACTERIZATION FILENAME> {filename}

9. "< Write data to Disk?>" {y}

10. "< Storage filename for S-Port: >" {filename}

11. **<PRINT>**

12. <Db/Phase>

SECTION III

APPENDIX

REFERENCE BOOKS AND PAPERS

1. Bauer, R.F. and P. Penefield, Jr., "De-embedding and Unterminating", *IEEE Trans. Microwave Theory Tech.*, VOL MTT-22, No. 3, March 1974.

2. Dunleavy, L. , " Discontinuity Characterization in Shielded Microstrip: A Theoretical and Experimental Study"., Dissertation, University of Michigan, 1988.

3. Eisenhart, R. L., " A Better Microstrip Connector ", IEEE International Microwave Theory and Techniques Symposoium Digest, 1978, P. 318.

4. Frazen, N.R. and R. A. Speciale, " A New Procedure for System Calibration and Error Removal in Automated S-Parameters Measurements", *5th European Micro. Symp.*, 1975.

5. HP8510 Automatic Network Analyzer, Palo Alto, CA.

6. Izadian, J.S. and S. M. Izadian, *Microwave Transition Design,* Artech House, Massachusetts, 1988.

7. Speciale, R.A., " A Generalization of a TSD Network-Analyzer Calibration Procedure, Covering n-Port Scattering-Parameter Measurements Affected by Leakage Errors", *IEEE Trans. Microwave Theory Tech.*, Vol. MTT-25 No 12, Dec. 1977.

8. Speciale, R.A. and N. R. Frazen, "Super TSD Generalization of the TSD Network Analyzer Calibration Procedure, Covering n-Port Measurements with Leakage", *IEEE Trans. Microwave Theory Tech.*, vol MTT-5, 1977.