Radio Frequency Testing Procedures

For Pickering Interfaces Switch Cards

Contents

Introduction

The purpose of this document is to define the methods for performing radio frequency (R.F) measurements in 50Ω & 75Ω unbalanced and 100Ω-120Ω balanced test systems using a 50Ω vector network analyser (referred to as "VNA" from this point forward).

In order to perform 75Ω tests with a 50Ω VNA it is necessary to use minimum loss pads (referred to as "min loss pads" from this point forward). A set of two pads will be required to perform the tests detailed within this document.

To perform balanced tests, it is necessary to use a purpose-built impedance converter and under certain circumstances min loss pads.

Please note that it is not possible to detail every test permutation i.e., multiple test cards etc that may be encountered. For this reason, the following sections will refer to testing a single card; the same principles can be applied to multiple cards.

This document assumes that the operator has been trained to safely operate and perform measurements on the test equipment and the device under test (referred to as "DUT" from this point forward). If in any doubt regarding this procedure or equipment consult a suitably qualified engineer.

Test Equipment

The following items will be required to perform R.F. measurements:-

Quantity	Description
1	VNA, 50Ω, 2-port with suitable frequency range

50Ω Unbalanced Tests

Quantity	Description
2	Inter-series 50Ω adapters for use with VNA (dependent on DUT)
1	50Ω calibration "Load" (type dependent on DUT)
1	50Ω calibration "Open" (type dependent on DUT)
1	50Ω calibration "Short" (type dependent on DUT)
1 set	Interconnection cables (50Ω)

75Ω Unbalanced Tests

Quantity	Description
2	Min loss pads (50Ω to 75Ω) with suitable frequency range
2	50Ω adapters for use with min loss pads (dependent on pad type)
2	Inter-series 75Ω adapters for use with min loss pads (dependent on DUT)
1	75Ω calibration "Load" (type dependent on DUT)
1	75Ω calibration "Open" (type dependent on DUT)
1	75Ω calibration "Short" (type dependent on DUT)
1 set	Interconnection cables (75Ω)

100Ω - 120Ω Balanced Load Tests

Quantity	Description
1	Impedance converter
1 set	Interconnection cables

Please note that not all pieces of equipment are required for all tests, refer to the individual test sections for specific requirements.

For the purpose of this document an Agilent (formally "HP") 8752A VNA will be used. For other instruments it will be necessary to consult the operating manual to determine the various functions.

It is essential that the correct impedance connectors & cables are used when performing calibration or testing routines. Mixing connectors with different impedances may result in mechanical damage and will result in unreliable results.

Min Loss Pads

Min loss pads are used to impedance match a 50Ω VNA (or similar test equipment) to a 75Ω test system. One min loss pad is required per VNA port.

The number of min loss pads required varies between the different R.F. tests. For example, VSWR (voltage standing wave ratio) & return loss tests utilise a single min loss pad; for insertion loss, isolation & crosstalk measurements two min loss pads are required.

Numerous versions of min loss pads are available. Some min loss pads are dedicated to a specific instrument, others general purpose. General purpose min loss pads may require connector series adapters \ converters to interface with the target instrument.

Min loss pads supplied by Agilent (formally "HP", part number 11852B) will be used (see Figure 1) throughout this document. These items are fitted with 50Ω N-type (jack) and 75Ω N-type (plug) connectors. The 50Ω N-type requires an N-type plug to plug coupler to interface with the VNA; the 75Ω N-type requires an adapter to convert to a connector series suitable for use with the test system i.e., BNC, SMB, MCX etc. Figure 1 illustrates a min loss pad, 50Ω coupler and 75Ω N-type to MCX adapter.

Figure 1 Min Loss Pad and Adapters

Unbalanced Load - Calibration

To correctly measure the R.F. performance of any item it is necessary to calibrate the test system prior to performing tests on the DUT; during this process, the DUT should not be connected. Each test type has a specific calibration procedure that compensates for the components outside of the DUT that would otherwise affect any measurements. The results from a calibrated system will reflect the performance of the DUT without influence of the test setup.

This document contains figures detailing the testing methods for a DUT equipped with both R.F. connectors i.e., SMB and non-R.F. connectors i.e., SCSI, D-type. The calibration and testing procedures will fundamentally be identical but there will be some minor changes during calibration. For this reason, the following sections detail both calibration procedures.

Once a calibration procedure has been completed the VNA should indicate a minimal error. If this is not the case the set-up should be inspected, and the calibration routine repeated.

Please note that during calibration it is likely that a compromise in system components will be required; compromises can be a coupler added which will not be used with the DUT or a DUT connector that should not be compensated for but has been. The selection of the most appropriate calibration routine will be dependent upon standard practices and operator experience.

Non-R.F. Connectors

In situations where the test system is fitted with non-R.F. connectors it is usually not possible \ desirable to use an "off the shelf" coupling connector to join the test leads together during calibration. There are typically two solutions that replace the use of a coupler:-

a) The first method uses a soldered joint to either connect the ends of the test leads either together or to attach a calibration "Load" etc to the cable.

This method does not compensate for the mating half of the DUT connector.

b) The second method uses a connector identical to the DUT interface that allow pins to be either connected together, or to a calibration "Load" etc.

The shortfall of this method is that the DUT connector has been compensated for and as such is not included in the results when DUT testing starts.

Please note that when working with un-terminated coax cables that the braid shield should be as close to the end of the cable inner insulator as possible. If the braid is cut \ pulled back from the end of the cable insulator the performance will degrade as the core of the cable is no longer characterised along its whole length. It is acceptable for the braid to end at the insulator and an additional wire connected to complete the ground connection. This method will always result in a short length of coax signal core being outside of the braid screen; every effort should be made to ensure that the unscreened sections are as short as possible.
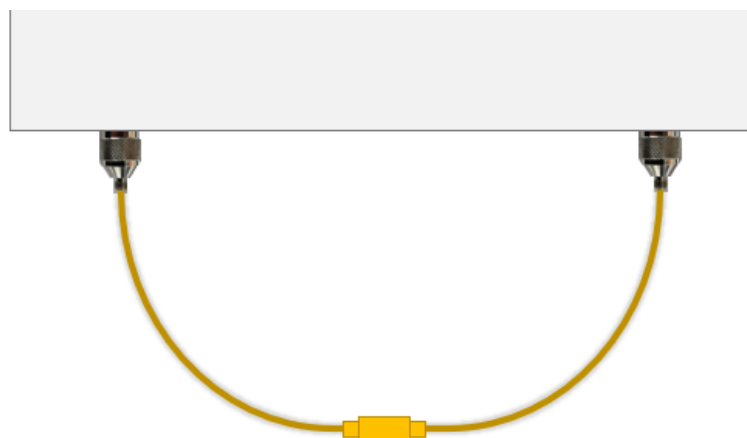
Insertion Loss (R.F. Connectors) 50Ω

The test system is connected as illustrated in Figure 2.

Using the VNA the calibration procedure is as follows:-

1. Attach one end of each test cable to the VNA's ports.

2. Join the remaining ends of the test leads together using a suitable coupling connector.

3. Set the VNA to measure "Transmission" in the format of "log mag".

4. Set the "start" and "stop" frequencies required for testing on the VNA.

5. Set the VNA scale to 1dB per division (this is a good starting point but may need to be revised when testing commences).

6. Access the VNA calibration menu and select "Response", "Thru", "Done : Response".

7. The calibration of the test system has been completed and testing can now begin.
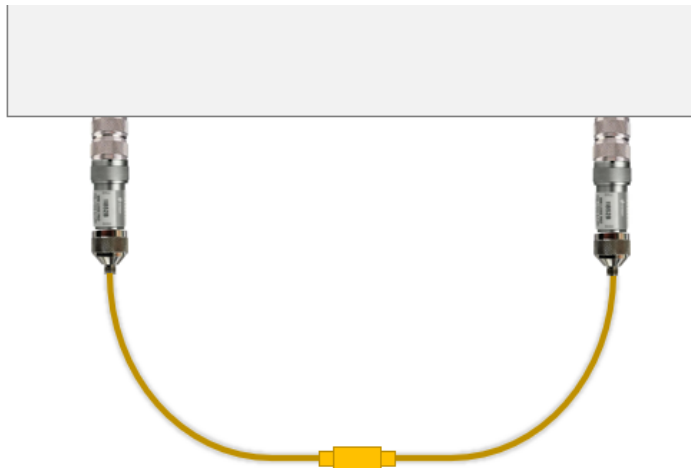
Figure 2 Insertion Loss (R.F Connectors) 50Ω Calibration

Insertion Loss (R.F. Connectors) 75Ω

The test system is connected as illustrated in Figure 3.

Using the VNA the calibration procedure is as follows:-

1. Attach the min loss pads to the VNA's ports.

2. Attach one end of each test cable to the min loss pads.

3. Join the remaining ends of the test leads together.

4. Set the VNA to measure "Transmission" in the format of "log mag".

5. Set the "start" and "stop" frequencies required for testing on the VNA.

6. Set the VNA scale to 1dB per division.

7. Access the VNA calibration menu and select "Response", "Thru" , "Done : Response".

8. The calibration of the test system has been completed and testing can now begin.

Figure 3 Insertion Loss (R.F Connectors) 75Ω Calibration,

Insertion Loss (Non-R.F. Connectors) 50Ω & 75Ω

For non-R.F. connectors the calibration procedure is identical to that for R.F. connector-based systems with the exception that one of the following methods (See Figures 4a & b) should be used to join the test cables together.

Method 1 simply solders the cable together; Method 2 uses a connector identical to the DUT interface and is fitted with a link.

Figure 4a Insertion Loss Non-R.F Connector interface Method 1

Figure 4b Insertion Loss Non-R.F Connector interface Method 2

NOTE: The green link wire is connected to front panel (FP) ground pin of the module (DUT).
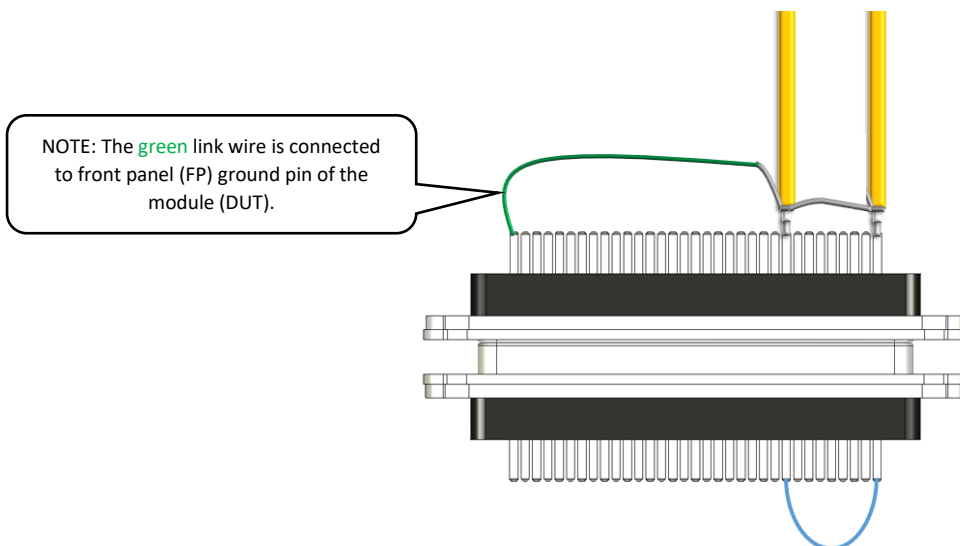
VSWR (R.F. Connectors) 50Ω

The test system is connected as illustrated in Figure 5.

Using the VNA the calibration procedure is as follows:-

1. Attach one end of a test cable to the VNA "R.F. out" (Reflection) port.

2. Connect a "Load" to the other end of the test lead.

3. Set the VNA to measure "Reflection" in the format of "SWR".

4. Set the "start" and "stop" frequencies required for testing on the VNA.

5. Set the VNA scale to 1 per division.

6. Access the VNA calibration menu and select "Reflection 1 port", "Load".

7. Remove the "Load" and fit a "Short".

8. From the calibration menu select "Short" – "Short M" – "Done".

9. Remove the "Short" and fit an "Open".

10. From the calibration menu select "Open" – "Open M" – "Done".

11. From the calibration menu select "Done: 1 port".

12. Remove the calibration "Open".

13. The calibration of the test system has been completed and testing can now begin.

Figure 5 VSWR (R.F Connectors) 50Ω Calibration
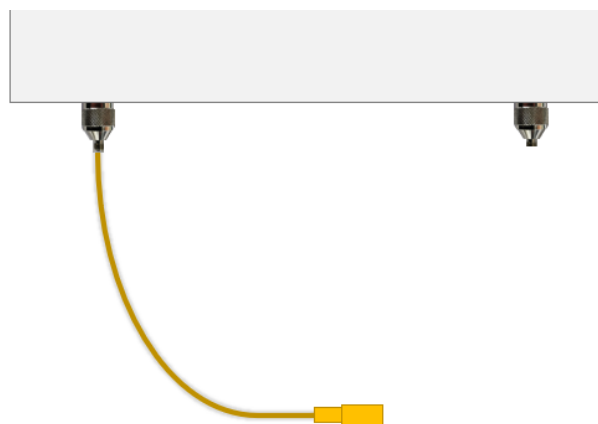
VSWR (R.F. Connectors) 75Ω

The test system is connected as illustrated in Figure 6.

Using the VNA the calibration procedure is as follows:-

1. Attach a min loss pad to the VNA's "R.F. out" (reflection) port.

2. Attach one end of a test cable to the min loss pad.

3. Connect a "Load" to the other end of the test lead.

4. Set the VNA to measure "Reflection" in the format of "SWR".

5. Set the "start" and "stop" frequencies required for testing on the VNA.

6. Set the VNA scale to 1 per division.

7. Access the VNA calibration menu and select "Reflection 1 port", "Load".

8. Remove the "Load" and fit a "Short".

9. From the calibration menu select "Short" – "Short M" – "Done".

10. Remove the "Short" and fit an "Open".

11. From the calibration menu select "Open" – "Open M" – "Done".

12. From the calibration menu select "Done: 1 port".

13. Remove the calibration "Open".

14. The calibration of the test system has been completed and testing can now begin.

Figure 6 VSWR (R.F Connectors) 75Ω Calibration
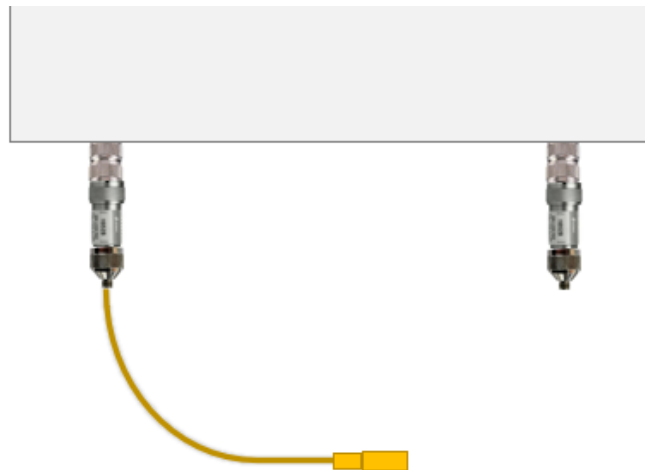
VSWR (Non-R.F. Connectors) 50Ω & 75Ω

For non-R.F. connectors the calibration procedure is identical to that for R.F. connector-based systems with the exception that one of the following methods (See Figures 7a & b) should be used to join the test cable to the calibration "load", "short" etc.

Method 1 uses a SMA connector soldered directly to the test cable which will be used to attach the calibration "load" etc; Method 2 again uses an SMA with the addition of a DUT interface connector.

Figure 7a VSWR Non-R.F Connector Interface Method 1
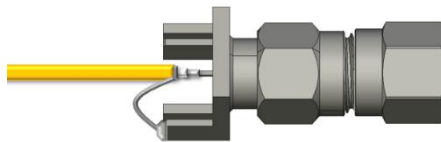
Figure 7b VSWR Non-R.F Connector Interface Method 2
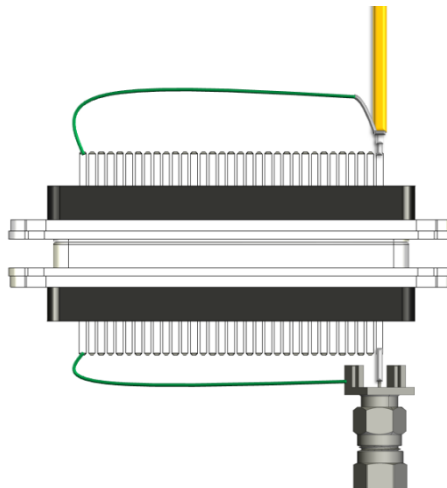
Return Loss

The calibration routine for return loss is identical to that for VSWR with the only exceptions that the VNA should be set to "Log Mag" instead of "SWR" and 10dB per division.

Please note that the dB / division setting may be altered to suit the DUT characteristics.

Isolation

The calibration routine for isolation is identical to that for insertion loss with the only exception that the VNA should be set to 10dB per division.

Please note that the dB / division setting may be altered to suit the DUT characteristics.

Crosstalk

The calibration routine for crosstalk is identical to that for insertion loss with the only exception that the VNA should be set to 10dB per division.

Please note that the dB / division setting may be altered to suit the DUT characteristics.

Unbalanced Load - Testing

The following sections assume that the calibration procedure for the specific test has been completed and prior to connecting the DUT the VNA measured a minimal error. As such it is assumed that the connections and set-up of the VNA are unchanged from the calibration procedure for the following tests.

Please note that for reasons of clarity the non-R.F. connector photographs in the following sections do not show the VNA connection(s); the connections of the VNA are identical for R.F. and non-R.F. connector systems.

Insertion Loss

For this type of testing a signal is transmitted from the VNA, it passes through the DUT and is fed back into the VNA's "R.F. in" (transmission) port.

The unit of measurement for this test is dB. Results are quoted as either the decibel loss at a specific frequency or the frequency of the -3dB point.

The DUT should be connected as illustrated in Diagram 1 & Figures 8a, b or c.

Using the VNA the testing procedure is as follows:-

1. Whilst keeping the test cables connected to the VNA separate the other cable ends.

2. Connect one test cable to the DUT input port.

3. Connect the other test cable to the DUT output port.

4. Close the required switch path in the DUT.

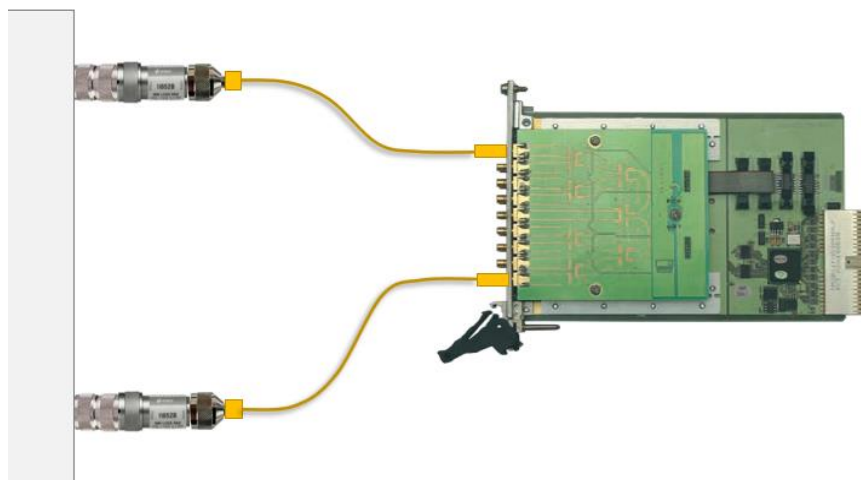5. The DUT performance is now indicated by the VNA and should be noted.
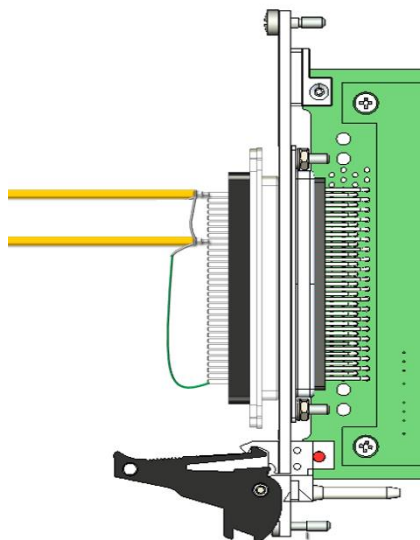
Diagram 1 Insertion Loss DUT Connections
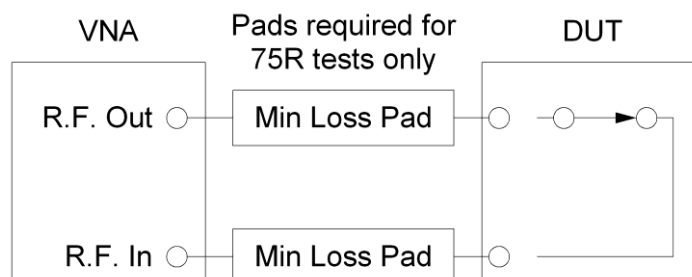
Figure 8a Insertion Loss & Isolation (R.F. Connectors) 50Ω Testing
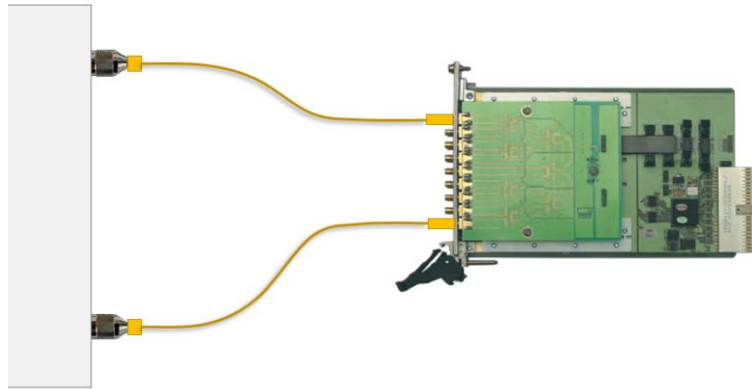
Figure 8b Insertion Loss & Isolation (R.F. Connectors) 75Ω Testing

Figure 8c Insertion Loss & Isolation (non-R.F. Connectors) 50Ω & 75 Ω Testing

VSWR

For this type of testing a signal is transmitted from the VNA's "R.F. out" port, it passes through the DUT and is absorbed by the calibrated "load". Any impedance mismatch in the DUT will cause a reflection of part of the signal back to the VNA port.

VSWR is a measure of impedance mismatch between the transmission line and its load; the higher the VSWR, the greater the mismatch.

Results will be a ratio of X.X: 1. The "X.X" component of the ratio will be indicated by the VNA. A perfect but non-achievable ratio would be 1:1 as this indicates that there are no impedance mismatches throughout the system.

The VSWR of a DUT can be calculated from the return loss using the following formula:-

$$VSWR = \frac{10^{\text{Return loss (db) / 20}} + 1}{10^{\text{Return loss (db) / 20}} - 1}$$

The DUT should be connected as illustrated in Diagram 2 & Figures 9a, b or c.

Using the VNA the testing procedure is as follows:-

1. Whilst keeping the test cable connected to the VNA.

2. Connect the test cable to the input of the DUT.

3. Fit a calibration "Load" to the output of the DUT.

4. Close the required switch path in the DUT.

5. The DUT performance is now indicated by the VNA and should be noted.

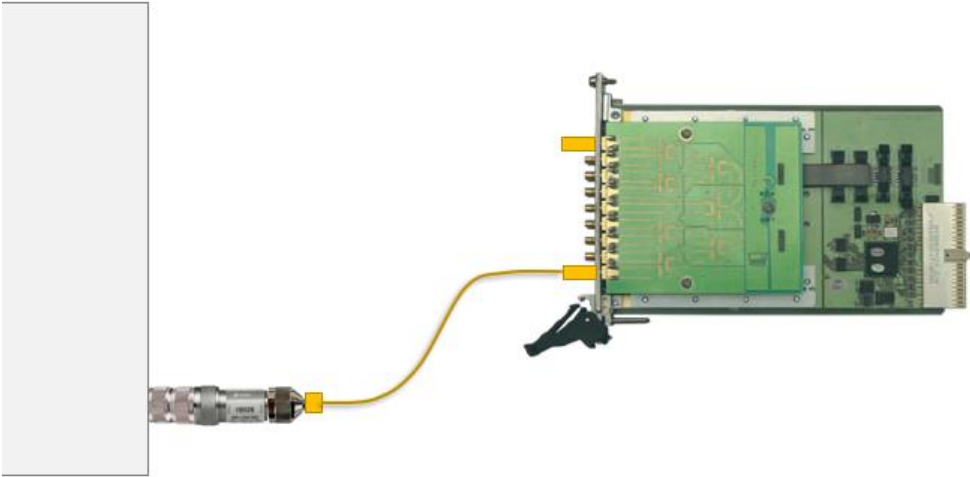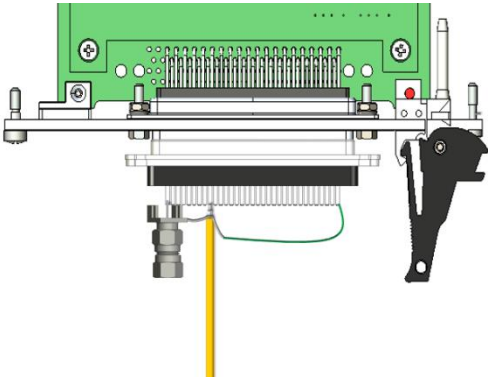***Diagram 2 VSWR DUT Connections***
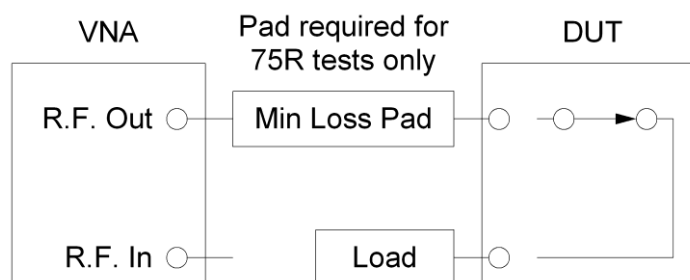
Figure 9a VSWR (R.F Connectors) 50Ω Testing
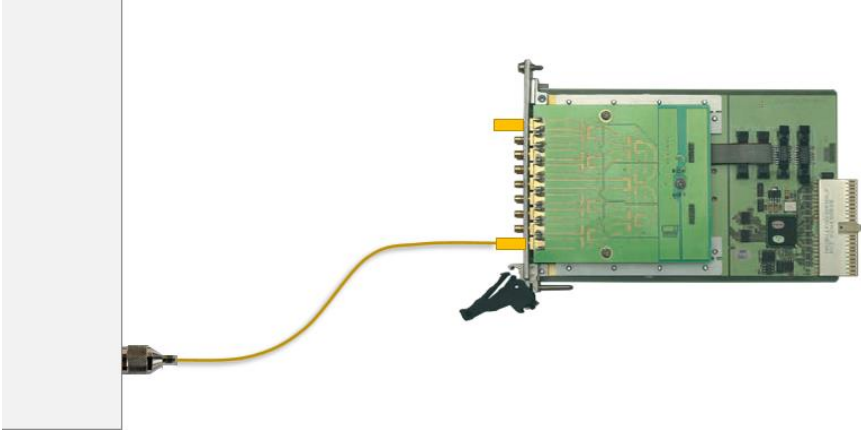
Figure 9b VSWR (R.F Connectors) 75Ω Testing

Figure 9c VSWR (Non-R.F Connectors) 50Ω & 75Ω Testing

Return Loss

Return loss is a measure of power reflected from imperfections in a transmission line. It is the ratio of the power of the wave reflected from the imperfection to that of the incident wave. The return loss value describes the reduction in the amplitude of the reflected energy, as compared to the forward energy

Return loss can also be considered as VSWR expressed in decibels, as such the test details are identical to those listed for VSWR.

It is possible to determine the return loss of a DUT based on its VSWR results although normally it is the VSWR that is calculated from the return loss result. The conversion formula is as follows:-

$$\text{Return Loss (dB)} = -20 \times \text{Log} \left(\frac{\text{VSWR}-1}{\text{VSWR}+1} \right)$$

Isolation

As the name implies isolation testing relates to the level of isolation between switch paths, connectors etc and is measured in decibels.

Testing comprises of a signal being applied to a switch path of the DUT that consists of one or more contacts, contact(s) are then opened to break the path; the resulting signal at the end of the now broken path is measured to determine the isolation.

For switch cards there are two types of isolation tests (See Diagrams 3a & b) that can be performed depending on the DUT configuration.

Please note that the connection of the test system to the DUT is identical to that used in insertion loss testing but has been included in the following sections for clarity.

Using the VNA and referring to Figures 8a, b or c the testing procedure for both test types is as follows:-

Isolation Test Method 1

1. Whilst keeping the test cables connected to the VNA separate the other cable ends.

2. Connect one test cable to the DUT input port.

3. Connect the other test cable to the DUT output port.

4. Ensure that one contact in the DUT switch path is open.

5. The DUT performance is now indicated by the VNA and should be noted.

Diagram 3a Isolation DUT Connections Method 1
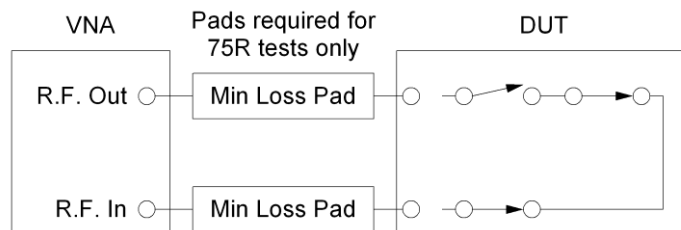
Isolation Test Method 2

1. Whilst keeping the test cables connected to the VNA separate the other cable ends.

2. Connect one test cable to the DUT input port.

3. Connect the other test cable to the DUT output port.

4. Ensure that all contacts in the DUT switch path are open.

5. The DUT performance is now indicated by the VNA and should be noted.

Diagram 3b Isolation DUT Connections Method 2
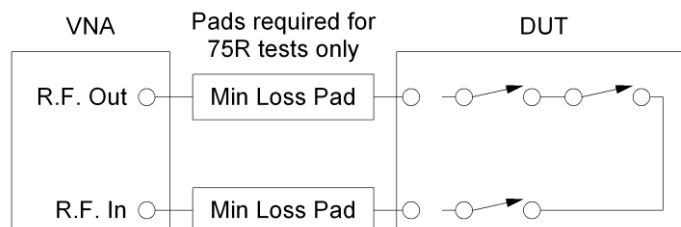
Of the two test types, type 2 is the preferred option if more than one contact is present in the switch path. The reason for this preference is that it represents a true indication of the results an end-user would find when testing a DUT.

Crosstalk

Crosstalk testing is used to determine the level of signals that are present on an (usually) adjacent path from the applied signal and is measured in decibels.

The DUT should be connected as illustrated in Diagram 4 and Figures 10a, b or c.

When testing an "X-Y" matrix it is possible to perform crosstalk measurements from either axis. For example, a signal can be applied to the "X-axis" and the VNA & load can be fitted to the "Y-axis"; alternatively, the signal can be applied to the "Y-axis" and the VNA & load connected to the "X-axis". It is best practice to perform crosstalk measurements from both axes to generate a comprehensive set of results for a product.

Testing comprises of all contacts in switch path A being closed, a calibration "Load" is fitted to the end of path A to correctly terminate the transmission line, path B (adjacent to path A) has all its contacts open, a signal is applied to path A from the VNA, and the resulting signal is measured at the end of path B. This defines the level of signal that passes along path A and crosses to path B.

1. Whilst keeping the test cables connected to the VNA separate the other cable ends.

2. Connect one test cable to the DUT input port (path A).

3. Connect the other test cable to the DUT adjacent path (path B).

4. Connect a calibration "Load" to the DUT output port (path A)

5. Close all contacts in path A.

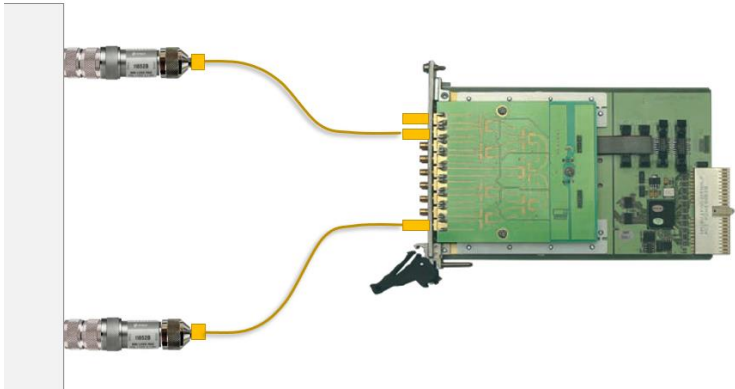6. The DUT performance is now indicated by the VNA and should be noted.
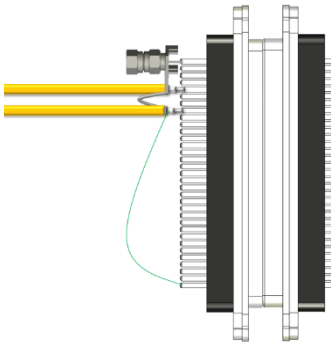
Diagram 4 Crosstalk DUT Connections
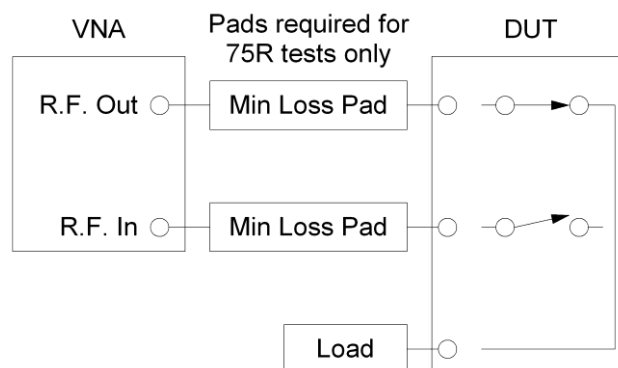
Figure 10a Crosstalk (R.F Connectors) 50Ω Testing
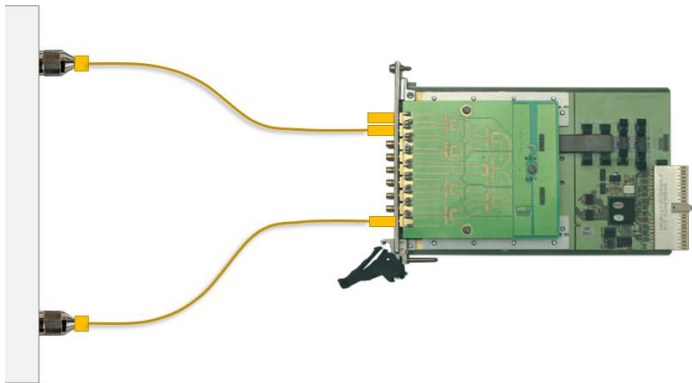
Figure 10b Crosstalk (R.F Connectors) 75Ω Testing

*Figure 10c Crosstalk (non-R.F Connectors) 50Ω & 75Ω Testing*

Balanced Load

To this point the calibration and testing procedures have been geared toward 50Ω \ 75Ω unbalanced tests on 1-pole switch cards. When testing 2-pole Pickering Interfaces switch cards the testing requirement changes from unbalanced to balanced; the result of this is an impedance change to 100Ω - 120Ω (depending to DUT).

To perform balanced load testing, a purpose-built converter (Figure 11) is required. The converter is based around R.F. transformers \ Baluns that interfaces the unbalanced VNA ports to the balanced test system (see Diagram 5). Depending on the impedance of the test system and the R.F. transformer used in the converter it may be necessary to also include the min loss pads in the test set-up.

Figure 11 Impedance Converter
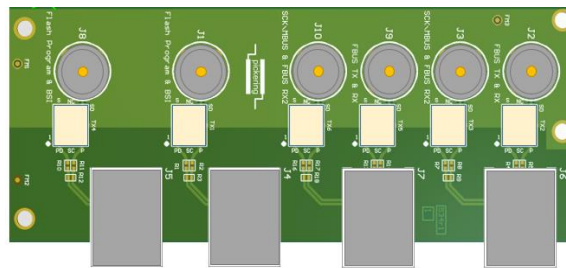
Diagram 5 Impedance Converter Circuit Diagram
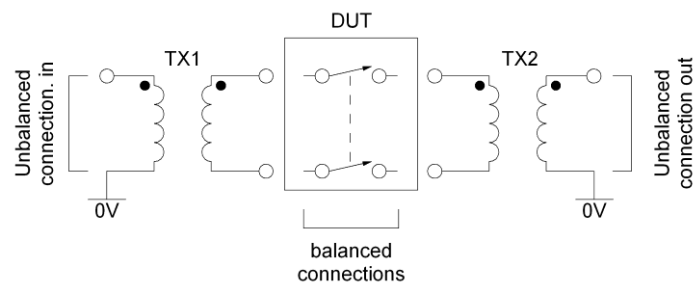
The Pickering Interfaces impedance converter has been designed with BNC connectors for unbalanced and RJ-45 connectors for balanced connections. The choice of the RJ-45 connector allows "standard" CAT 5 \ 6 cable with an impedance of 100Ω - 120Ω to be used. Please note that the impedance of CAT 5 \ 6 cable is only applicable when cables pairs are twisted together as such when making connections to the DUT it is necessary to maintain the twisted pairs for as much of the signal path as possible.

The use of min loss pads when performing balanced load tests is dictated by the impedance of the test system and the turn ratio of the impedance converters R.F. transformers (presently 1:1.5). Please note that when using this ratio, the balanced impedance is subject to a square law. For example, with a 50Ω source and a transformer ratio of 1:1.5 the balanced impedance would be 50Ω x 1.5^2 = 112.5Ω.

The provision of RJ-45 connectors on the Impedance converter allows several possible methods of calibration connection (see Figures 12a-c & 14a-c). Of the three methods number 1 would give the best results as the cable is fully characterised along the complete signal path; if, however the DUT does not use RJ-45's Method 1 will not fully reflect the test set-up. For this reason, either Method 2 or 3 should be used; the preference being Method 2.

As with unbalanced testing it is necessary to calibrate the system prior to performing tests on the DUT. The following sections define the procedures necessary for the various tests.

Note:- Each of the following test procedures assume that the VNA is set-up and connected as defined in the relevant calibration section.

Insertion Loss

The concept of the calibration and test procedures are identical to those used in unbalanced testing with the exception of the impedance converter added to the signal path.
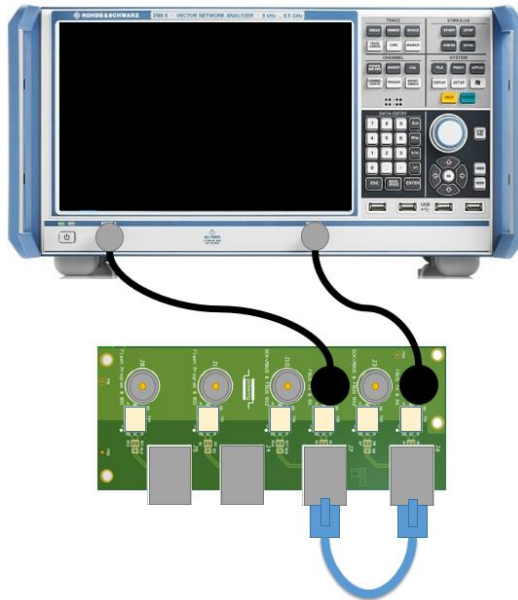
Calibration

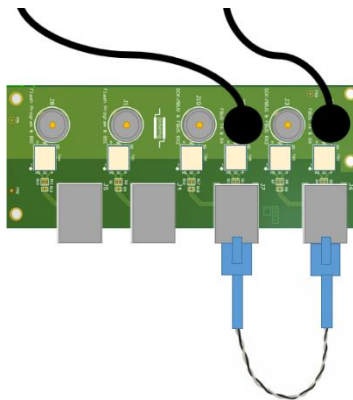Using the VNA the calibration procedure is as follows:-

1. Attach one end of the BNC test cables to the VNA's ports.

2. Attach the other end of the BNC test cables to the impedance converter.

3. Attach one end of the RJ-45 test cables to the impedance converter.

4. Join the remaining ends of the RJ-45 test leads together.

5. Set the VNA to measure "Transmission" in the format of "log mag".

6. Set the "start" and "stop" frequencies required for testing on the VNA.

7. Set the VNA scale to 1dB per division.

8. Access the VNA calibration menu and select "Response", "Thru", "Done : Response".

9. Disconnect the test lead ends that were joined together.

10. The calibration of the test system has been completed and testing can now begin.
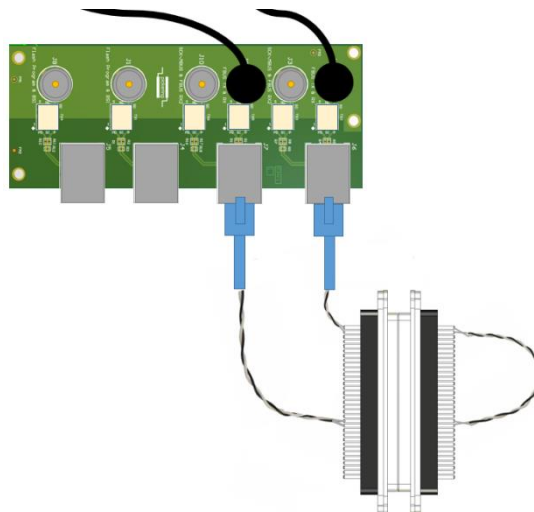
Figure 12a Insertion Loss Calibration Method 1

Figure 12b Insertion Loss Calibration Method 2

*Figure 12c Insertion Loss Calibration Method 3*

Testing

The DUT should be connected as illustrated in Diagram 6 and Figure 13.
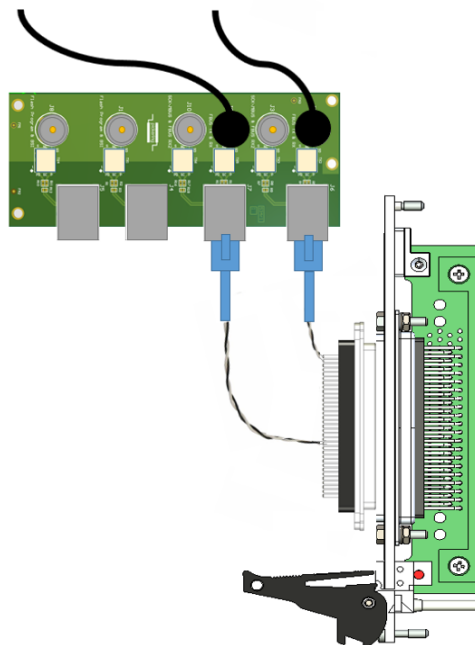
Using the VNA the testing procedure is as follows:-

1. Attach the separated test lead ends to the DUT.

2. Close the required switch path in the DUT.

3. The DUT performance is now indicated by the VNA and should be noted.

Diagram 6 Insertion Loss DUT Connections
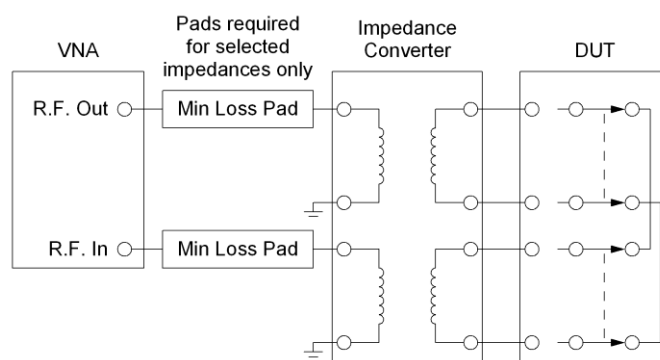
Figure 13 Insertion Loss & Isolation Testing

VSWR

Both the calibration and test procedures are identical to those used in unbalanced testing with the exception of the impedance converter added to the signal path and the calibration "Load", "Short" etc placed on one impedance converter port.
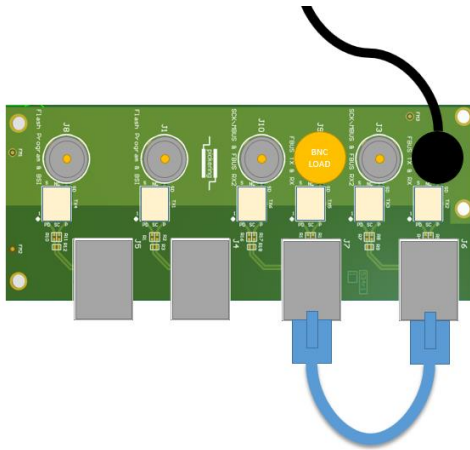
Calibration
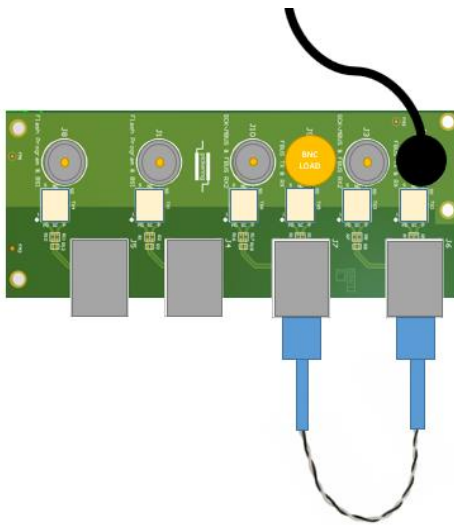
Using the VNA the calibration procedure is as follows:-

1. Attach one end of a BNC test cable to the VNA "R.F. out" (Reflection) port.

2. Attach the other end of the BNC test cable to the impedance converter.

3. Attach one end of the RJ-45 test cables to the impedance converter.

4. Join the remaining ends of the RJ-45 test leads together.

5. Connect a BNC calibration "Load" to the impedance converter.

6. Set the VNA to measure "Reflection" in the format of "SWR".

7. Set the "start" and "stop" frequencies required for testing on the VNA.

8. Set the VNA scale to 1 per division.

9. Access the VNA calibration menu and select "Reflection 1 port", "Load".

10. Remove the "Load" and fit a "Short".

11. From the calibration menu select "Short" – "Short M" – "Done".

12. Remove the "Short" and fit an "Open".

13. From the calibration menu select "Open" – "Open M" – "Done".

14. From the calibration menu select "Done: 1 port".

15. Remove the calibration "Open".

16. Separate the RJ-45 test lead ends are too connected to the DUT during testing.

17. The calibration of the test system has been completed and testing can now begin.

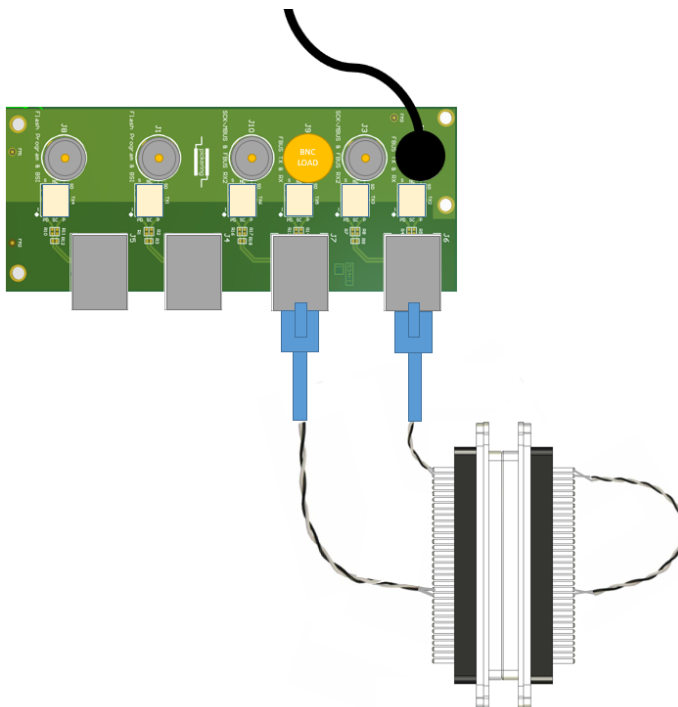*Figure 14a VSWR Calibration Method 1*

Figure 14b VSWR Calibration Method 2
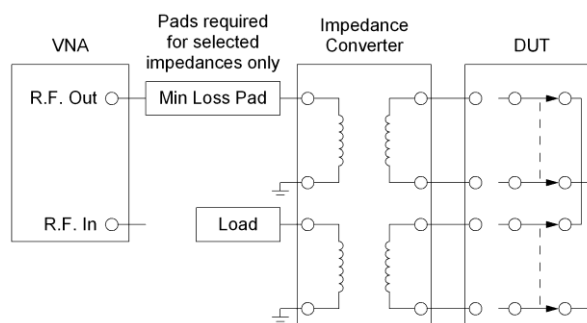

Figure 14c VSWR Calibration Method 3

Testing

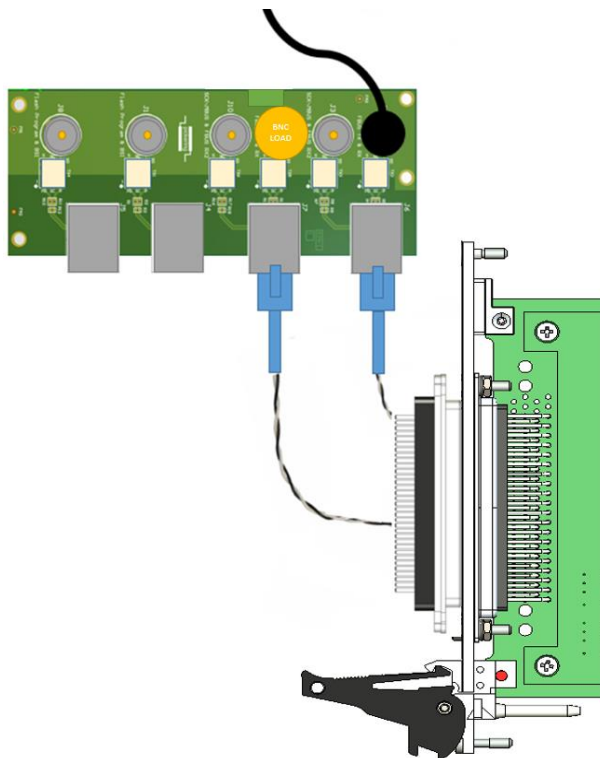The DUT should be connected as illustrated in Diagram 7 and Figure 15.

Using the VNA the testing procedure is as follows:-

1. Connect a "Load" to the impedance converter.

2. Close the required switch path in the DUT.

3. The DUT performance is now indicated by the VNA and should be noted.

4.

Diagram 7 VSWR DUT Connections

Figure 15 VSWR Testing

Return Loss

The calibration and testing routines for balanced return loss are identical to that for balanced VSWR with the only exceptions that the VNA should be set to "Log Mag" instead of "SWR" and 10dB per division.

Isolation

Both the calibration and test procedures are identical to those previously described for balanced insertion loss with the exception of the impedance converter added to the signal path.
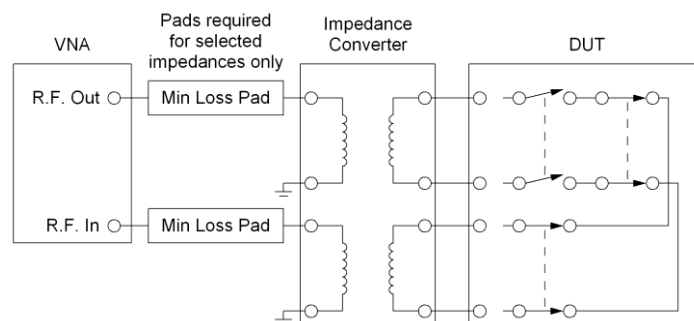
Calibration

The calibration routine for balanced isolation is identical to that for balanced insertion loss with the only exception that the VNA should be set to 10dB per division.
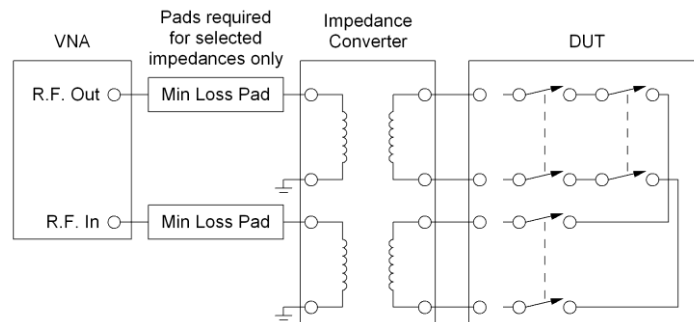
Testing

In common with unbalanced isolation testing there are two methods of performing measurements; these are listed in the following sections.

Diagrams 8a & b and Figure 13 illustrate the two methods for balanced isolation testing. The connection to the DUT and set-up of the VNA is identical to that used for balanced insertion loss testing.

Diagram 8a Isolation DUT Connections Method 1

Diagram 8b Isolation DUT Connections Method 2

Crosstalk

The calibration routine for balanced crosstalk is identical to that for balanced insertion loss.

Calibration

Please refer to the calibration routine for balanced insertion loss but set the VNA to 10dB per division.
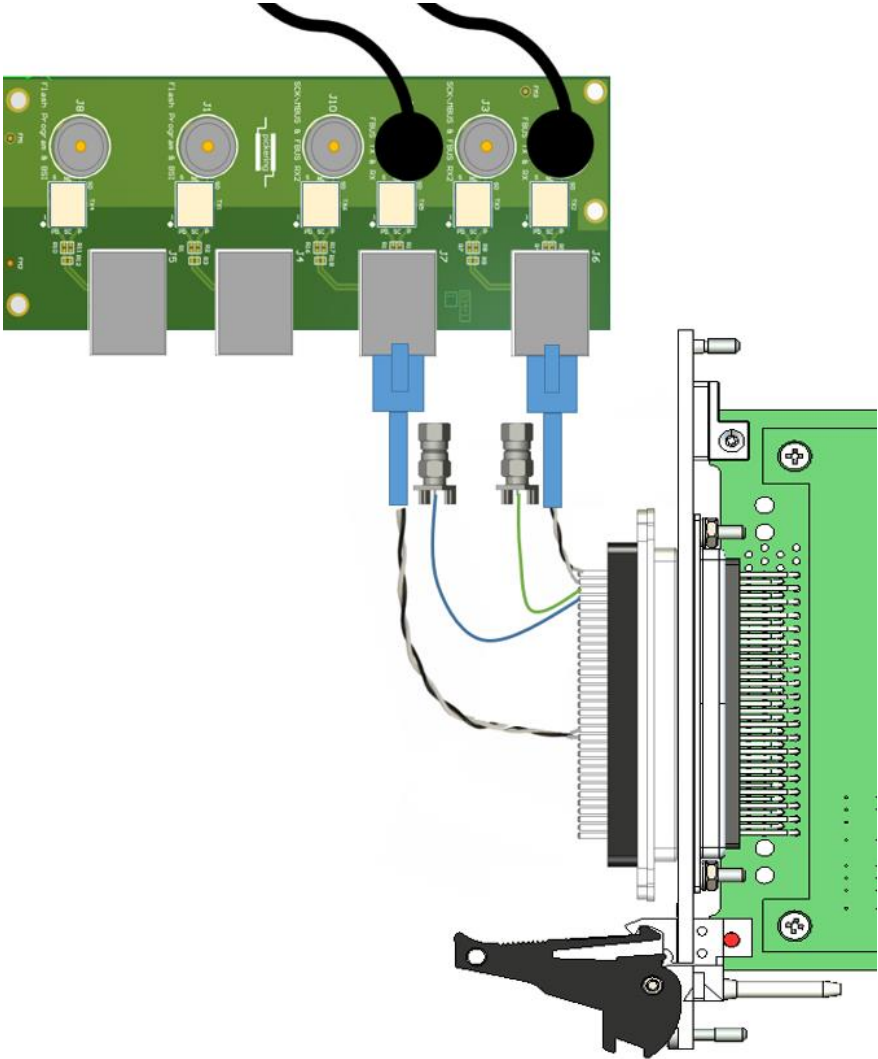
Testing

Diagram 9 and Figure 16 illustrate the method for balanced crosstalk testing. The connection to the DUT and set-up of the VNA is identical to that used for balanced insertion loss testing with the addition of a calibrated "Load".

For balanced crosstalk testing it is necessary to fit a "Load" to the closed switch path of 100Ω - 120Ω depending on the DUT. Unlike the unbalanced system (50Ω / 75Ω "Load" between paths & ground) the balanced system requires a 100Ω - 120Ω "Load" between switch paths i.e. not referenced to ground. Figure 19 shows one SMA 50Ω "Load" connected to each switch path and the ground contact of the two connectors joined together but not to ground. This configuration provides the required 100Ω between paths; it would also be acceptable to connect a single 100Ω "Load" \ resistor across the two paths.

Diagram 9 Crosstalk DUT Connections
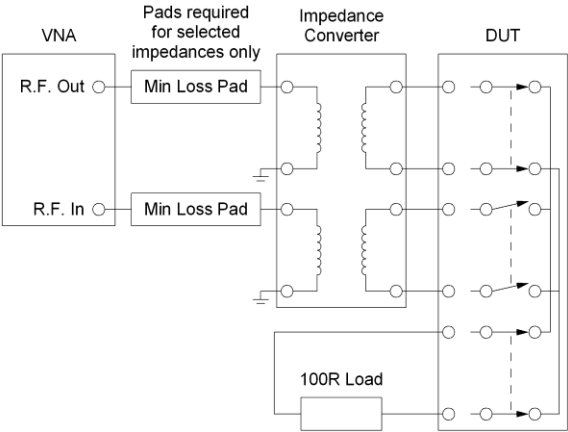
Figure 16 Crosstalk Testing

Notes