# Calibration Fixture Measurements & Associated Data-Based Standards

The FEE Test Fixture (figures 1 and 2) is designed for measurements of the LWA Antenna Front End Electronics (FEE). To allow connection of the unbalanced 50 ohm port of a vector network analyzer (VNA) or spectrum analyzer tracking generator output to the balanced feedpoints of the FEE, the FEE Test Fixture includes a Coupler Printed Circuit Board (PCB) with a 180° hybrid coupler that provides the unbalanced to balanced transformation. Unless the hybrid coupler on the Coupler PCB is de-embedded from the measurements of the FEE, the measurements will include the characteristics of both the hybrid coupler and FEE. This paper describes using Data-Based Standards to perform the de-embedding.

The FEE Test Fixture V1 uses the HX62A hybrid coupler on the Coupler PCB, and the FEE Test Fixture V2 uses the AMT-32+ hybrid coupler on the Coupler PCB. All Calibration Fixtures use the AMT-32+ hybrid coupler. For consistency, it is necessary to use the FEE Test Fixture V2 in all measurements described below.

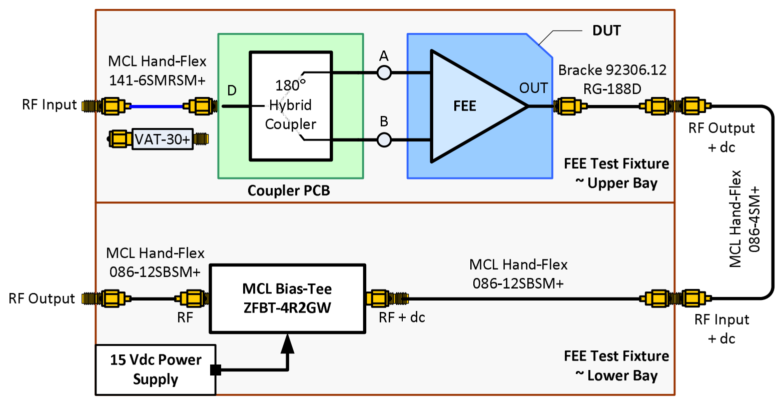


Figure 1 ~ FEE Test Fixture block diagram. The main components are the Coupler PCB and FEE Device Under Test in the Upper Bay, and Bias-Tee and 15 Vdc Power Supply in the Lower Bay. Both bays are aluminum enclosures. An external coaxial jumper cable connects the two bays together. A VNA or spectrum analyzer tracking generator is connected to the RF Input (upper-left) and another VNA port, 50 ohm termination or spectrum analyzer receiver is connected to the RF Output port (lower-left).

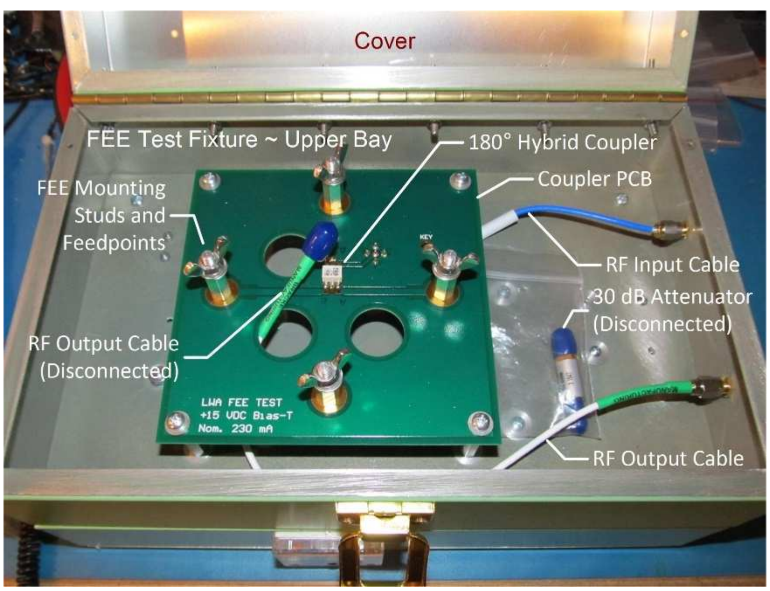


Figure 2.a ~ FEE Test Fixture Upper Bay showing the Coupler PCB and input and output cables. The RF Input cable connects to the difference port of the 180° hybrid coupler. The A and B ports of the hybrid coupler connect to the FEE Mounting Studs, which also serve as Feedpoints. Four studs are seen on the Coupler PCB but only the left and right studs are used during testing. The RF Output cable connects to the FEE output port. The 30 dB attenuator, shown loose in a reclosable bag, is used when measuring the FEE gain with a spectrum analyzer and tracking generator.

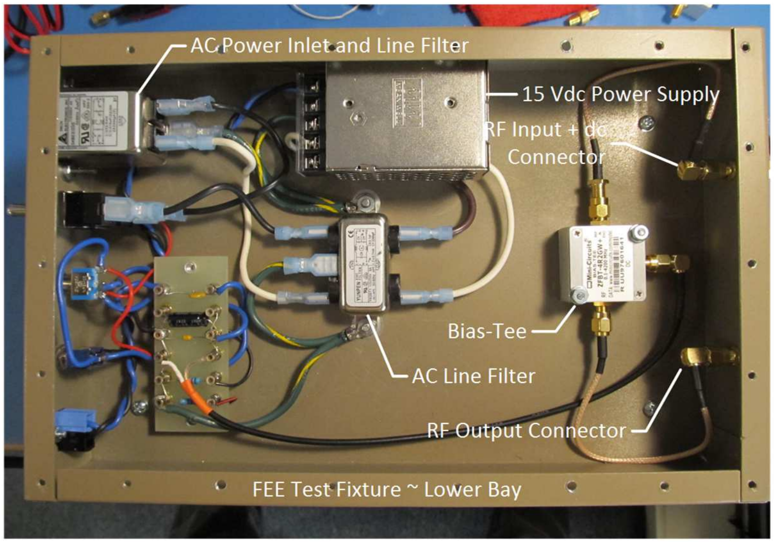


Figure 2.b ~ FEE Test Fixture Lower Bay showing the dc power supply, bias-tee and ac line filter components. Two stages of ac line filtering are used, and the ac power inlet is fused. Other components are current limiting resistors for the power indicating LEDs, and dc filter capacitors. The FEE Test Fixture also has selection switches for the internal or an external power source. Not visible in this image is a dc ammeter for measuring FEE load current.

VNAs are used to measure four S-parameters S11, S21, S12 and S22 but, here, we are concerned only with the S11 reflection coefficient measured at the FEE feedpoints. All VNAs require calibration prior to use. The most common VNA calibration methods involve Open, Short and Load mechanical calibration standards. A set of commercial calibration standards is called a Calibration Kit (commonly called a Cal Kit). The typical Cal Kit consists of precision coaxial devices characterized by a propagation delay term that accounts for the distance of the open or short from the reference plane of their coaxial connectors and a frequency-dependent polynomial expression that accounts for fringe capacitance in the Open and inductance in the Short standards.

The balanced feedpoint structure of the FEE consists of two annular ring pads (figure 3) that preclude connection of coaxial mechanical calibration standards, so a set of custom Open, Short and Load Calibration Fixtures was designed and fabricated (these are the same standards used for calibration in the LWA Antenna measurements). The Calibration Fixtures (figure 4) include the same type of 180° hybrid coupler and layout as the Coupler PCB described above.

The surface mount technology (SMT) resistors used in the Short and Load Calibration Fixtures are located next to the balanced feedpoints but are not connected to them. The feedpoints are transformed to the unbalanced measurement port by the hybrid coupler. The Open Calibration Fixture has no resistors (infinite resistance) but includes the hybrid coupler and empty SMT pads. Because of the hybrid coupler, the Calibration Fixtures are not easily characterized in the same terms as the commercial mechanical calibration standards described above.

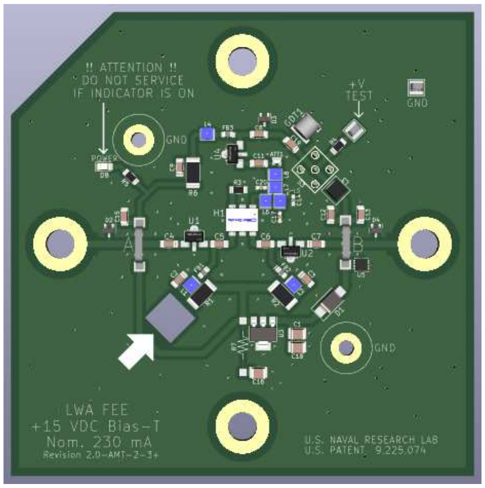


Figure 3 ~ CAD image of the FEE. Dimensions are 4.5 x 4.5 in (114.3 x 114.3 mm). The FEE consists of two identical PCBs except for the direction of the SMA connector (the connector pads are seen near the middle of the upper-right quadrant). The PCBs are sandwiched back-to-back to provide a dual assembly. The left and right annular rings are connected to circuitry facing out of the page and the upper and lower annular rings are connected to the circuitry on the other PCB facing into the page. The ring hole diameters are slightly more than ¼ in (6.35 mm). During normal operation, the FEE is mounted to studs in the LWA Antenna central hub. The corner notch (upper-left) ensures proper alignment in the antenna hub. For test purposes, the FEE is mounted in the FEE Test Fixture, which has an identical stud layout that provides connections to the Coupler PCB.

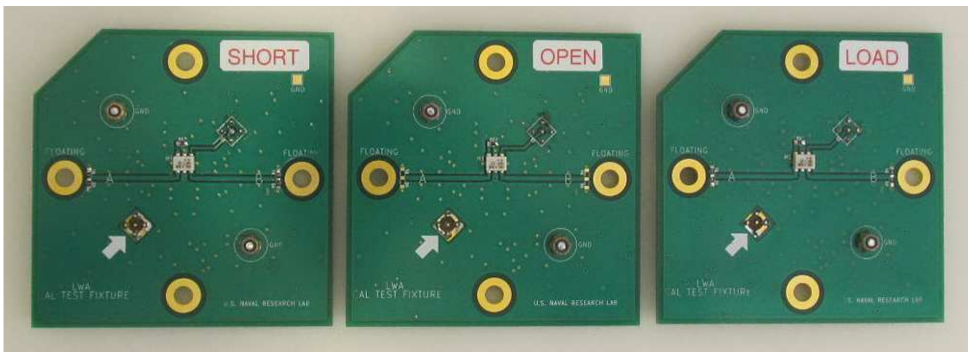


Figure 4 ~ Calibration Fixtures. Each fixture is a dual assembly of two identical PCBs. The SMT pads for the Short and Load resistors are adjacent to the annular rings. The Open Fixture has pads but no resistors. All use the AMT-32+ hybrid coupler.

An alternative characterization method involves carefully measuring the S11 reflection coefficients of the Calibration Fixtures and then using those measurements as Data-Base Standards for VNA calibration. In this method, the VNA is used to measure the reflection coefficient of each Calibration Fixture. Ideally, the data base is created by measurements with a metrology-grade VNA that has been calibrated with primary standards in a controlled environment laboratory. As a practical matter, the measurements can be made with a high-quality VNA after it has been calibrated with an Automatic Calibration Module (ACM) (figure 5).


Figure 5 ~ Copper Mountain Technologies USB-controlled ACM6000T-111 Automatic Calibration Module with two ports and SMA-female connectors shown adjacent to an 8 mm wrench. The ACM allows more precise VNA calibration than a mechanical Cal Kit. The device is controlled through a USB port and provides Short, Open, Load and Thru standards in one small package.

The measurement data includes the embedded hybrid coupler in the Calibration Fixtures, which, by proxy, includes the embedded hybrid coupler on the FEE Test Fixture Coupler PCB. This method assumes that the electrical differences between the hybrid couplers used in the Calibration Fixtures and the hybrid coupler in the Coupler PCB are negligible. The Calibration Fixtures and their associated measurement data are then used to recalibrate the VNA before measuring an FEE, thus moving the measurement reference plane from the VNA port to the balanced feedpoints of the FEE in the FEE Test Fixture.

The ACM includes the Open, Short, Load, and Through standards in one unit and is controlled by the VNA through a USB port. One advantage of an ACM is that it is individually characterized at the factory, including thermal modeling, allowing more precise VNA calibration than normally possible with mechanical calibration standards. Although mechanical standards are precision devices, they normally are not individually characterized or thermally modeled as is the ACM. The same delays and polynomial coefficients apply to thousands of mechanical calibration standards with the same part number, and the uncertainties in these parameters are unavoidably higher than in an ACM.

<u>Calibration Fixture Data Base Measurements</u>

The Copper Mountain Technologies (CMT) M5045 Vector Network Analyzer and CMT ACM6000T-111 Automatic Calibration Module are used to measure the Calibration Fixtures. The same cable arrangement is used during VNA calibration with the ACM and during measurements of the Calibration Fixtures; thus, the cables are *calibrated out*. The VNA is setup with the start and stop frequency, number of measurement points, and IF bandwidth. The ACM is automatically detected when the ACM has been connected to a PC USB port.

The ACM is installed at the end of the VNA *Test Cable Arrangement* on port 1 and a 50 ohm termination is connected to the unused ACM port. A *Full 1-Port* calibration is initiated. The Test Cable Arrangement includes a 1 m long Test Cable from the VNA and a 6 in long Jumper Cable that is the proxy for the internal RF Input Jumper Cable inside the FEE Test Fixture. This establishes the calibration reference plane at the end of the Test Cable Arrangement. When the automatic calibration has finished, the Calibration Fixtures are installed one by one at the end of the Test Cable Arrangement (figure 6). The S11 parameter measurements are saved as S1P Touchstone files, one each for the Side A Open, Short and Load Calibration Fixtures. The measurements are then repeated for the Side B Open, Short and Load Calibration Fixtures. Two sets of Calibration Fixtures have been constructed and marked with a Red or Yellow dot. All measurements are repeated for both sets of Calibration Fixtures.

The Define STD Data and Define STD CLS functions in the VNA software are then used to define a Data-Based Open, Short and Load from the S1P data files obtained above. Four sets of definitions, or Cal Kits, are produced, one each for Side A and Side B of the Red and Yellow Calibration Fixtures. The definitions are saved to the list of calibration kits available in the VNA. Now, when the VNA is calibrated with these Cal Kits, the hybrid coupler and cables are de-embedded and the measurement reference plane is at the balanced feedpoint of the FEE installed in the FEE Test Fixture.

Several sets of measurements were made to 1) check for hand-capacitance effects, 2) determine if the Calibration Fixtures may be placed on the outside of the FEE Test Fixture and 3) determine if the RF Input Jumper Cable in the FEE Test Fixture may be temporarily replaced with a separate but identical Jumper Cable. Placing the Calibration Fixtures outside the FEE Test Fixture and using an external Jumper Cable minimizes the mechanical disassembly and reassembly of the FEE Test Fixture during the several steps of calibration and FEE measurements. The only hand capacitance effects observed were when the exposed pads or component leads on the Calibration Fixtures were physically touched while holding the fixture, which is not done during calibration or measurements. Also, there were no differences observed between setting the Calibration Fixtures in the FEE Test Fixture and setting them on the test bench external to the FEE Test Fixture with the proxy Jumper Cable.

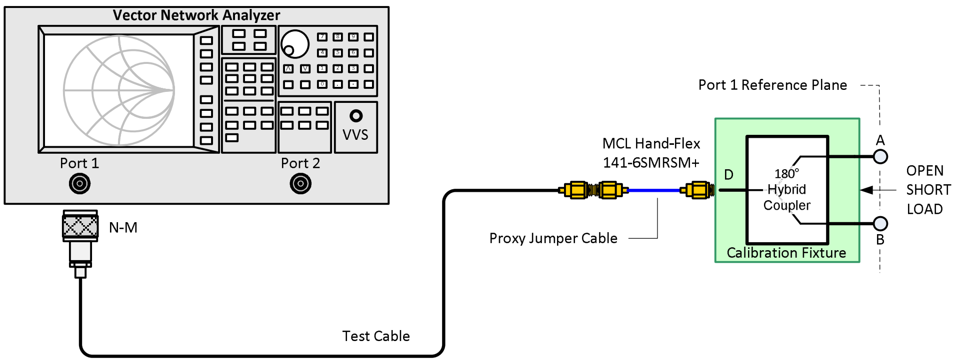


Figure 6 ~ Calibration setup diagram for Calibration Fixture measurements. Measurements have demonstrated that the Calibration Fixtures may be set outside of the FEE Test Fixture during VNA calibration to minimize mechanical disassembly and reassembly of the FEE Test Fixture. The MCL 141-6SMRSM+ Jumper Cable used in calibration is a proxy for an identical cable used in the FEE Test Fixture.

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Procedures:

These procedures produce the data necessary for defining Calibration Fixture Data-Based Standards. These standards apply only to the frequency range 5 to 200 MHz and with an MCL ULC-1M-SMNM+ Test Cable and MCL 141-6SMRSM+ Jumper Cable. Four Cal Kits are produced: Red-A, Red-B, Yellow-A, and Yellow-B:

Step 1 – Initial VNA Calibration:

1. Connect the VNA Port 1 Test Cable to the proxy RF Input Jumper Cable (MCL 141-6SMRSM+)
   Notes:
   a. The proxy cable includes an SMA-female coupler on one end and SMA-male right-angle connector on the other end (same as in the FEE Test Fixture);
   b. The combination of the Test Cable and proxy cable is called *Test Cable Arrangement*
2. Setup the VNA for frequencies, number of measurement points and IF bandwidth
3. Connect the ACM Port A to the Test Cable Arrangement and Port B to a 50 ohm termination
4. Select AutoCal → 1-Port AutoCal (AutoCal is initiated)
5. After calibration has finished, the calibration is applied automatically

Step 2 – Measure S11 reflection coefficient of the Calibration Fixtures. This step is required for each of the three Calibration Fixtures:

1. Connect Side A of the Yellow Dot Open Calibration Fixture to the Test Cable Arrangement
2. Terminate Side B of the Yellow Dot Open Calibration Fixture with a 50 ohm termination
3. Measure 1-Port S11 reflection coefficient on VNA Port 1
4. Save measurements as S1P and PNG files
5. Repeat steps 1 through 4 for Side B of the Yellow Dot Open Calibration Fixture
6. Repeat steps 1 through 5 for Side A and B of the Yellow Dot Short Calibration Fixture

7. Repeat steps 1 through 5 for Side A and B of the Yellow Dot Load Calibration Fixture
8. Repeat steps 1 through 7 for the Red Dot Open, Short and Load Calibration Fixtures

Step 3 – Prepare Data-Based Standards for the Calibration Fixtures:

1. Using the S11 measurements of the Open, Short and Load for each set, prepare four Data-Based Standards Cal Kits
2. Define STDs Open, Short and Load, one set of each for Side A and Side B of the Red Dot Calibration Fixtures and one set of each for Side A and Side B of the Yellow Dot Calibration Fixtures
3. Define CLSs, Open -F-, Short -F- and Load -F-

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**Document Information**

Author: Whitham D. Reeve

Revisions: 0.0 (Original draft started, 07 Jan 2023)
0.1 (Major edits, 08 Jan 2023)
0.2 (Updates per tests, 18 Jan 2023)
0.3 (Edited procedures, 19 Jan 2023)
0.4 (Replaced ACM image, 20 Jan 2023)
0.5 (Record, 21 Jan 2023)

Word count: 2892

File size (bytes): 1927712