

3:1 Bandwidth Dual-Polarized Compact Range Feeds for RCS Measurements

Jeffrey Fordham, Jacob Kunz, Edwin Barry

NSI-MI Technologies

Suwanee, GA 30024, USA

Jeff.Fordham@Ametek.com, Jacob.Kunz@Ametek.com, Edwin.Barry@Ametek.com

Abstract— A set of Dual-Polarized Antennas with a 3:1 operating bandwidth has been developed for use in near-field ranges as the probe or range antenna and for use as a Compact Antenna Test Range (CATR) feed [1]. Key development parameters of the antenna are: a wideband impedance match to the coaxial feed line, E and H-plane 1 dB beam widths in excess of 30 degrees, -30 dB on axis cross-polarization, minimum polarization tilt and a phase center that varies over a small region near the aperture. To accomplish these design parameters, a family of range antennas has been developed and previously introduced. Two versions of the antenna have been manufactured and tested for performance. A 2-6 GHz version has been developed using traditional machining techniques and a 6-18 GHz version has been produced using additive manufacturing (3D printing) techniques [4].

These antennas provide proper illumination of the quiet zone for compact ranges used for antenna measurements as well as radar cross section (RCS) measurements. For RCS measurements, an additional requirement for time-based energy storage performance is considered. Energy storage in the feed can result in a pulse spreading or additional copies of the pulse in time, resulting in poor performances of the target characterization. This effect is called ‘ringdown’.

In this paper, we focus on the RCS ringdown performance of the 6-18 GHz antenna produced using additive manufacturing. The measured performance of the antenna will be presented and discussed. Finally, the applicability of the antenna as a CATR feed for RCS measurements will be discussed.

Keywords— CATR, Compact Range, Dual-Polarized Feed

I. INTRODUCTION

Requirements for broadband antenna and radar cross-section (RCS) testing exist which necessitate an antenna with a wide frequency band of operation suitable for use as a compact antenna test range (CATR) feed. In a single reflector CATR, a low gain antenna is located at the focal point of a parabolic reflector to create a plane wave over a defined test region [2]. The performance of the plane wave created by a CATR is defined by its amplitude taper and phase taper across the test region or quiet zone. Typically, there are requirements for less than 1 dB of amplitude taper and a phase taper of less than 22.5 degrees in the quiet zone. To accomplish such performance while considering other design parameters of a CATR, requirements are placed upon the feed antenna’s radiation pattern. To meet the amplitude specification, a derived pattern

requirement is a 1 dB beamwidth of +/- 15 degrees in both the E-plane and H-plane. The quiet zone illumination phase taper requirement and wideband frequency of operation combined with a fixed focal point of the reflector, leads to a derived requirement for minimal movement of the location of the apparent phase center of the antenna across the 1 dB beamwidth as frequency changes [3].

An additional requirement to minimize energy storage in the radar and feed, also exists. In an RCS measurement system, energy storage in the radar components, RF cabling and the feed that persist into the measurement time window is misinterpreted as energy returned from the target resulting in reduced dynamic range and measurement uncertainty. Based upon a desire for an unambiguous return from the target, the feed needs to have radiated all energy prior to the desired target return.

CATR’s for RCS measurements need wide instantaneous bandwidths for proper imaging of test objects. Previously, feeds such as dual-ridged and quad-ridged horns have been used in applications where the need for wideband operation was greater than the need to maintain an optimal plane wave in the quiet zone [3].

A family of four dual-polarized antennas, each capable of meeting the quiet zone illumination requirements, covering a total frequency bandwidth from 0.5 to 18 GHz have been previously introduced by Cortes-Medellin [1]. Each of the reported feed antennas covers a 3:1 bandwidth within the overall bandwidth of operation. The requirements for proper illumination of a CATR over a 3:1 bandwidth leads to a small aperture (~ 2 wavelength) at the highest frequency, and by extension, an electrically small aperture (< 1 wavelength) at the lowest frequency of operation. This paper describes and reports on the ringdown performance of the 6-18 GHz antenna.

The antenna described in this technical note is designed to operate over a 6 – 18 GHz frequency range and has an aperture measuring 33 mm in diameter. The design of the critical RF input area of the antenna is complicated by the dual-polarized requirement. The small RF coaxial transition points creates challenging tolerances and makes for difficult manufacturing and assembly. To meet the challenges of creating such a small, wideband antenna, additive manufacturing techniques were chosen as the best means to create the antenna structure. The antenna consists of a quad-ridge structure with a conical section fed by two 2.92 mm connectors. The design and details of the manufacturing of this feed have been previously reported [4].

The following sections describe the design and simulation process, the manufacturing process and material used to build the antenna. Measured test data is presented in Section IV.

II. DESIGN

The antennas were designed and developed to meet the requirements which included a low VSWR of less than 2:1 (return loss of 9.54 dB). A good input match is necessary across a wide bandwidth to minimize standing waves in the RF cables connected between the radar and the feed. These standing waves are radiated over time and appear as copies of the desired signal in the radar return. Additional requirements include a 1 dB amplitude pattern greater than 30 degrees and low cross-polarization. Design requirements for the antenna are shown in Table I.

TABLE I. SUMMARY OF DESIGN REQUIREMENTS

Parameter	Requirement
Frequency Range	6-18 GHz
VSWR	2:1 (9.54 dB Return Loss)
E-Plane 1 dB Minimum Beamwidth	> +/- 15 degrees
H-Plane 1 dB Minimum Beamwidth	> +/- 15 degrees
Cross Polarization Isolation within 1 dB Beamwidth	< -25 dB
Polarization	Dual Linear

During design, it was noted a tendency for the beam pointing direction to tilt at some frequencies. Higher order mode suppression techniques were incorporated in the ridges of the antenna to minimize the beam tilting.

III. MANUFACTURING:

The antenna feed was produced in aluminum using a powder bed fusion metal additive manufacturing process i.e., a 3D printer. Additive manufacturing works by successively building a structure one layer at a time, where each layer is on the order of 10 – 60 μm . A fine layer of metal powder is evenly distributed on a build tray while a high power laser welds the powder into the specific geometry for that layer. After printing, the antenna feed proceeds through a number of post-processing steps that remove support structure and provide mechanical interface for connectors and mounting locations.

Figure 1. shows the printed antenna feed after the post-process CNC machining steps necessary to add the 2.92 mm coaxial connectors on the side. Post-process CNC machining on coaxial interfaces is critical to maintain flatness on the mating surface of the coaxial connector, allowing for the proper ground at this critical feed point. The integrated nature of the antenna feed significantly reduces the total part count and assembly process of the antenna, which was critical for ensuring tight tolerance control between the fins of the feed.

Figure 2. shows the fully assembled antenna feed after Alodine surface treatment and with 2.92 mm coaxial connectors

installed. Figure 3. shows the antenna being tested in the radar ringdown enclosure.



Figure 1. Photo showing antenna post machining



Figure 2. Photo showing completed antenna

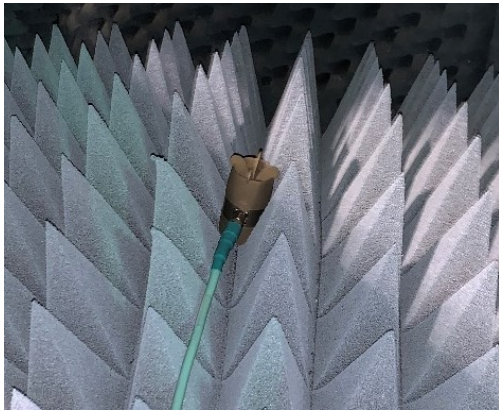


Figure 3. Photo of the antenna during testing in ringdown enclosure

IV. MEASURED DATA

The constructed antenna was tested first for return loss. Figure 11. shows the measured return loss. The performance of this feed exceeded its design requirement and provides some performance margin in frequency above and below the desired frequency band. This additional margin helps to maintain pulse quality during operation.

The antenna was tested in a SNF range at NSI-MI's facility in Atlanta, GA. This system is configured with a roll over azimuth positioning system and uses open-ended rectangular waveguide probes for the measurement.

Figure 4. plots the directivity of the two ports of the antenna vs. frequency. Note that is a slight reduction in the directivity curve near 9.5 GHz. This reduction in directivity correlates to a broadening of the beamwidth over a narrow region of frequencies.

Figure 5. shows the measured cross-polarization for the two ports. Expected sources of the cross-polarization are scattering from the absorber surrounding the feed and support structure during testing, finite tolerances in manufacturing and cross-polarization contributions from the range antennas used to measure the antenna.

Figure 12. shows measured E-plane and H-plane patterns of the 6-18 GHz feed at selected frequencies. The patterns shown are over the typical included angle of a CATR to show the antenna is expected to meet the CATR illumination requirements. There is some noted ripple in the patterns at some frequencies as well as some residual beam tilt in the patterns. During simulations, the antenna did not have mounting structures, cables or absorber in the vicinity of the aperture that are necessary during testing. Multiple measurements in different configuration show the feed is sensitive to absorber near the aperture and reflections from the cables feeding the two ports.

Figure 5. shows the measured cross-polarization of the two ports of the 6-18 GHz antenna. Due to the symmetric feed design, the cross-polar component of the measured radiation pattern is small within the 1 dB beamwidth and meets the requirements for supporting the desired RCS measurements.

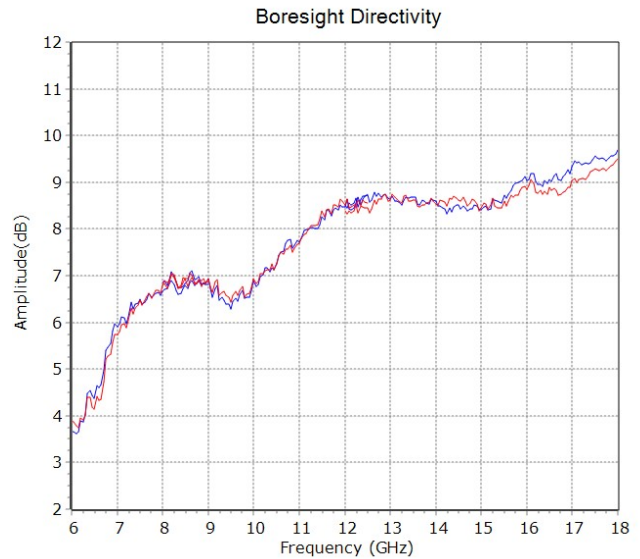


Figure 4. Measured directivity vs. frequency

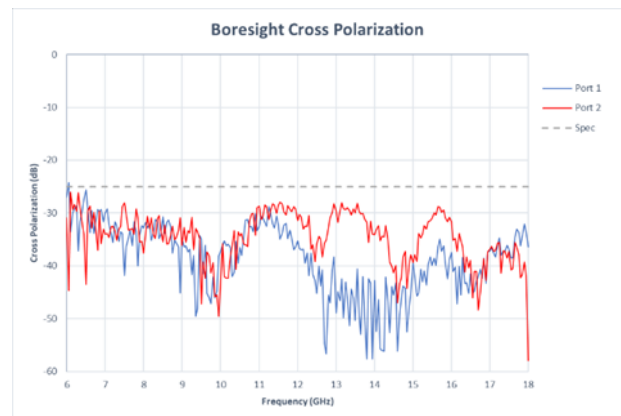


Figure 5. Measured on-axis cross polarization vs. frequency of ports 1 and 2

V. ANTENNA RINGDOWN PERFORMANCE

Use of compact ranges for performing RCS measurements has many advantages over outdoor ranges related to security, RFI, clutter, and weather among others. compact range feeds used for RCS testing have a time-based performance requirement related to the use of pulsed transmit waveforms which does not exist for compact ranges used for CW measurements. After the transmit pulse has radiated from the transmit feed, there can still exist residual energy in the transmit feed, radar electronics front end, or coupled energy from the transmit feed to the receive feed as shown in Figure 6. In the case of monostatic feed configurations where the transmit and receive ports of the radar are connected to the same port of the feed antenna, the coupling does not exist but resonant ringing in the feed can still be a problem. For high quality RCS measurements, all these forms of residual energy remaining from the transmit pulse must dissipate before reflected energy from the DUT being measured arrives at the focal point for collection. The selection and design of feeds to be used for monostatic RCS measurement in a compact range, the resonant ringing of energy in the feed

structure itself is of the greatest concern as it can last long enough to remain when the DUT signal of interest arrives. Measurement of how long it takes for the residual energy in the feed to dissipate below the noise level is referred to a ringdown test.

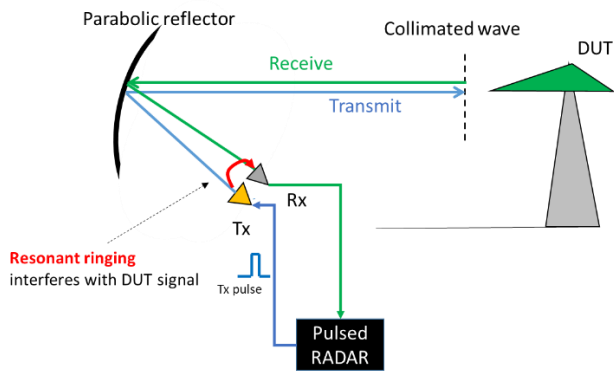


Figure 6. RCS measurements in a compact range requires resonant ringing in feeds to dissipate before the received target return arrives back at the focal point

Design and testing of new feeds for RCS testing in compact ranges requires laboratory testing of the feeds for ringdown to prove performance before installation into the compact range. This is accomplished with a high-quality test radar in the lab. The test radar must have a similar if not identical architecture to the final radar to be used in the compact range so that any interactive affects between the front-end radar electronics and the feed can be observed and quantified. Ideally, the exact radar and feed cables that are to be used in the compact range should be used for laboratory ringdown testing.

Ringdown testing of the wideband RCS feeds developed by NSI-MI was conducted using the radar depicted in the block diagram in Figure 10. This laboratory test radar incorporates many features and components similar to radars utilized in the latest generation of RCS measurement systems. These features, shown in the block diagram, include refined secondary transmit pulse bracketing with transient filters, built in diagnostic loops both before and after the high power transmit amplifiers, amplifier harmonic rejection filters, low-loss electromechanical feed selection switches, and high fidelity receive signal LNAs.

Testing feeds for ringdown in the laboratory requires an environment that allows the feed to radiate with full test power but will also dissipate all the radiated energy such that only the resonant energy in the feed itself if measured. This is accomplished at NSI-MI utilizing a metal enclosure lined with absorber into which the feed radiates as shown in Figure 7. The absorber helps dissipate the energy while the symmetrical design of the box allows precise prediction of reflections within the box which can be used to scrutinize the data for resonance within the box itself. Various platforms with special absorber arrangements can be placed in the bottom of the box opposite of the feed to optimize the dissipation of the radiated energy. The dimensions of the cubic box are kept small at 1.2 meters so that the radiated energy makes many reflections within the box, each reflection being attenuated by the absorber, in a small amount of time. Because compact ranges are much larger than the enclosure, the

time-period of interest to examine resonant energy in the feed is after the box has effectively attenuated the radiated energy.

Mono-Static Feed Ringdown Test Configuration

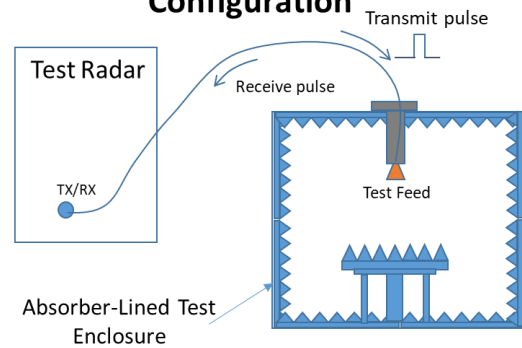


Figure 7. Ringdown test setup using test radar and absorber enclosure

A ringdown measurement campaign for evaluating a feed for use in an RCS compact range begins with setup and calibration of the test radar. The diagnostic loops in the test radar allow a preview of the pulse waveform and behavior of the transmit electronics before the feed is added to the setup. Figure 8. shows a range walk utilizing the test radar high-power loop where the narrow receive bracket has its time delay progressively increased allowing a capture of the receive power over time. The figure shows the range walk conducted at 6, 12, and 18 GHz. The relative output power of the electronics across the frequencies is observed at the peaks of the transmit pulse which is configured to be 10ns wide. The test radar provides a pulse with a fast rise-time, minimal overshoot, and flat top which all mimic the behavior of compact range radars to capture feed behavior. The test radar is seen to have some internal residual energy after the actual transmit pulse has passed but the time period until all internal energy dissipates is very quick compared to the time period of interest.

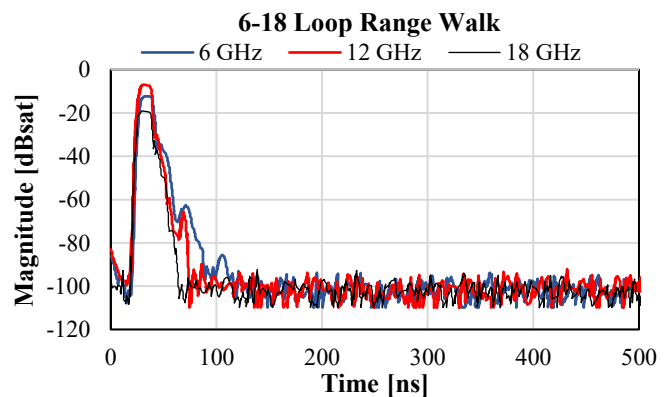


Figure 8. Test radar high-power diagnostic loop range walk

Connecting the test radar to the feed in the test enclosure occurs after the diagnostic loops have been determined to be acceptable. Figure 9. shows the range walk for the broadband 6-

18 GHz feed. The transmit pulse is still seen beginning at 27ns but it is significantly attenuated. During the transmit period, the feed is connected to the amplifier via the T/R switch while the receive path is on the unconnected port of the T/R switch. Therefore, the observation of the actual transmit pulse is due to the isolation of the T/R switch. After the T/R switch connects the receive path to the feed, the signal is much higher. Resonance is seen in the received signal from 65ns to 215ns. During this period, the radiating energy is being attenuated in the enclosure while the reflected energy in the feed cabling attenuates. It is seen that there are some periodic reflections observed which have an observed period of 40ns. This can be explained by the combined reflection path from the radar electronics through 4.7m of feed cabling, 1.4m across the enclosure, and back.

The key takeaway from the ringdown test in Figure 9. is how long it takes for all the energy to dissipate to the level of noise which is 150ns after the Tx pulse is first observed. If this exact feed and radar was utilized in a compact range with a focal length larger than about 5.5m, then it is certain that the resonant energy would fully dissipate before the DUT signal of interest would arrive at the feed. Evaluation of the data shows that the feed itself does not exhibit known internal resonance phenomenon whereby significantly higher levels of energy resonate within the feed structure for periods on the order of milliseconds due to the inability of the feed to dissipate the energy internally. Refinement of the ringdown period up to the initial 150ns could be accomplished with further testing utilizing various feed cable lengths and by moving the feed to anechoic chambers of various sizes to help discern the major contributors to the initial ringdown.

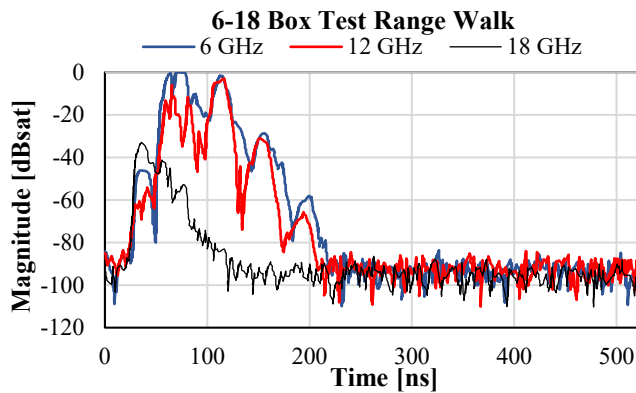


Figure 9. Test radar radiating range walk in test enclosure

VI. CONCLUSION

The design and measured data show the described antenna to have a good input impedance match to the planned RF source, low cross-polarization and a wide frequency bandwidth of operation; making it well suited to be used as a dual-polarized compact range feed operating over a 3:1 bandwidth.

Investigation of the patterns further indicate the feed does not have nulls in the forward hemisphere and is potentially suitable for use as a PNF probe. The broad nature of the antenna patterns is stable over frequency and, with pattern characterization, the antennas are capable of being used for probe pattern correction. Pattern measurements were obtained using a SNF system.

Ringdown performance measurements in the test enclosure show the feed does not store energy for any appreciable time after excited by a pulse from the radar system. Further testing is planning once the full compact range is built and assembled.

REFERENCES

- [1] G. Cortes-Medellin and B. T. Walkenhorst, "3:1 Bandwidth Dual Polarized Feeds for Compact Range and Near-Field Probes," *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, Atlanta, GA, USA, 2019, pp. 969-970, doi: 10.1109/APUSNCURSINRSM.2019.8888785.
- [2] R. Johnson, H. Ecker and R. Moore, "Compact range techniques and measurements," in *IEEE Transactions on Antennas and Propagation*, vol. 17, no. 5, pp. 568-576, September 1969, doi: 10.1109/TAP.1969.1139517.
- [3] Fordham, J., A., Park, T., "Compact Range Phase Taper Effects Due to Phase Center Shift in Wideband Quad-ridge Feeds", *AMTA Symposium 2002*.
- [4] Fordham J., Barry E., Burge R., Hollenbeck M., and Smith R., "Additive Manufactured 3:1 Bandwidth Dual-Polarized Range Antenna," *2020 Antenna Measurement Techniques Association Symposium (AMTA)*, 2020, pp. 163-168.

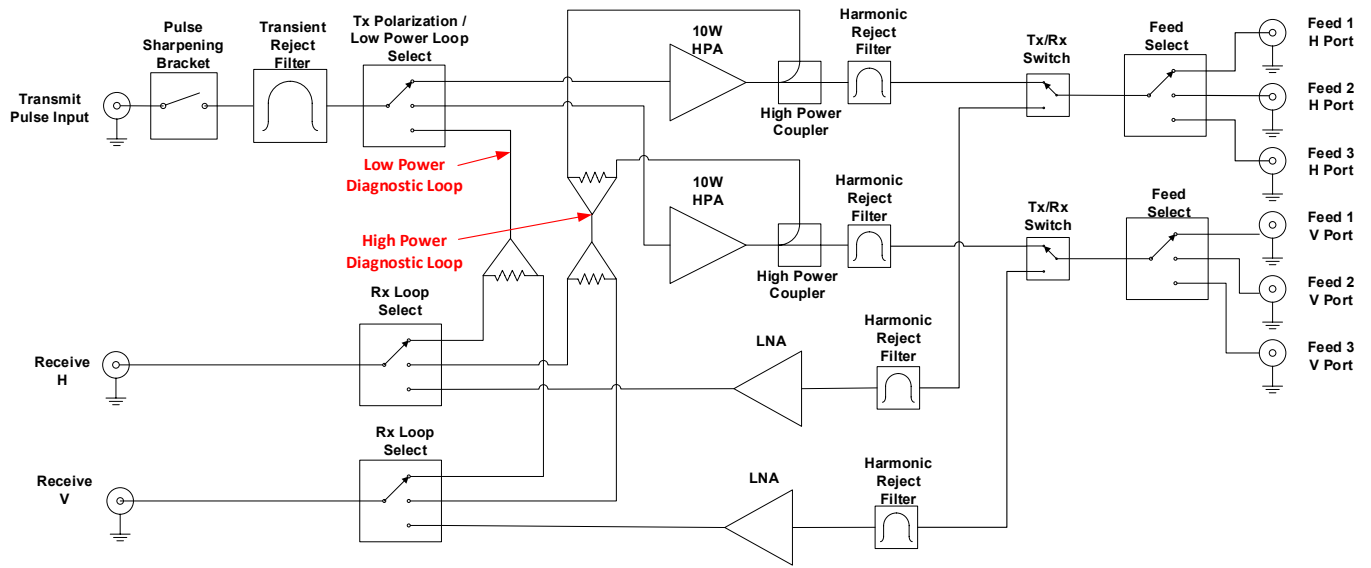


Figure 10. Block diagram of radar electronics used for ringdown testing

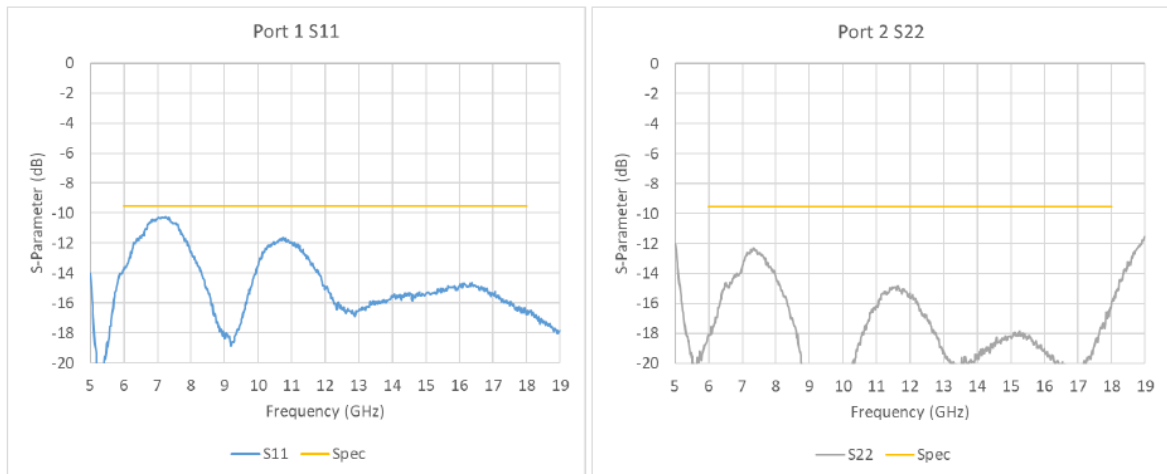


Figure 11. Measured return loss

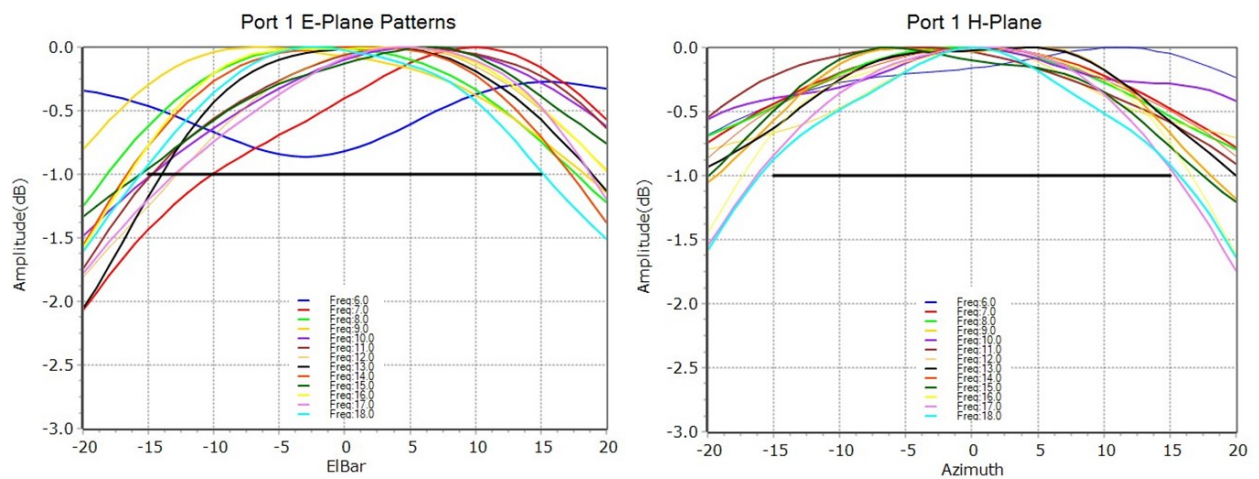


Figure 12. E-Plane and H-Plane patterns of Port 1