# Chapter 7 - Experimental Verification

## 7.1 Introduction

This chapter details the results of measurements from several experimental prototypes of Stub Loaded Helix antennas that were built and tested. Due to the complex nature of the SLH structure, as much engineering effort was put into the mechanical design of the prototypes as their electrical design. All of the examples presented are designed for operation at approximately 2.4 GHz, the ISM/WLAN frequency band. Table 7.1 lists the prototype identification numbers used in this chapter along with a short description. The identification consists of a the letter 'P', for prototype, followed by the number of turns of the prototype helix and a sequence number .

Radiation patterns and gain measurements presented here were measured at an indoor far-field antenna range facility of Sandia National Laboratories, Albuquerque, NM, and at the near-field indoor range at Virginia Tech.

**Table 7.1 Prototype Descriptions**

| Prototype ID | Description |
|---|---|
| P15-1 | 15-turn SLH (VT) |
| P10-1 | 10-turn SLH (3Di) |
| P30-1 | 30-turn SLH (VT) |
| P15-2 | 15-turn conventional helix (VT) |
| P15-3 | 15-turn SLH (VT) |

## 7.2 Measurement Methodology

A few words about the measurement methodology are in order. Measurements made at Sandia Labs were made in an indoor far-field range. The antenna-under-test (AUT) served as the source and a dual polarization ridged waveguide horn was used for receiving both vertical and horizontal amplitude and phase simultaneously. Gain and patterns were calculated based on the sum of both vertical and horizontal channels to produce true circularly polarized gain and pattern.

For some of the antennas tested at Sandia, the axial ratio was measured by fixing the AUT at boresight and rolling it 360° while measuring the vertical and horizontal channels, simulating a spinning linear measurement. In this case, the axial ratio was calculated as the difference between the maximum and minimum amplitudes of each channel. The average of the axial ratios calculated for the horizontal and vertical channels individually was used. As a side note, the differences in the axial ratio measured between the two channels using the spinning linear technique was at most a few tenths of a dB, indicating good matching of the gain between the channels. In cases where the spinning linear measurement was not made, the axial ratio was calculated from the pattern measurements using the amplitude and phase of the vertical and horizontal channels jointly [IEEE, 1979].

The Virginia Tech indoor antenna range consists of an 11' by 11' by 11' box attached to a 19' long taper for use with far-field measurements. The entire room is lined in copper/aluminum sheet with anechoic absorber on top. The majority of the absorber is 12", with 18" absorber on the back wall, but smaller absorber is used in strategic locations where possible. The heart of the Virginia Tech indoor antenna range is a near-field scanner and measurement system manufactured by Antcom. The Antcom system uses an HP/Aglilent 8510/8530 vector network analyzer for data collection. The system is capable of near-field scanning in spherical, cylindrical, and planar modes as well as operation in a far-field mode upon reconfiguration of the chamber. The Virginia Tech measurements presented here were all made using the Antcom system in the spherical near-field mode. Gain measurements were made using a Seavey SGA-20 standard gain horn as a gain reference.

All of the prototypes presented included an impedance matching section to provide a reasonable impedance match, i.e. VSWR less than 2:1, to a 50 Ω system over the frequency range of operation. Thus the gain results that are presented include the effects of mismatch loss, although they are typically very small. The gain results should be called realized gain to completely correct. However, because the impedance mismatch loss is so small over the operating range, there is only a slight variation from actual gain. The pattern and axial ratio results are unaffected by the mismatch losses. The gain and axial ratio values reported are for boresight of the antenna pattern.

## 7.3 15-turn VT SLH (P15-1)

A 15-turn SLH antenna, designated as prototype P15-1, designed for 2.4 GHz and constructed at Virginia Tech is shown in Figure 7.1. The mechanical design values for the prototype are given in Table 7.2. The helix structure was built around a 1” diameter polyethylene tube with a 0.060” wall thickness. Polyethylene typically has a dielectric constant on the order to 2.2-2.4, and is not considered a lossy material at RF frequencies. Given the relatively low dielectric constant of polyethylene and thin wall thickness of the support tube, it was assumed that there would be minimal dielectric loading of the helix due to the support tube. Subsequent empirical evidence proves this to be valid.

The helix was constructed using enamel coated 22-ga magnet wire. The helix winding with stubs was formed from a continuous piece of wire. Holes were drilled into the helix support tube at the location of each stub and the stubs were inserted through the holes to protrude toward the center axis of the helix. Figure 7.2 shows a close-up of the details of the stubs and their installation in the prototype. The stubs are twisted in order to provide additional mechanical stability and rigidity to the structure. The stubs do not short out because the magnet wire is covered with a layer of enamel insulation. The twisting of the stub wires might introduce a small amount of additional capacitance and inductance to the stub, but this should be insignificant in regards to the electrical performance of the stubs. Both twisted and untwisted stubs have been tested and the results are indistinguishable. For the handmade prototypes we have constructed, twisting the stubs provided for additional mechanical stability that was desirable.

The completed helix is wrapped with a single layer of black electrical tape with a thickness of approximately 15 mils. This outer layer of tape is used to insure that the helix wire lays tightly to the support tube to reduce the tendency for the helix winding to spring back from the tube due to the natural spring tension in the wire. This layer of tape is thin enough that dielectric loading is not a significant issue. Earlier experiments using polyvinyl chloride (PVC) heat shrink tubing for the outer layer did demonstrate significant dielectric loading and losses and was thus deemed unacceptable. PVC heat shrink tubing tends to be rather thick, on the order to 75-100 mils, and there may be additional losses due to carbon in the PVC added for color purposes.

The helix prototype is attached to a square stainless steel groundplane with a side dimension of 3.75”. This was supplied to us by the company 3Di, who constructed another of the prototypes. Visible in Figure 7.1 is the tapered matching section of the feedpoint. This tapered transmission line section functions as an impedance transformer from the high impedance of the helix to a 50Ω system impedance. Small adjustments to the impedance match may be made by varying the height of the matching section above the groundplane. Using this technique, a VSWR of less than 2:1 can be obtained across a wide bandwidth. Details of the matching section are discussed in Section 7.7.

Figure 7.3 shows the gain and axial ratio of the 15-turn VT SLH prototype P15-1 measured from 2.0-2.8 GHz on the Virginia Tech indoor antenna range. Measurements were made in 100 MHz increments across this bandwidth. The gain peaks at 2.5 GHz with a value of 10.05 dBic. The axial ratio is less than 3 dB from 2.35 to above 2.6 GHz. The gain rolloff across this bandwidth is less than 2 dB, with the gain being approximately 8.6 dBic at 2.35 GHz and 9.6 dBic at 2.6 GHz. Although designed for a nominal center frequency of 2.4 GHz, the gain and axial ratio performance appear to be centered around 2.5 GHz. Using the 3 dB axial ratio bandwidth and 2.5 GHz as the center frequency, this antenna exhibits a performance bandwidth of approximately 10%.

Figure 7.4 shows the measured radiation patterns of this antenna from 2.0-2.8 GHz. Concentrating on the 2.4-2.6 GHz patterns where the prototype exhibited good gain and axial ratio performance, the patterns exhibit good performance expected of a typical helix antenna. There is a well defined main lobe, all sidelobes are greater than 10 dB below the main lobe peak, and the front-to-back is approximately 15 dB or greater. At frequencies above 2.6 GHz, the pattern begins to lose a smooth shape structure, as might be expected by the dramatic drop in gain and axial ratio performance. Below 2.3 GHz, the patterns demonstrate the basic shape expected from an endfire helix, but the gain and axial ratio performance is degraded.

**Table 7.2 Design values of 15-turn VT SLH for 2.4 GHz (P15-1)**

| | |
|---|---|
| C, circumference | 3.141" |
| D - diameter | 1" |
| $\alpha$ - pitch angle | 8° |
| S - turn-turn spacing | 0.44" |
| $N_s$ - # stubs/turn | 4 |
| $l_s$ - stub depth | 0.33" |
| N - # of turns | 15 |

**Figure 7.1.** 15-turn VT SLH prototype on a 3.75” square groundplane with matching section (P15-1)

**Figure 7.2.** Detail of stub construction of 15-turn VT SLH (P15-1)

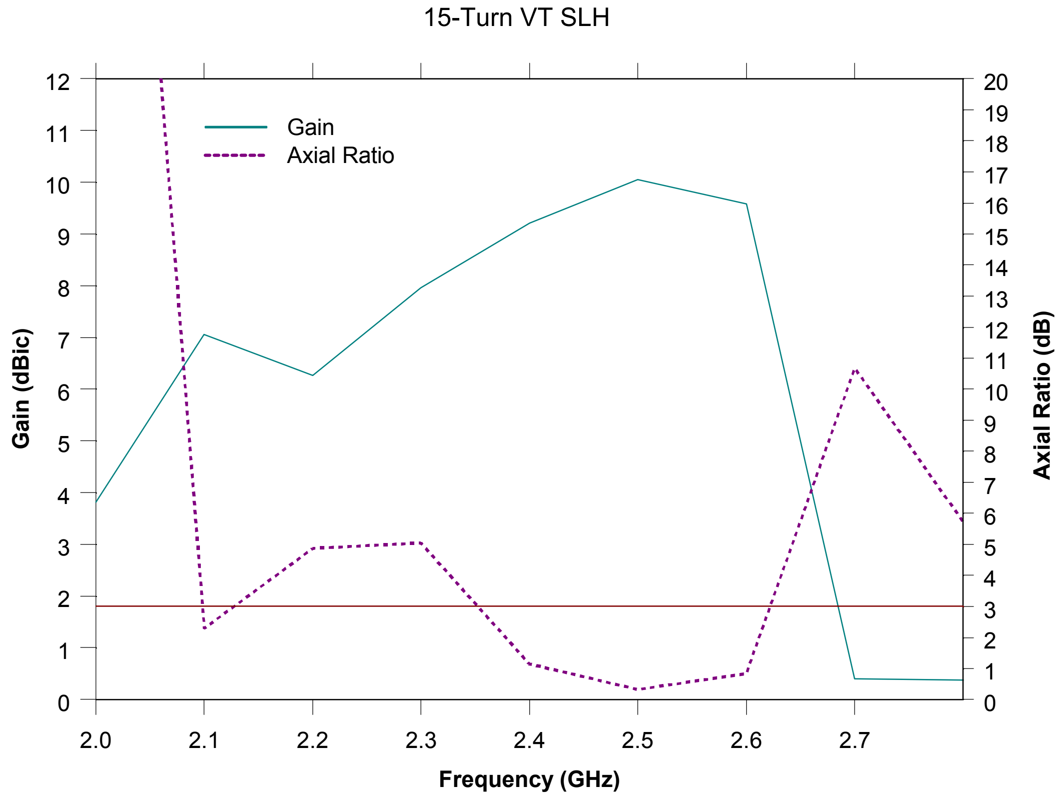



**Figure 7.3.** Boresight gain and axial ratio measured at VT for the 15-turn VT SLH of Table 7.2 (P15-1)

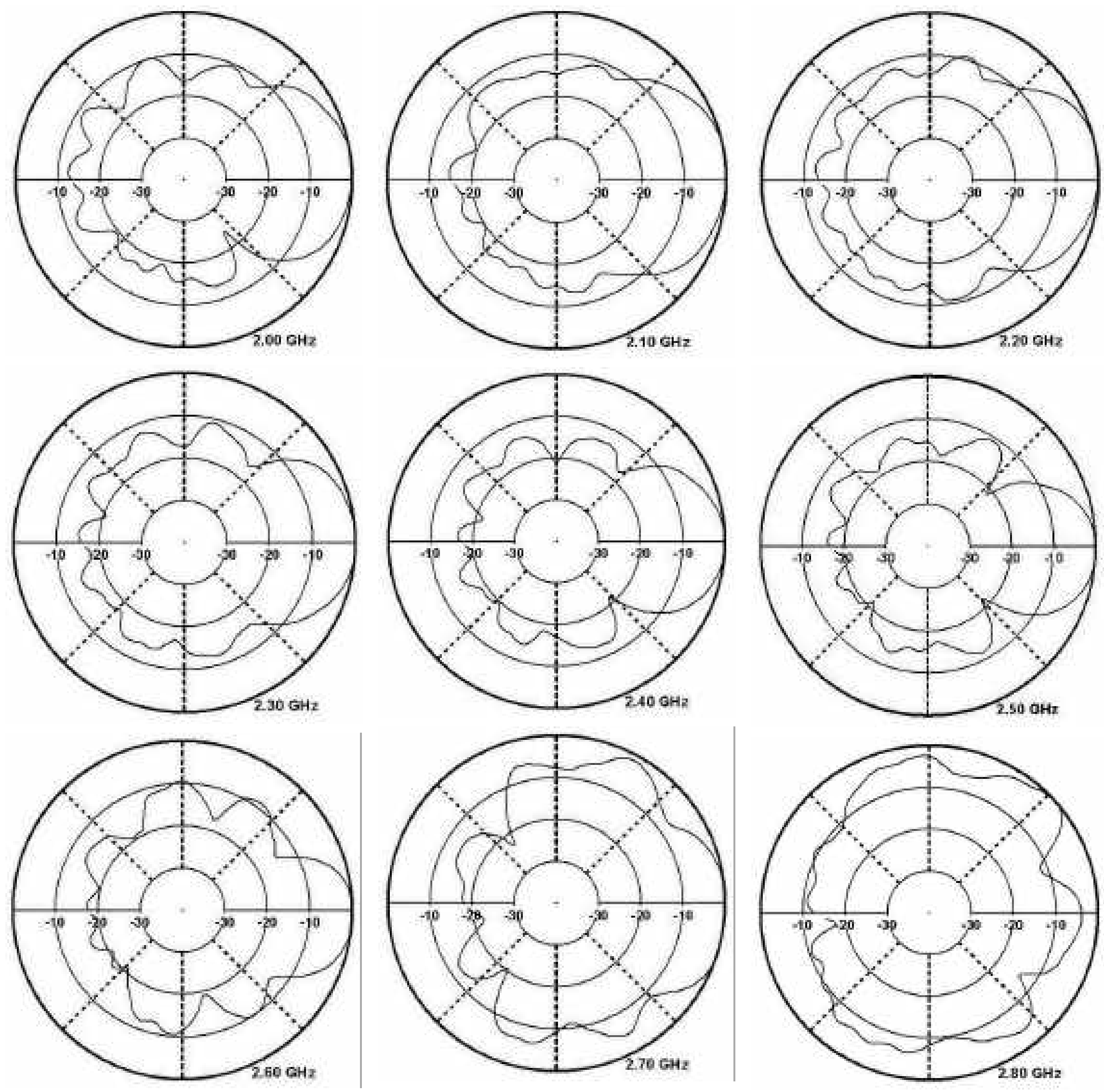



**Figure 7.4.** Radiation patterns measured at VT for 15-turn VT SLH of Table 7.2 from 2 - 2.8 GHz (P15-1)

## 7.4 10-turn 3Di SLH Prototype (P10-1)

The second SLH prototype antenna has the same design characteristics as those given in Table 7.2 except the number of turns is reduced from 15 to 10. It is designated as prototype P10-1. This version was constructed by 3Di, a manufacturing company cooperating with Virginia Tech in developing a mass-produced version of the SLH. This prototype, shown in Figure 7.5, is electrically identical to the previous example, but mechanically quite different. Instead of using a dielectric tube as the support for the helix structure, the helix is self supported and was formed from phosphor-bronze with a square cross-section of 60 mils on a side. The helix was formed mechanically using custom tooling.

By using large cross-sectional wire and phosphor-bronze wire material, the helix structure becomes nearly self-supporting. As shown in Figure 7.5, only a thin dielectric rod is used as a center support. This avoids any issues related to dielectric loading by a support tube or outer covering such as was used in the previous prototype. Because of the large wire diameter, formation of the stubs is more difficult. Creating the sharp bend in the fold of the stub is quite difficult. The result is that the stubs in this prototype are larger, and the gap greater than in the previous example, although they have the same stub depth.

The same tapered matching section for the feed and same size groundplane are used as in the previous example. Details of the matching section are discussed in Section 7.7.

Figure 7.6 shows the measured gain and axial ratio for this antenna from 2.25-2.65 GHz on the antenna range at Sandia Labs. Measurements were made every 50 MHz across this frequency range. The gain is relatively constant from 2.45 GHz to above 2.65 GHz, beyond where measurements were made. Within this frequency range, the gain averages approximately 9.13 dBic with a maximum gain of 9.57 dBic and minimum gain of 8.65 dBic. The axial ratio is less than 3 dB from 2.4 GHz to above 2.65 GHz. At 2.4 GHz, where the AR goes to 3 dB, the gain has decreased to 6.25 dBic, an approximately 3 dB rolloff from the average gain.

Ideally, we would like to have collected data above 2.65 GHz, because we anticipate that the gain and axial ratio behavior of this antenna will degrade in a manner similar to that of the previous prototype shown in Figure 7.3. However, due to the constraints of data processing required to extract the data, and limited testing time available to us on the testing range at Sandia Labs, we could not go back and make those measurements. Based on the data we do have available for this antenna, we can conservatively estimate the 3 dB axial ratio and gain bandwidths to be at least 10%.

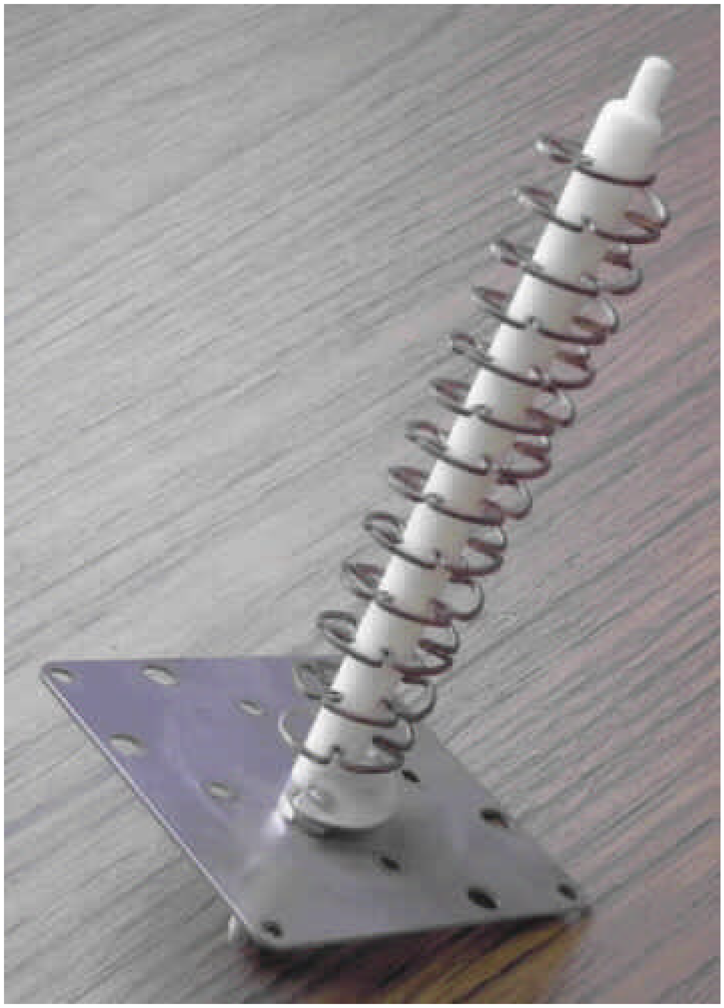


**Figure 7.5.** 10-turn 3Di SLH on 3.75” square groundplane (P10-1)

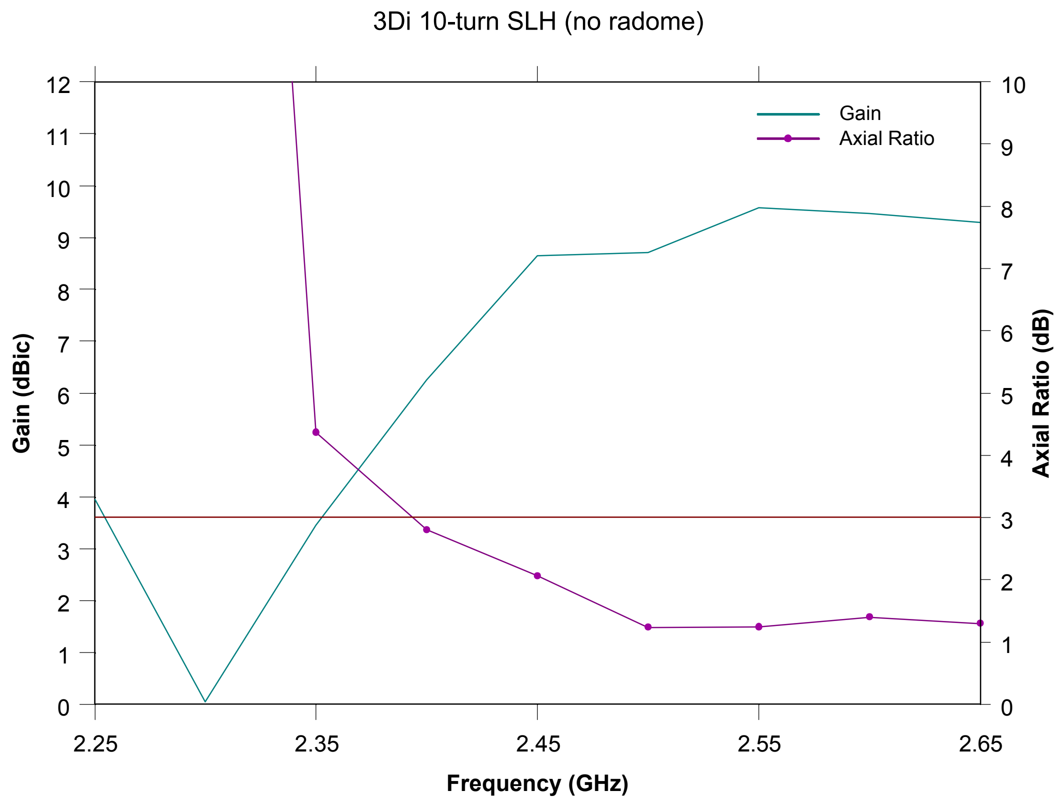



**Figure 7.6**. Boresight gain and axial ratio measured at Sandia Labs for the 10-turn 3Di SLH (P10-1)

Figure 7.7 shows the radiation patterns for this antenna measured from 2.25-2.65 GHz. Except for 2.25 GHz, the patterns are essentially those expected from an axial mode helical antenna structure. A well defined main lobe is evident and it is relatively symmetric and has, if not always distinct, sidelobe structures. The front-to-back ratio is typically 20 dB across most of the frequency range. At 2.6 and 2.65 GHz, there is some significant asymmetry in the sidelobe structure. Based on other measurements, this is most likely due to radiation from the tapered matching section at the feedpoint. But the sidelobe produced by this radiation is more than 10 dB down from the main beam peak.

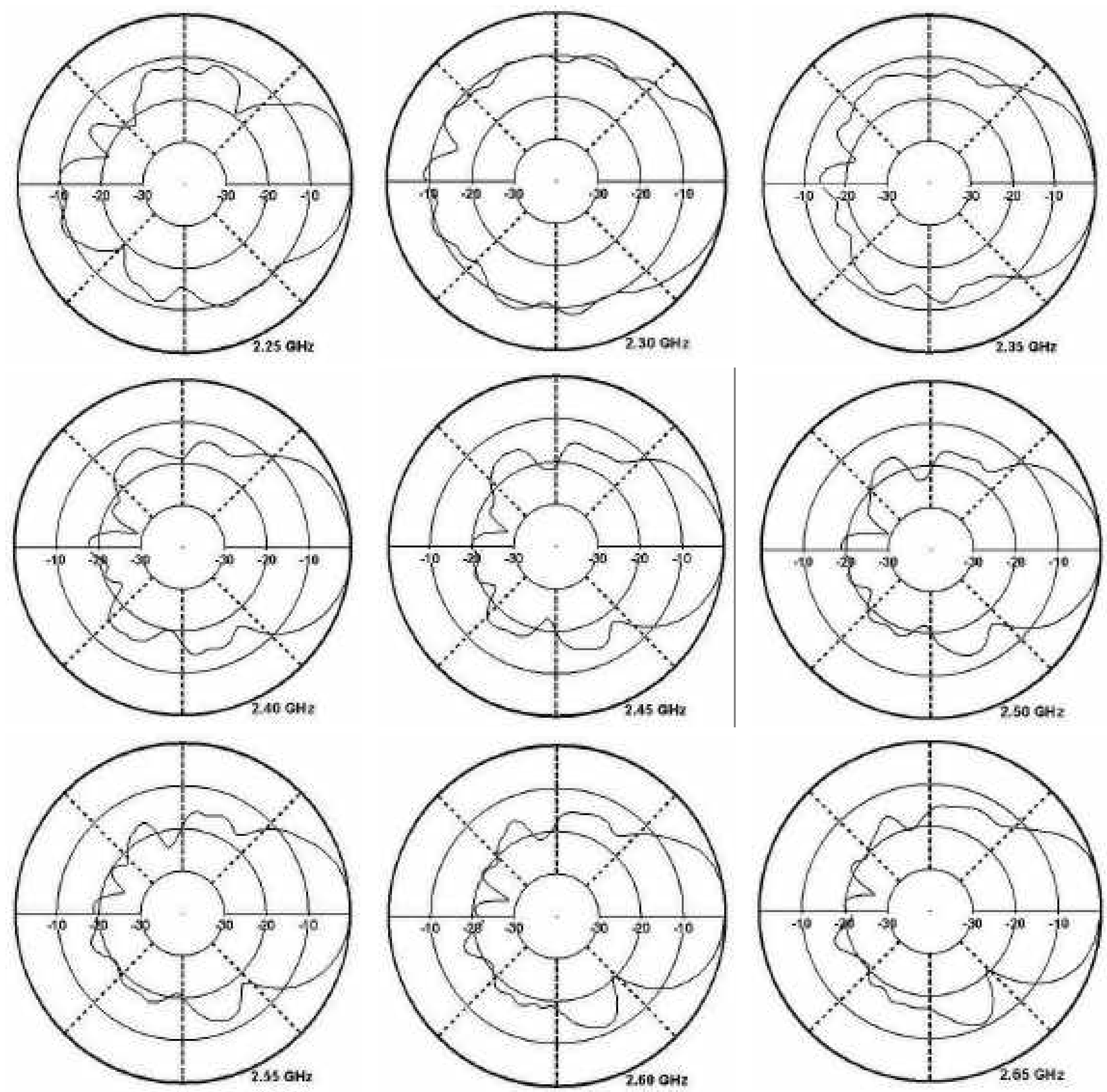



**Figure 7.7**. Radiation patterns of 10-turn 3Di SLH measured at Sandia Labs indoor antenna test range. (P10-1)

## 7.5 30-turn VT SLH with Cup Reflector (P30-1)

The previous examples shown utilized helices of relatively moderate size, 10- and 15-turns. They also used relatively small groundplane reflectors, approximately $3/4\lambda$ across. Small groundplanes were used in an effort to minimize the overall size of the antenna in addition to the size of the helix. The results were reasonably successful.

In an effort to improve the gain, sidelobe and front-to-back ratios, a long helix, 30-turns, was constructed utilizing a cupped reflector surface. The SLH with the cup reflector is shown in Figure 7.8 and is designated as prototype P30-1. The reflector utilized a flat bottom plate and an octagonal wall with a 45° outward slant to form the cup. The outer diameter of the cup was 6.5" with a depth of 2". This helix used the same construction method as the 15-turn SLH in Section 7.3 and utilized the design parameters as shown in Table 7.2, except that the number of turns was increased to 30. As shown in Figure 7.8, the same type of tapered matching network was used for impedance matching as used in the previous prototypes.

Figure 7.9 shows the measured gain and axial ratio for the prototype shown in Figure 7.8 measured from 2.25-2.65 GHz. The most striking aspect of these results is the flatness of the gain and axial ratio curves, indicating that the performance bandwidth of this antenna is significantly greater than the frequency range measured. Across the measured bandwidth, the gain averaged 11.99 dBic with a maximum gain of 13.32 dBic and a minimum of 10.14 dBic. The axial ratio is less than 3 dB across the entire band. Conservatively, the operating bandwidth of this antenna covers the entire 2.25-2.65 GHz frequency range, giving it a bandwidth greater than 16%.

Figure 7.10 shows the measured radiation patterns for the 30-turn SLH with cup reflector. The most striking feature of these patterns is the improvement in front-to-back ratio and cleaner and lower sidelobe behavior. The improvement in front-to-back ratio is most likely due primarily to the cup reflector, both because of its shape and its larger diameter compared to the small, flat reflectors used on other prototypes. Over most if the measured frequency range, the front-to-back is approximately 30 dB or greater.

The gain of the long 30-turn SLH (12 dBic) was not significantly greater that of the 10- or 15-turn SLH prototypes, only being approximately 3 dB greater. However, it appears that the additional turns, produced a significantly wider operating bandwidth in terms of gain flatness and axial ratio performance.

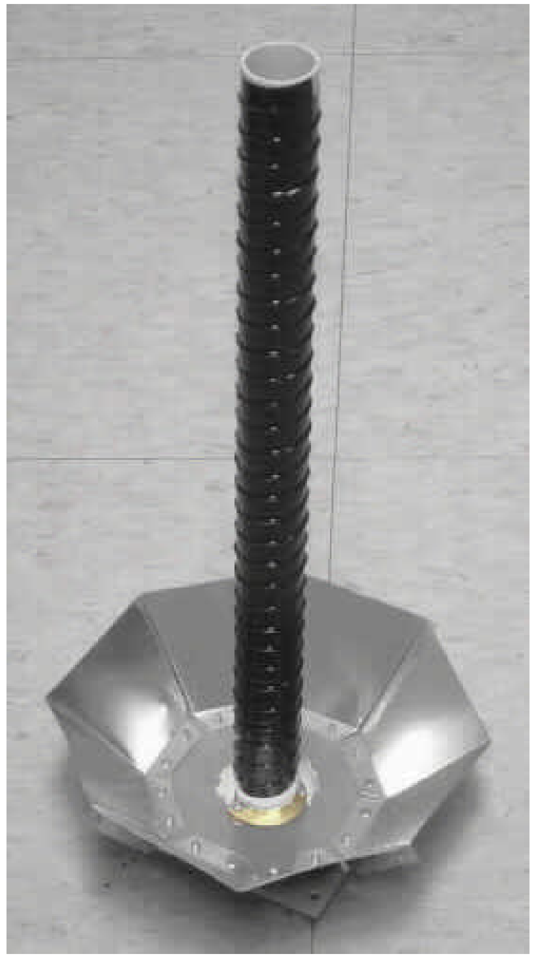


**Figure 7.8.** 30-turn VT SLH with cup reflector (P30-1)

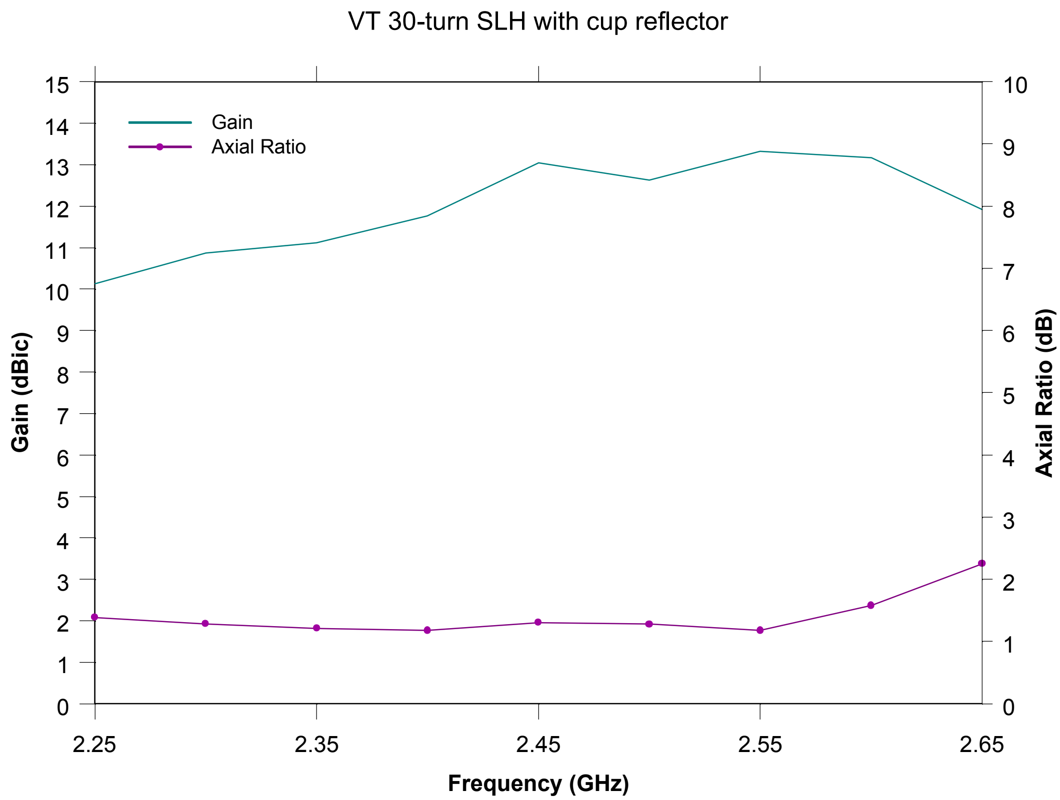



**Figure 7.9.** Gain and axial ratio of 30-turn VT SLH with cup reflector (P30-1) measured at VT.

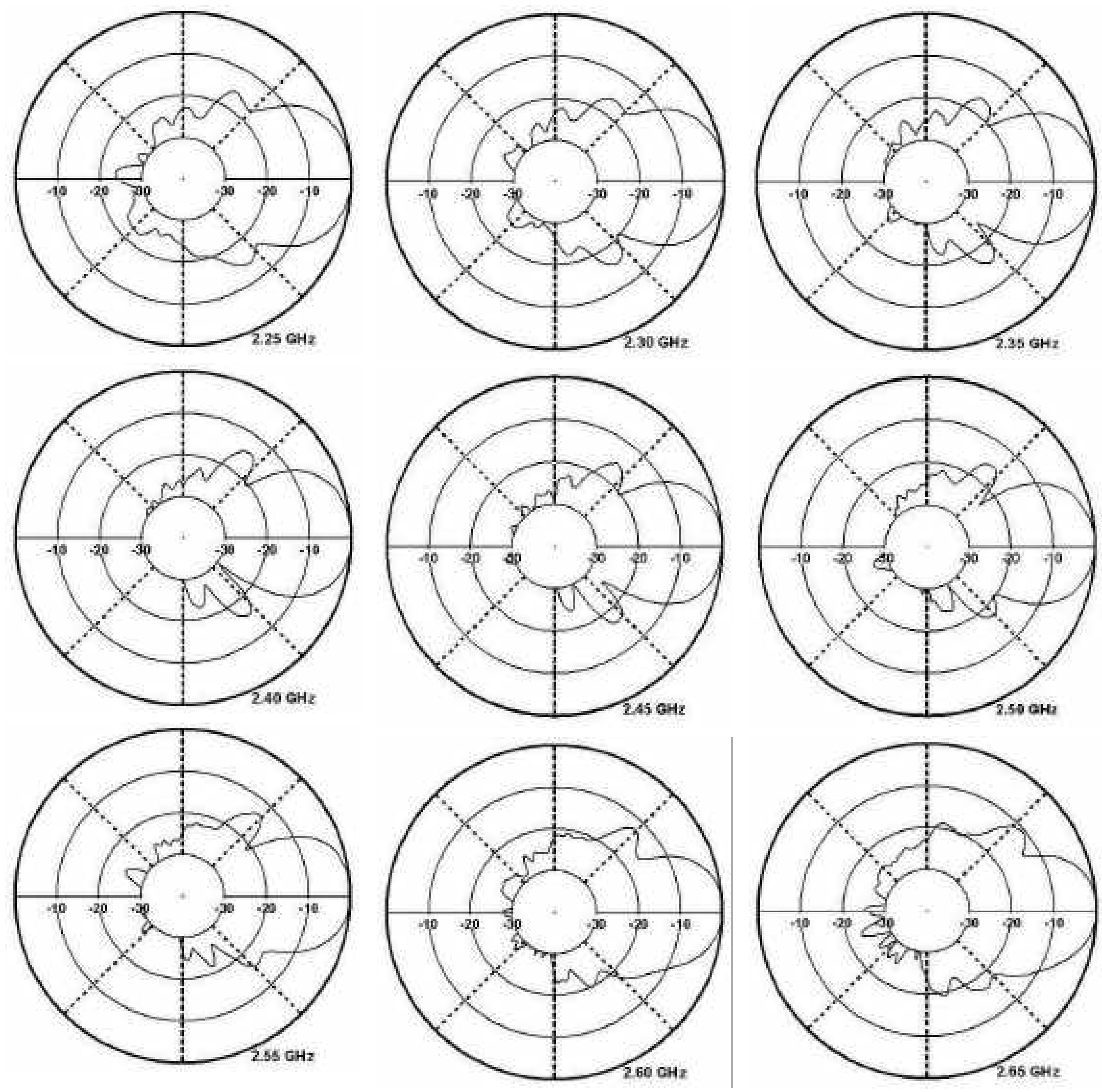



**Figure 7.10**. Measured radiation patterns of 30-turn VT SLH with cup reflector (P30-1)

## 7.6 Comparison of SLH to Conventional Helix

A 15-turn full size conventional helix and 15-turn Stub Loaded Helix (SLH) were constructed and measured using the Virginia Tech indoor antenna range using the near-field system to compare the performance between the two types of antennas. The design details of the two helices are shown in Table 7.3. The conventional helix was designated as prototype P15-2 and the SLH prototype was designated as P15-3.

The helix sizes were chosen based on a combination of our experiences with previous SLH prototypes and readily available construction materials. The 1" SLH diameter operates at approximately 2.4 GHz, a frequency range in which our antenna range works well. Additionally, we already had the necessary tooling and processes developed for making SLH antennas for this frequency range. The number of turns was chosen to obtain a reasonably high gain without making the conventional helix too large to easily fit into our chamber. The same number of turns was chosen for both the SLH and conventional helix in order to make a comparison that in some sense would be "apples to apples". The choice could have been made to compare equal axial length helices, but that would have resulted in an SLH design that would be much larger and would not have illustrated the full size reduction capabilities of the SLH.

The helices were measured from 2.0 to 2.6 GHz in 100 MHz steps. The measured patterns for each frequency are shown in Figure 7.11. The general trend is that the patterns are comparable between the full size helix and the SLH but the SLH has slightly less gain and lower sidelobes.

**Table 7.3 Helix Dimensions for Prototypes P15-2 (Full Size) and P15-3 (SLH)**

| | Full size Helix | Stub Loaded Helix |
|---|---|---|
| N, # of turns | 15 | 15 |
| D, diameter | 1.5" | 1" |
| L, length | 16.5" | 8" |
| $\alpha$, pitch angle | 13° | 8° |
| $l_s$, stub depth | no stubs | 0.425" |
| groundplane diameter | 10" | 10" |

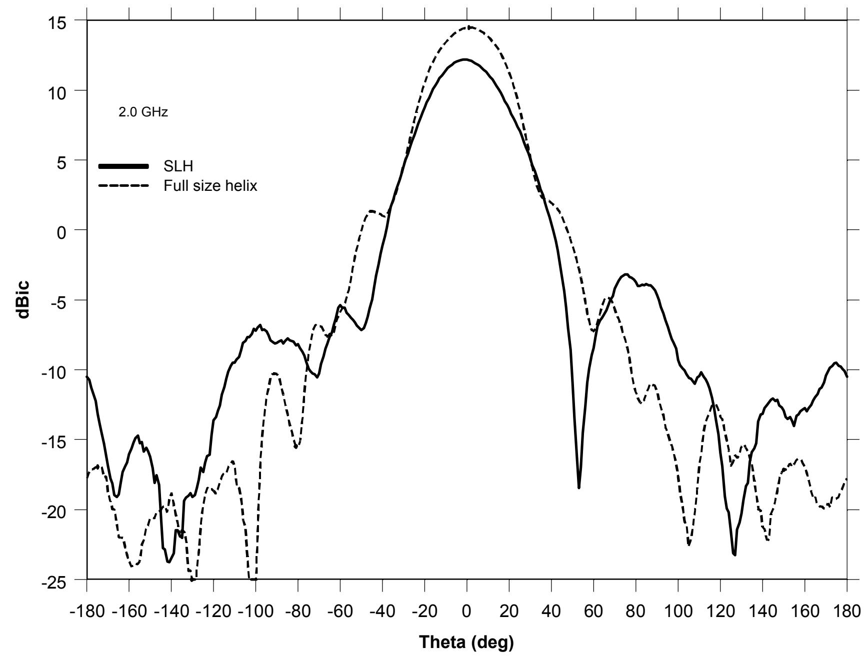
Figure 7.12 shows the measured directivity and axial ratio of the full size and SLH antennas. Directivity is shown rather than gain due to issues related to the measurement processing. These measurements were made using the Antcom near-field system at the Virginia Tech Antenna Range. At the time these measurements were made there were questions about how the Antcom software derived the gain measurements. In order to avoid having to address complications related to those questions, the directivity results have been reported here. The directivity is computed and reported by the Antcom software using the pattern data it collects. Details of the computation are not available to the user, but our experience has been that the directivity reported by the Antcom software is comparable and consistent with measured gain results, which is expected for antennas

with little internal loss. In this case, we are making comparative measurements between two antennas so the relative differences in directivity are consistent with the relative gain differences.

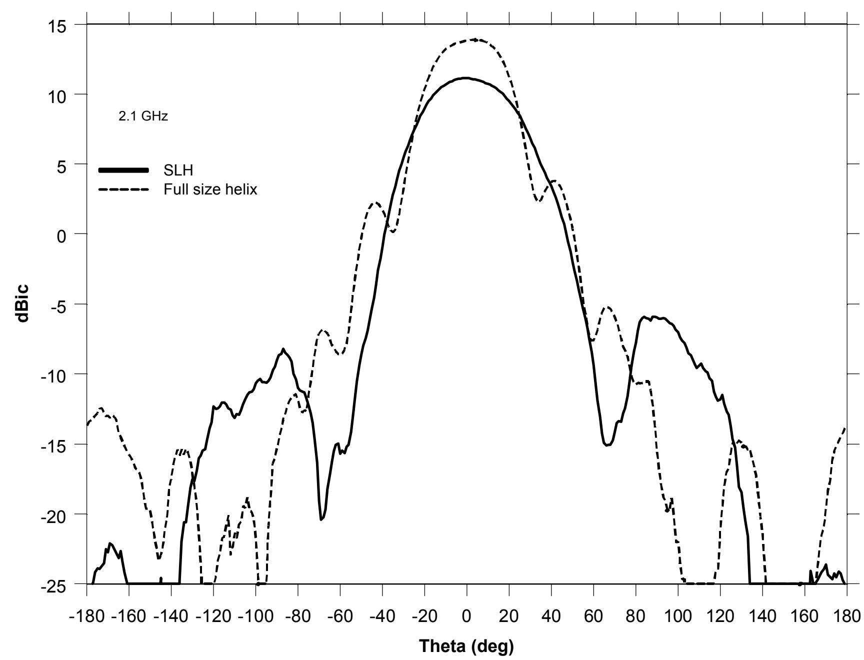
Figure 7.12 shows that the gain of the SLH is on average approximately 1- 1.5 dB below that for the full size helix across the 2 - 2.6 GHz frequency range measured. The largest variation between SLH and full size helix gain occurs at 2.4 GHz, where it is 2 dB.

The axial ratio bandwidth of the SLH is less than the full size helix. Using the 3 dB axial ratio criteria to define bandwidth, the SLH has an AR bandwidth of over 400 MHz, approximately 17% of the center frequency. The full size helix axial ratio just does exceed 3 dB at 2.6 GHz. The typical bandwidth value of 50% for a full size helix seems to be easy supported by the axial ratio performance measured here. However, from Figures 7.11 and 7.12, it is obvious that above 2.5 GHz, the gain and main lobe of the full size helix begin to deteriorate significantly. As these measurements show, the operational limits of the SLH are determined primarily by its axial ratio performance.

The main beam of the full size helix has a slightly narrower beamwidth than the SLH and narrows more as the frequency increases. This is quite evident in Figure 7.13 which shows the 3 dB beamwidth of the full size helix and SLH measured. The beamwidth of the full size helix peaks at 2.1 GHz and then monotonically decreases with frequency. This is generally indicative of increasing gain with frequency. At 2.6 GHz, the beamwidth measurement is misleading due to the splitting of the main beam, as seen in Figure 7.11. The beamwidth of the SLH does not vary in a simple manner with frequency. However, it should be noted that the beamwidth of the SLH shows less variation with frequency than does the full size helix.

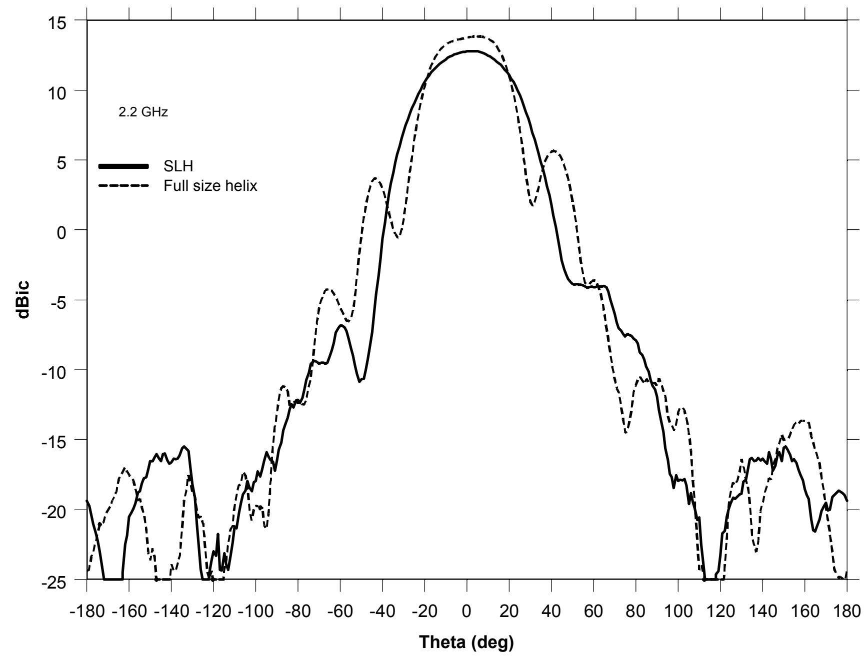



(a)

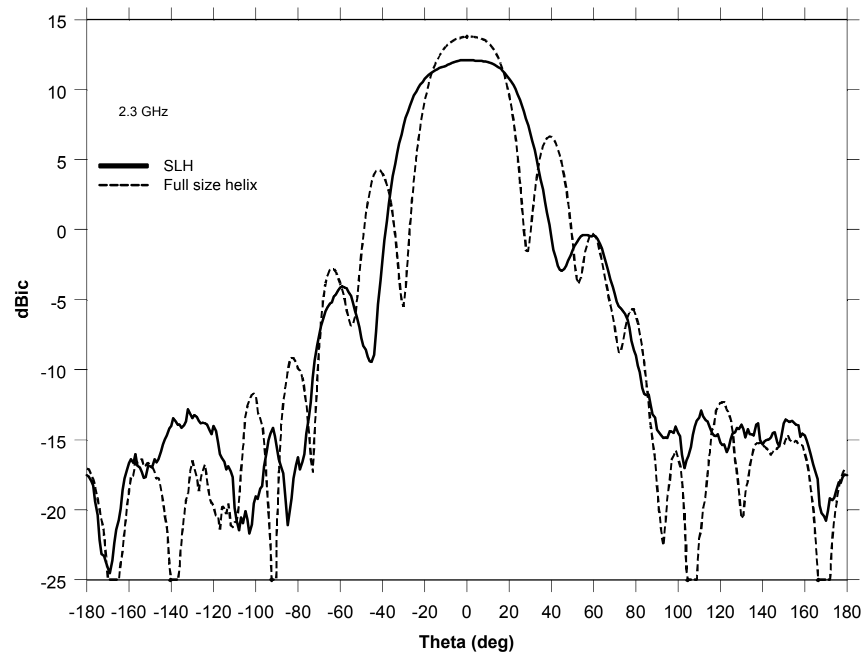



(b)

**Figure 7.11**. Radiation patterns of 15-turn full size helix (P15-2) and Stub Loaded Helix (P15-3) measured at VT.

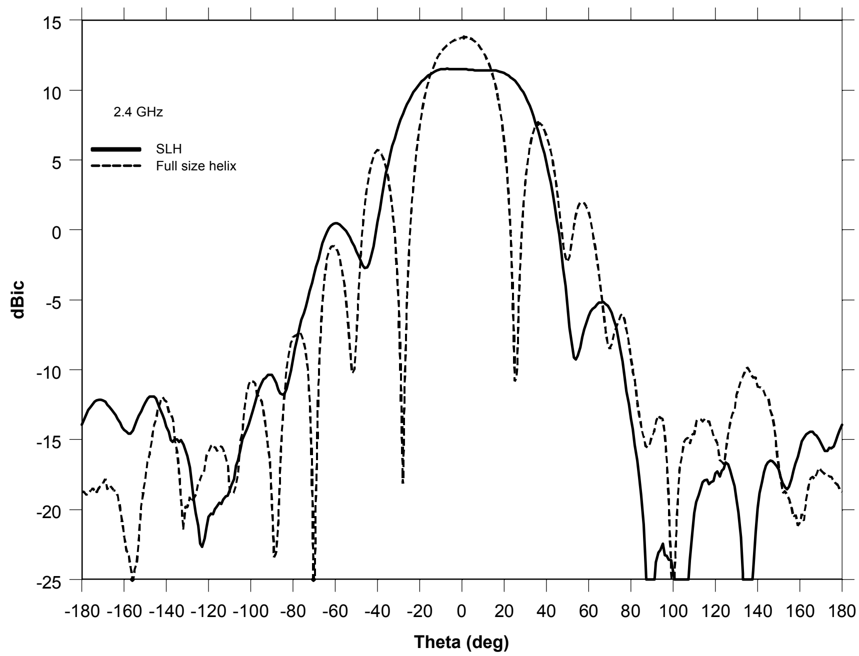



(c)

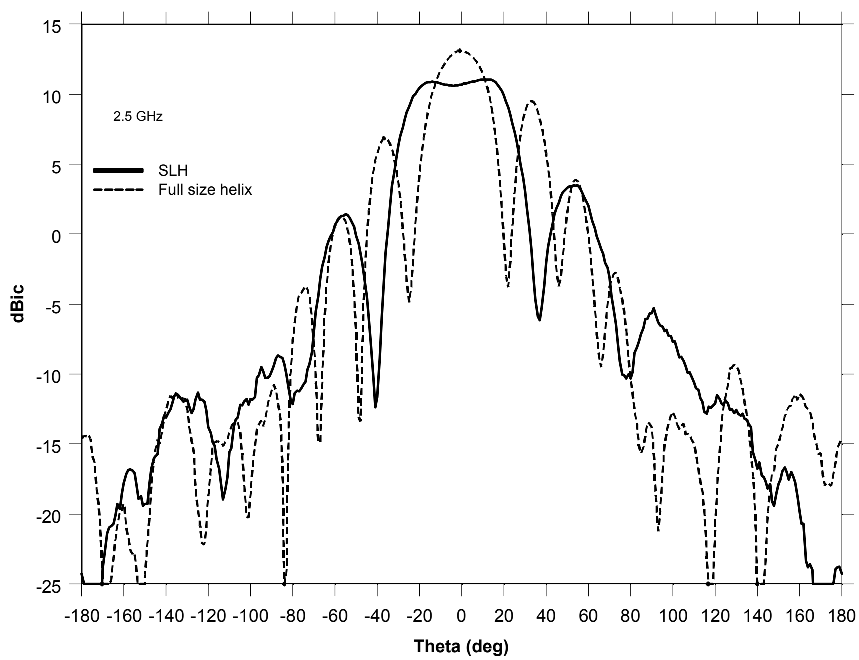



(d)

**Figure 7.11** (cont.). Radiation patterns of 15-turn full size helix (P15-2) and Stub Loaded Helix (P15-3) measured at VT.

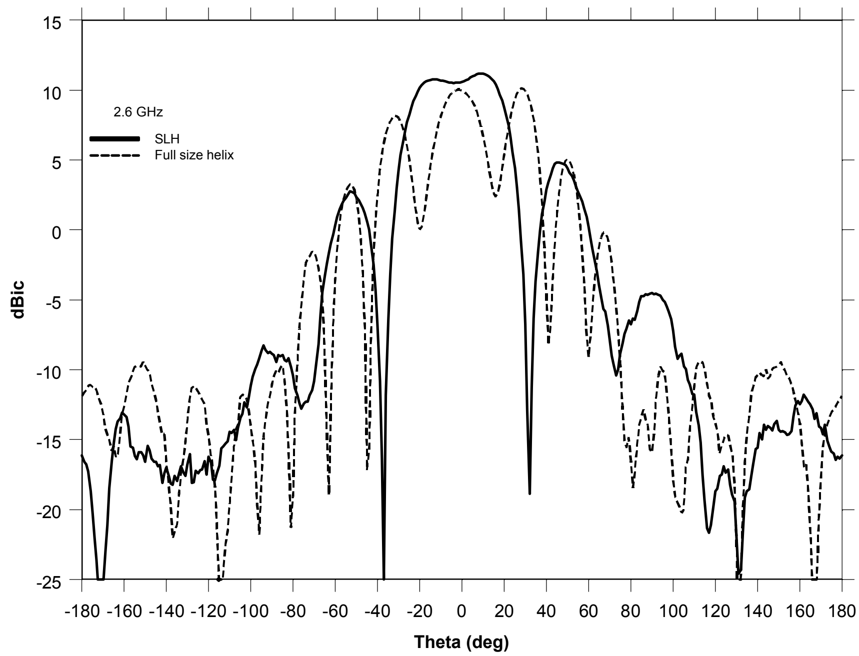



(e)




(f)

**Figure 7.11**.(cont.) Radiation patterns of 15-turn full size helix (P15-2) and Stub Loaded Helix (P15-3) measured at VT.




(g)

**Figure 7.11**.(cont.) Radiation patterns of 15-turn full size helix (P15-2) and Stub Loaded Helix (P15-3) measured at VT.

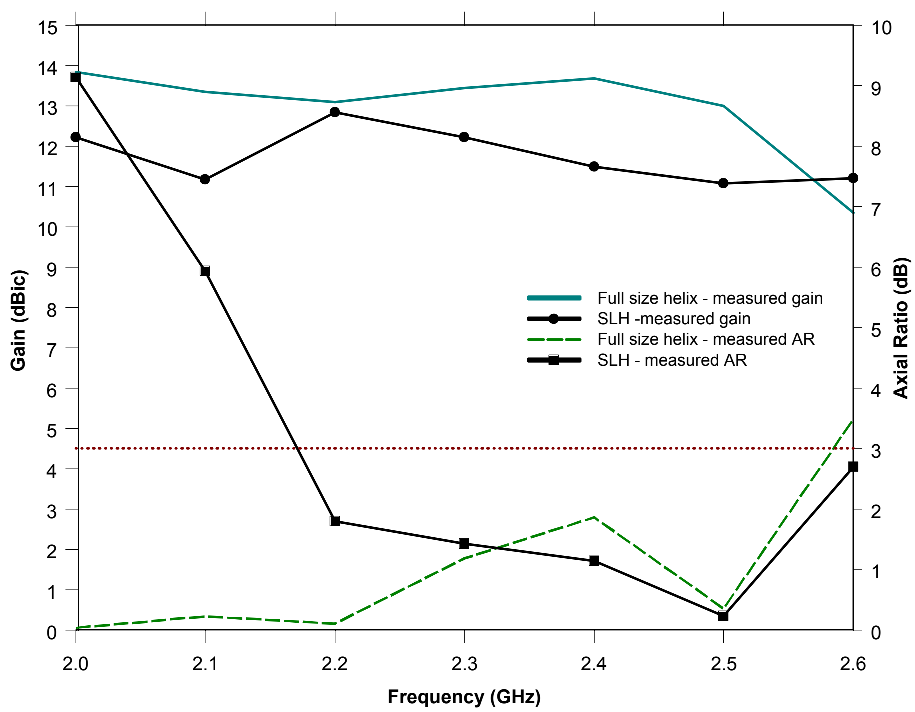



**Figure 7.12.** Directivity and axial ratio of 15-turn full size (P15-2) and Stub Loaded helices (P15-3) measured at VT.

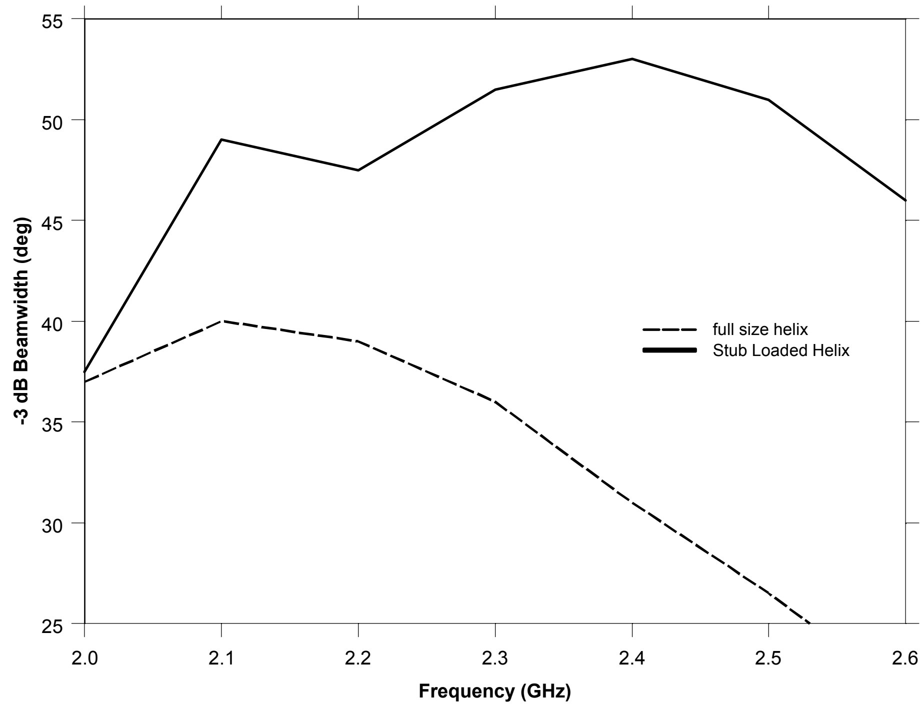



**Figure 7.13**. Measured -3 dB beamwidth of 15-turn full size (P15-2) and Stub Loaded helices (P15-3)

## 7.7 Summary of Gain and Axial Ratio Measurements

Table 7.4 summarizes the gain and bandwidth measurements of the prototypes in the preceding sections. The center frequency and bandwidth are based on the 3-dB axial ratio bandwidth measured for each prototype. The minimum and maximum gains reported correspond to the minimum and maximums across the 3-dB axial ratio bandwidth. In several cases it was not possible to accurately specify these parameters since the measured data did not span the entire 3-dB axial ratio bandwidth. In these cases, the center frequency and bandwidths are noted as approximate.

**Table 7.4 Summary of Prototype Performance Parameters**

| Prototype | $f_c$ (GHz) | BW (MHz) | %BW | $G_{max}$ (dBic) | $G_{min}$ (dBic) |
|---|---|---|---|---|---|
| P15-1 | 2.485 | 270 | 10.8 | 10.1 | 7.4 |
| P10-1 | ~2.60 | >250 | >10 | 9.5 | 5.9 |
| P30-1 | ~2.45 | >400 | >16 | 13.1 | 10.1 |
| P15-2* | ~2.30 | >550 | >>24 | 14.8 | 10.9 |
| P15-3 | 2.38 | 430 | 18 | 12.9 | 11.1 |

* a conventional, full-size helical antenna

## 7.8 Helix Impedance Measurements

Input impedance is equally important to the pattern, gain and polarization characteristics of an antenna. The antenna input port must provide an acceptable impedance match to the rest of the system, if efficiency penalties are to be avoided. Most modern communications systems utilize a 50 Ω system impedance, so it is natural to characterize an antenna's impedance with respect to this standard value.

For the sake of comparison, the input impedance of a conventional full size helix for a nominal frequency of 2 GHz was measured. This helix used a conventional tapered transmission line section of approximately one-half wavelength in length to provide an impedance match to 50 Ω [Kraus, 1988]. Figures 7.14 and 7.15 show the impedance match of the full size helix from 1 to 3 GHz. In Figure 7.14, the return loss (RL), or $|S_{11}|$ s-parameter, is shown. The RL exhibits a standing wave pattern below approximately 1.6 GHz. This indicates that the helix structure does not support a traveling wave mode at these frequencies, or at least not a decaying traveling wave mode. From 1.6 GHz to approximately 2.4 GHz, the return loss is greater than 10 dB, which equates to a VSWR of approximately 2:1 or less. Above 2.6 GHz the impedance again begins to exhibit a standing wave type behavior, indicating the presence of higher order modes on the helix

The input impedance of a 15-turn Stub Loaded Helix with no matching network was measured for comparison. The SLH antenna was designed for operation at approximately 2.3 GHz. Figure 7.16 shows the RL ($S_{11}$) measured for the SLH with no matching. Although the return loss indicates a poor match to 50 Ω with a return loss of approximately 3 dB, equivalent to a VSWR of 5.85:1, the behavior of the impedance is remarkably similar to that for the full size helix shown in Figure 7.14. Below 2 GHz, the impedance exhibits a standing wave type behavior, is relatively constant between 2 and 2.6 GHz, and again begins a standing wave type behavior above 2.6 GHz.  This characteristic behavior of the input impedance is quite useful for determining over what frequency range axial mode propagation is likely to be supported.  From measurements on similar antennas, we know that an SLH of this design will produce good gain and polarization behavior across the 2 to 2.6 GHz frequency range.

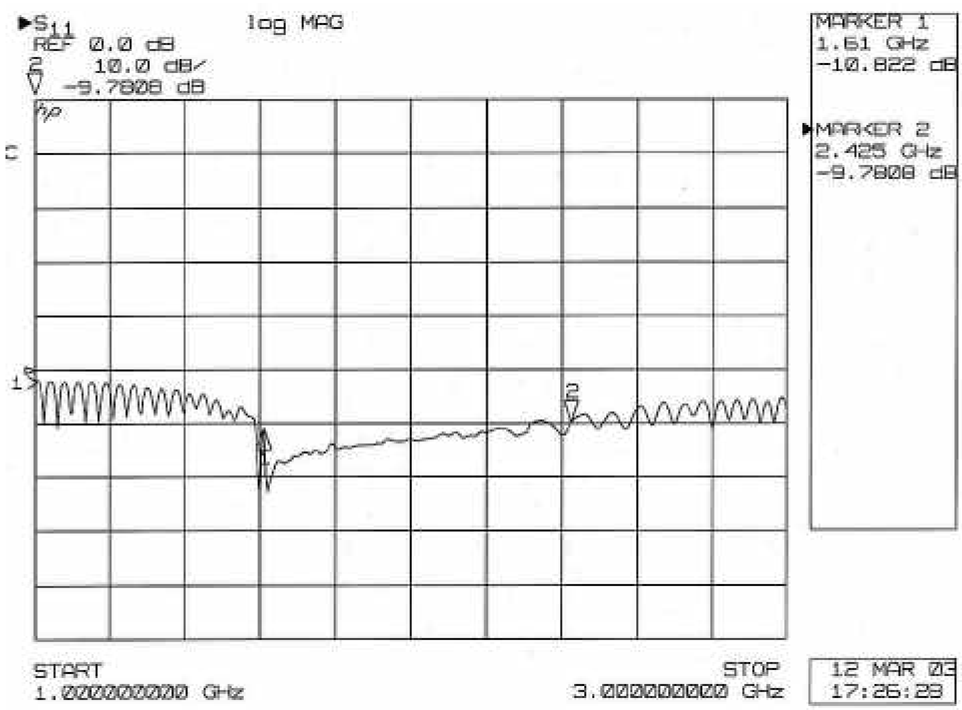



**Figure 7.14** Measured return loss ($S_{11}$) of 28 turn full size helix

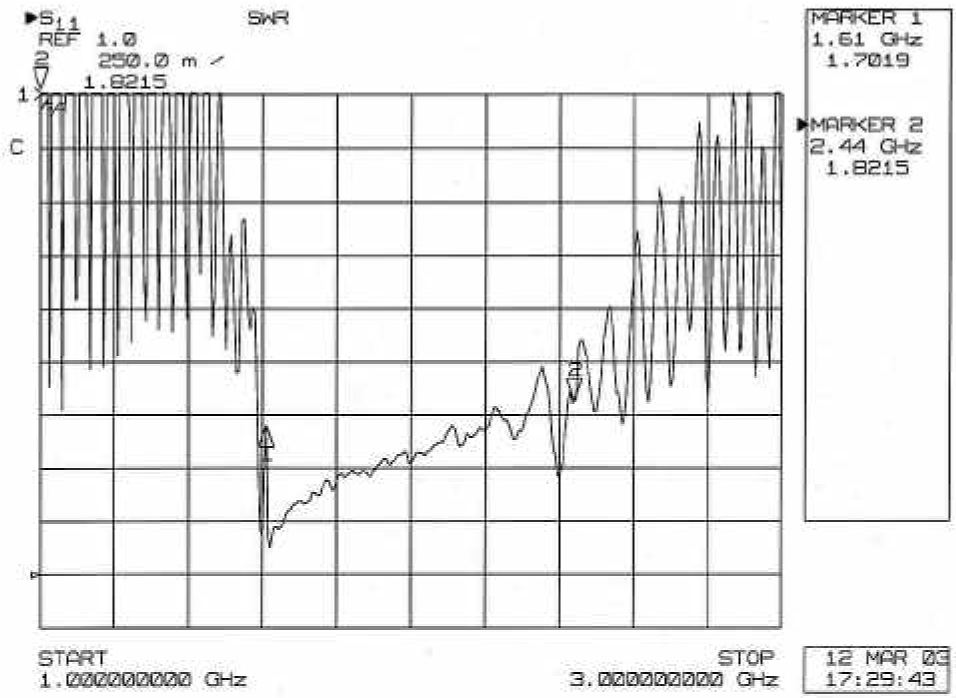



**Figure 7.15** Measured VSWR of 28 turn full size helix

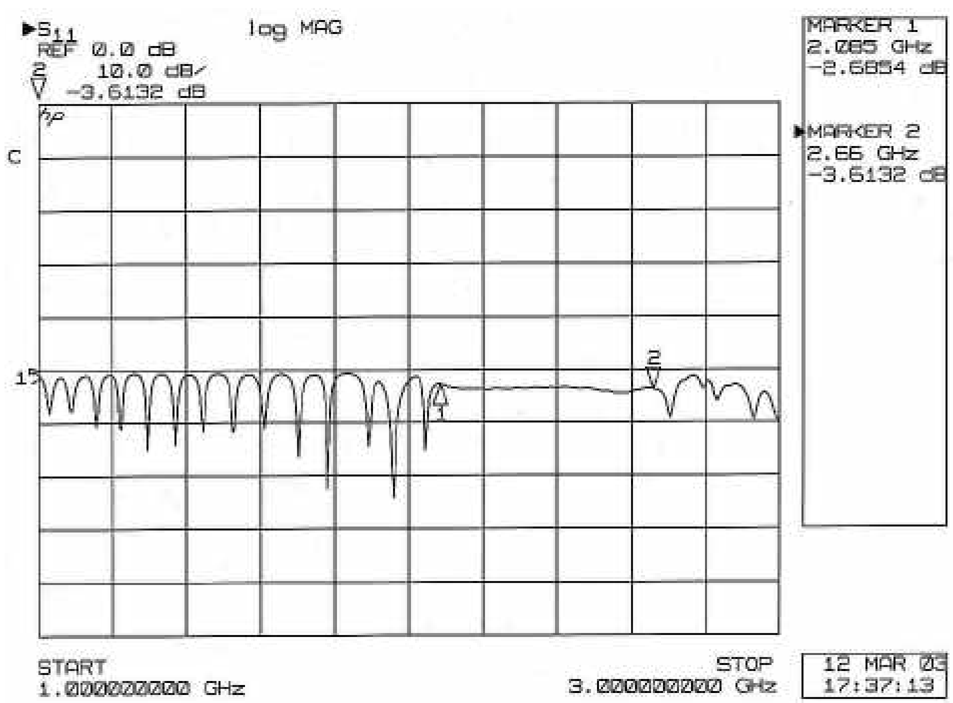



**Figure 7.16** Measured return loss ($S_{11}$) of 15 turn SLH with no matching

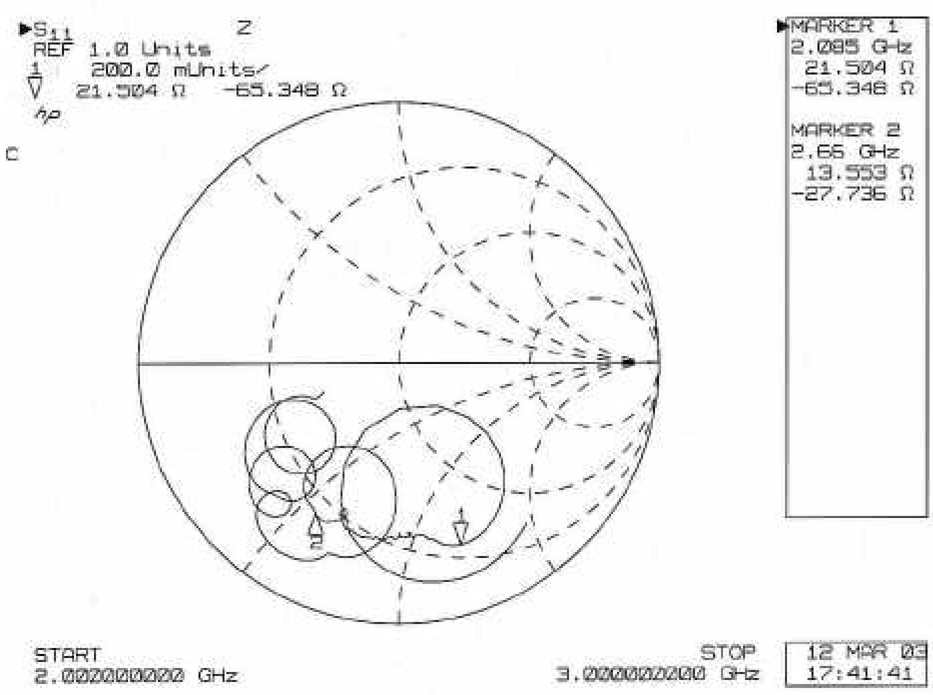



**Figure 7.17** Measured impedance of 15 turn SLH with no matching

Figure 7.17 shows the same input impedance data as in Figure 7.16 plotted on a Smith Chart. Notice that between the markers (2 and 2.6 GHz) the impedance shows a relatively constant real component, varying primarily in the reactive component. Outside this frequency range where axial mode propagation is expected, the impedance varies widely and rapidly as evidenced by the many loops in the Smith Chart trace.

In order to provide a reasonable match to 50 Ω for the SLH antenna, a tapered transmission line, similar to that often used for full size helices [Fox, 1988], was developed. The tapered matching section was developed empirically, and as such, may not represent an optimum solution. It has, however proven to be simple and easy to implement. The SLH matching section, show in Figure 7.18 consists of a curved metallic sheet with a length equal to one-half the circumference of the SLH. At the feedpoint connector end the width of the matching section is equal to the radius of the SLH. It tapers linearly to the attachment point of the helix wire, where its width is essentially equal to the wire diameter. At the wide (connector) end of the matching section, it attaches to the center pin of a coaxial connector of the desired type. The matching section suspended over the helix groundplane, effectively constitutes an air dielectric microstrip structure. The input impedance at the connector is affected by the height of the matching section above the groundplane and this must be determined empirically for best matching. The matching section height is usually tapered slightly so that the helix wire starts at approximately the height of one turn above the groundplane.

Figure 7.19 shows the measured return loss for a 15-turn SLH with the above described matching section. The return loss is approximately 10 dB from 2.1 to 2.6 GHz and relatively constant over this frequency range. Figure 7.20 shows the same data plotted on a Smith Chart. Figure 7.21 shows the impedance match plotted as VSWR.

Given the large surface area of the matching section, there is concern that it will radiate, distorting the pattern or affecting the gain and polarization performance. Our experience has been that this is not a significant problem. All of the SLH test article results presented in previous sections used this matching section. There appears to be a slight asymmetry in the sidelobe pattern at some frequencies in Figures 7.4 and 7.7 that may be attributable to radiation from the matching section and feed.

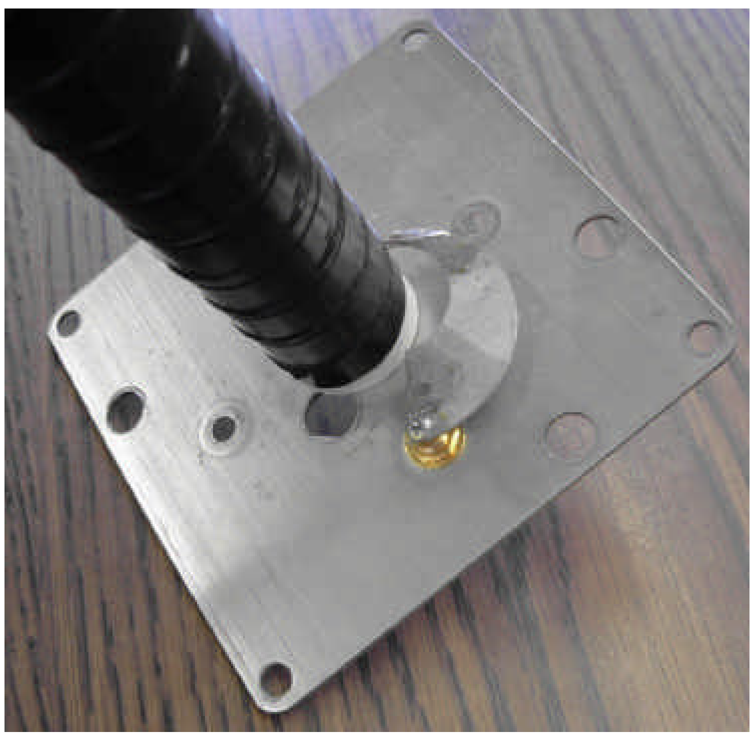


**Figure 7.18** Tapered matching section of Stub Loaded Helix

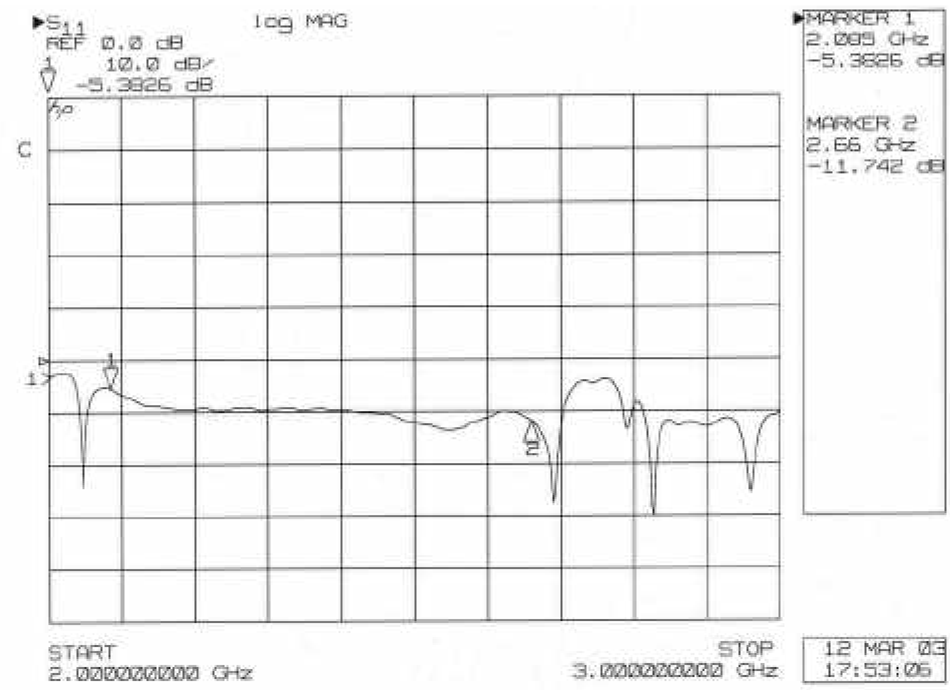



**Figure 7.19** Measured return loss ($S_{11}$) of 15 turn SLH with matching section

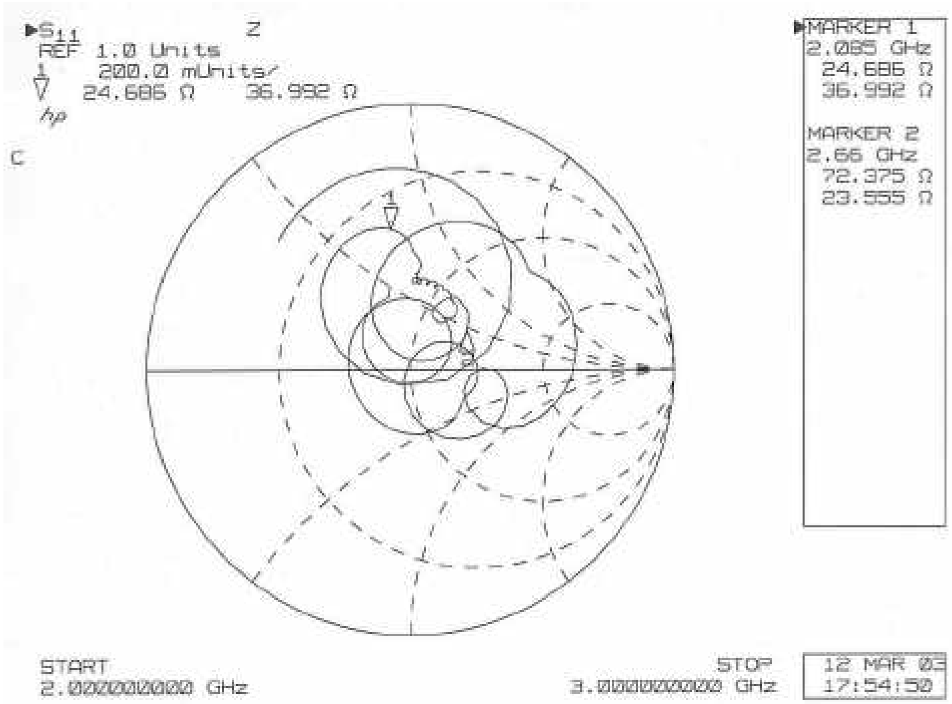



**Figure 7.20** Measured impedance of 15 turn SLH with matching section

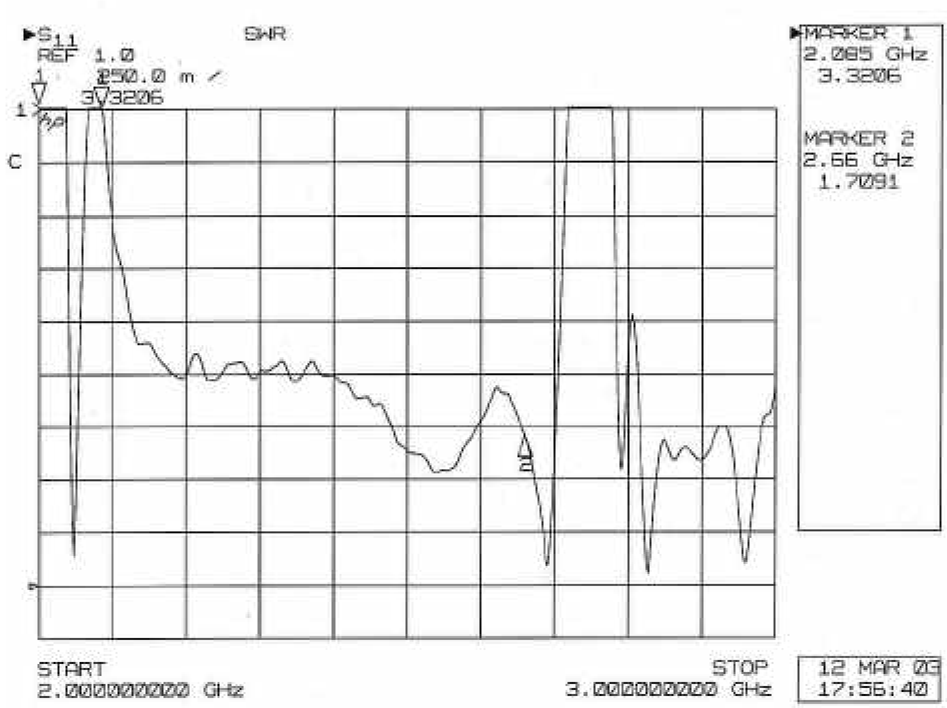



**Figure 7.21** Measured VSWR of 15 turn SLH with matching section

The impedance matching technique presented here makes no claim of being optimal in any sense, except that it has been used extensively and does provide a reasonable impedance match for a 50 Ω system over a sufficiently wide enough bandwidth. In [Fox, 1988] there is a good overview of different impedance matching techniques used for conventional axial mode helices. Included is also a new matching techniques called the "Fox Method" that may be applicable to the SLH as well. The "Fox Method" is also an empirically derived matching technique that uses a length of insulated wire over the groundplane from the helix beginning to the feed connector. By adjusting the orientation and height of the wire over the groundplane, an impedance match may be found. It is assumed that the length of the wire would also have some effect on the impedance matching behavior. We have not investigated this method, but its simplicity does recommend an investigation.