

Improvised Methods for Preliminary Characterization of Linear Tapered Slot Antenna Performance

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Abstract:

Certain wireless applications, such as radar systems, require an antenna that covers a relatively wide (e.g. octave) band of frequencies. The linear tapered slot antenna described in this application note is a useful broadband antenna that can be constructed without excessive cost. After constructing such an antenna, it is useful to verify the antenna's performance, without the expense of sending the antenna to a professional laboratory. While the techniques discussed are not recommended for final characterization of antennas, the ability to tentatively verify performance without shipping antennas off to a professional antenna measurement laboratory may help speed up and beneficially direct antenna design efforts.

Keywords:

antenna measurement, field strength, VSWR, return loss, linear tapered slot antenna

Introduction:

A useful antenna design that covers the wide RF bandwidth typically needed by radar systems is the linear tapered slot antenna (LTSA). It is often useful to experimentally verify the performance of a physical antenna prototype in development before the final design is set. Preferably, such experiments can take place “in house” to avoid the expense of sending away test antennas to a measurement laboratory. An engineering firm responsible for radar systems design will often have the rudimentary laboratory equipment necessary to generate and measure RF at the frequencies of design interest. The additional expense needed for improvised antenna measurement lies mainly in the construction of an anechoic chamber. This feat has been accomplished by graduate students over the decades at a number of universities, including here at Michigan State University. The antenna pattern test results for two LTSAs will be discussed and compared with the antenna pattern of a more expensive broadband horn antenna. A general process for measuring the antennas is presented. A brief overview of LTSA design is also presented in this application note.

Objectives:

- Give details of an improvised procedure for LTSA azimuth pattern measurement
- Brief overview of LTSA design considerations

Discussion:

The linear tapered slot antenna (LTSA) has been successfully used in experimental radar systems for some time. The LTSA may be constructed out of common FR4 laminate, without expensive specialized tools. Broadband horn antennas typically cost at least several hundred dollars each. For the researcher looking to work with a system having two or more antennas, the cost of broadband horn antennas may exceed the project budget. This budget concern faced the NRL Senior Design team, and thus the team opted for an LTSA design for the radar transmit and receive antennas. LTSAs may also be used on nearly any wireless device requiring broad RF bandwidth (e.g. octave bandwidth).

The design process for an LTSA generally involves configuring the length of the LTSA for the desired gain, and setting the width of the LTSA vee openings for the desired RF bandwidth to be covered. Finally, the LTSA feedpoint is chosen for the best return loss over the RF band of interest. The “feedpoint” is where the coaxial cable connects to the antenna, to efficiently couple energy into the antenna. The LTSA optimization process can be accomplished experimentally, through the use of a vector network analyzer (VNA) to measure the return loss of the LTSA over the RF bandwidth of interest. The optimization of an LTSA covers not only return loss, but also a verification of directivity.

A typical professional antenna measurement facility charges \$1800 [1] for an antenna pattern measurement. An antenna pattern measurement shows the directivity of an antenna with respect to orientation of the antenna. Specifically, a directional antenna such as an LTSA radiates more effectively in certain directions than in others. The radiation pattern as measured above and below the horizontal plane of primary radiation is called the elevation pattern, and the radiation pattern measured as the antenna is rotated horizontally is called the azimuth pattern. Unless a rotator system is employed with the ability to control elevation and azimuth simultaneously (as would likely be the case at a professional measurement facility), the antenna measurement system will only measure one radiation pattern at a time—typically azimuth.

The azimuth pattern is considered more often in practice than the elevation pattern. The elevation pattern is important if the design involves communicating with or detection of satellites and/or aircraft. Because many laboratory designs concern only terrestrial communications or target detection in dedicated frequency bands where interference to satellites and aircraft is not a concern, the azimuth pattern is typically considered of primary importance in the laboratory environment. The elevation pattern is considered more casually, to be sure that excessive power isn’t being wasted into the ground or sky. The priority concern is more typically avoiding interference to/from other terrestrial sources, thus the antenna’s azimuth pattern is typically of primary importance. These assertions are based on the author’s decade of experience in wireless systems design for government and public safety entities.

The azimuth plot shows magnitude on a linear, or more typically, decibel scale. A typical LTSA design will send most of the RF energy in one direction, and send little energy in all other directions. There is a finite beamwidth in the primary direction of radiation, which is typically given in degrees, measured as the points at which the radiation intensity is -3dB from the intensity at the peak direction of the antenna [2]. In the extreme case, an omnidirectional antenna radiates with approximately equal intensity over the entire azimuth. The geometry of the LTSA may affect the directionality, which is measured by the antenna pattern measurement system.

Antenna measurement considerations:

The exact procedure for measuring the azimuth radiation pattern of an antenna depends strongly on the equipment at the facility. A spectrum analysis should be conducted across the frequency band of interest, to ensure that no strong outside transmissions are occurring at the frequency of interest. If strong interfering signals exist at the measurement frequencies, the measurements will be corrupted and meaningless at the frequencies in question. A professionally engineered sealed anechoic chamber can cost tens of thousands of dollars or more, thus, many companies and universities have anechoic chambers that have been built in-house. These in-house built chambers may have much less than the 50+dB of isolation that might be expected from a pre-built anechoic chamber. This means that the antenna pattern measurements are not completely immune to effects from the outside world. Also, the anechoic chamber foam has frequency-dependent isolation behavior. Typically, as the measurement frequency lowers, the foam rapidly loses effectiveness beyond its lower design frequency. That is, the foam becomes more transparent to RF—making the measurements interact greatly with the surrounding environment (causing the measurements to lose accuracy) [3].

Assuming that the anechoic chamber has been designed for the frequency band of interest, and that the measurement equipment (which may consist of as little as a signal generator, vector voltmeter, and directional coupler) are appropriate for the frequency band of interest, the next concern is the measurement antenna. The measurement antenna is the device that couples energy to or from the antenna under test. Practical antennas function over limited frequency ranges. Thus, if the measurement antenna is not

designed for the frequency range of measurement, the measurements may be meaningless. Before taking measurements, the engineer must determine that the measurement antenna is appropriate for the frequency range of interest. The reference characteristics of the measurement antenna allow the measurements to be interpreted with respect to a known reference. Without a known reference level, the directionality may be known, but only to within a scale factor—e.g., the antenna could be radiating energy very poorly, but still directionally. It is typically desired to have an *efficient* directional antenna.

Antenna measurement procedure:

Assuming the signal generator, vector voltmeter, directional coupler, and measurement antenna are designed for and characterized at the frequency band of interest; the following general antenna measurement procedure may be applied. The process is easily extended to multiple-frequency measurements by simply programming the signal generator to change frequency at each azimuth position. The antenna measurements may be taken in any desired degree increment; a useful range of azimuth increments is from about 1 to 5 degrees. This translates to a range of 360 to 72 steps, depending on the increment value selected. The measurements shown later in the application note used 72 and 144 steps, translating to 5 and 2.5 degree increments for LTSA “B” and “A” respectively.

The initial setup requires the antenna under test (AUT) to be pointed directly at the measurement antenna. Ideally, the AUT will be pointed on boresight to the measurement antenna, with a shared axis between the two antennas. Boresight refers to the 0 degree angle where the antenna is pointed straight at the other antenna or object of interest. Anti-boresight is the 180 degree rotated position where the antenna is pointed directly away from the other antenna or object of interest. By reciprocity, either antenna may be used for transmit or receive [2]. In the example setup, a cable is provided from the vector voltmeter to the AUT. Thus, the example setup uses the AUT for receiving, and the measurement antenna for sending. The signal generator connects to the directional coupler, with the through port of the directional coupler connecting to the measurement antenna. The test (or coupled) port on the directional coupler feeds into

one port of the vector voltmeter. This typically -20dB sample of the signal generator output allows a rough estimate of absolute receive strength magnitude, and hence the gain of the antenna system. However, since the measurement antenna is not an isotropic radiator with perfect 0dBi gain at all frequencies, the -20dB sample does *not* account for frequency-dependent behavior of the measurement antenna. In effect, the measurements are biased by the characteristics of the measurement antenna. A practical method to de-embed this bias is to measure the antenna pattern of a known antenna (such as a horn antenna), and then use the results from the known antenna to show how the measurement antenna is affecting the measurements. Finally, there is significant loss caused by the free-space between the measurement antenna and the AUT. This loss is also frequency-dependent, and a reference measurement with a known antenna will serve to facilitate de-embedding this error term. A general diagram of an antenna measurement system is given in Figure A.1.

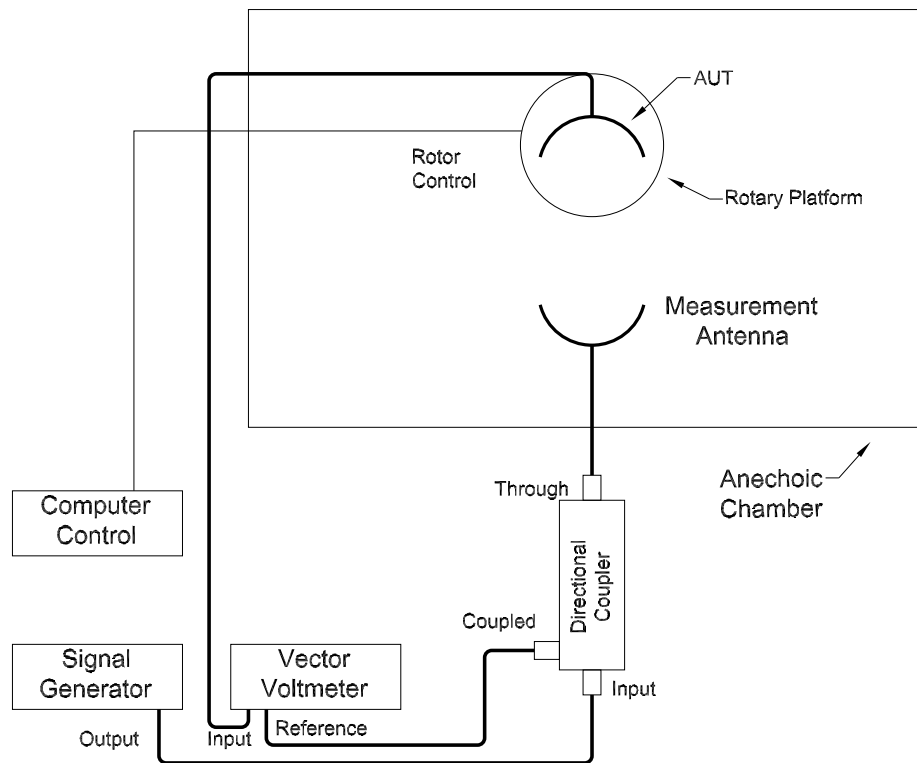


Figure A.1: Antenna Measurement System Block Diagram

After the AUT is pointed directly at the measurement antenna, the anechoic chamber door is closed behind the person exiting the chamber, so that the measurements

are as isolated from the outside world as possible. Then, the antenna measurement program is executed. The measurement program will rotate the AUT in the increments specified (e.g. 2.5 degrees). At each increment, the antenna rotator will pause, and the signal generator/vector voltmeter pair will sweep through the programmed frequency band of interest. The frequency step size is chosen by the user, depending on the frequency sensitivity of their application and the time available to test the antenna. Because each frequency takes a few seconds to measure, measuring thousands of frequencies at each rotation step could take an excessively long amount of time, and generate enormous amounts of data. When measuring a broadband antenna such as an LTSA, the exact performance at 1MHz increments may not be as important as understanding the performance of the antenna across a broad bandwidth (e.g. 2-4GHz). Thus, a 50MHz or 100MHz frequency step size may be more appropriate to the measurement application.

A proprietary LabVIEW application has been developed at Michigan State University to control this measurement process. Virtually any programming language with the ability to control a stepper motor and communicate using the GPIB protocol to the RF test instruments might be used for antenna measurement system control. A pseudocode implementation could be as follows:

```
For i=1 to NumOfPositionSteps
    For j=1 to NumOfFrequencySteps
        Measure SignalStrength at Frequency "j"
    End
    Move to next position "i"
End
```

Obviously, the code will also include a section to accept user input of the frequency band limits and step size, as well as position step size. The program should also give the ability to save the measured data, and display the data in graphical format.

Overview of Linear Tapered Slot Antenna Design:

The LTSA has been described in many texts and throughout the literature. References 4 through 9 give only a small sampling of the rich discussion of LTSA design

in the literature and monographs. The LTSA's measured for this application note were developed by Dr. Gregory Charvat for his PhD dissertation project [13]. Dr. Charvat donated two of his prototype LTSA's for use on the NRL Senior Design project radar system. The LTSA's were designed to cover approximately 2 to 4GHz. One of the LTSA's (LTSA "A") was created early in development, and it does not perform as well as the later prototype (LTSA "B"). Dr. Charvat used a chemical etch process to create these prototypes. The chemicals for such a process are available from Radio Shack and many electronics wholesalers at a reasonable cost. The difference in design between the two LTSA's will illuminate the sensitivity of the measurement process to changes in the LTSA physical characteristics.

The LTSA shown in Figure A.2 is a general design for an LTSA. Parameter "L", the length of the tapered aperture, affects primarily the directivity, and hence the beamwidth of the LTSA. Several of the following parameters are developed in Reference 4. "L" is typically chosen to be greater than 2.6 times the free-space wavelength as in Equation 1. Parameter "W", the aperture width, is typically chosen to be greater than ½ the free-space wavelength of the lowest frequency the LTSA will be used at, as in Equation 2. As a good design practice, the cutoff frequency should be set about 10% lower than the actual frequency of lowest use, to avoid the risk of the traveling waves failing to propagate as expected near the lower edge of the desired frequency band [11].

$$\frac{L}{\lambda_0} > 2.6 \quad (1)$$

$$W > \frac{\lambda_0}{2} \quad (2)$$

The peak gain of the LTSA (near boresight) is approximated by Equation 3. The beamwidth of the antenna is approximated by Equation 4. A useful value for the aperture angle α has been cited in the literature as 11.2 degrees [4], however, minor variations from 11.2 degrees do not adversely affect the antenna performance from Equations 1-4. Increasing α has been observed to reduce antenna beamwidth. In this radar application, a broader beamwidth is desired, so the angle α will be maintained near 11 degrees. λ_0 is the free space wavelength of the RF frequency in use.

$$Gain[dB] = 10 \log \left(4 \frac{L}{\lambda_0} \right) \quad (3)$$

$$Beamwidth[deg] = \frac{77}{\sqrt{\frac{L}{\lambda_0}}} \quad (4)$$

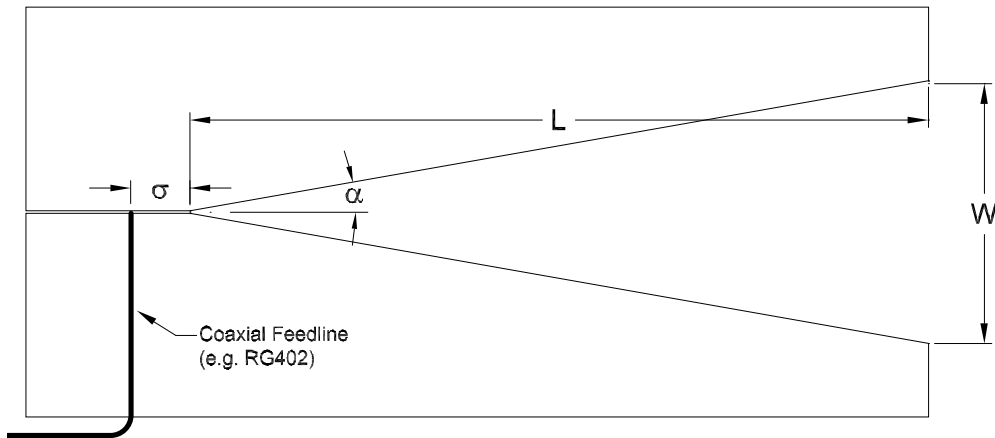


Figure A.2: Typical LTSA geometry

Measurement Results:

Two LTSAs were measured in the Electromagnetics Teaching Laboratory at Michigan State University. A helical antenna was used as the measurement antenna. A helical antenna is sometimes used as a measurement antenna due to its circular polarity—the helical antenna is theoretically equally sensitive to any linear polarization [10,12]. A photo of the LTSA designed as LTSA “A” is given in Figure B.1. LTSA “B” is shown in Figure B.2. LTSA “A” was an earlier prototype, with non-idealities in the slot feed region—instead of being approximately 1mm as is typical for an antenna in this frequency range, the gap is over 4mm wide. The widened slot degrades the return loss, as will be shown later in this application note. Figure B.3 shows the feedpoint of LTSA “B”—this feed method using coaxial cable is an easy way to feed an LTSA, but will not have as broad a bandwidth as more advanced feed methods [9]. The extra ground solder joints seen are for physical robustness. The FR4 laminate had a relative epsilon of 4, and was 1.524mm thick. The literature gives further detail about the types of substrate that may be used (including Styrofoam) [4].



Figure B.1: LTSA “A” photo



Figure B.2: LTSA “B” photo



Figure B.3: Photo of LTSA “B” feed method

Two issues immediately arose in the measurement system that could not be corrected, since their correction required equipment replacement. The first issue was that the signal generator and vector voltmeter pair could only go up to 2.0GHz. The intended frequency range of the LTSAs for the Senior Design project was from 2.0 to 2.5GHz. The second issue was that the helical measurement antenna was designed for 1.2GHz, and was thought by the MSU technical staff not to work at all above 1.6GHz. It turned out that the measurements of the LTSAs were indeed going to be improvised, since the LTSAs could not be measured within their designed frequency range. Since it was necessary to get some confirmation, even if crude, that the LTSAs were radiating energy with some reasonable directivity, it was decided to proceed despite the undesirable measurement system.

Two distinct LTSA designs were measured. Both followed the geometry of Figure A.2, but had unique L and σ values. The data are given in Table B.1.

LTSA	L (m)	W (m)	σ (mm)	α (deg)
A	0.451	0.162	61.9	10.2
B	0.368	0.162	101.6	12.4

Table B.1: As-built LTSA geometry

The experimental measurements were observed to not meet expectations above 1.6GHz, as expected from conversation with the technical staff. Performance parameters were calculated at 2.0GHz, since 2.0GHz was the lowest frequency the LTSAs were designed for. It is expected that since the LTSAs are measured at 1.6GHz, there may be some deviation of the measurements from the calculated values. These calculated data are given in Table B.2. It is apparent from the calculated cutoff frequency that there is a potentially critical issue, since the antenna may perform poorly below the cutoff frequency due to the traveling waves necessary for the LTSA to function not behaving as expected.

LTSA	Gain (dB)	Beamwidth (deg)	Cutoff freq. f_c (GHz)
A	10.8	25.6	1.85
B	9.9	31.3	1.85

Table B.2: LTSA calculated performance

The MATLAB code in Appendix A was generated to give a graphical view of the relevant calculated parameters. It must be noted that the calculated values are not reliable below the cutoff frequency of 1.85GHz. The plot in Figure B.4 shows the gain with respect to frequency, Figure B.5 shows the beamwidth with respect to frequency, and Figure B.6 shows the normalized length with respect to frequency (this should be greater than 2.6 for proper functionality of the LTSA [4]).

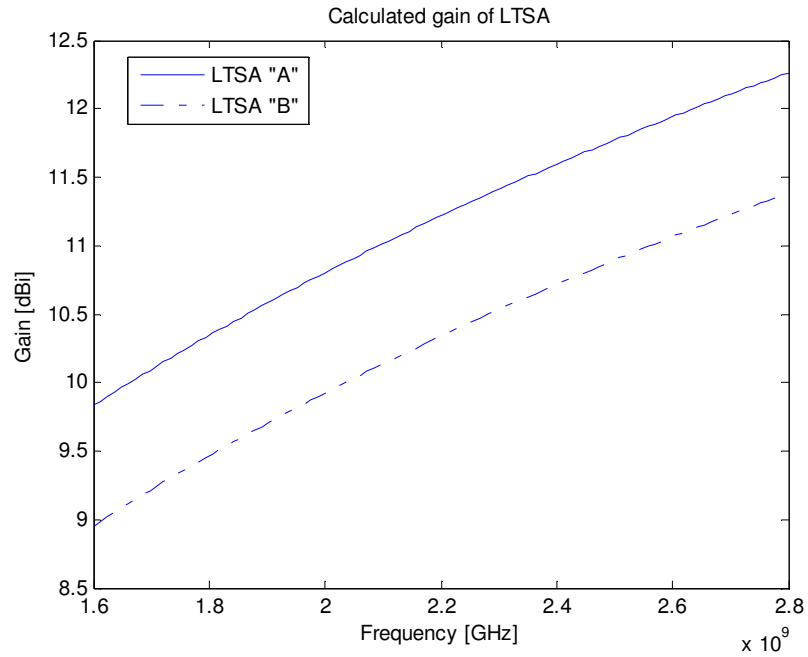


Figure B.4: LTSA calculated gain w.r.t. frequency

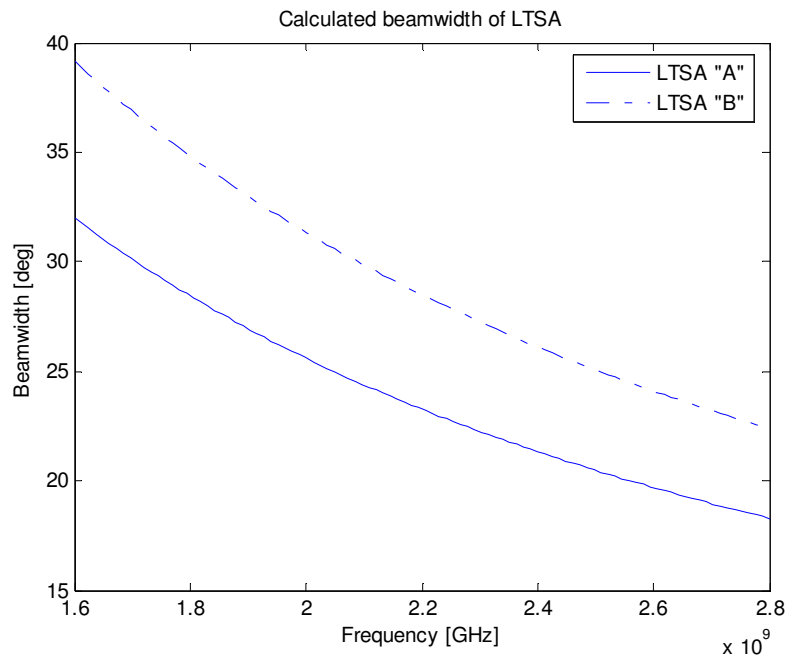


Figure B.5: LTSA calculated beamwidth w.r.t. frequency

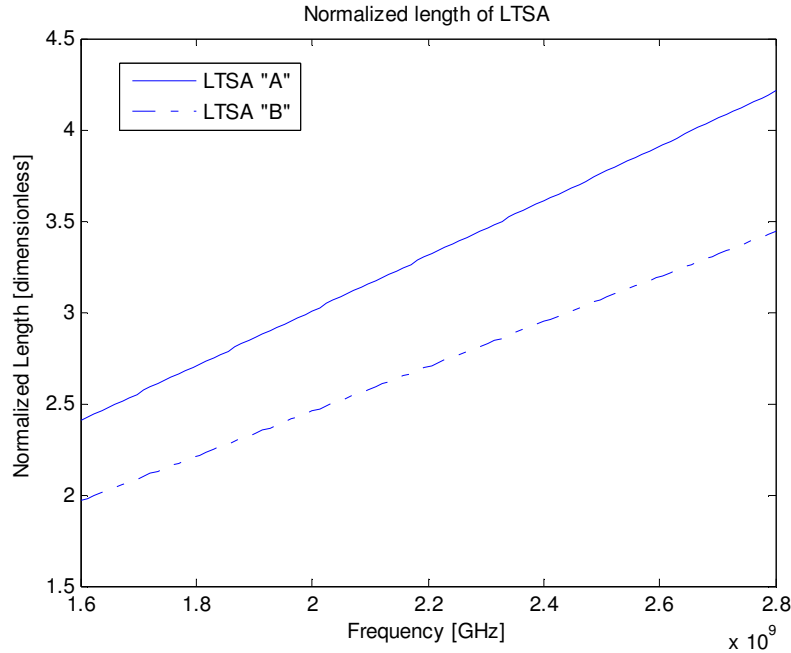


Figure B.6: LTSA calculated normalized length w.r.t. frequency

An additional issue with the measurement system is that the geometry of the anechoic chamber is not large enough to put the antenna in the far-field region. Ideally, a specially shaped scatterer would be used to generate the effect of the AUT being in the far-field region. The desirability of having the AUT in the far-field region is detailed in Balanis [12]. Since a more suitable antenna measurement facility is not available, it will have to be realized that there is another layer of error embedded with the measurement data. An overview sketch of the anechoic chamber is given in Figure B.7. Dimensions in Figure B.7 are approximate and in meters. There is an entry door in the center of the left wall of the chamber. The view given in Figure B.7 is from the top down. Figure A.1 gives a block diagram of the antenna measurement system.

Several photos are given of the anechoic chamber equipment, to give a concept of how an improvised anechoic chamber system may be configured. Figure B.8 is a photograph of the helical measurement antenna. Figure B.9 depicts the AUT on the rotary platform inside the anechoic chamber. Figure B.10 shows the rotary platform base, in which a stepper motor is contained to precisely position the antenna in azimuthal increments. Figure B.11 gives a photo of the AUT and measurement antenna—the experienced observer will note that the two antennas are rather close together. The AUT

is not in the far zone, causing increased difficulty in antenna pattern measurement. To put the AUT in the far zone would require a larger anechoic chamber with more sophisticated equipment (as discussed in Reference 12), thus the improvised chamber will have to suffice. Figure B.12 shows the external equipment used to measure the antenna—the signal generator is on the upper left, and the vector voltmeter and directional coupler are on the upper right.

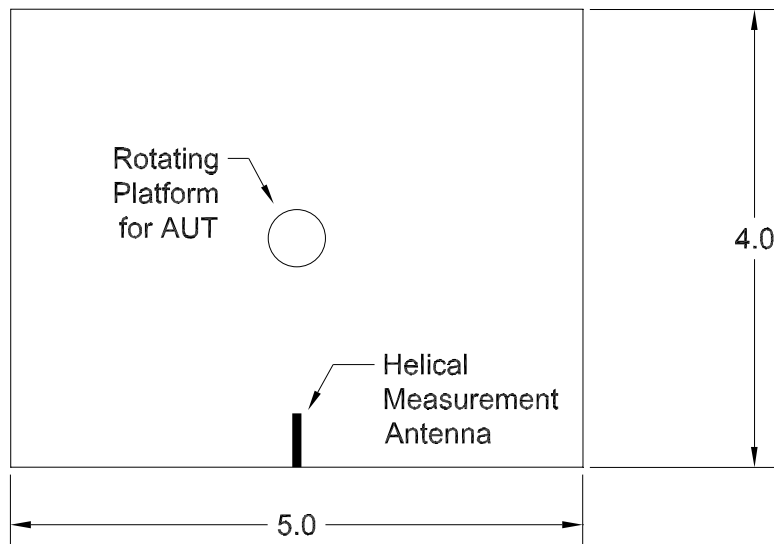


Figure B.7: MSU EM Teaching Lab Anechoic Chamber Dimensions



Figure B.8: Helical measurement antenna

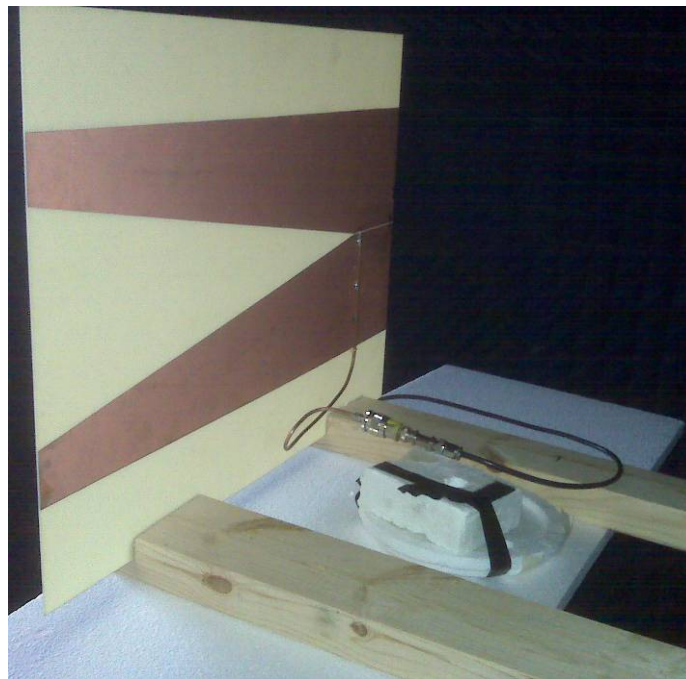


Figure B.9: AUT in anechoic chamber



Figure B.10: Base of rotary AUT platform

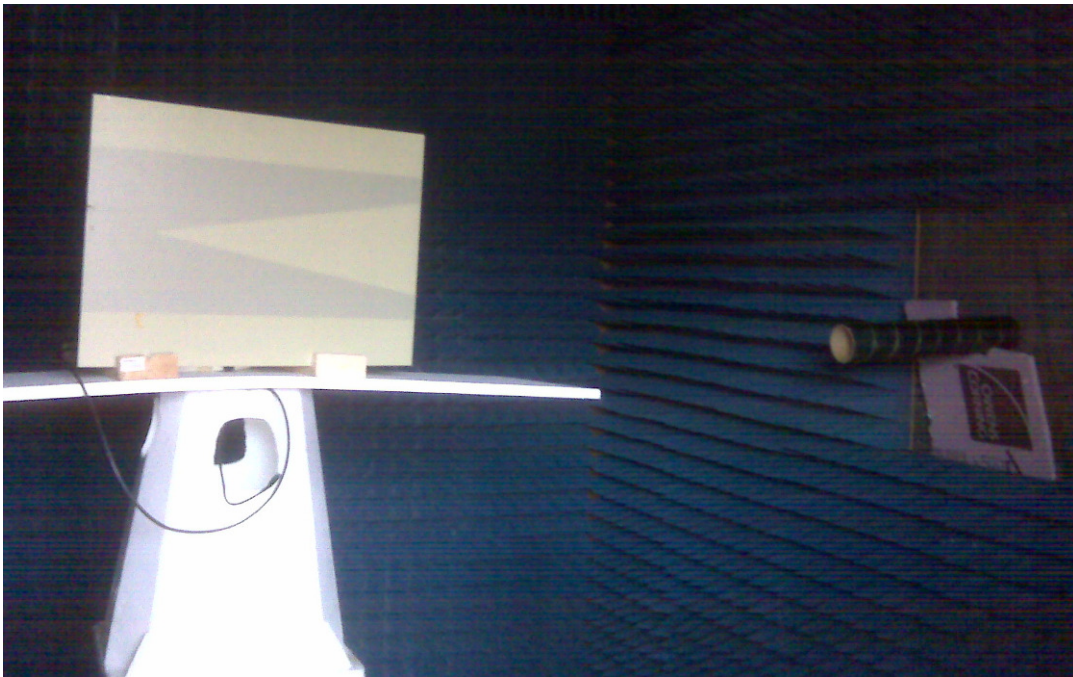


Figure B.11: View of AUT and Measurement Antenna



Figure B.12: View of Measurement/Control Equipment

Since it is difficult to work out the absolute gain of the antenna with the equipment used and the configuration of the anechoic chamber, a first glance at the antenna pattern data should focus on the front-to-back ratio (FBR) of the antenna. A basic desirable FBR would be on the order of 10 to 20dB for a laboratory radar system, based on the author's experience. The FBR of the LTSA helps the radar avoid "seeing" targets behind it. In a communications system, FBR helps the system receive and transmit to only stations in one direction, within the finite beamwidth of the antenna.

For the sake of brevity, only antenna pattern plots taken at 1.6GHz will be shown. It is known from MSU technical staff experience that the antenna measurement configuration in the MSU Electromagnetics teaching laboratory does not work above 1.6GHz. Going lower than 1.6GHz will just take the LTSA even further outside its designed RF bandwidth. Such a configuration runs the risk of getting bad results, which can sometimes be worse than no results if the bad results lead to false design conclusions. The justification for taking the risk in this case is that since the return loss of the LTSA could be measured across 1.4-2.8GHz, and the LTSA return loss was adequate across much of this range, the physics of traveling wave antennas would be relied upon. That is, literature spanning the past three decades discusses the robustness of the LTSA design

when the angle α is maintained near 11 degrees on substrates similar to the FR4 type used to build these LTSAs. Finally, since the antenna characteristics can be informally verified with the sensitive magnitude display of the radar using a known calibration target moved horizontally about the antenna center, the anechoic chamber results are not relied upon as the sole source of antenna performance information. Essentially, a well-known antenna design (LTSA) is being used with design parameters within commonly used limits. The anechoic chamber tests are being used as a rough verification that something has not gone critically wrong with the construction of the LTSAs, versus an exact measurement of performance, which is not possible with the antenna measurement system used.

The LTSA “A” antenna pattern at 1.6GHz is shown in Figure C.1. It is again noted that all antenna patterns in this application note are azimuthal only, since azimuthal information is of primary interest for the particular laboratory radar system these LTSAs will be used with. It is noted that the peak gain is approximately -44dB relative near boresight, while the gain in the anti-boresight direction is at about the -58dB relative level. Thus, LTSA “A” exhibits 24dB of front-to-back ratio, despite being outside its designed frequency range. Tentatively, it can be said that the LTSA appears to be functioning “OK” with respect to FBR.

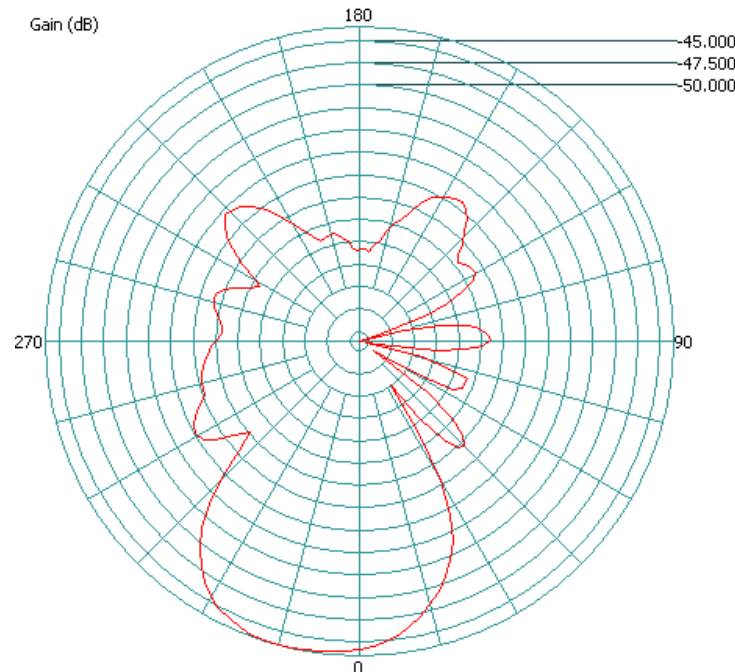


Figure C.1: LTSA “A” antenna pattern at 1.6GHz

The azimuthal antenna pattern for LTSA “B” is shown in Figure C.2. Boresight gain of -40dB relative is observed, with anti-boresight gain of -54dB relative. Thus, a FBR of 14dB is realized, which is an adequate level of performance, considering that the LTSA is being operated outside of its intended frequency band. Note that for both LTSAs, the gains given were relative. It could be instructive to compare these results with an antenna designed to radiate at 1.6GHz.

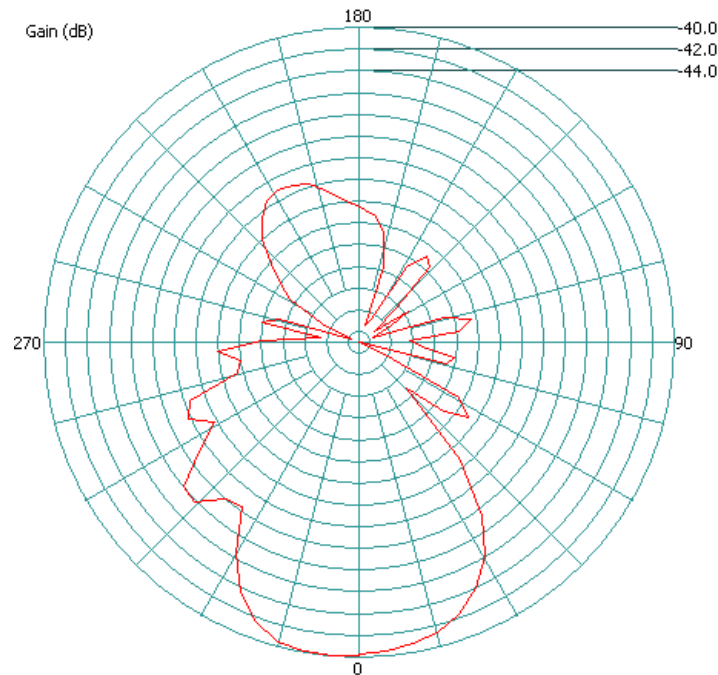


Figure C.2: LTSA “B” antenna pattern at 1.6GHz

A manufactured horn antenna designed for at least 1.0GHz to 2.0GHz was available for testing. The manufacturer of the horn antenna is unknown, but the horn antenna was in like new condition, with a specified gain of 10dBi. The horn antenna pattern was measured at 1.6GHz in an effort to establish an order of magnitude estimate for the gain of the LTSAs. The horn antenna pattern is given in Figure C.3. A photo of a typical horn antenna is given in Figure C.4. This is not the actual horn antenna used in testing; a photo of the tested horn was not available.

It is instructive to compare the antenna pattern measurements of the horn antennas with both LTSAs, as shown in Table C.1. It is tentatively noted that LTSA “B” appears to have 16dBi gain, and LTSA “A” appears to have 12dBi gain. These assertions are based on that the horn antenna has -46dB relative gain, and given that the horn antenna is

supposed to have 10dB gain, the LTSA “A” relative gain of -44dB yields $10\text{dBi}+2\text{dB}=12\text{dBi}$ gain. For LTSA “B” with a relative gain of -40dB, comparing the relative gain with the horn antenna yields $10\text{dBi}+6\text{dB}=16\text{dBi}$. The calculated gains for these LTSAs were 9.9dBi and 11.3dBi, respectively. The absolute gain measurements should not be relied on too much, because of the near-field interactions occurring in the test setup, among other factors. The absolute gain measurements here do provide a bit more assurance of functionality than if the LTSAs measured -20dB gain relative to the horn antenna, as an informal check.

Antenna	Relative Gain (dB)	Beamwidth (deg)	FBR (dB)
LTSA “A”	-44	40	24
LTSA “B”	-40	45	14
Horn	-46	50	14

Table C.1: Antenna measured performance comparison

Table C.1 shows that LTSA “B” has the highest gain, but that LTSA “A” has the best FBR. For a radar system, typically a high FBR is valued, so it could be tempting to state that LTSA “A” is the “best” antenna, even beating out a commercial horn antenna. It is seen that the measured beamwidth is roughly 1.5 times the calculated beamwidth. The beamwidth is not critical to the radar project, thus the measured performance is considered adequate for the radar. However, LTSA “A” has some design irregularities that impair return loss performance, also very important to radar systems design, and the irregularities would be difficult to duplicate. Essentially, LTSA “A” is actually not the best design, and details on this assertion will be seen presently through an examination of the return loss.

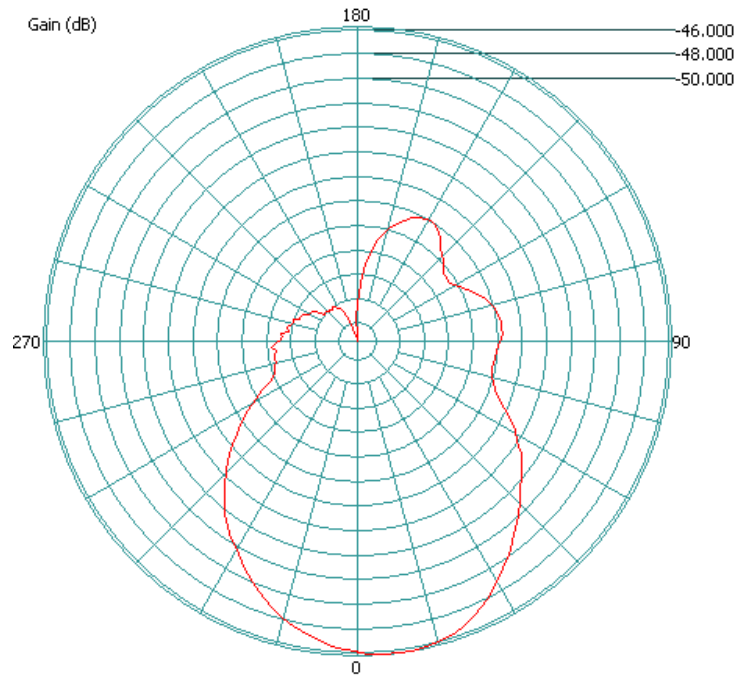


Figure C.3: 10dBi horn antenna pattern at 1.6GHz

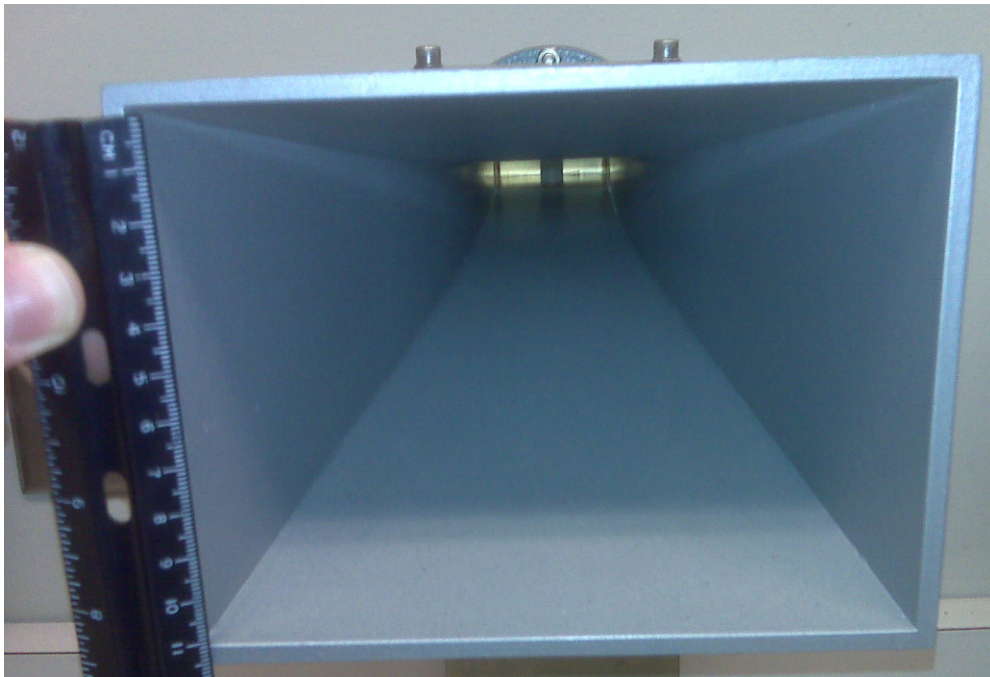


Figure C.4: Photo of typical horn antenna

The return loss of an RF device essentially refers to how well a device absorbs power (versus reflecting it back to the source, an undesirable situation) [2]. Ideally, the magnitude of the return loss will be a large negative value (e.g. -40dB). For antennas, a

“good” return loss is often taken as being -10dB or less, from the author’s experience. An alternative expression of how well a device is absorbing the power transmitted to it is VSWR, the voltage standing wave ratio. Ideally, VSWR=1. For antennas, a VSWR less than 2 is considered desirable (VSWR=2 is approximately equivalent to a return loss of -10dB) [12]. The return loss of an LTSA is optimized by selecting the feedpoint distance σ from the LTSA apex. σ is typically experimentally determined by connecting the feedpoint of the antenna to a VNA through a coaxial cable, and then sliding the feedpoint back and forth along the slit (increasing or decreasing σ) until the best overall return loss is observed over the band of interest [9]. At frequencies far from the design frequency band of the LTSA, poor return loss will typically be observed, indicating that the antenna is rejecting most of the power sent to it—hence, the antenna will radiate signals very poorly when the return loss is poor (return loss $\gg$ -10dB or VSWR $\gg$ 2).

The return loss of the LTSAs was measured using a configuration similar to that seen in Figure D.1. The VNA is on the right-hand side of the photo. The VNA was calibrated using the standard procedures (calibration of the VNA is device-specific, and outside the scope of this application note). It is noted that only return loss magnitude was measured across the frequency band of interest, thus, no electrical delay compensation was applied. The LTSA did not appear overly sensitive to the orientation of the cables as shown in the photograph. Adverse affects on return loss were observed if objects were brought within the “vee” area of the LTSA, so the sliding of the feedpoint was accomplished from behind the antenna, that is, the upper right hand quadrant of Figure D.1. It is best for the engineer to read a primer on return loss measurements if they are unfamiliar with return loss measurements; such documents are entire booklets unto themselves, and so this information cannot be contained within this application note. References 11 and 12 are suggested for a discussion of return loss measurement considerations.

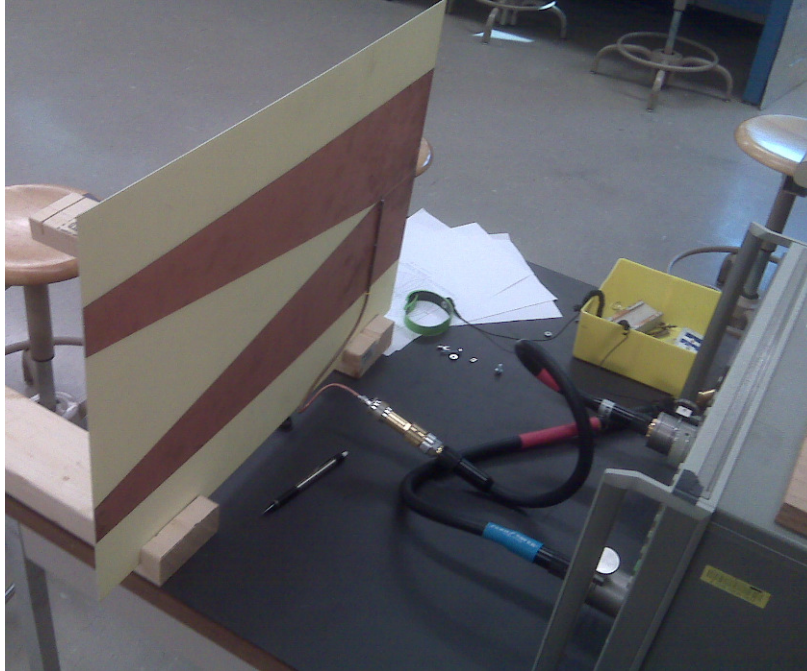


Figure D.1: Photo of return loss measurement configuration

The GPIB interface between the computer and VNA was non-functional, so as a last resort, photographs were taken of the VNA display. This is a crude method, and limits the amount of analysis that can be accomplished. However, the LTSAs were successfully tuned visually under these conditions.

Figure D.2 shows the VSWR for LTSA “A”. The LTSA “A” has VSWR worse than 2 across much of the band of interest. The VSWR does stay below 3, so the match is not extremely terrible, but this is not an antenna desirable for use on a radar transmitter. High amounts of reflected power can disrupt the proper operation of a radar transmitter. It was elected to put LTSA “A” on the radar receiver, since the main impact the poor VSWR would have on the receiver is believed to be slightly increased loss (reduction in maximum possible gain) [2, 12]. It is apparent in Figure D.3 that the VSWR for LTSA “B” is under 2 from just over 2.0GHz to 2.8GHz. Thus, more than adequate VSWR=2 bandwidth was accomplished for LTSA “B”. The VSWR for the horn antenna is shown in Figure D.4. It is apparent that the horn antenna has VSWR<2 as high as 7GHz. The lower frequency for VSWR<2 is around 1.4GHz, but the jumps up to about 2.5 VSWR are noted around 2GHz. These imperfections are to be expected in a broadband antenna, even manufactured antennas.



Figure D.2: VSWR of LTSA "A" from 1.4GHz to 2.8GHz



Figure D.3: VSWR of LTSA "B" from 1.4GHz to 2.8GHz



Figure D.4: VSWR of horn antenna from 400MHz to 12GHz

Conclusions:

An improvised method for characterizing the performance of linear tapered slot antennas was implemented as explained in this application note. The design procedure developed from information in the literature was applied to two distinct LTSA designs, and compared with their measured performance. The limitations imposed by the antenna measurement equipment were significant, but were mitigated to an extent by insights into the general behavior of LTSAs and antenna measurement systems in general.

The performance of the LTSAs as measured cannot be guaranteed, due to the limitations described throughout the application note. However, the engineer may gain some confidence that the LTSA design may not be completely useless, since the manufactured horn antenna showed comparable results, despite the many limitations of the measurement system. By following the procedures in this document, an engineer may develop a broadband radar antenna with only modest measurement facilities. The performance of the antenna may be further verified by implementing the antenna on a radar system of known performance, or by sending the antenna to a professional antenna measurement laboratory.

Appendix A:

```
clear all, close all
% approximations only valid when LTSA is above the curoff frequency ( $W > \lambda/2$ )

f=linspace(1.6e9,2.8e9,100);
w=2.*pi.*f;

c=299792458;

lambda=c./f;

L(1)=17.75*0.0254;
L(2)=14.5*0.0254;

Gain(:,1)=10.*log10(4.*L(1)./lambda);
Gain(:,2)=10.*log10(4.*L(2)./lambda);

Beamwidth(:,1) = 77./(L(1)./lambda);
Beamwidth(:,2) = 77./(L(2)./lambda);

NormLength(:,1) = L(:,1)./lambda;
NormLength(:,2) = L(:,2)./lambda;

figure
plot(f,Gain(:,1)), hold on, plot(f,Gain(:,2),'-.'), hold off
legend('LTSA "A"', 'LTSA "B"')
xlabel('Frequency [GHz]'), ylabel('Gain [dBi]')
title('Calculated gain of LTSA')

figure
plot(f,Beamwidth(:,1)), hold on, plot(f,Beamwidth(:,2),'-.'), hold off
legend('LTSA "A"', 'LTSA "B"')
xlabel('Frequency [GHz]'), ylabel('Beamwidth [deg]')
title('Calculated beamwidth of LTSA')

figure
plot(f,NormLength(:,1)), hold on, plot(f,NormLength(:,2),'-.'), hold off
legend('LTSA "A"', 'LTSA "B"')
xlabel('Frequency [GHz]'), ylabel('Normalized Length [dimensionless]')
title('Normalized length of LTSA')
```

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