CH201 and ICU-20201 Acoustic Housing Reference Designs

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1 INTRODUCTION

The purpose of this document is to provide information on the acoustic housing reference designs for the Chirp CH201 and ICU-20201 ultrasonic sensors. This document will provide an overview of how to compare acoustic housing designs and present performance profiles of the reference designs. All dimensions mentioned in this document are in mm, unless otherwise specified.

The information in this guide only covers information related specifically to Chirp Microsystems' CH201 and ICU-20201 sensors, and not other sensors, such as the CH101 and ICU-10201.

It is recommended to review the following application documents for further information on the integration, assembly, and handling of the CH201 and ICU-20201 sensors:

AN-000159, CHx01 and ICU-x0201 Ultrasonic Transceiver Handling and Assembly Guidelines

AN-000221, CH201 and ICU-20201 Mechanical Integration Guide

AN-000223, Acoustic Interface Gluing Procedure for Chirp Ultrasonic Sensing Modules

2 ACRONYMS AND ABBREVIATIONS

Some commonly used acronyms and abbreviations in this document are listed in Table 1.

Acronym or Abbreviation	Definition
ADC	Analog-to-digital converter
dB	Decibel
FoV	Field-of-View
FWHM	Full-width half-maximum
IR	Infrared
LSB	Least significant bit (ADC counts)
MEMS	Micro-electro-mechanical system
PIF	Particle ingress filter
PMUT	Piezoelectric micromachined ultrasonic transducer
SNR	Signal-to-Noise ratio
ToF	Time-of-Flight

Table 1. Acronyms and Abbreviations

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3 OVERVIEW

3.1 THEORY OF OPERATION

The CH201 and ICU-20201 are ultrasonic transceiver rangefinders that use a piezoelectric micromachined ultrasonic transducer (PMUT) to send out short pulses of sound waves into the air. These waves, upon hitting an object, reflect towards the PMUT, causing it to vibrate and generate an electrical signal.

As ultrasonic transceivers, the CH201 and ICU-20201 sensors can both transmit and receive ultrasound signals. Unlike various types of passive sensors which simply measure their surrounding conditions, the CH201 and ICU-20201 actively inject a signal into their environment. To perform a basic distance measurement, the sensor will emit a very brief pulse of ultrasound into the air in front of it. It then immediately enters a “listening” state, in which it samples the received sound, attempting to identify an echo of the pulse that has been reflected off an object in the sensor’s vicinity. If an ultrasound pulse is identified, the sensor will analyze the signal to determine the timing and then report the time-of-flight (ToF) of the received pulse. The actual distance travelled by the ultrasound can then be calculated from the ToF based on the speed of sound.

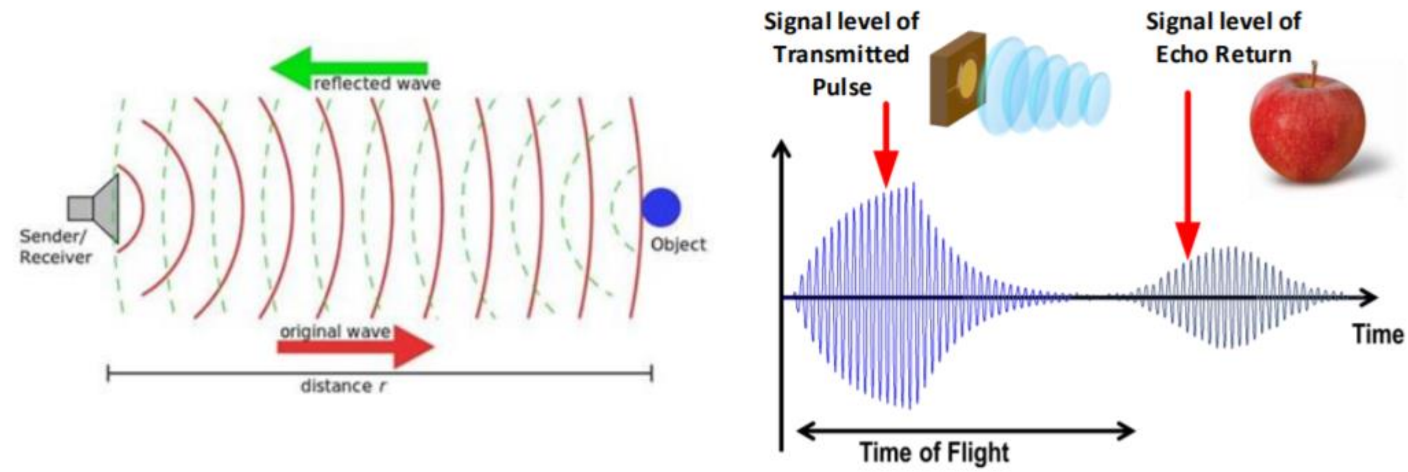


Figure 1: Ultrasonic Sensing Basics.

3.2 REFLECTED SIGNAL AMPLITUDE

For the sensor to accurately determine the TOF from the reflected signal, the amplitude of the echo signal must be greater than the detection threshold. As the distance between the sensor and the target object increases, the ultrasound pulse must travel further, and the echo’s reflected signal will become weaker. Similarly, when the target object is not directly in front of the sensor but is located at an angle away from the direction the ultrasound pulse was emitted, less of the pulse’s energy will be reflected in the direction towards the sensor. When the amplitude of the signal returning from the target object is lower than the detection threshold, the sensor will no longer be able to detect the object or calculate its distance from the sensor. Therefore, the amplitude of the ultrasound signal reflected from the target object is what limits how far and from what angle the sensor can detect an object’s distance correctly.

In addition to the distance and angle between the sensor and target, the size and shape of the target object also affect the amplitude of the echo signal received by the sensor. In general, larger and flatter targets will reflect the ultrasound waves more intensely than smaller and more curved objects.

In this document the echo signal amplitude, also called intensity, has the units of least significant bits (LSB). LSB is a unit of measure used by the Analog-to-digital converter (ADC) to quantify the sensor’s analog signal as a binary number. In some cases, intensity will also be represented as a signal-to-noise ratio (SNR), which is the signal level in decibels (dB) minus the noise level in dB.

3.3 THE PURPOSE OF ACOUSTIC HOUSINGS

Without an acoustic interface, the CH201 and ICU-20201 have poor sound output performance. This is due to the large acoustic impedance difference between the PMUT (the source) and the air (the load) resulting in the energy from the PMUT not being transferred efficiently to the air. In this regard, acoustic impedance can be thought of as analogous to electrical impedance. To improve the transfer of sound energy to the air, an acoustic housing is required in front of the sensor port hole to better match the impedance. In addition, the dimensions and geometry of the acoustic housing dictate the field-of-view (FoV) of the sensor by focusing and directing the ultrasound waves. Two broad categories of acoustic housings are used with the CH201 and ICU-20201: tubes and horns.

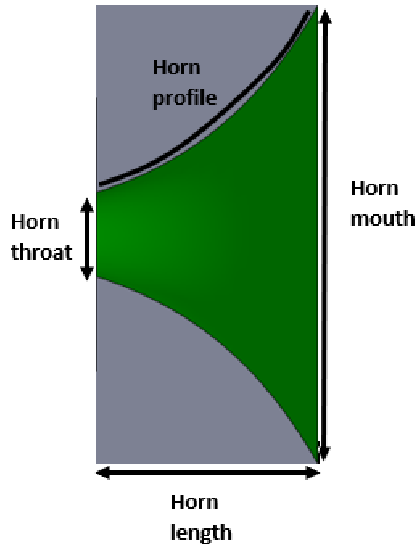


Figure 2: Terminology for Acoustic Horns.

The process of calculating and determining the required dimensions for different horns is complex and beyond the scope of this document. This document presents several reference designs with a range of performance characteristics for the evaluation of the CH201 and ICU-20201.

4 ACOUSTIC HOUSING CHARACTERIZATION AND TEST METHODS

4.1 TEST SETUP

In order to characterize the performance of an acoustic housing, a test sweep is performed to measure the sensor's ability to detect a target object at varying angles and distances, as well as different types of target objects. The characterization test setup consists of a target object positioned at a series of discrete distances away from the sensor. The sensor is assembled with the acoustic housing under test. At each test distance, the angle between the sensor and target is swept 180 degrees with range and reflection intensity measurements collected as the angle changes. The results of this test sweep are then used to compare the detection range and signal intensity of each acoustic housing tested.

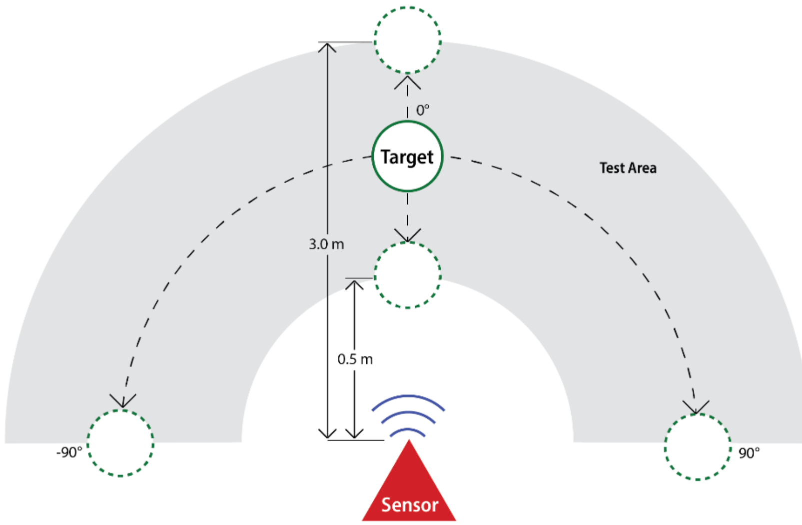


Figure 3: Sensor Test Sweep Setup Diagram.

The test data presented in this document has been collected using a target object that is either:

- a flat, 609 mm x 609 mm square target
- a 60 mm Diameter x 1524 mm height cylindrical pole target

These target objects were selected based on tests conducted that indicate the flat square target is an appropriate proxy for a flat wall, while the cylindrical pole of the specified diameter serves as an appropriate proxy for an average person standing in front of the sensor.

4.2 TESTING ENVIRONMENT

The acoustic housing characterization tests in this document were conducted in an uncluttered indoor office environment with a clean power supply. The test results presented for the acoustic housings were minimally affected by the environment and the real-life performance of the housings may differ in less ideal conditions. The typical noise values measured in the tests for this document are 65-80 LSB.

4.3 TEST THRESHOLDS

The sensor intensity threshold for range detection used in the characterization tests is 800 LSB. This limit was chosen based on the relatively ideal conditions in the testing environment and may not be optimal for other environments. Users are encouraged to conduct their own tests in an environment representative of their intended application to choose an appropriate intensity threshold.

Maximum detection distance values reported for each housing are the furthest distance the sensor can accurately detect the range of the target with a signal threshold of 800 LSB, or a 20dB SNR relative to typical noise levels. In place of a maximum detection distance for flat targets, a benchmark SNR value of 35dB is used to compare the relative detection range between housings.

4.4 POLAR BEAM PATTERN PLOT AND FIELD-OF-VIEW

A beam pattern plot, represented in polar coordinates, is a common way of visualizing how the measured amplitude of the signal from the detected target changes as the angle between the sensor and target changes. A polar beam pattern plot is also useful for understanding how Field-Of-View (FoV) is defined.

The acoustic FoV is defined as the full-width half-maximum (FWHM) of the round-trip beam pattern. FWHM refers to the width (in degrees) of the beam pattern curve at an amplitude level that is half of the maximum. In the example beam pattern shown in Figure 4, the solid red arc at -6 dB is the half-maximum level. The dashed red lines mark the extents of the beam width where it intersects with the half-maximum level, and the angular distance between the lines is the FoV. The example beam pattern in Figure 4 has a FoV of approximately 52-degrees.

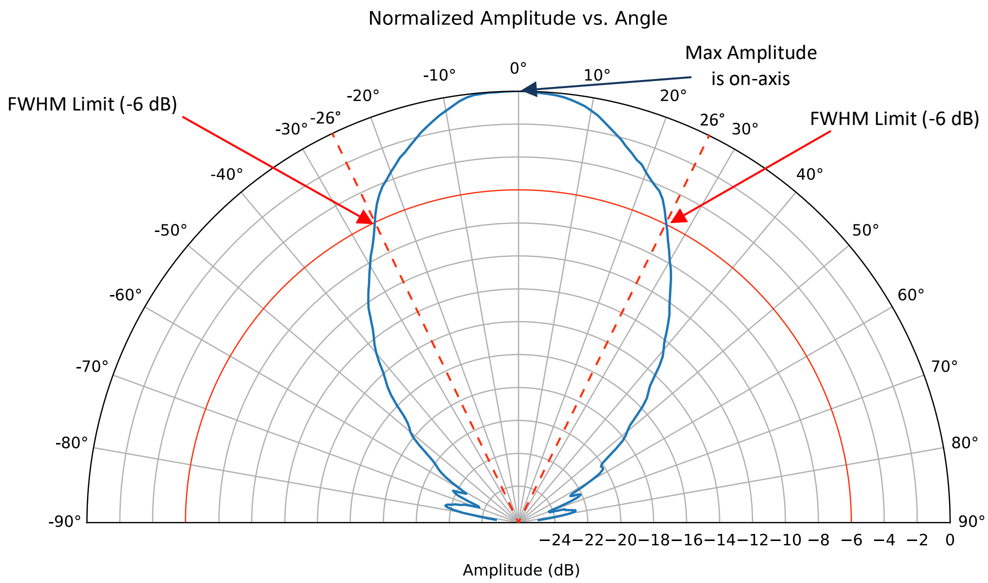


Figure 4: Example Polar Beam Pattern Plot of a ~52° FoV Horn to a Flat Target 1 meter Away.

Note how the amplitude does not fall abruptly to zero (absolute units) and that depending on the target and the distance, it will still be possible to detect targets outside the rated FoV.

While FoV is a good relative measure of how narrowly an acoustic housing focuses the sensor's acoustic waves, it is not a hard limit of what the sensor can detect.

The polar beam pattern plot is useful for visualizing the acoustic directivity of an acoustic housing, but it only shows the reflected signal amplitude at a single distance. In order to show how the signal amplitude of the sensor changes as the distance between the sensor and target changes, a different type of plot is necessary.

4.5 SNR CONTOUR PLOT

To visualize how the amplitude of the sensor and acoustic housing changes with both angle and distance, a contour plot in rectangular coordinates is used. Unlike the polar beam pattern, which shows the normalized amplitude, the contour plots presented in this document show Signal-to-Noise ratio (SNR) to enable accurate comparisons of signal amplitude between different acoustic housings.

Figure 5 shows an example of the type of SNR contour plot that will be presented for each of the reference acoustic housings in this document. The plot is created using the amplitude data from the data points where the target was accurately detected by the sensor module, represented by the gray point on the plot. The colored contour lines show the boundary within which the sensor will detect the target with a certain SNR value labeled on the line.

As an example, if the target was located at the green point labeled A on the plot, the measured SNR at that point would be between 28 dB and 26 dB. Point A and Point B are both located the same distance from the 26dB line and therefore the sensor would detect the target with the same SNR if the target were at either of those points. Point B is a good example of how the sensor can detect the target outside of the FoV because there is still sufficient signal being reflected at that position to exceed the detection threshold.

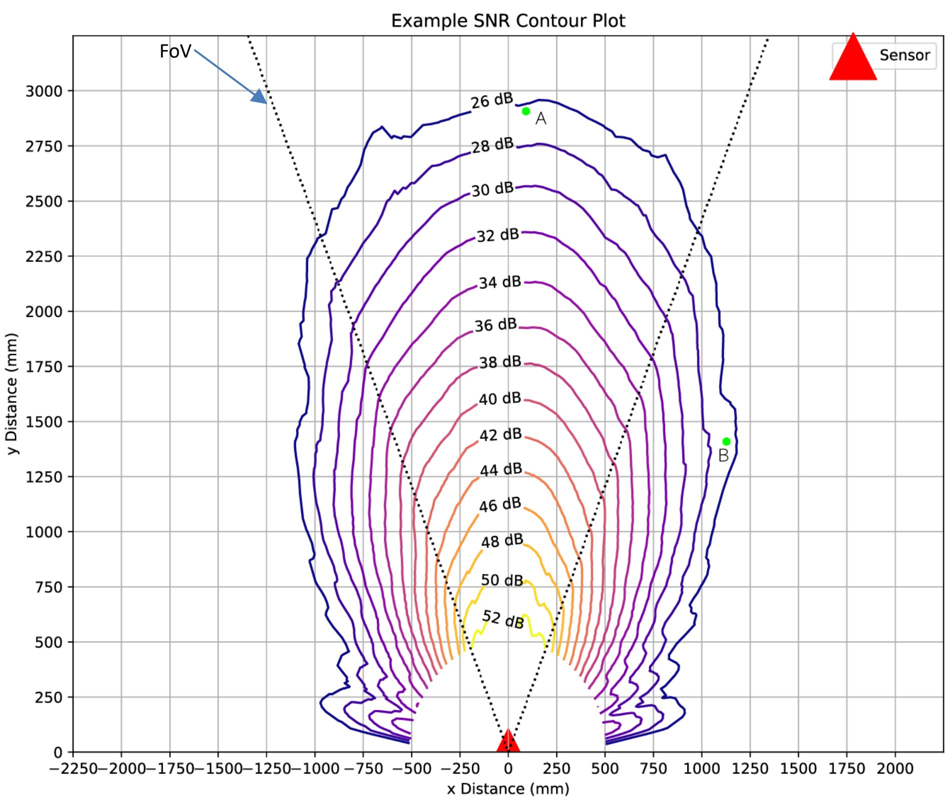


Figure 5: Example Signal-to-Noise Ratio Contour Plot for a 45-Degree Horn and Flat Target

5 ACOUSTIC HOUSING PROFILES

The following section presents several acoustic housing reference designs. The housings vary in size, maximum detection distance, FOV, and environmental protection. The characteristic information provided for each housing is intended to aid in selecting the best suited device for the user's application.

Please note that all reference housings were tested with a PIF attached, and that the PIF does affect the acoustic performance. Information on which PIF material was used and the attachment location is provided in each of the housing's profile.

5.1 REFERENCE ACOUSTIC HOUSINGS OVERVIEW

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating	Grille
AH-20129-045045-01	Horn	6.0	2.9	45	2100	1650	SAATI Acoustex B042HY[c]	IP5X	No
AH-20182-030030-01	Horn	8.5	8.2	30	3000	2300	SAATI Acoustex B042HY[c]	IP5X	No
AH-20180-045045-01	Horn	5.6	8.0	45	2350	2000	SAATI Acoustex B042HY[c]	IP5X	No
AH-20159-060060-01	Horn	4.3	5.9	60	2250	1700	SAATI Acoustex B042HY[c]	IP5X	No
AH-20140-075075-01	Horn	3.4	4.0	75	1700	1300	SAATI Acoustex B042HY[c]	IP5X	No
AH-20298-025025-01	Horn	12.7	9.8	25	2200	1750	Microvent MV-2SFG-01	IP68	Yes
AH-20222-180180-01	Tube	1.6	2.2	180	800	800	Gore GAW337	IP68	No

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.
[c]Part number provided is for bulk mesh material.

Table 2: Characteristics of Reference Acoustic Housing Designs.

5.1.1 AH-20129-045045-01 Profile

GENERAL INFORMATION

The AH-20129-045045-01 is a horn-type acoustic housing that provides a symmetrical 45-degree FoV in both the horizontal and vertical plane. It is assembled with a PIF for dust protection.

DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating
AH-20129-045045-01	Horn	6.0	2.9	45	2100	1650	SAATI Acoustex B042HY[c]	IP5X

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.
[c]Part number provided is for bulk mesh material.

Table 3: AH-20129-045045-01 Characteristics.

- CAD file for 3D printing of AH-20129-045045-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20129-045045-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.

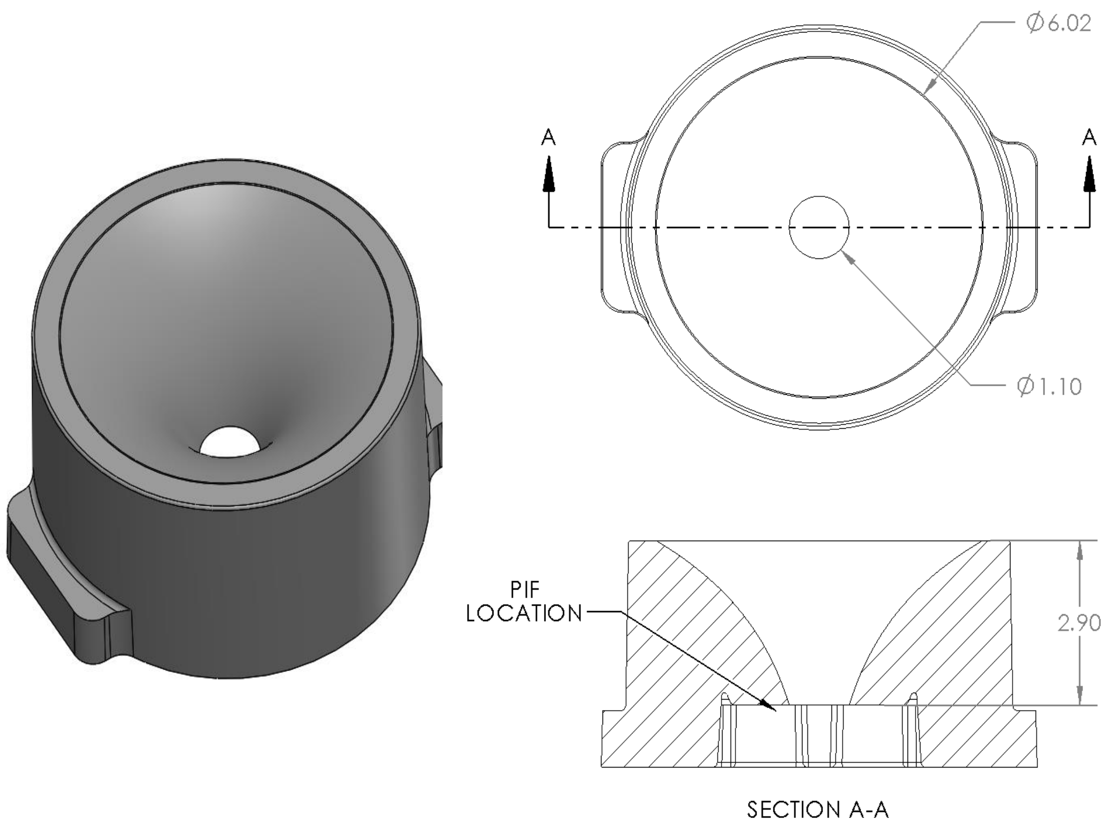


Figure 6: AH-20129-045045-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20129-045045-01 PERFORMANCE PLOTS

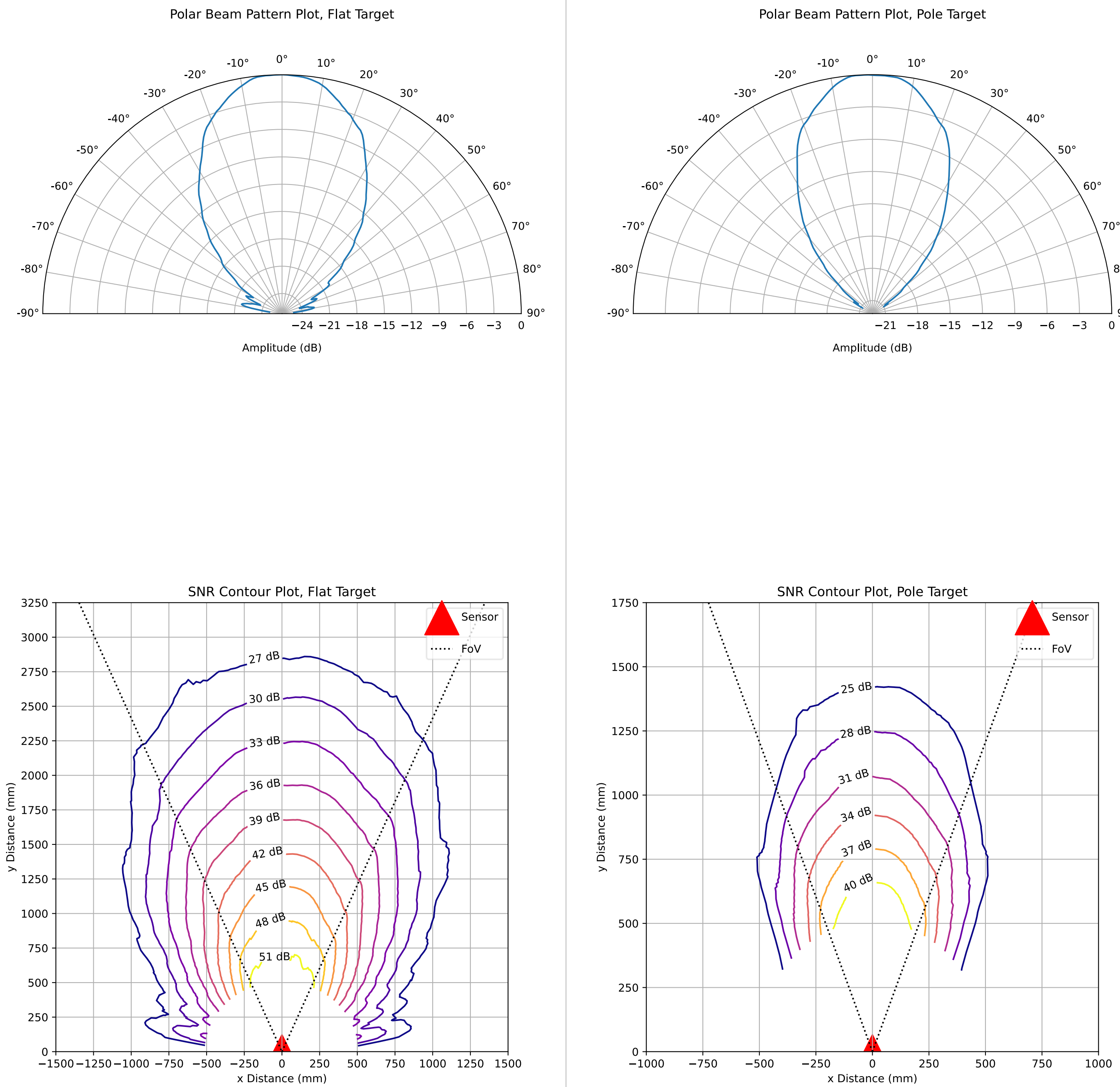


Figure 7: AH-20129-045045-01 Performance Plots for Flat (left) and Pole (right) Targets.

5.1.2 AH-20182-030030-01 Profile

GENERAL INFORMATION

The AH-20182-030030-01 is a horn-type acoustic housing that provides a symmetrical 30-degree FoV in both the horizontal and vertical plane. It is assembled with a PIF for dust protection.

DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating
AH-20182-030030-01	Horn	8.5	8.2	30	3000	2300	SAATI Acoustex B042HY[c]	IP5X

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.
[c]Part number provided is for bulk mesh material.

Table 4: AH-20182-030030-01 Characteristics.

- CAD file for 3D printing of AH-20182-030030-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20182-030030-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.

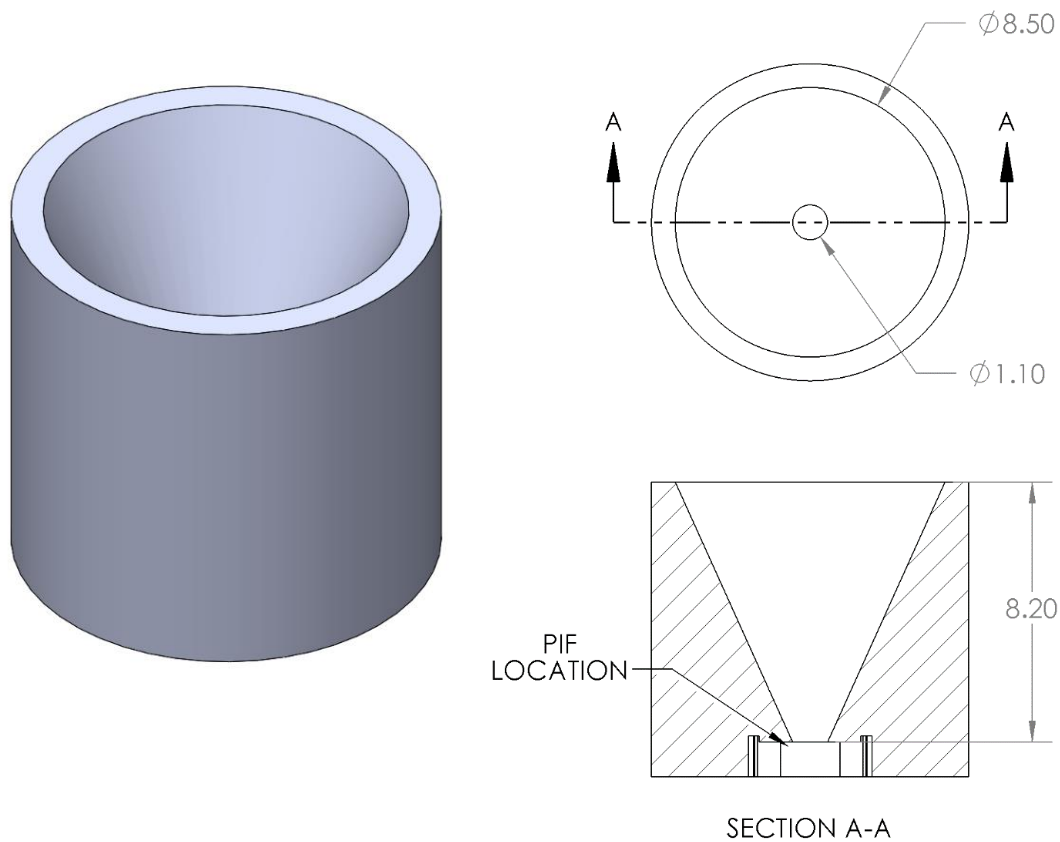


Figure 8: AH-20182-030030-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20182-030030-01 PERFORMANCE PLOTS

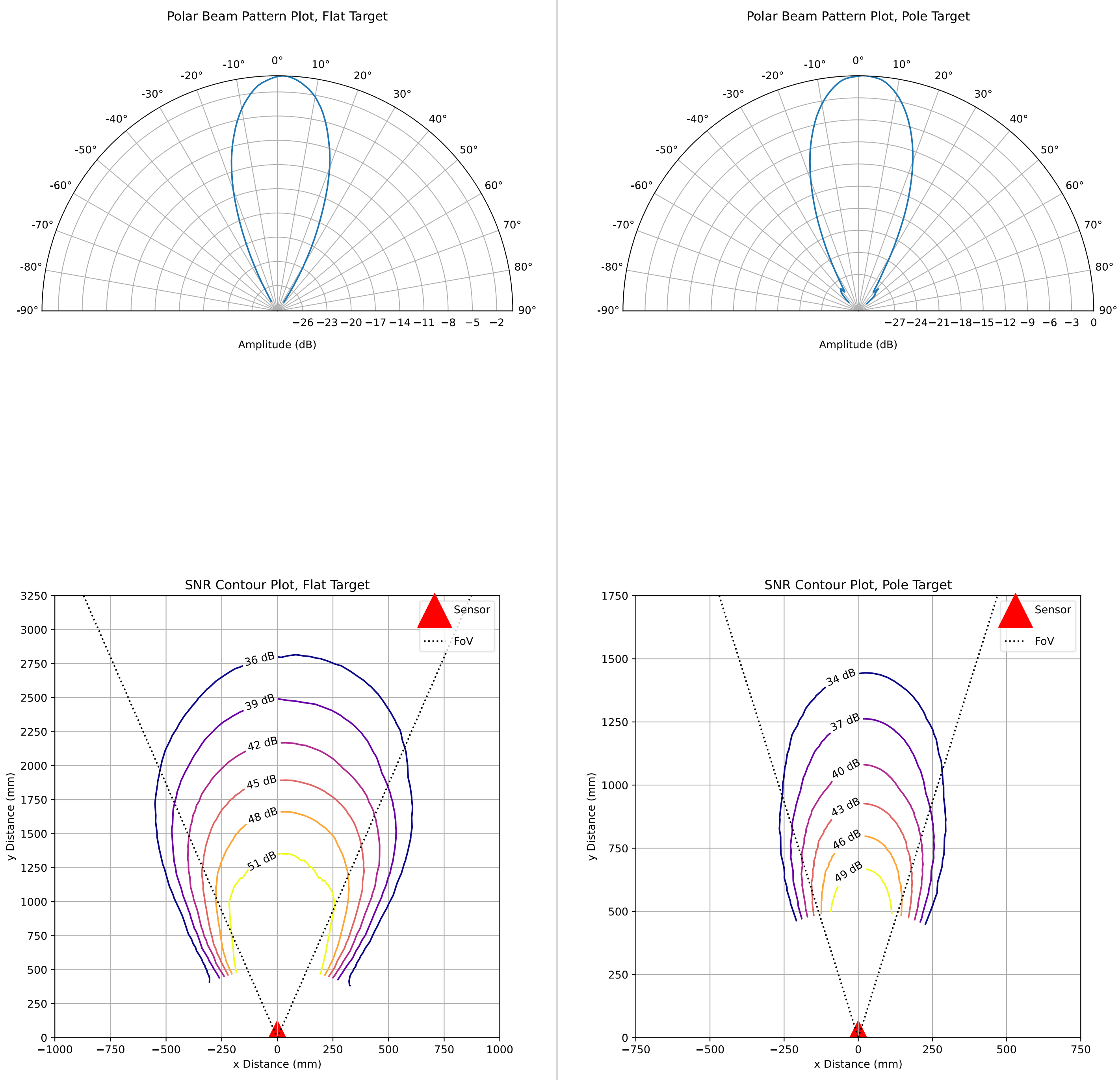


Figure 9: AH-20182-030030-01 Performance Plots for Flat (left) and Pole (right) Targets.

5.1.3 AH-20180-045045-01 Profile

GENERAL INFORMATION

The AH-20180-045045-01 is a horn-type acoustic housing that provides a symmetrical 45-degree FoV in both the horizontal and vertical plane. It is assembled with a PIF for dust protection.

DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating
AH-20180-045045-01	Horn	5.6	8.0	45	2350	2000	SAATI Acoustex B042HY[c]	IP5X

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.
[c]Part number provided is for bulk mesh material.

Table 5: AH-20180-045045-01 Characteristics.

- CAD file for 3D printing of AH-20180-045045-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20180-045045-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.

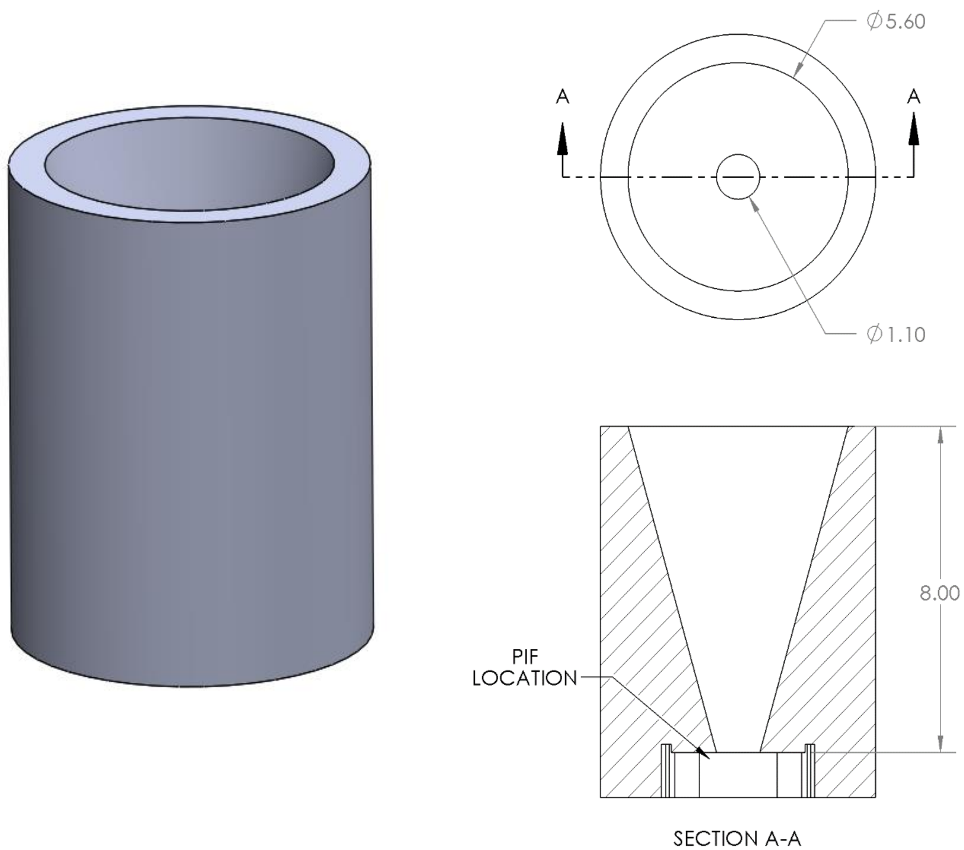


Figure 10: AH-20180-045045-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20180-045045-01 PERFORMANCE PLOTS

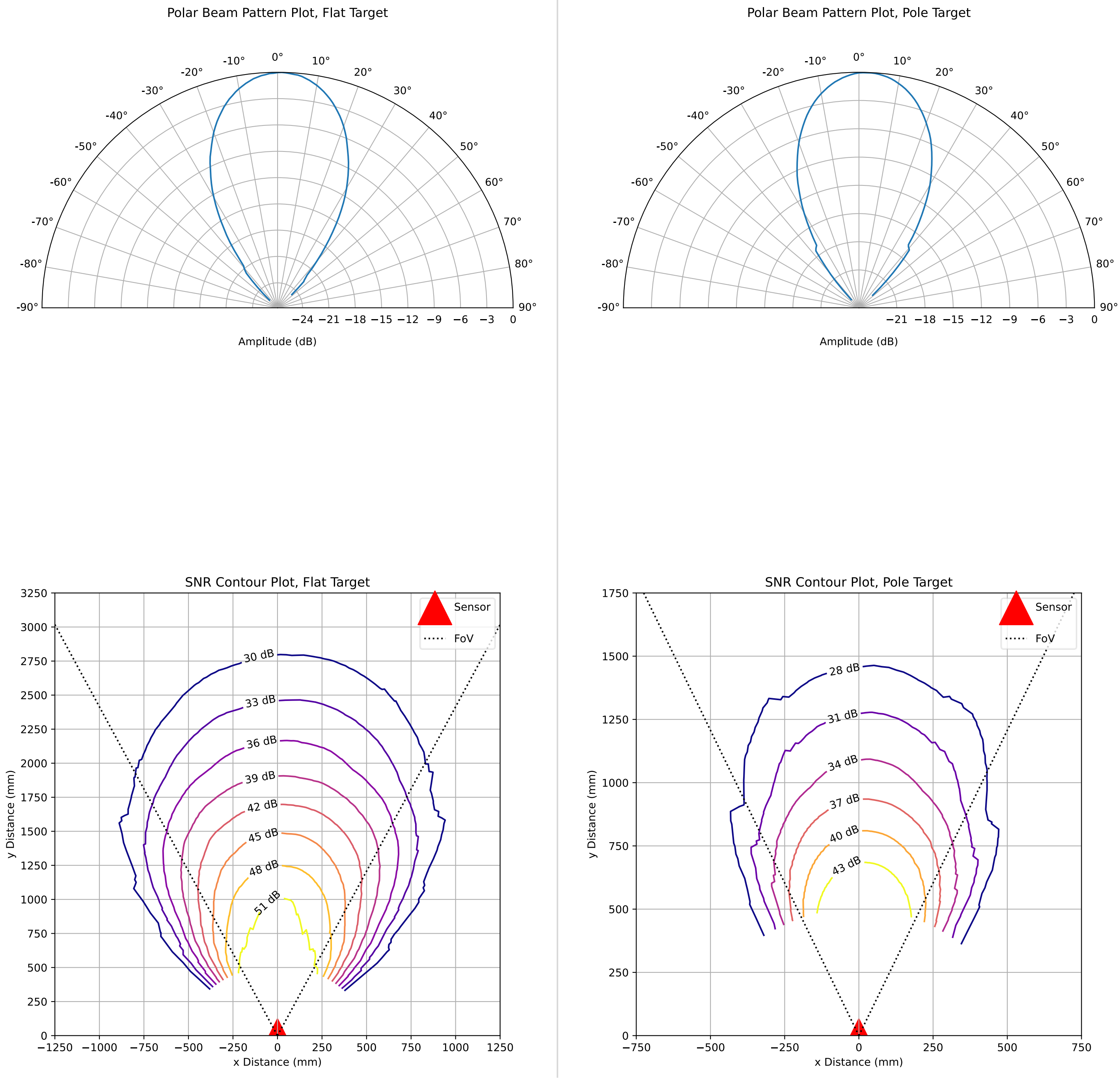


Figure 11: AH-20180-045045-01 Performance Plots for Flat (left) and Pole (right) Targets.

5.1.4 AH-20159-060060-01 Profile

GENERAL INFORMATION

The AH-20159-060060-01 is a horn-type acoustic housing that provides a symmetrical 60-degree FoV in both the horizontal and vertical plane. It is assembled with a PIF for dust protection.

DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating
AH-20159-060060-01	Horn	4.3	5.9	60	2250	1700	SAATI Acoustex B042HY[c]	IP5X

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.
[c]Part number provided is for bulk mesh material.

Table 6: AH-20159-060060-01 Characteristics.

- CAD file for 3D printing of AH-20159-060060-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20159-060060-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.

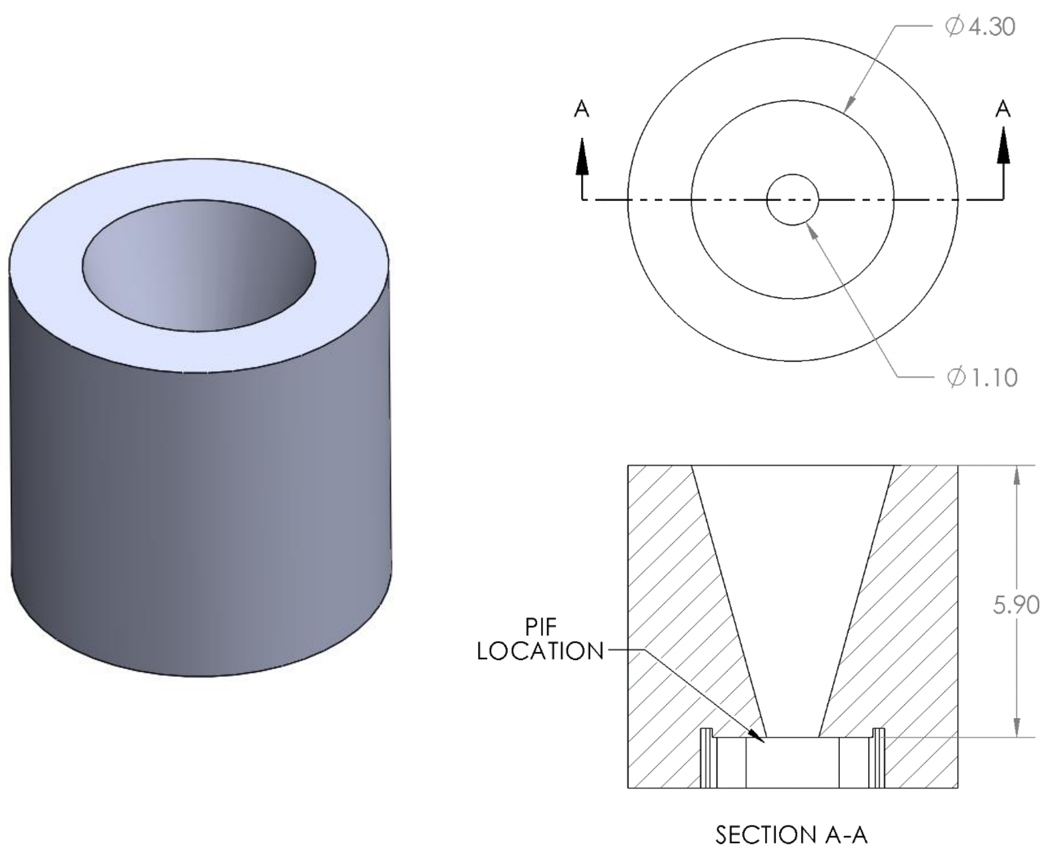


Figure 12: AH-20159-060060-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20159-060060-01 PERFORMANCE PLOTS

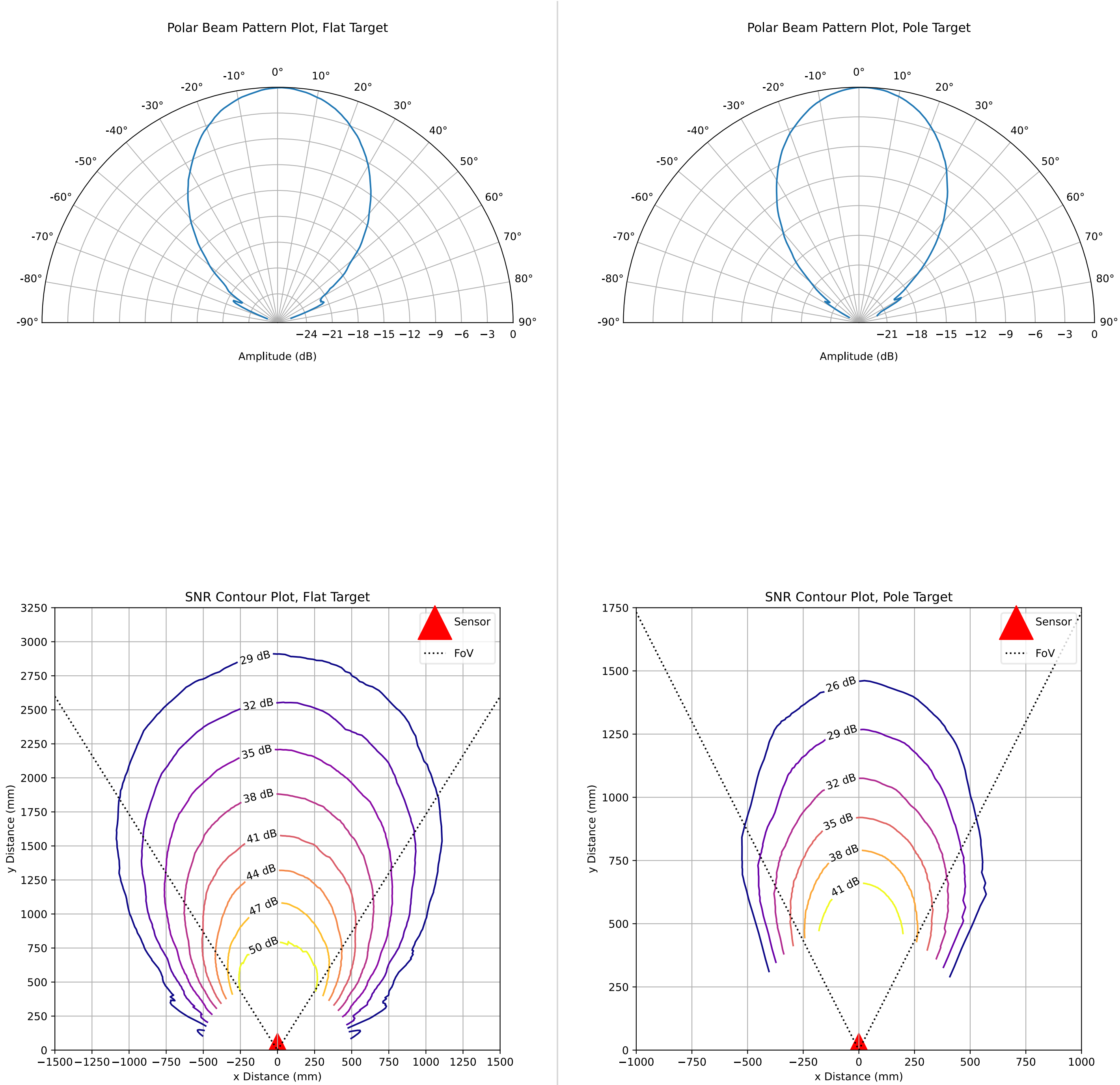


Figure 13: AH-20159-060060-01 Performance Plots for Flat (left) and Pole (right) Targets.

5.1.5 AH-20140-075075-01 Profile

GENERAL INFORMATION

The AH-20140-075075-01 is a horn-type acoustic housing that provides a symmetrical 75-degree FoV in both the horizontal and vertical plane. It is assembled with a PIF for dust protection.

DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating
AH-20140-075075-01	Horn	3.4	4.0	75	1700	1300	SAATI Acoustex B042HY[c]	IP5x

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.
[c]Part number provided is for bulk mesh material.

Table 7: AH-20140-075075-01 Characteristics.

- CAD file for 3D printing of AH-20140-075075-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20140-075075-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.

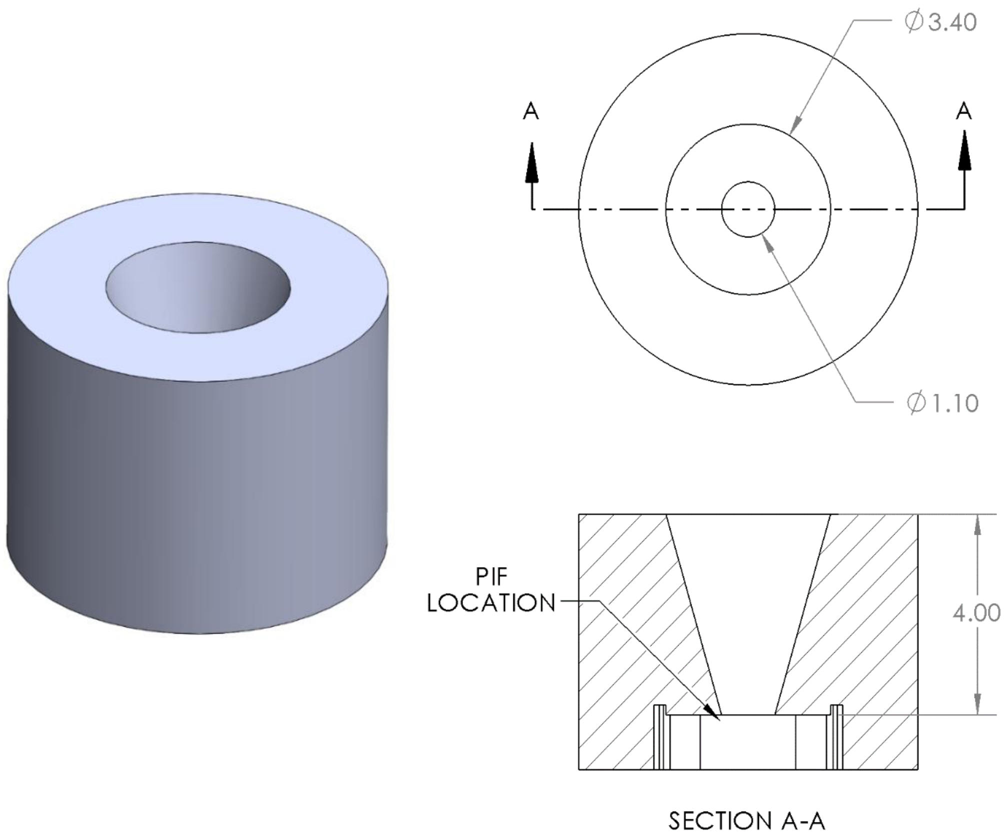


Figure 14: AH-20140-075075-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20140-075075-01 PERFORMANCE PLOTS

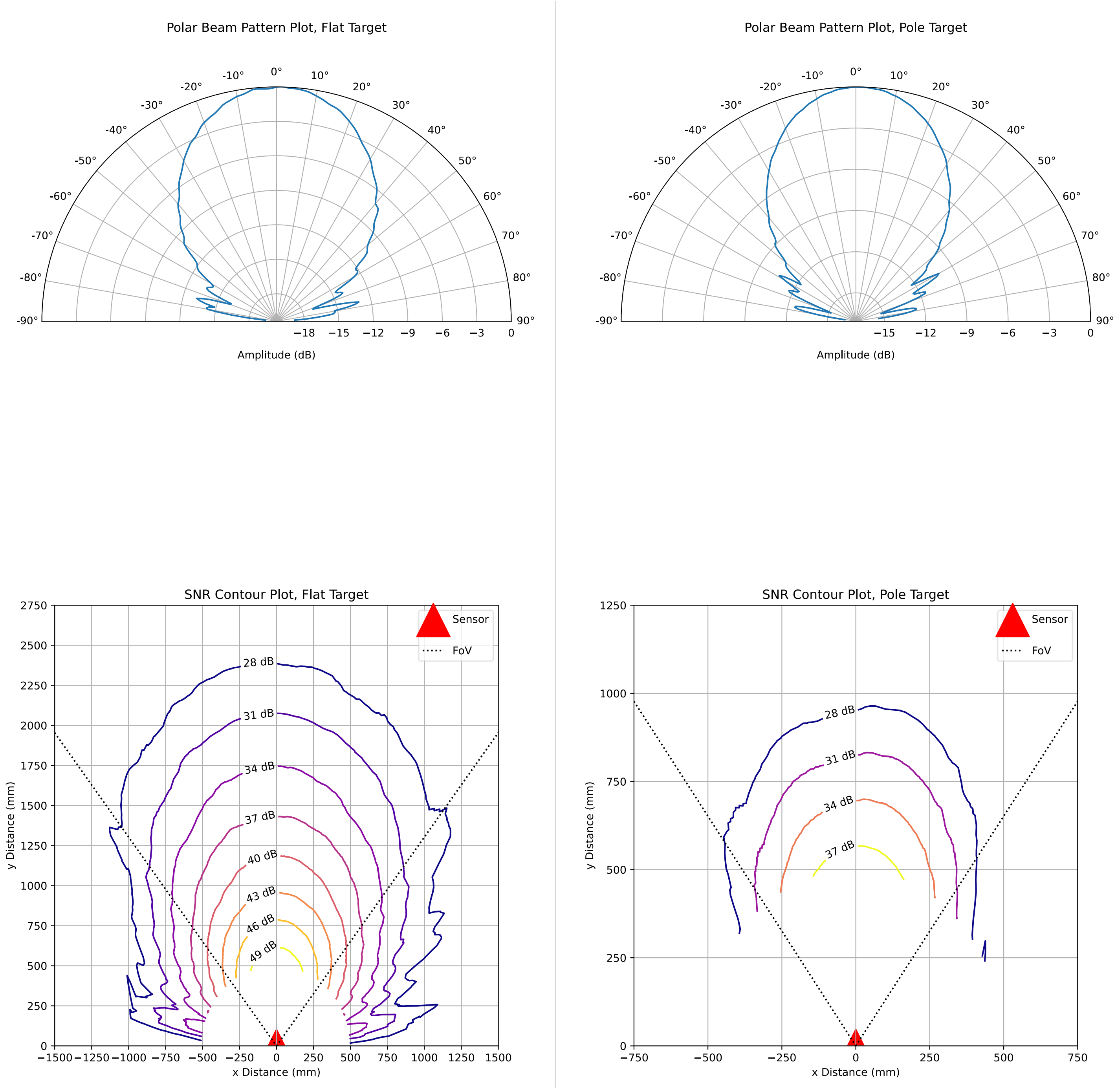


Figure 15: AH-20140-075075-01 Performance Plots for Flat (left) and Pole (right) Targets.

5.2 OUTDOOR ACOUSTIC HOUSINGS

For some applications that take place in outdoor environments, an additional level of protection from the elements is required. The AH-20298-025025-01 and AH-20222-180180-01 were designed with outdoor use in mind. Both housings incorporate an IP68 rated PIF.

Unlike the other acoustic housings presented in this document, these outdoor housings are assemblies that include multiple pieces in addition to the PIF. It is important to refer to **AN-000221**, the "CH201 and ICU-20201 Mechanical Integration Guide", for additional information on assembling and integrating these acoustic housings.

5.2.1 AH-20298-025025-01 Profile

GENERAL INFORMATION

The AH-20298-025025-01 is a horn-type acoustic housing assembly that provides a symmetrical 25-degree FoV in both the horizontal and vertical plane. It is designed for use in outdoor environments and is assembled with a PIF for water protection and a metal grille for mechanical protection. This housing maintains sensor performance when wet and incorporates a drain feature to channel water away. Suitable applications include continuous outdoor presence detection, such as in smart door locks.

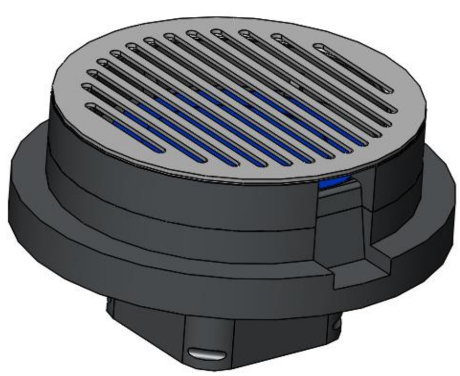
DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating	Grille
AH-20298-025025-01	Horn	12.7	9.8	25	2200	1750	Microvent MV-2SFG-01	IP68	Yes

[a]Distance benchmark is based on 35dB intensity threshold on a square flat target.
[b]Maximum on-axis distance based on 20dB intensity threshold on cylindrical pole target.

Table 8: AH-20298-025025-01 Characteristics.

- CAD file for 3D printing of AH-20298-025025-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20298-025025-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.



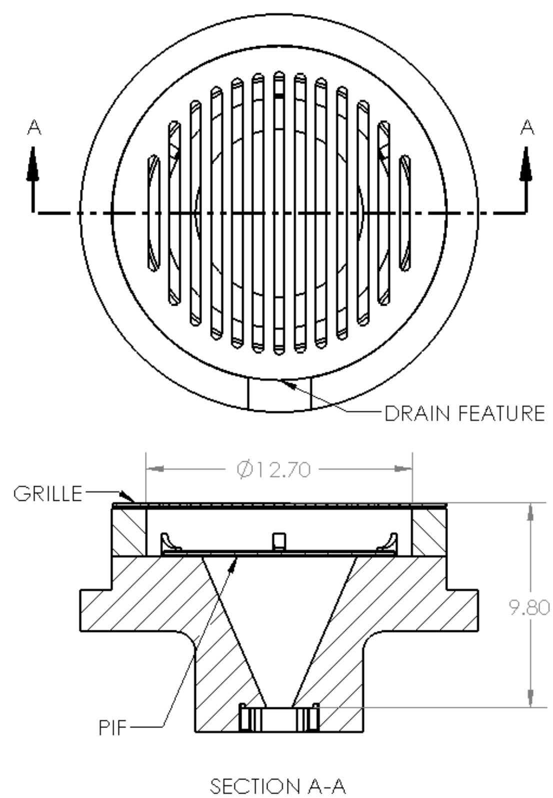


Figure 16: AH-20298-025025-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20298-025025-01 PERFORMANCE PLOTS

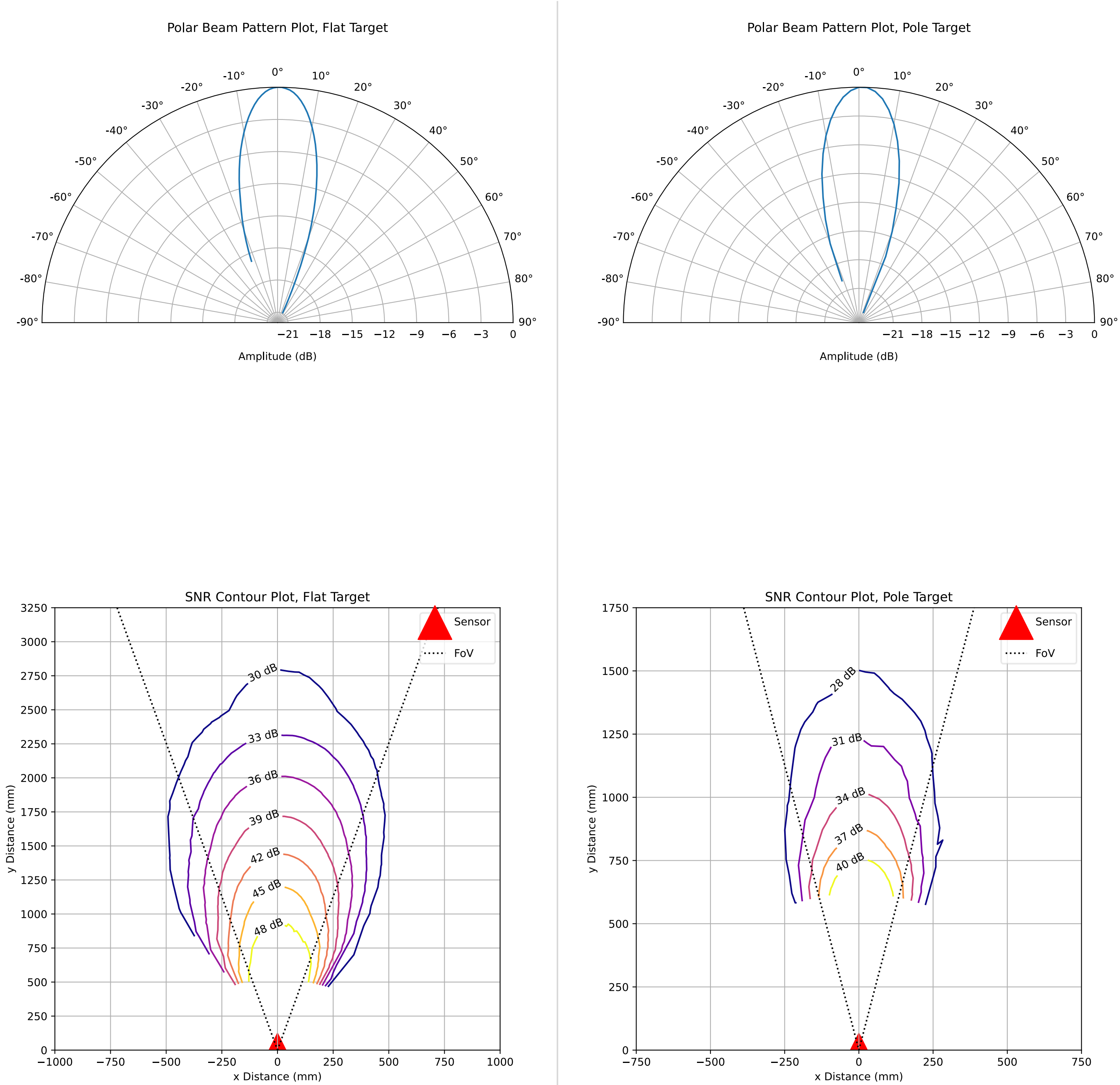


Figure 17: AH-20298-025025-01 Performance Plots for Flat (left) and Pole (right) Targets.

5.2.2 AH-20222-180180-01 Profile

GENERAL INFORMATION

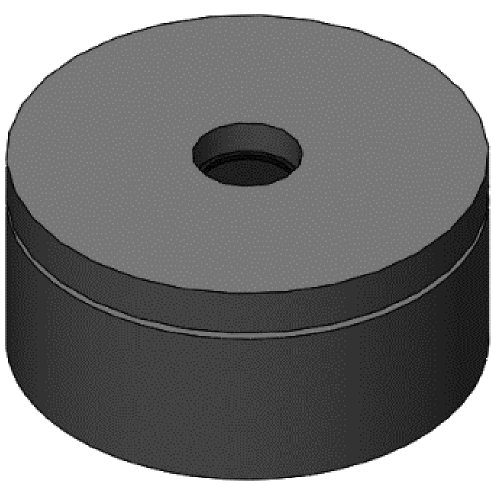
The AH-20222-180180-01 is a tube-type acoustic housing assembly that provides a symmetrical 180-degree FoV in both the horizontal and vertical plane. It is designed for use in outdoor environments and is assembled with a PIF for water protection.

DEVICE INFORMATION

Part Number	Type	Mouth Diameter (mm)	Horn Length (mm)	Field of View, FOV (degrees)	Distance at 35dB, On Axis (0°), Flat Target[a] (mm)	Max Distance, On Axis (0°), Pole Target[b] (mm)	PIF	IP Rating	Grille
AH-20222-180180-01	Tube	1.6	2.2	180	800	800	Gore GAW337	IP68	No

Table 9: AH-20222-180180-01 Characteristics.

- CAD files for 3D printing of AH-20222-180180-01 is available from Chirp Microsystems.
- Recommendations for adhesives, gluing instructions, 3D printing guidelines, and basic verification after installation of AH-20222-180180-01 see document AN-000223.
- The overall size of the model provided for this housing is intended to serve as an example. The dimensions provided in the drawings below specify the parameters that affect the acoustic performance. The model's external dimensions may be changed without affecting acoustic performance.



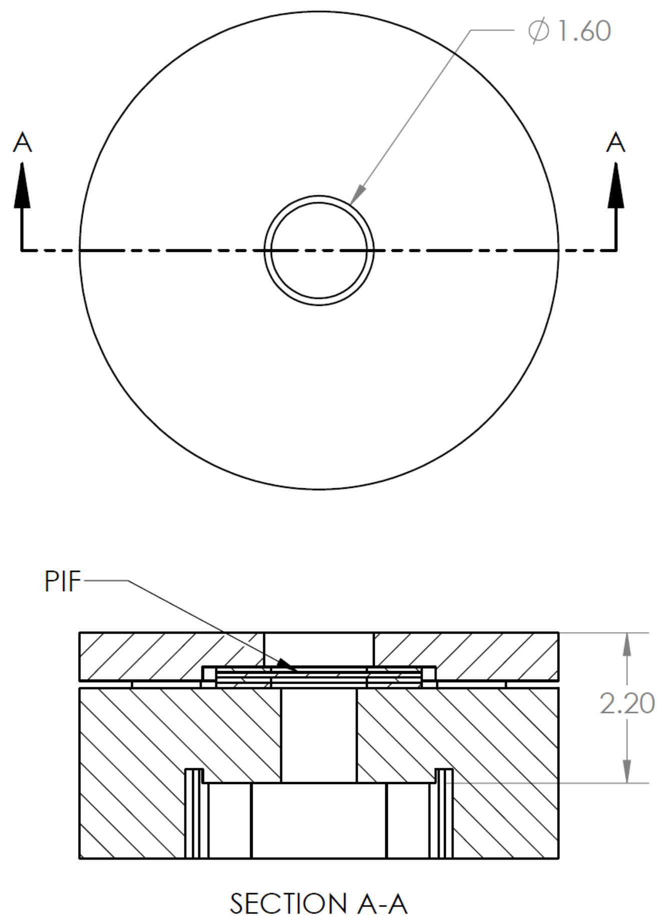


Figure 18: AH-20222-180180-01 3D Model View (left), Top View (upper right), and Cross-Section View (lower right).

AH-20222-180180-01 PERFORMANCE PLOTS

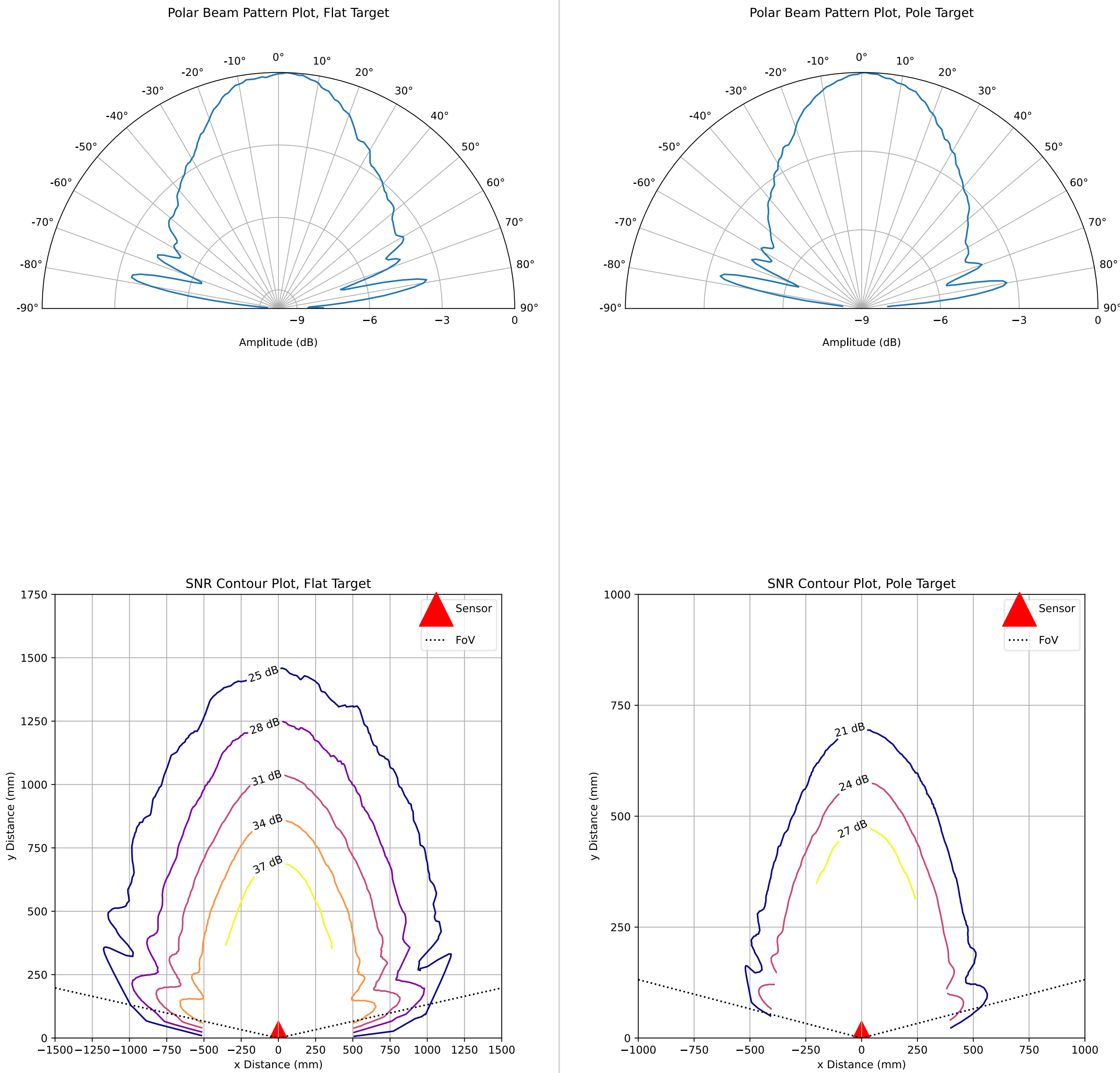


Figure 19: AH-20222-180180-01 Performance Plots for Flat (left) and Pole (right) Targets.

6 REVISION HISTORY

Revision Date	Revision	Description
1/06/2022	1.0	Initial Release