Operation Manual

Team 14
Noise Mitigation in an Organic Rankine Cycle (ORC) Turbine Bypass Line

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Acknowledgement

Team 14 would like to extend our deep appreciation to the FAMU-FSU College of engineering and the Mechanical engineering department for their time and devotion to organizing this year's senior design projects. We also want to personally thank Verdicorp, our sponsor Bala Datla and Corey Nelson, and our advisor Dr. Cattafesta for their time, consideration, and experience in their fields. We also send our appreciation to Tanner Smith at Bruel & Kjaer for his industry experience and their generosity in letting team 14 borrow equipment.

Abstract

The information provided in this operation manual will detail the proper procedure to the measurement, construction, and fitment of the prototype as designed by Team 14 “Noise Mitigation in an Organic Rankine Cycle (ORC) Bypass Line”. Due to the passive nature of the prototype, the proper measurement procedures will be included for implementation on additional ORC systems. The construction and fitment of the various pieces of the system will be discussed and tips for decreasing the construction time from the first prototype. Due to the nature of sound measurement, a trouble shooting guide will be provided to ensure accurate measurements and problems encountered on the assembly of the prototype. With this manual Verdicorp should have little difficulty in replicating this solution across their ORC fleet.

1. Functional Analysis

1.1 Prototype Overview

The prototype's function is the mitigation of noise emanating from an organic rankine cycle (ORC) when the working fluid is diverted through a turbine bypass line. When passing through bypass the desired noise levels are desired to be comparable to steady-state levels when passing through the turbine. The ORC system is installed within a steel shipping container both limiting the types and quality of measurements taken and adds to the overall sound pressure within the room. The status of the system is unacceptable to Verdicorp due to the potential health implications for employees and the annoyance to residential areas.

The health and safe implementation of this prototype are a primary concern, where the noise levels and the exposure time dictates the potential hazard to employees. From figure 1 the duration at which employees can endure the noise level of the system varies depending on the loudness. From OSHA figures 1/3 of all reported work related illnesses at industrial jobs are caused by exposure to loud sound levels. This can result in temporary or permanent hearing loss known as tinnitus, and is known in industry as noise induced hearing loss (NIHL) [2].

OSHA's Permissible Noise Exposures	
Duration per day, hours	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
<.25	115

Figure 1: OSHA Permitted Noise Limits [1]

1.2 Verdicorp Requirements

Along with dampening the noise levels of the ORC in bypass to steady-state levels, Verdicorp has set other project expectations that concern the development of a solution. The solution must not extend outside the direct vicinity of the piping, making dampening of the shipping container walls or implementing an enclosure around the system not permitted. Due to the shielding and other components of the ORC, there is minimal spacing for the concept and in some areas only three inches are available from the OD of the pipe. Being restricted to the piping itself, the temperature of the piping at 150˚C is a significant factor due to the lower melting temperature of the absorptive foam. Due to the nature of the requirements the solution will be passive in nature and be localized to the bypass line itself.

1.3 Prototype Function

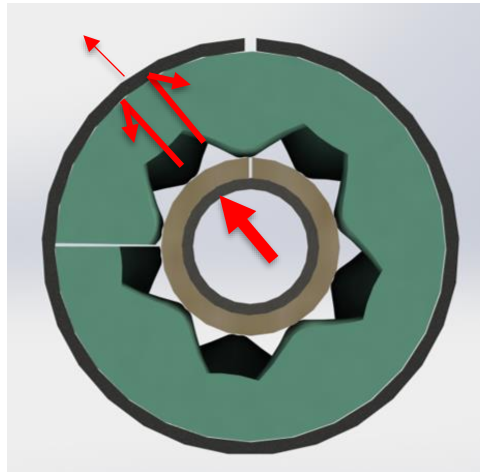
Figure 2: Composite Pipe Lagging Concept

The function of the prototype is a passive composite pipe lagging which is widely used in many industrial applications for noise reduction. The two principle concepts in sound reduction in our pipe lagging concept is noise absorption and sound transmission. These concepts are implemented into the design as an egg foam open cell foam, and a mass load vinyl transmission barrier as shown in figure 2. The acoustic foam is the prominent layer in reducing the noise and the shape of the foam is responsible for increased surface area and breaking up the sound wave propagation. In figure 2 the sound will transmit through the pipe radially and exit from the outer surface of the pipe. From here the thermal layer is a barrier to prevent the acoustic layer from direct contact with the pipe and will have the added benefit of absorbing and initially breaking up the sound from the pipe. The absorptive layer is next and will be the primary layer in dissipating the acoustic energy emanated by the pipe. As the sound waves exit the far side of the foam the sound waves are then redirected back to the interior layers by the reflective layer comprised of mass loaded vinyl. The process of reflecting the sound reintroduces the sound waves back to the absorptive layer improving the dissipative timeline of the acoustic foam. The resultant sound waves from the lagging results in an insertion loss which is the change in the sound from the pipes compared before and after the pipe lagging concept has been applied.

2. Performance Specifications

Prior to stating the specifications of the prototypes, the instruments and procedures used to conduct measurements will be briefly stated. The initial measurements were recorded and stored with a National instruments PXI 1031, and the microphone used was a Pom-3535 omni direction as shown in appendix A. Measurements were taken 1 m from all obstructive surfaces such as walls or large enough objects to disrupt the sound waves. Additional measurements were taken with a Bruel & Kjaer 2270 kit which was used to take intensity samples, the data sheet is available in appendix B. These tools were used to quantify and direct the concept as descried in the next part.

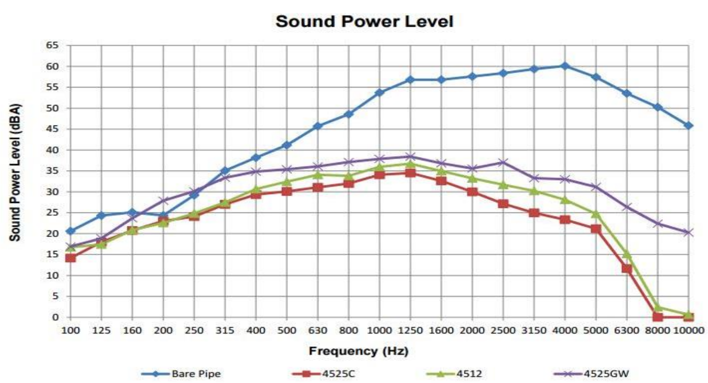

Figure 3: Pyrotek soundlag frequency dampening

The design of our concept is a pipe lagging that is commonplace among industrial applications due to its passive nature and large cost vs return. The first layer of the concept to be parted out was the absorptive layer, which was based off the frequency spectrum data. From research the selected foam would be an open cell, meaning that sound is easier to pass through but is conditioned and filtered to dissipate pressure energy to the foam. An open cell foam was not selected for this layer due to the higher density and lower flexibility which would become a hindrance to the construction of the prototyping of the model and may not work around the smaller 1 in nominal pipe diameters. With this a 1-1.5 in textured open cell foam was our first chose, after seeing what was available to order a combined mass loaded vinyl and foam product produced by Pyrotek was selected. This product was made of 1/8 in thickness mass loaded vinyl bonded to a 1 in egg foam open cell foam, model 425C. This offered good insertional losses as shown in figure 5 from 1 kHz up to 6.3 kHz where most of our noise was emanated from frequency range. With the foam's operating level at 100˚C the thermal layer was required to protect this layer. The selected thermal insulation layer is a spun needled ceramic fiberflax blanket. This thermal product has a specific heat of 1130 J/kg˚C and a thermal conductivity around 0.06 W/mK for the temperature range expected for this project application. The fiberflax blanket also has sound absorption properties due to its high density.

3. Product Assembly

The following section lists the recommend steps to properly assembly the prototype on the bypass line. Note that from figure 5 the fasteners such as the vinyl tape, velcro, and cinch straps were changed on site to simply the prototype.

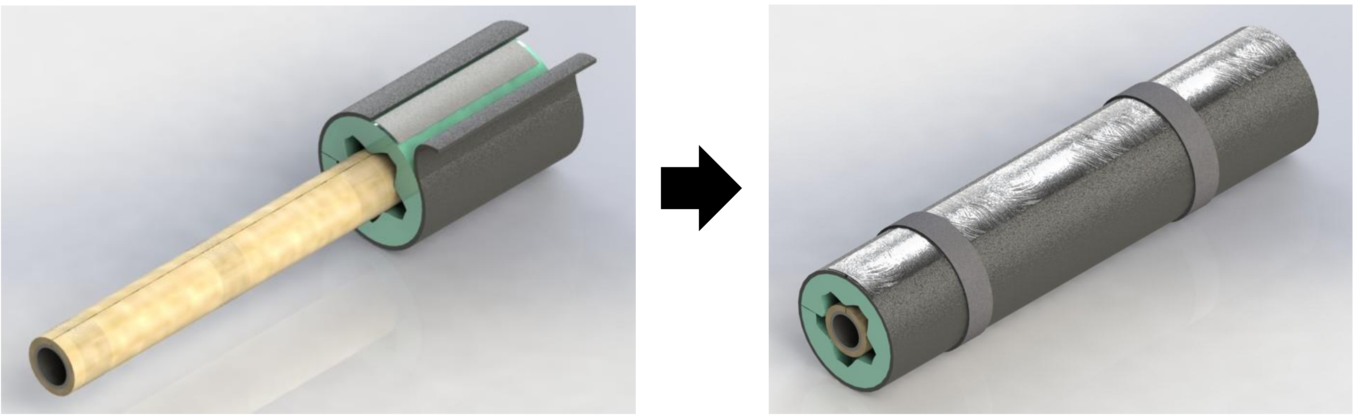

Figure 4 Concept design iterations

Prototype Assembly Steps

Before any fabrication, be sure to equip proper personal protective gear such as dusk masks, gloves, and eyewear to prevent irritation from ceramic fibers

1) Gather tools for assembly: flexible measuring tape, blade for cutting fiberflax, scissors, writing utensil, and wire clippers
2) Inspect surface to be covered and that the surface is clear of particulates
3) Cut a thin strip of the fiberflax about 1/5 in in width down the short side of the fiberflax roll, use as a measurement piece
4) Starting from the highest point of the piping system, measure the diameter using the strip cut in step 3 and mark on the fiberflax roll
5) Using the flexible tape measure, measure the length of the pipe segment that enables the longest section before elbows or other fittings on the pipe.
6) Mark and then cut the previous measurements from the fiberflax roll using a blade
7) Check the fitment of the section on the pipe, remove material as required for tight fitment against the pipe without any gaps where the section wraps around itself.

8) Hold the section against the piping section and proceed to fasten with wire, it is recommended to cross the wires like tying a knot and cinching until tight. Twist wires to secure and cut excess wire pieces. Add more wires if required to secure piece (see figure 6)

Figure 5 Thermal barrier installed

9) If wrapping a T-junction or a transducer is located on the pipe section, cut circular piece out of material to fit around transducer. Then cut straight line of material from circle radially to the nearest longitudinal seam of the layer.
10) Repeat step 3 with a strip of the soundlag roll
11) Repeat steps 4-7 with the soundlag to cover the rest of the piping (Provide an extra inch for the diameter of the soundlag to provide overlap)
12) Use the blade to remove the foam of the soundlag for the 1 in overlapped area.
13) The soundlag layer will then be secured using the included acoustic tape, for tight spaces for bends it is recommended to use smaller pieces of tape for better fitment. Multiple layers may be required depending on how flush the tape is applied.
14) Check overall fitment of lagging, if no observed sagging or peeling of acoustic tape then it should appear as the following in figure 7.

Figure 6 Lagging installed on pipe

4. Operation Instructions

Due to the passive nature of our prototype, no steps are required for the noise reduction to perform. Instead of steps for the prototype to perform as expected, extra attention should be spent on improving the safety of any persons near the system while during operation. Although the installed prototype has the added advantage of preventing burns from touching the bypass line, there are still many surfaces at 150˚C that can cause serious burns. The prototype has also had a significant effect on the noise generated by the ORC system, but given the standard level of the ORC during steady-state in the upper 80 dBA hearing protection should still be worn at all times when in close proximity of the system.

5. Troubleshooting

For potential issues arising from the prototype a table with solutions has been created.

Table 1 Troubleshooting guide

Issue encountered with prototype	Steps to resolve issue
Installation Issues	
Soundlag edges not even/ not overlapping	When cutting the layers to fit the pipe, it is suggested cutting a thin strip of the soundlag and thermal layers along the width of the roll provided by the manufacturers to use as a circumference guide. Take the length and wrap around the pipe to be covered and give about an inch of overlap with the soundlag to ensure seal. This 1 in overlap will improve the acoustic seal and ease the application of tape when applied longitudinally.
Not enough tension in wire to ensure secure fit of the thermal layer to the pipe	It is recommended when securing the thermal layer to the pipe that the wire is tied in a knot like manner enabling the thermal layer to be cinched tight enough against the pipe to then twist the wires for a more permanent hold.
Post installation issues	
Smell of burning or smoke	If the thermal layer were to fail or the assembly was not performed properly the acoustic layer may burn and begin to decompose. Shut the ORC off as soon as safely permittable, visually inspect lagging for signs of damage then proceed to score acoustic tape and remove the soundlag layer after the system has cooled off. Check and replace the thermal and acoustic layers if damage is seen.
Noticeable acoustic leakage around pipe segments	May be due to improper surface contact between acoustic tape and the aluminum surface of the mass loaded vinyl layer. If bubbles or the ends are visible proceed to smooth and remove them after the system has cooled off. If require remove tape and reapply or add a second layer to improve seal. If results are not noticed additional intensity measurements are recommend locating problem locations.
Layer separation or sagging	Most likely a result of loose instillation or improper fastening of the thermal layer. Check acoustic tape for slack, if the section of soundlag is too large remove and cut strips longitudinally to remove slack. Over time it is expected for certain sections of the pipe to compress near the top were most of the weight is carried. In these instances, if permanent compression of the foam is seen replace problem section with new soundlag, ensure thermal layer has not been damaged in the removal of the outer layer.

6. Regular Maintenance

Due to the passive nature of the prototype and the constraint considerations during the design, the lagging can go for extended periods of time without requiring invasive inspection. This is not to say that while in operation that the system should go unsupervised particularly after the installation of a new lagging to an ORC. It is recommended that visual inspection of the lagging should be performed before and after the ORC is began shut down after operation each day to catch potential failures before they become more serious. To ensure the continued performance and safety of the system the lagging should be physically inspected at least once a month while the system in not running and has had sufficient time to complete cool off. The physical inspection is performed to determine if any slack in the soundlag layer has developed. This can be a result of the acoustic tape losing its adhesion to the outer surface of the soundlag. If the sagging is signification (more than 1 in width) the soundlag section in question should be removed and inspected for permanent deformation on top side where the foam was resting on the pipe. If the foam is permanently compressed it is recommend replacing that section with a new section of soundlag.

References

1) **Patrick J. Brooks, P.E.Sep 28, 2007, "Industrial Noise Control,"** ***Occupational Health & Safety*****. [Online]. Available: https://ohsonline.com/Articles/2007/09/Industrial-Noise-Control.aspx. [Accessed: 03-Apr-2017].**

2) **"The Impact of noise at work," European Agency for Safety and Health at Work. [Online]. Available https://osha.europa.eu/en/tools-and-publications/publications/factsheets/57 [Accessed: 03-Apr-2017].**

3) **"POM-3535L-3-R Omni-Directional Microphone," pui audio. [Online]. Available http://www.puiaudio.com/pdf/POM-3535L-3-R.pdf [Accessed: 03-Apr-2017].**

4) **"Hand-held Analyzer Type 2270-S for Sound Intensity Measurements," Bruel and Kjaer. [Online]. Available https://www.bksv.com/-/media/literature/Product-Data/bp2341.ashx [Accessed: 03-Apr-2017].**

5) **"Hand-held Analyzer Type 2270-S for Sound Intensity Measurements," Bruel and Kjaer. [Online]. Available https://www.pyroteknc.com/products/soundlag/soundlag-4525c/ [Accessed: 03-Apr-2017].**

Appendix A

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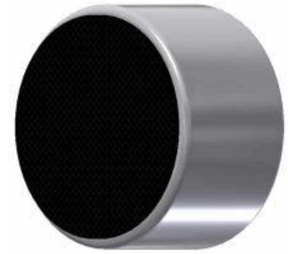
3541 Stop Eight Road • Dayton, Ohio 45414

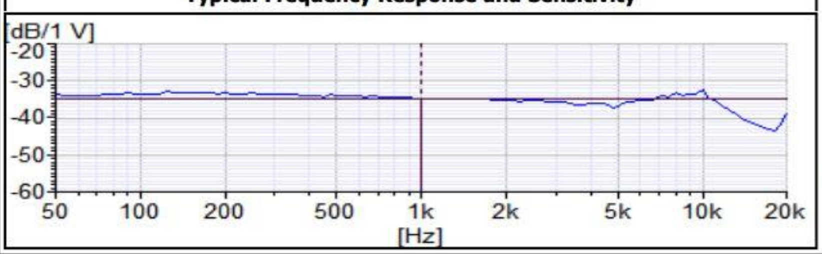
POM-3535L-3-R Omni-Directional Microphone



Product Overview

- 6mm overall diameter and 3.5mm height with solder pads
- -35 dB sensitivity for picking up low level sound
- Wide 2 to 10 VDC operating voltage and 50-16,000 Hz frequency response
- >68 dB signal-to-noise ratio and 2.2 kOhm impedance
- Omni-directional polar pattern for great off-axis response
- Built-in 33 pf and 10 pf capacitors filter out GSM TDMA noise

Typical Frequency Response and Sensitivity



cfsi

RoHS Compliant

REACH COMPLIANCE

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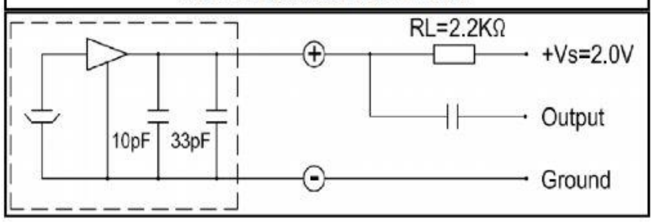
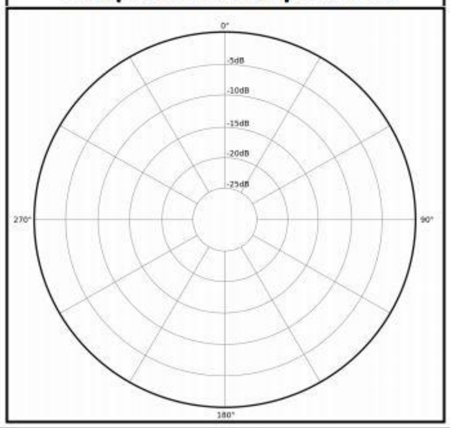
POM-3535L-3-R
Omni-Directional
Microphone

Mechanical and Environment Testing	
Test Description	**Test Condition**
High Temperature	70°C with random humidity for 200 hours
Low Temperature	-25°C with random humidity for 200 hours
Humidity	40°C with 90% relative humidity for 200 hours
Vibration	3 mm movement for 3 minutes in each of 3 axis
Drop Test	70 cm free fall onto 20 mm thick board, two directions
Temperature Cycle Test	-10°C to 50°C, 5 cycles

Recommended Drive Circuit



Microphone Polar Response Plot

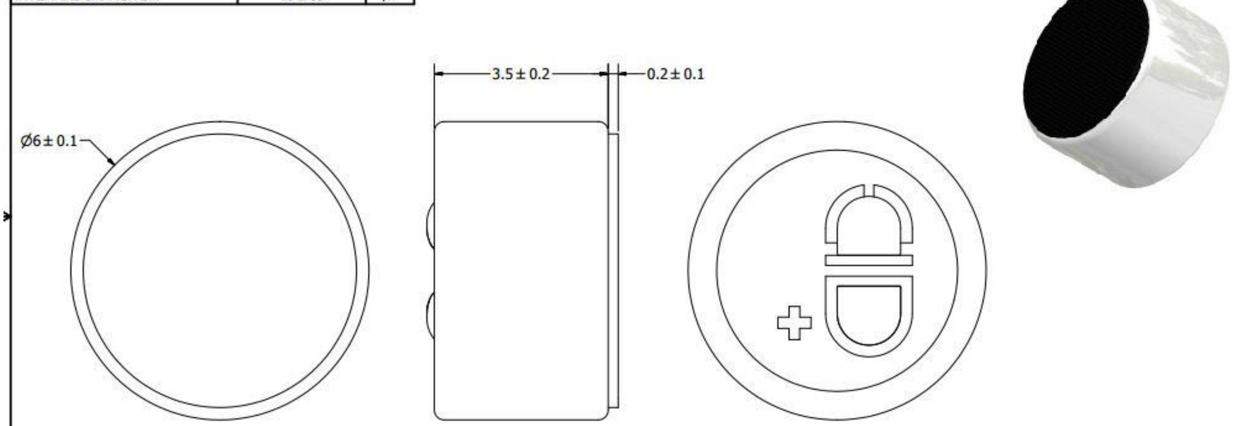


SPECIFICATIONS

PARAMETERS	VALUES	UNIT
DIRECTIVITY	OMINI	-
SENSITIVTY	-35 ± 4	dB
STANDARD OPERATING VOLTAGE	2	Vdc
MAX OPERATING VOLTAGE	10	Vdc
CURRENT CONSUMPTION (MAX)	0.5	mA
IMPEDANCE	2.2	KOhm
SIGNAL TO NOISE RATIO (MIN.)	68	dB
TERMINAL	SOLDER PADS	-
INTERNAL CAPACITOR	10 & 33	pF

REVISION HISTORY

LTR	DESCRIPTION	DATE	APPROVED
-	RELEASED FROM ENGINEERING	11/21/2012	
A	REVISED SIGNAL TO NOISE & CAPACITOR	5/9/2013	B.R.
B	REVISED TO INVENTOR 3-D DRAWING TEMPLATE	7/22/2013	B.R.
C	REVISED SOLDER PAD LAYOUT	3/18/2014	M.L.



NOTES:

1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. SPECIFICATIONS SUBJECT TO CHANGE OR WITHDRAWL WITHOUT NOTICE.
3. THIS PART IS RoHS 2011/65/EU COMPLIANT.
4. THIS PART IS BACK ELECTRET.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS, TOLERANCES ARE ±0.5 AND ANGLES ARE ±3°.

SIZE A3

POM-3535L-3-R.idw

Designed by	Date	Checked by	Date	Approved by	Date	Drawn Date
B.M.	11/21/2012	M.L.	11/21/2012	B.R.	11/21/2012	7/22/2013

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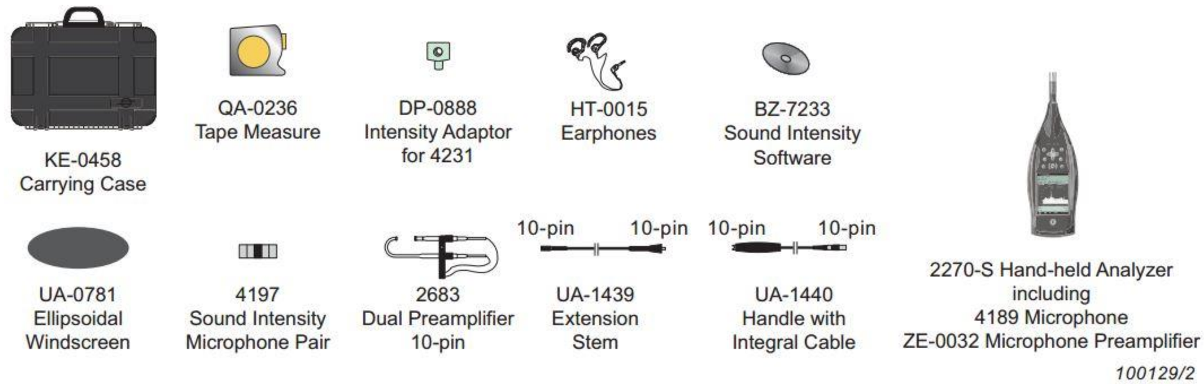
POM-3535L-3-R

Microphone — Edition: - — Sheet: 1 / 1

Appendix B



Specifications

Capacitance	14 pF
Diameter	½
Dynamic range	14.6 – 146 dB
Frequency range	6.3 – 20000 Hz
Inherent noise	14.6 dB A
Lower limiting frequency -3dB	4 Hz
Optimised	Free field
Polarization	Prepolarized
Polarization voltages	V
Pressure coefficient	-0.01 dB/kPa
Sensitivity	50 mV/Pa
Temperature coefficient	-0.006 db/°C
Temperature range	-30 – 150 C
Venting	Rear
Weight	gram
Sound field	Free-field
Microphone type	Free field

Appendix C