NCE REPORT 2024-079

Vessel-Generated Underwater Radiated Noise Comparison Study (Tugs): *eWOLF*, *Tioga, and Leader*

Revision 0

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REVISION HISTORY

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0.0 EXECUTIVE SUMMARY

Noise Control Engineering, LLC (NCE) has performed a study for the Maritime Administration (MARAD) to measure, assess, and understand the underwater radiated noise from three tugs owned and operated by Crowley. One of the vessels is powered using a battery-electric system and the other two are powered using diesel engines. The overarching goal of this effort is to compare the underwater noise generated by the vessels and identify potential noise reductions that can be linked to vessel designs with reduced greenhouse gas emissions. Underwater noise benefits seen in this study may be applied to future vessels to help reduce acoustic impacts to marine life and reduce greenhouse gas emissions.

NCE assessed the following tugs in San Diego Harbor in California:

- *eWOLF*: Battery-electric, L-drive propulsion
- *Tioga*: Diesel propulsion engine, Z-drive propulsion
- *Leader*: Diesel propulsion engine, Voith Schneider propulsion

The primary function of these vessels is to assist larger vessels with navigation and docking in San Diego Harbor. When they are not performing 'tug assist' operations, they are transiting from one location to another or are docked. To capture the noise during these operations, measurements were performed for free transit conditions between 2 to 10 knots and Simulated Tug Assist (STA) conditions ranging from 20% to 100% power. STA consisted of pulling on a rope connected to land.

Underwater noise was measured using a hydrophone positioned on the bottom of the harbor. The vessel location relative to the hydrophone was tracked using GPS. Measurement data was processed to identify 1-meter 'source level' spectra for each vessel and operating condition. Source level spectra have been used to enable comparisons of noise to these and other vessels. Data processing was performed in accordance with ANSI S12.64, with necessary changes to account for practical constraints such as available water depth. Deep-water source level spectra have also been estimated to account for shallow water measurement effects.

The primary design advantage of the *eWOLF* for underwater noise and greenhouse gas emissions is the use of battery power instead of diesel engines. **At all transit speeds, the *eWOLF* overall level is at least 6 dB lower than those of the *Tioga* and *Leader* at comparable speeds.** Underwater noise contributions from the *Tioga* and *Leader* diesel engines are partially responsible for higher overall noise as compared to the *eWOLF* during transit operations. This is because the propulsion engines are "hard mounted, i.e., directly connected to the ship without any noise control features. For this reason, *eWOLF* overall noise levels are lower than the other two vessels during transit conditions. However, noise from the *Tioga* and *Leader* could be similar or lower than the *eWOLF* at transit conditions if noise control features, such as resilient mounting of the propulsion engines, were implemented for their diesel engines.

At STA conditions, the *eWOLF's* noise is similar to or louder than the other vessels. This is because the *eWOLF* propellers produce significant noise once cavitation is present. *eWOLF* propeller cavitation noise is similar to the *Tioga* because the propeller designs have overarching similarities, and both utilize L- or Z-drive propulsion systems. Conversely, propeller noise from the *Leader* is generally lower than the *eWOLF* and *Tioga* because the Voith Schneider propulsion system produces significantly lower amounts of cavitation at comparable operating conditions.

Noise contributions from other machinery, such as the L- and Z-drive gearing, and noise associated with electric propulsion motors, are also present and create peaks in the measured noise spectra at specific frequencies. This is particularly true for the *eWOLF* and *Tioga.* Propulsion engine noise appears to be louder than most other machinery sources on the *Leader*.

The measurement data indicate underwater noise reductions for tugs are possible by implementing battery-electric propulsion systems. Such systems can also provide a reduction in greenhouse gas emissions. However, these reductions will typically be limited to slower speed transit and low power tug assist operating conditions when propeller cavitation is not present or is minimal. Cavitation noise from conventional propellers should be expected to contribute to or dominate underwater noise levels at higher vessel speeds and during tug assist activities unless measures have been implemented to limit cavitation. It is important to recognize that the impact of battery-electric propulsion systems on noise reduction will be further diminished when compared to tugs that have applied noise controls for their diesel engines.

Conventional propeller designs with reduced cavitation may be possible if underwater noise control is implemented as a goal at the design stage. Alternative propulsion systems, such as the Voith Schneider system, also present opportunities for reduced underwater noise due to the reduced levels of induced cavitation. This study could not directly assess the fuel efficiency of Voith Schnieder systems, so the impact of this system on greenhouse gas emissions is not known directly.

1.0 INTRODUCTION

Noise Control Engineering, LLC (NCE) has performed a study for the Maritime Administration (MARAD) to measure, assess, and understand the underwater radiated noise from three tugs owned and operated by Crowley. One of the vessels is powered using a battery-electric system and the other two are powered using diesel engines. The overarching goal of this effort is to compare the underwater noise generated by the vessels to identify potential noise reductions that can be linked to vessel designs with reduced greenhouse gas emissions. Underwater noise benefits seen in this study may be applied to future vessels to help reduce acoustic impacts to marine life and greenhouse gas emissions.

NCE measured the following tugs in San Diego Harbor in California:

- *eWOLF*: Battery-electric, L-drive propulsion
- *Tioga*: Diesel propulsion engine, Z-drive propulsion
- *Leader*: Diesel propulsion engine, Voith Schneider propulsion

The vessel particulars for these vessels are provided in Table 1 through Table 3.

Table 1: General Parameters of the *eWOLF*
(Battery-Electric, L-Drive Propulsion)

Parameter	Value
Overall Length	82 feet
Beam	40 feet
Draft	16 feet 5 inches
Gross Tonnage	<200 GRT
Propulsors	2x Schottel L-drives, Model SRP 430 LE FP, 2.867:1 gear ratio
Propulsion Motors	2x 2800 HP, 760 RPM
Gensets (long haul transit only)	2x John Deere Model 6135AFM85, Powertech 13.5L Engine, 334 kW @ 1800 RPM
Design Speed	12 knots on battery, 8 knots on genset
Year Built & Shipyard	2024, Master Boat Builders

Table 2: General Parameters of the *Tioga*
(Diesel Engine, Z-Drive Propulsion)

Parameter	Value
Overall Length	78.7 feet
Beam	30 feet
Draft	14 feet
Gross Tonnage	147 tons
Z-drives	2x Ulstein 1650H, 2,200 HP
Propulsion Engines	2x Caterpillar 3512C, 2,200 HP each, 1800 RPM, hard mounted
Year Built & Shipyard	1994, Tri State Marine Inc.

Table 3: General Parameters of the *Leader*
(Diesel Engine, Voith Schneider Propulsion)

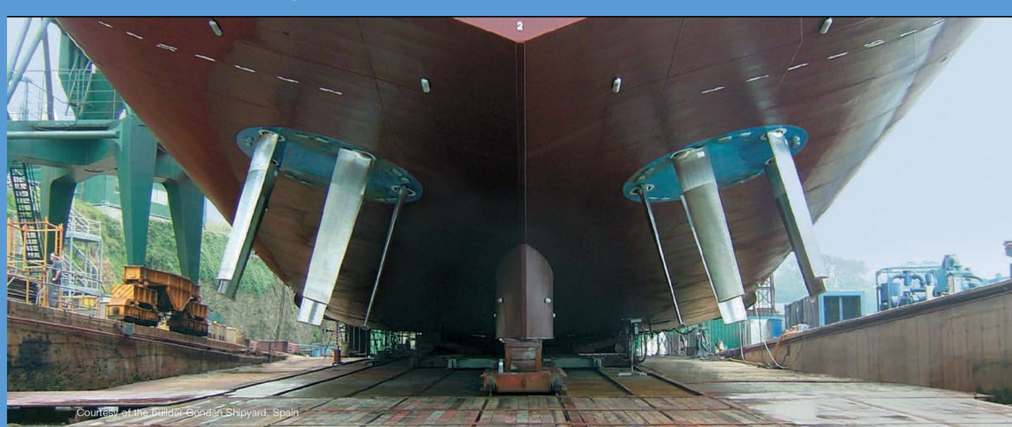
Parameter	Value
Overall Length	96.7 feet
Beam	36 feet
Draft	19 feet
Gross Tonnage	275 tons
Propulsors	2x Voith Schneider Propulsion
Propulsion Engines	2x Caterpillar 3516-B, 2,400 HP, RPM hard mounted
Gearboxes	2x Falk 427A1S, 1.828:1 gear ratio
Gensets	2x BOLLARD MG105-KA1, 105 kW, 1800 RPM
Year Built & Shipyard	1998, Nichols Brothers Boat Builders

L-Drives, Z-Drives, and Voith Schneider Propulsion

L-drives and Z-drives use conventional propellers attached to an appendage that protrudes from the hull. They typically include a duct that surrounds the propeller, as seen in the image below. The entire propeller/duct/appendage can rotate 360 degrees to provide thrust in any direction. The “L-Drive” has a shaft that is oriented vertically inside the ship and through the appendage, and then turns 90 degrees via a gear to connect to the propeller. A “Z-Drive” is similar, and uses another 90 degree bend via gearing inside the ship before connecting to the prime mover.

L-Drive System on *eWOLF* (3D Rendering)

A Voith Schneider Propeller (VSP) is an alternative marine propulsor with blades protruding from the vessel bottom, rotating around a vertical axis. The movement of the blades is complex; the “pitch” of blade, being the angle of the blade relative to its direction of motion, can be modified to produce thrust in any direction. Details can be found at voith.com



VSPs on Drydocked Vessel [3]

2.0 METHODOLOGY

An underwater noise "source level" was calculated for each vessel at various operating conditions in accordance with ANSI S12.64. The source level is a convenient metric used to compare underwater noise across different vessels. It is calculated by taking noise data collected at a distance from the vessel and correcting it for geometric spreading losses. The source level is an estimate of the noise that would exist at 1 meter from the source, if the noise could be approximated as emanating from a single point. Source levels can be presented as single-valued "overall" levels, being the combined noise at all frequencies, or as a spectrum, which provides the details of noise level vs. frequency.

Testing was performed in general accordance with the Test and Analysis Plan [1]. The approach is in line with ANSI S12.64 [2], with modifications applied where necessary for practical reasons, particularly relating to available water depth.

2.1 Overview

A primary goal of this effort is to measure and assess underwater noise during standard tug operating conditions. The function of these vessels is to assist larger vessels with navigation and docking in San Diego Harbor. When they are not performing 'tug assist' operations, they are transiting from one location to another or are docked. To capture the noise during these operations, measurements were performed for free transit and Simulated Tug Assist (STA) conditions.

Transit operations were measured at nominal speeds of 2, 4, 6, 8, and 10 knots. Each vessel was instructed to pass over the hydrophone at specific shaft speeds corresponding to these nominal transit speeds. Shaft speed, measured in rotations per minute (RPM) was used as the operational target to produce better data consistency, as vessel speed is subject to currents and wind. Note that the *Leader's* propeller pitch can be changed with shaft RPM to control vessel speed; specific propeller pitch and shaft speed combinations were used for each vessel speed. A minimum of four measurements were performed for each transit condition, with two transits in the northwest direction and two southwest.

STA operations were performed by pulling on a line attached to a stationary object on land. Each tug was positioned over the hydrophone and generally remained stationary for the STA tests. STA measurements were performed while pulling at nominal 20, 40, 60, 80, and 100% power. Shaft speed (and propeller pitch) were held constant for each power setting, as described above for the transit operating conditions. Note that the line was attached to the stern for the *Tioga* and *Leader* but was attached to the bow of the *eWOLF* due operational limitations on the day of testing. At least three measurements were performed at each power level for each vessel.

Note that the *Tioga's* minimum engine speed is 600 RPM, which limits its slowest transit speed to 5 knots. This also limits the *Tioga's* lowest STA power to 30%. All nominal conditions were measured for the *eWOLF* and *Leader*.

All tests were performed in San Diego Harbor on May 14, 2024. Wind speed varied between 10-14 mph. The water was calm for all tests.

2.2 Test Location

The hydrophone was located near the 10th Avenue Marine Terminal for all tests, as shown in Figure 1. The hydrophone was approximately 80 meters from the dock and was cabled back to the dock as described in Section 2.3.2. The GPS location of the hydrophone was recorded at deployment and verified at retrieval. Water depth at the hydrophone was 46 feet and varied by less than 2 feet over the course of testing. Currents were observed to be 1 knot or less over the test period.

Docked vessels were located at the Marine Terminal during testing. However, they were positioned sufficiently far from the hydrophone to not produce extraneous noise relative to the noise of the tugs.

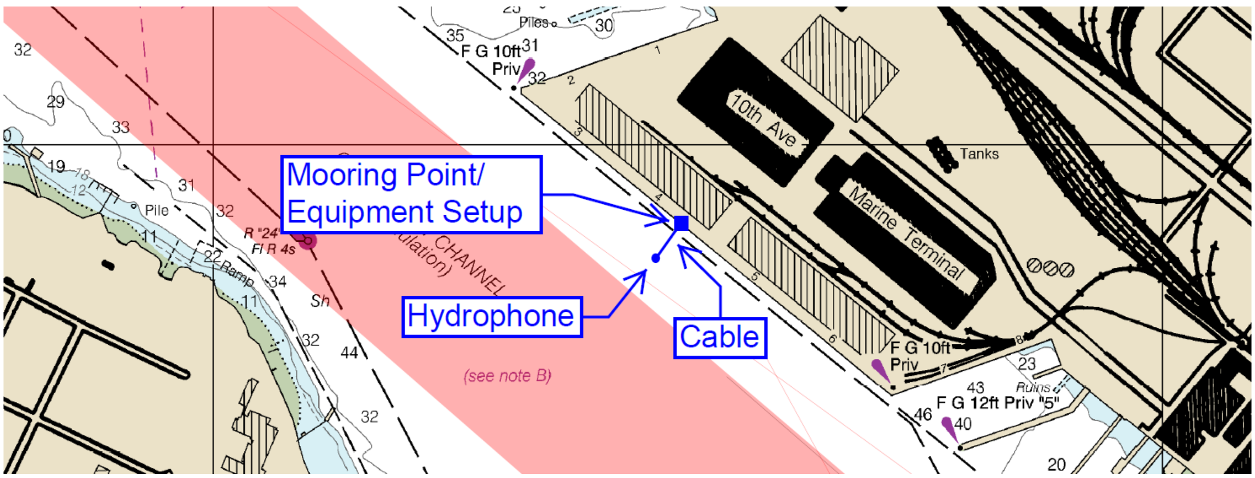


Figure 1: Hydrophone Deployment Location for Transit & STA Operations

2.3 Data Collection Systems

2.3.1 Acoustic Data Collection Systems

The primary acoustic measurement system consisted of a cabled hydrophone, data acquisition system (DAQ), and a portable GPS tracking unit.

The hydrophone was a Reson Model TC4033, which is nearly omnidirectional with a usable frequency response from 4 Hz to 100 kHz. The data acquisition system uses custom software designed for the collection of underwater noise data with National Instruments 9250 hardware capable of sample rates up to 102.4 kHz, allowing for the analysis of frequencies to 40+ kHz. The system was set up to record acoustic data when the test vessels were near the hydrophone.

A field calibrator was used at the beginning and end of the measurement period to calibrate the measurement system and verify system stability over the course of the testing.

A Garmin GPSMAP 79sc GPS unit was placed on board each vessel while under test to track vessel position. GPS data were then combined with the static hydrophone location to calculate the relative distance between the hydrophone and the vessel at regular intervals throughout each test.

Additionally, a backup acoustic measurement system was used consisting of an HTI-99 hydrophone connected to an RTSYS Sylence-LP recorder. Data from this system was used for supplemental data processing purposes as discussed in Section 5.0.

All acoustic test equipment was laboratory calibrated traceable to National Institute of Standards and Technology (NIST) standards within 12 months prior to testing.

2.3.2 Mooring & Deployment

The primary hydrophone was mounted to a metal frame temporarily installed on the bottom of the harbor. A drawing of the frame is provided in Figure 2. The base of the frame is 18" x 18"; the top of the frame is about 13" from the bottom. The primary hydrophone was mounted inside the frame, positioned approximately 9" off the sea floor. The secondary hydrophone was mounted approximately 7" off the sea floor and was oriented perpendicular to the primary hydrophone. Weights were attached to the bottom of the frame to help secure it in place and prevent movement from currents.

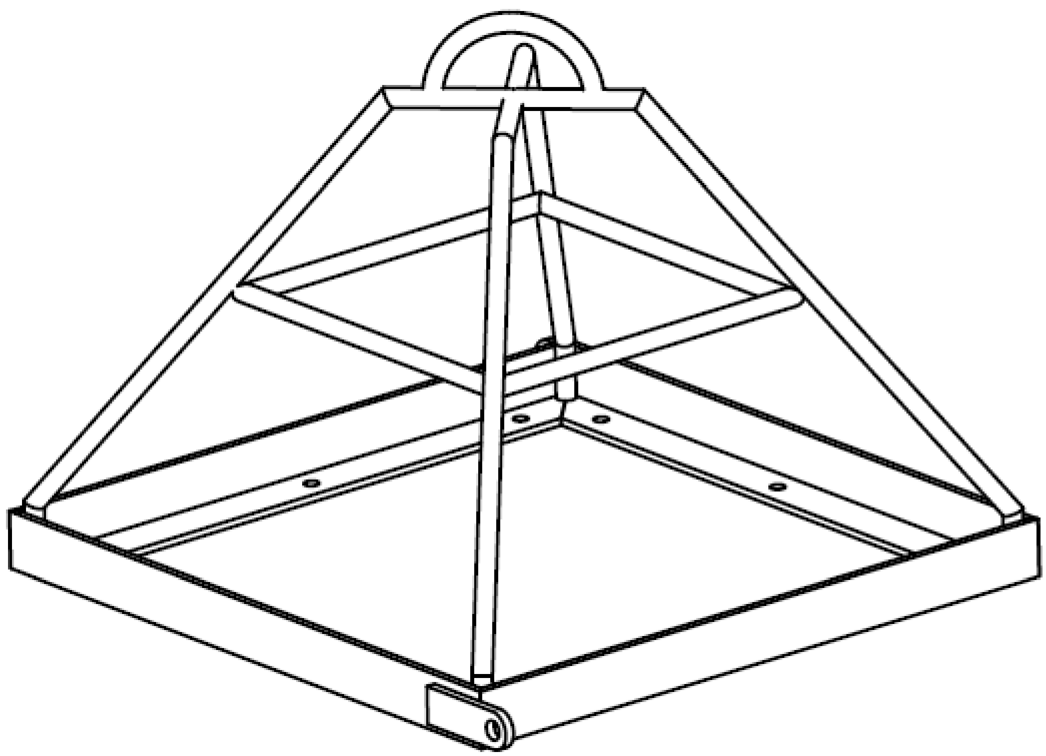


Figure 2: Drawing of Hydrophone Support / Mooring

The mounting frame and hydrophone were deployed by hand from the vessels under test and the GPS location of the hydrophone was recorded. The hydrophone cable was spooled out to the dock; weights were intermittently attached to the cable to help prevent movement. The cable was secured to the dock and was connected to the data acquisition system. A schematic of the deployment arrangement is shown in Figure 3.

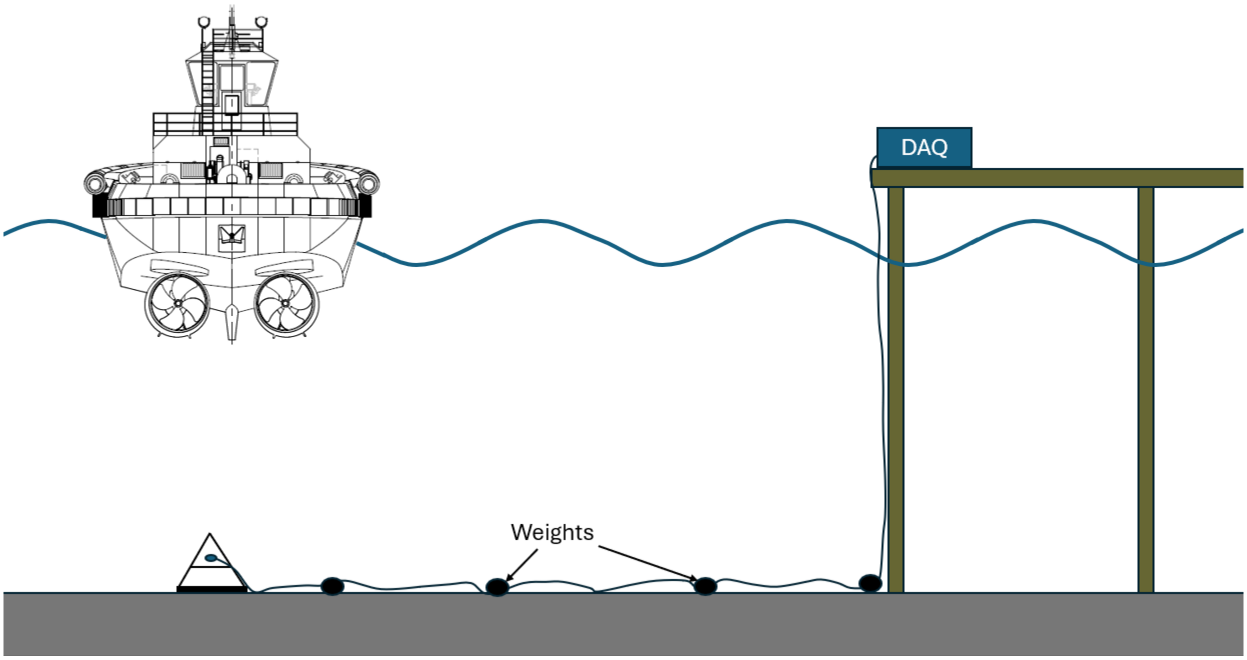


Figure 3: Schematic of Deployment Arrangement, Not To Scale

2.4 Data Collection

Prior to all tests, NCE and Crowley confirmed all vessel machinery was properly configured.

Underwater noise was measured when the vessels were directly over the hydrophone or as close as possible. This maximizes signal-to-noise ratio between the vessel noise and background noise. It also minimizes deleterious effects of long-range propagation in shallow water from multiple reflections of sound off the bottom and surface; these reflections complicate estimations of source level.

Background noise measurements were taken throughout the test period. Testing was suspended when other vessels or sources of noise were nearby, such as vessels transiting the channel. Background noise was seen to have small or negligible effects for all but the quietest vessel operating conditions.

2.4.1 Data Collection Procedure – Transit

The following steps were performed for all transit operation tests. These steps were repeated at least four times for each speed condition.

1. The vessel under test transited the channel in a straight line with the goal of passing directly over the hydrophone.
2. Propeller RPM and vessel speed were kept as stable as possible within 200 meters prior to reaching the hydrophone.
3. Data collection with the primary hydrophone system started when the vessel was at least 200 meters from the hydrophone and ended when the vessel was at least 200 meters past the hydrophone.
4. NCE verified the requested operating conditions were met as the vessel passed over the hydrophone. Runs with significant deviations were rejected.

Despite best attempts at vessels transits directly over the hydrophone, during most transit tests the vessels passed to the side of the hydrophone. NCE attempted to communicate this with the vessel captains who made corrections as possible. The average lateral offset for all measurements was about 13 meters (42 feet). However, the offset was relatively consistent, with the average standard deviation being about 6 meters (20 feet). Therefore, the measurements are self-consistent, at a minimum. Furthermore, commercial vessels have been shown to have very small changes in underwater noise for a range of lateral offsets, including those encountered here, particularly when propeller cavitation is the dominant source [4]. In addition, comparisons of individual runs collected at different lateral offsets show consistent results. Therefore, this offset does not appear to impact the source level estimation.

2.4.2 Data Collection Procedure – STA

For STA, the vessel's propellers were positioned over the hydrophone for the duration of the test. The tow line was adjusted as needed to achieve this positioning.

The following steps were performed for all STA tests. These steps were performed at least three times for each power condition.

1. The vessel pulled against the shore at the nominal test power, using stated propeller RPM.
2. RPM was held constant for 30-60 seconds while acoustic data were collected.
3. NCE verified the requested operating conditions were met throughout the duration of the measurement. Runs with significant deviations were rejected.

Similar to the transit operations, the vessel operators kept the vessel position and engine RPM as constant as possible. Although the goal was to have the vessels hold position directly over the hydrophone, lateral offset distances up to 15 meters (49 feet) occurred. This offset was considered and does not appear to impact the source level estimation (see Section 2.5).

2.5 Data Processing to Calculate Source Levels

The source level calculation was performed for each operating condition as follows:

1) *Collate operational information for each vessel*. The operational data provided for each test (Appendix A) were compiled and prepared for assignment to the associated acoustic data.
2) *Calculate Background Noise.* 'Background noise,' being any noise that is not caused by the vessel under test, varies depending on the activity of other vessels near the hydrophones, weather, and other factors. The noise spectrum of each background measurement was calculated, giving representative background noise spectra throughout the measurement period. Background corrections, discussed below, were performed as needed.
3) *Calculate the received noise level for each test.* Acoustic data corresponding to times when the vessel was over the hydrophone were extracted and analyzed.
    a) *Verify time of maximum noise level.* For transit operating conditions, the data were processed to assess the overall level vs. time. The time at which the maximum noise level corresponding to a vessel pass was then identified. This time was used as the Closest Point of Approach (CPA) as defined in ANSI S12.64. For STA operating conditions, all collected data were considered to be steady state and were used for data processing. A spectrogram of an example vessel pass is provided in Section 5.2.

b) *Calculate the received noise spectrum at the hydrophone.*
   i) For transit operating conditions, the noise spectrum was calculated by averaging the data collected when the vessel was close to the hydrophone. This was done in a similar manner to the methodology of ANSI S12.64, which states the time window used for data processing should correspond to the time when the vessel is at CPA +/- 30 degrees. Note that the ANSI S12.64 30-degree window is in the horizontal plane. Since the vessel passed over the hydrophone, the 30-degree window was applied to the test data in a diagonal plane connecting the ship track and the hydrophone, as shown in Figure 4.
   ii) The time data used to process the received noise is dependent on the vessel speed. The average noise level in this time period was calculated in accordance with ANSI S12.64.

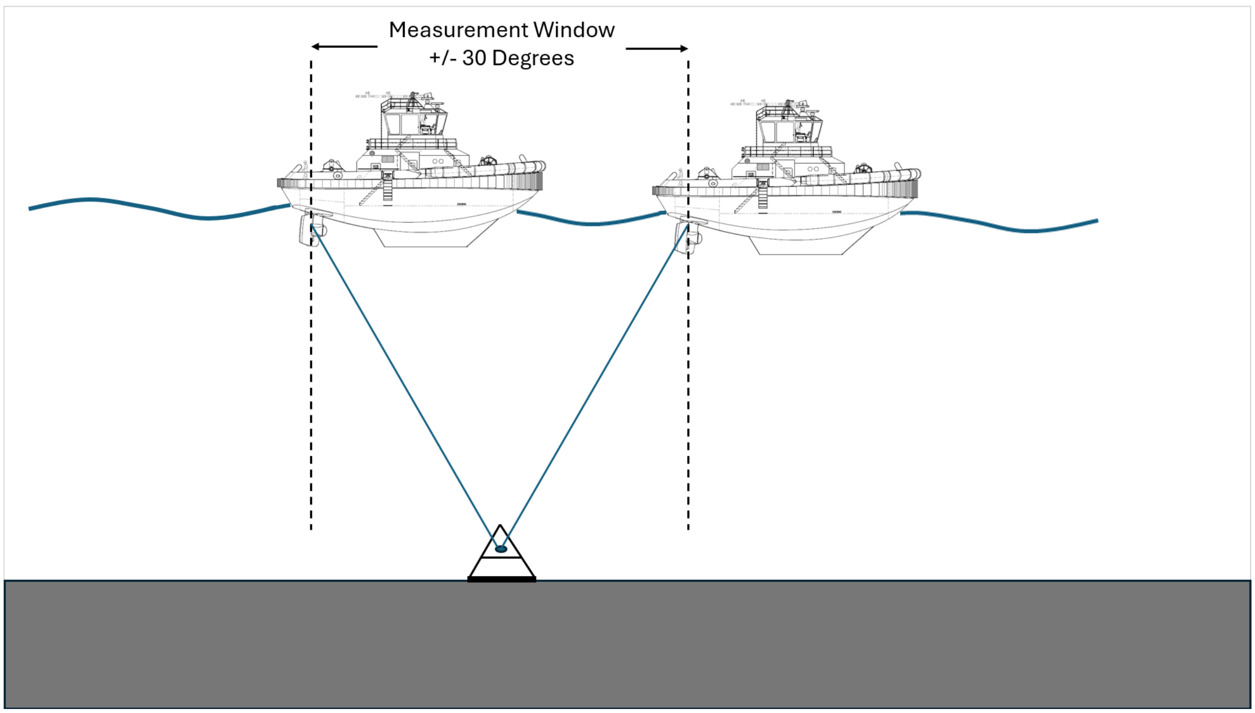


Figure 4: Diagram of Measurement Window

c) *Inspect data for clear measurement issues or signs of interference.* Each calculated spectrum was inspected to identify signs of interference from other vessels or the presence of other clear issues with the measurement. Measurements with issues were rejected. This assessment relied primarily on NCE's experience with underwater noise measurements and data quality, aural cues, and information relating to proximity to other vessels and other notes of importance.
d) *Compare noise spectrum to background levels.* The calculated vessel noise was then compared to background noise measurements representative of the period in which they were captured. Where received levels at specific frequencies were between 3-10 dB above the background noise, corrections were performed in accordance with ANSI S12.64. Levels less than 3 dB above the background noise levels have been highlighted

as being background limited. A spectrogram of an example background measurement is provided in Section 5.2.

4) *Calculate the distance-corrected 1-meter source level.* The received levels were corrected using the measured distance between the hydrophone and vessel in accordance with ANSI S12.64 Grade A. This correction is performed on a second-to-second basis throughout the passby based on the distance to the propulsors from the hydrophone. Received noise levels were increased by $20*\log_{10}(d)$ for each one-second interval, where d is the distance between the measurement hydrophone and the vessel at each second. This approach corresponds to spherical spreading from the noise source; additional details are provided in Section 5.1.
5) *Add calculated noise levels to vessel run information spreadsheet/database.* The received noise spectrum, 1-meter source level spectrum, applicable background noise spectrum, and vessel distance at CPA were combined with the data discussed in Step 1.
6) *Aggregate data for multiple runs.* For each vessel and operating condition, the calculated source level spectra for each valid run were compiled, and average source levels were calculated in accordance with ANSI S12.64. Maximum and minimum spectra were also identified.

The primary results of this process are root mean square (RMS) source level spectra, normalized to 1 meter, of each vessel as a function of operating condition. The spectra were processed into one-third octave bands and narrowbands with 1-Hz bandwidth, forming the basis for vessel design assessments and comparisons in the following sections.

3.0 GENERAL RESULTS

This section discusses the calculated source levels for each vessel and condition. The data are presented using the following structure:

1) Section 3.1 provides a summary comparison of each vessel/condition using overall levels.
2) Sections 3.2 to 3.4 provide details of the causes of noise for the *eWOLF*, *Tioga*, and *Leader*, respectively.
3) Section 3.5 provides a comparison across vessels for each operating condition.

Average, maximum, and minimum one-third octave band levels for each vessel and operating condition are provided in Appendix B. Appendix C presents the average noise levels with corrections to estimate the deep water spectra, as described in Section 5.4.

A summary of potential design benefits from the *eWOLF* battery-electric propulsion system is given in Section 4.0. Details on the application of distance correction to the measurements are provided in Section 5.1.

3.1 Overall Levels

Overall levels are useful as a simple, single number metric to compare the relative noise impact between vessels and conditions. These levels are "unweighted" sound pressure levels (SPLs), meaning there has been no correction applied to the levels at different frequencies. Weighting is sometimes applied to account for hearing capabilities of the receiver, such as A-weighting for humans. Analogous weightings can be used for marine life. Receiver hearing capabilities are not considered in this report, though it is noted that understanding noise levels at different frequencies can be important when considering impacts of vessel noise on the marine environment.

Figure 5 and Figure 6 present the average overall 1-meter noise levels for the three vessels at the transit and STA conditions, respectively. At all transit speeds, the *eWOLF* overall level is at least 6 dB lower than those of the *Tioga* and *Leader* at comparable speeds. These noticeably reduced levels are largely a consequence of the battery-electric propulsion system of the *eWOLF* versus the conventional diesel-geared systems of the *Tioga* and *Leader*. There are other factors that also contribute to these differences which will be explored in later sections.

However, this trend does not hold for the STA conditions. At all STA powers, the *eWOLF* and *Tioga* are within a few dB of each other at comparable conditions. The *Leader* is the quietest vessel at 100% power, but is the loudest at 80% and below. In contrast to the transit conditions, these trends are due in part to the nuances of propeller cavitation generation plus machinery noise from the various propulsion systems. This will be explored more in later sections.

For all three vessels, the highest measured levels occur during the 100% STA condition. By definition, this was the highest power condition measured for each vessel; transit at 10 knots requires lower propulsion power than 100% STA.

In summary, the battery-electric *eWOLF* is only sometimes quieter than the conventionally powered vessels for equivalent operating conditions. Insight as to the reasons for this result is provided in the following sections.

Sound Pressure Level Weighting for Marine Measurements

Frequency weighting can be applied to sound pressure levels to make them representative of the hearing capabilities of the receiver. Weightings generally emphasize noise within a certain frequency range and deemphasize noise outside of this range. The National Marine Fisheries Service (NMFS) provides general underwater weighting functions for five different groups of marine mammals, with the generalized hearing ranges shown in the table below.

Hearing Groups and Hearing Ranges [5]

Hearing Group^	Generalized Hearing Range*
UNDERWATER	
Low-frequency (LF) cetaceans (baleen whales)	7 Hz to 36+ kHz
High-frequency (HF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
Very High-frequency (VHF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*)	200 Hz to 165 kHz
Phocid pinnipeds (PW) (true seals)	40 Hz to 90 kHz
Otariid pinnipeds (OW) (sea lions and fur seals)	60 Hz to 68 kHz

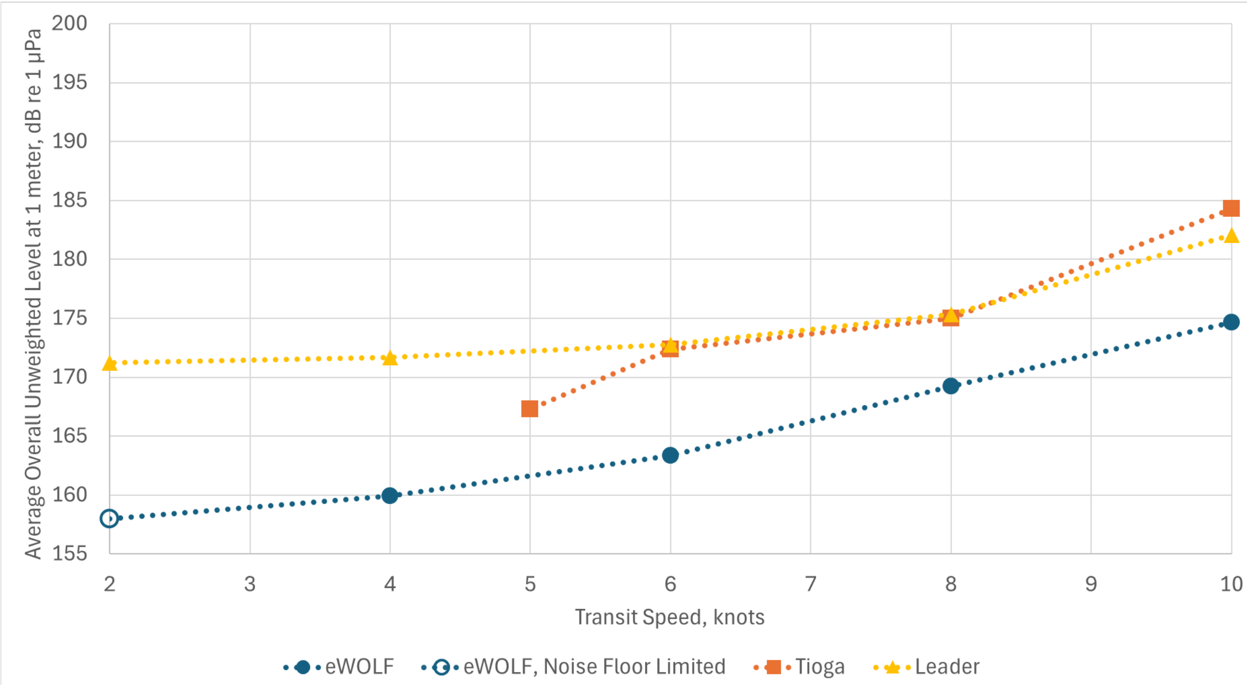


Figure 5: Transit Condition, Average Overall Levels at 1-meter

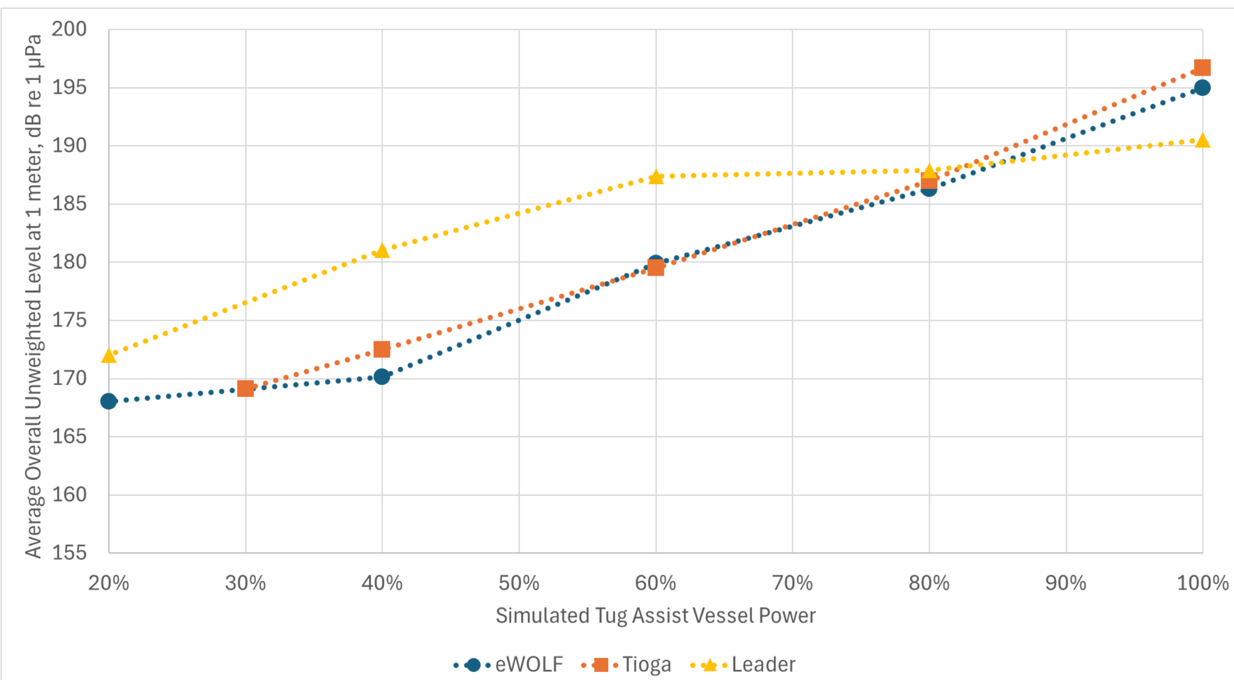


Figure 6: STA Condition, Average Overall Levels at 1-meter

3.2 <u>*eWOLF* Causes of Noise</u>

Underwater radiated noise levels from the *eWOLF* are largely driven by propeller cavitation and propeller excitations that occur at blade rate frequencies. Additional contributions are also present from the L-drive gearing, propulsion motors, and auxiliary machinery for some conditions.

Figure 7 and Figure 8 present the *eWOLF* one-third octave source level spectra for all transit and STA conditions, respectively. The one-third octave spectra provide insight into the noise levels present at different frequencies. The overall levels presented in Section 3.1 are the logarithmic sum of the one-third octave band levels for a given condition. By identifying frequencies with higher one-third octave band levels, the frequency ranges that are primarily responsible for the total overall noise level can be identified.

The *eWOLF* overall noise levels at transit conditions above 4-knots are typically controlled by noise at frequencies above 200 Hz. The noise in this range is largely due to propeller cavitation, though tones from the L-drive gears and the electric propulsion system are also present (further clarified below). Propeller blade rate excitations, which occur at frequencies below 100 Hz and are influenced by cavitation, also contribute to overall noise levels. At slower speeds, noise levels are caused primarily by machinery sources, including L-drives, propulsion motors, and other auxiliary machinery systems. However, the levels are close to or below background noise levels at most frequencies; i.e., the levels are generally low.

At STA conditions, the overall levels are influenced by propeller cavitation noise at nearly all frequencies. Cavitation noise clearly increases with each step up in power. Tones related to machinery are generally masked by propeller cavitation, particularly at 60% power and above.

“Narrowband” spectra provide another method to assess noise levels at different frequencies. In this report, the narrowband plots present the noise in 1-Hz steps. Figure 9 shows the narrowband source level spectrum for one example 8-knot transit event. Annotations illustrating the frequency ranges associated with different noise sources are provided.

Blade rate excitations control noise levels at frequencies below 100 Hz, with clear peaks at each harmonic. Broadband cavitation controls noise levels above 600 Hz, though it is present at all frequencies and contributes to the one-third octave band levels above 200 Hz in this example. Tones related to L-drive gearing and propulsion motors are prominent between 100 to 600 Hz. However, the tones above 300 Hz are less important when considering one-third octave band levels and overall noise levels.

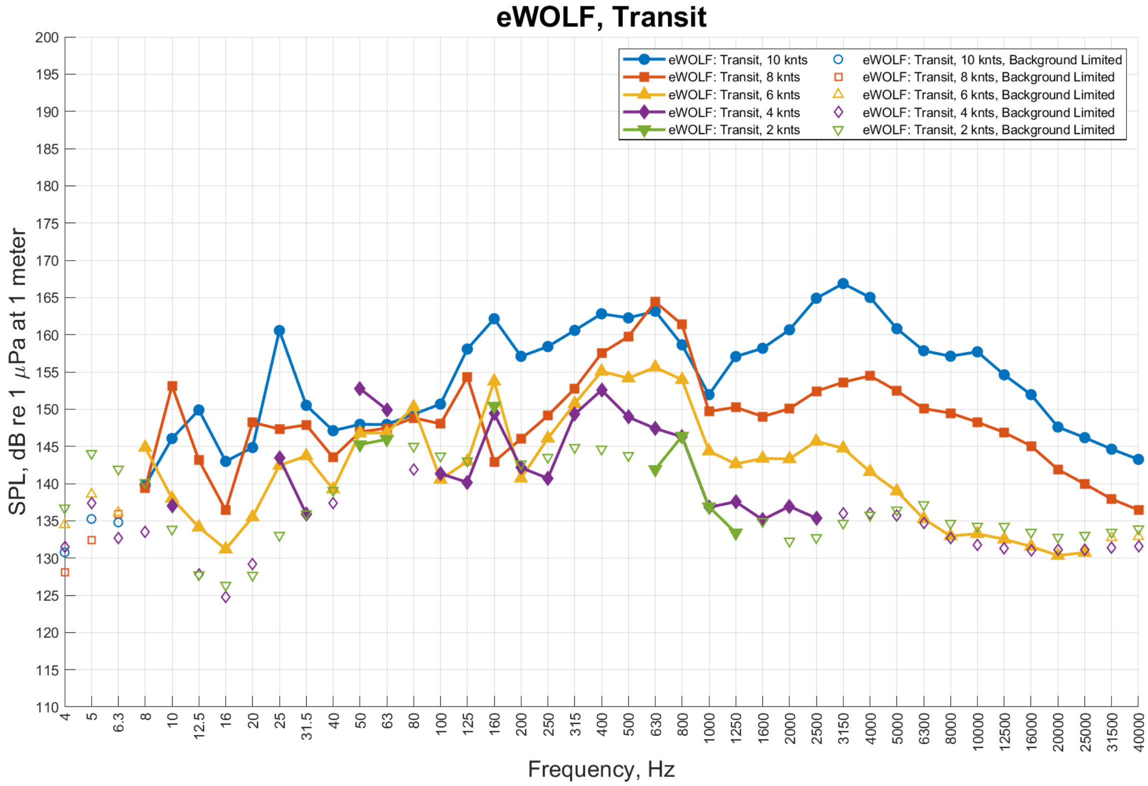


Figure 7: One-Third Octave Band Average Spectra, *eWOLF*, Transit Conditions

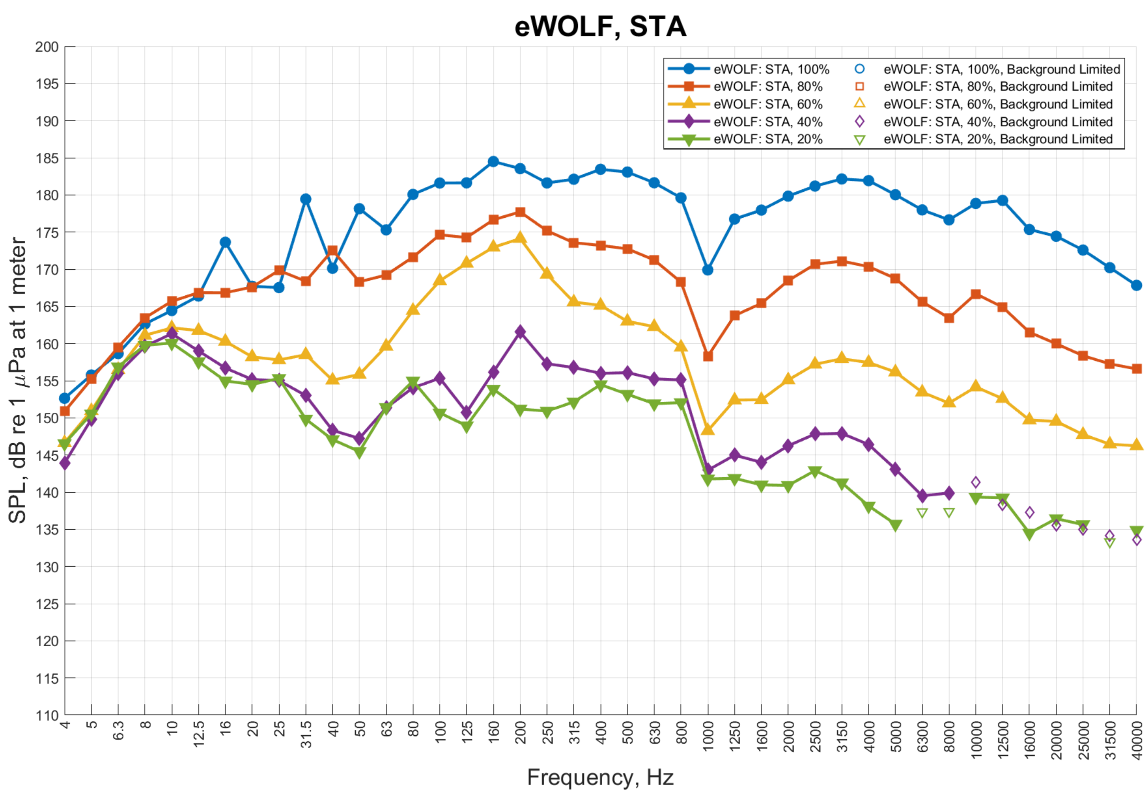


Figure 8: One-Third Octave Band Average Spectra, *eWOLF*, STA Conditions

A significant dip is also present in the spectrum at 1 kHz. A similar dip is present in all noise measurements and is a consequence of the hydrophone being close to the seafloor. This dip is discussed in more detail in Section 5.4.

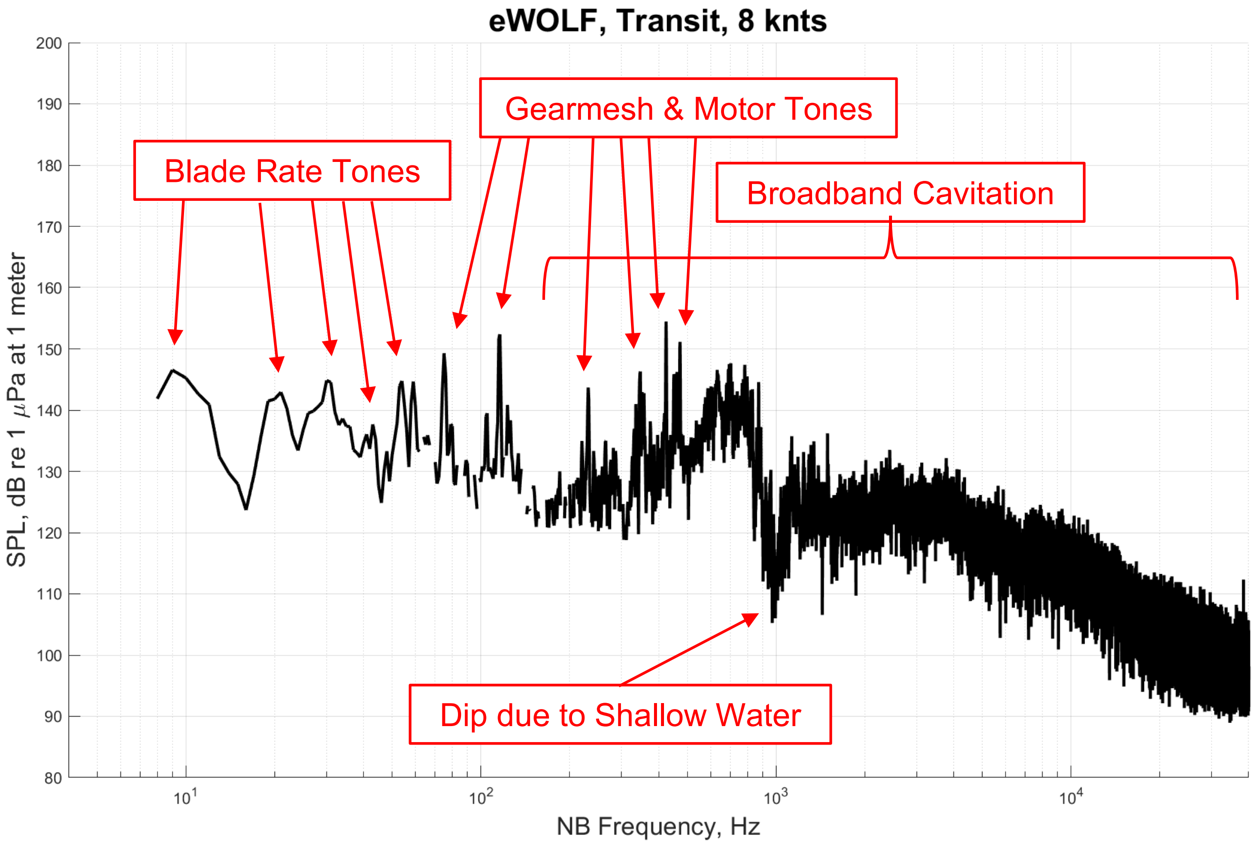


Figure 9: Narrowband Spectrum of *eWOLF*, 8 knot Transit [Run 31]

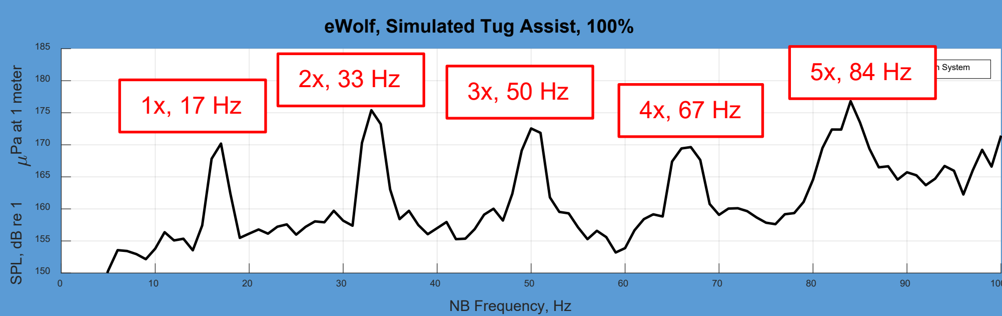
Rotation Rate, Blade Rate, and Harmonics

Rotation Rate is the rotation speed of a given component such as an engine shaft, motor shaft, or propeller. This is typically measured in revolutions per minute (RPM) but can also be expressed in cycles per second (Hz).

Blade Rate is the rate at which an individual propeller blade passes a specific point, measured in Hz. It can be calculated by multiplying the propeller Rotation Rate by the number of propeller blades. For example, a 4 bladed propeller spinning at 3 Hz has a Blade Rate of 12 Hz.

Propellers typically produce noise at Blade Rate and integer multiples thereof. These multiples are known as “harmonics.” That is, a propeller with a Blade Rate of 12 Hz has a “first harmonic” or “1x” Blade Rate of 12 Hz, a 2x Blade Rate of 24 Hz, a 3x Blade Rate of 36 Hz, and so on.

The example plot below shows the 1x to 5x Blade Rate Harmonics for the *eWolf* during the 100% power Simulated Tug Assist Condition.



Similarly, diesel engines will produce tonal excitations at multiples of their Rotation Rate.

L-Drive and Z-Drive Gear Tones

L-Drives, Z-Drives, and all gearboxes create tones at "gearmesh" frequencies. Gearmesh is the rate at which the teeth of a gear engage with each other. Similar to blade rate, tones are often found at the fundamental gearmesh frequency of each gear, as well as at harmonics of that frequency.

3.3 *Tioga* Causes of Noise

The *Tioga* underwater radiated noise levels are primarily controlled by propulsion engine excitations and propeller cavitation.

Figure 10 and Figure 11 present the *Tioga* one-third octave band source level spectra for the transit and STA conditions, respectively. Noise in the 20-5000 Hz range broadly controls the total, overall noise levels. Engine excitations are responsible for the noise through most of this frequency range at most operating conditions. However, propeller cavitation becomes increasingly prominent at speeds above 5 knots and above 30% STA power, and contributes to overall levels at higher transit speed and STA power conditions.

Figure 12 presents the narrowband source level spectrum from an 8-knot transit event. Similar to the *eWOLF*, broadband cavitation controls noise levels at middle and higher frequencies. However, lower and middle frequencies (below 500 Hz for this example) are largely controlled by propulsion engine excitations, which are created at regular frequency intervals related to rotation rate. These tones are absent on the *eWOLF* due to the battery-electric propulsion system. There is also a transition region between the middle and high frequencies where both engine harmonics and broadband cavitation contribute.

In the Figure 12 example, the fundamental propeller blade tone is the only prominent blade rate excitation seen. Higher blade rate harmonics are masked by other noise. This is typical of most measured *Tioga* spectra, though at lower transit speeds/STA powers the fundamental blade rate tone is often below the background noise level.

Tones related to sonar systems are seen at frequencies above 10 kHz. These are present at all conditions except the 100% power STA, where broadband cavitation fully masks them. These tones do not contribute to the overall noise of the vessel.

Gearmesh tones from the Z-drive propulsion were expected to be present as noted for the *eWOLF* but any such tones seem to be masked by engine excitations. As discussed for the *eWOLF*, a significant dip is present in all *Tioga* spectra at 1 kHz due to the location of the hydrophone near the bottom.

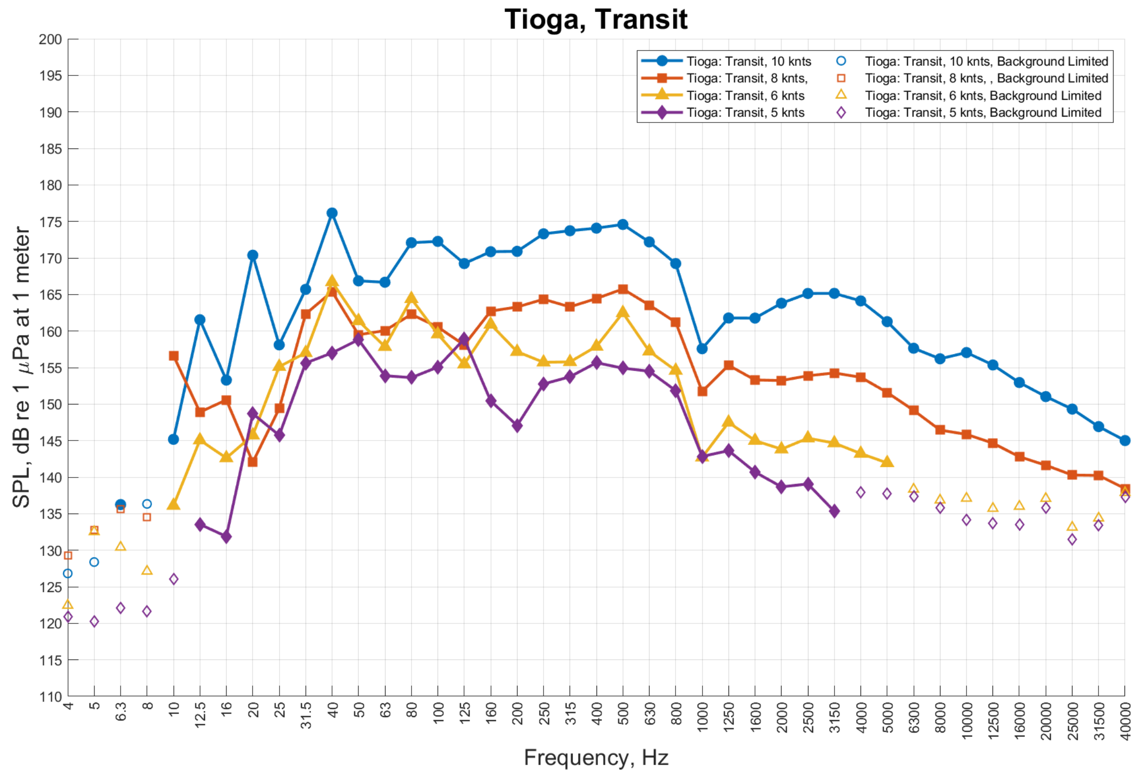


Figure 10: One-Third Octave Band Average Spectra, *Tioga*, Transit Conditions

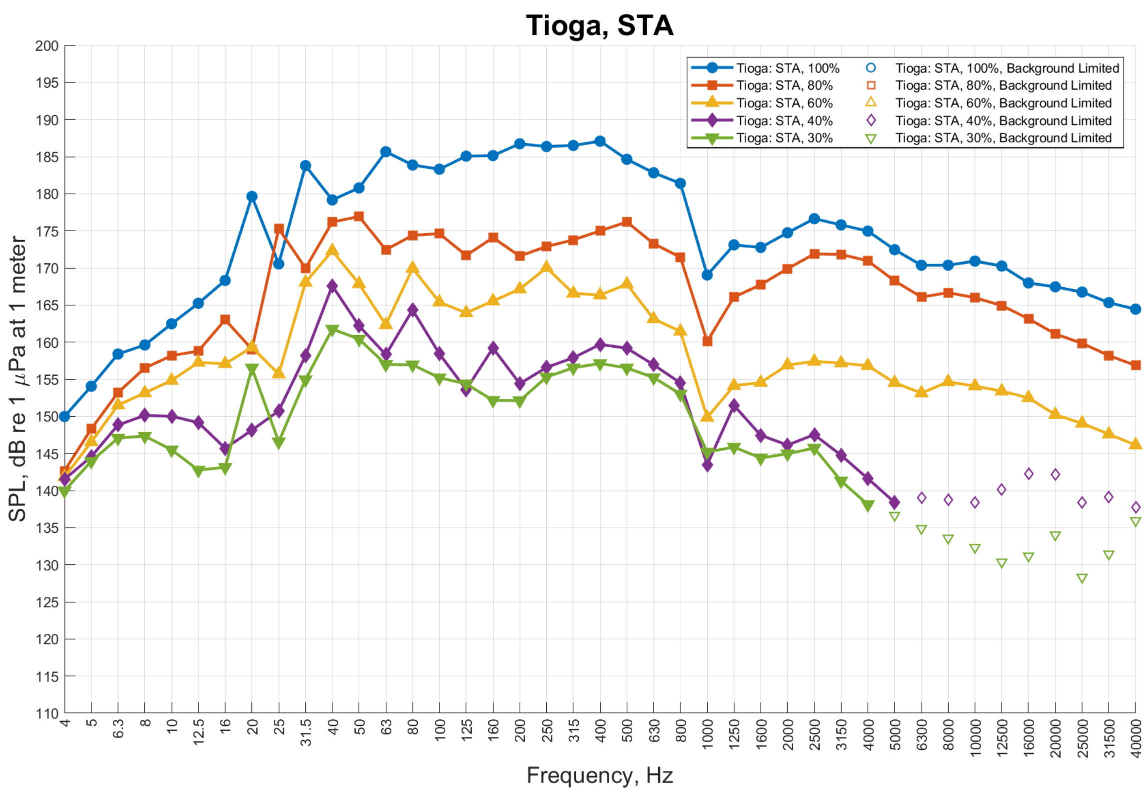


Figure 11: One-Third Octave Band Average Spectra, *Tioga*, STA Conditions

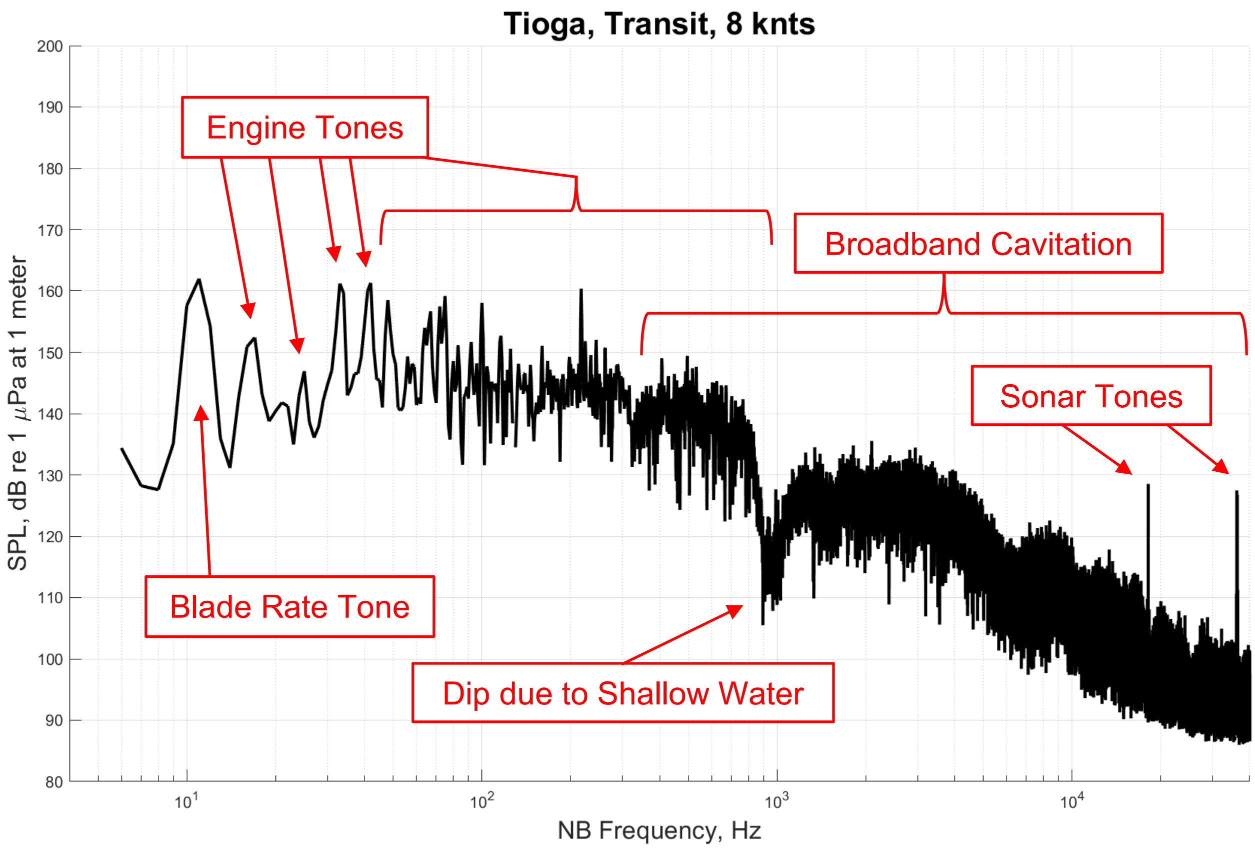
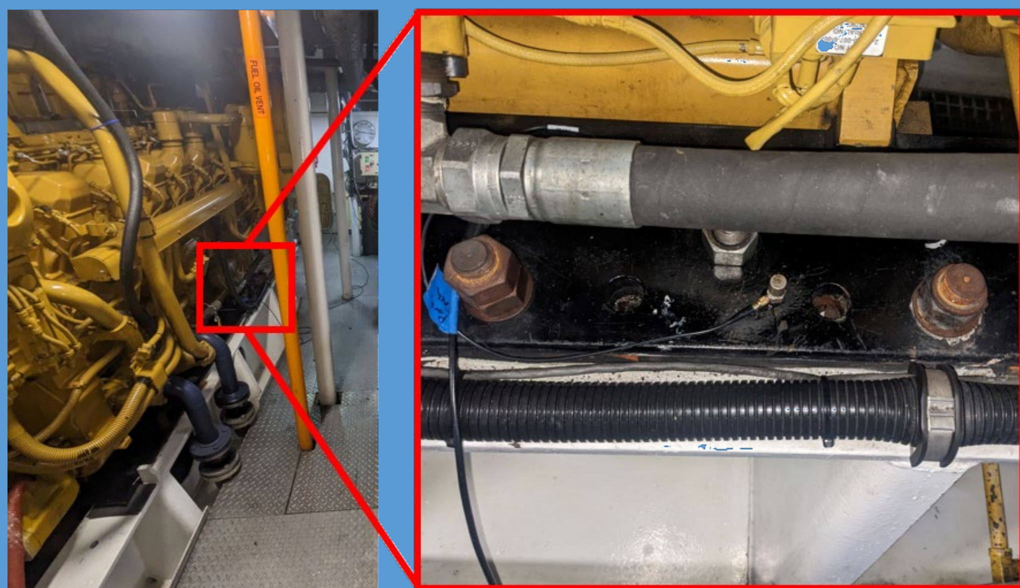


Figure 12: Narrowband Spectrum of *Tioga*, 8 knot Transit [Run 123]

The *Tioga* propulsion engine excitations are prominent because the engine is directly mounted to the structure. This is called "hard mounting." As a result, the engines are the dominant source, essentially controlling the overall levels of all measured *Tioga* conditions. If the engines were treated for noise via resilient mounting and/or other engine room treatments, the noise created by the propulsion engines would be reduced and the noise from the *Tioga* may approach that of the *eWOLF* for all measurement conditions.

Hard Mounting and Resilient Mounting

Hard mounted machinery is directly connected to the ship via the foundation. The image below shows two views of the *Tioga* starboard propulsion engine, which is directly bolted to its foundation. Hard mounting transfers more vibration to the vessel structure than resilient mounting (see below). As a result, hard mounted engines are a common source of underwater radiated noise.



A resilient mount is a soft spring that is installed between a machinery item and its foundation. When designed and installed correctly, resiliently mounted machinery will transfer less vibration to the vessel structure as compared to hard mounting. This usually results in less underwater noise from the machinery item. The mounts themselves can be made from rubber elements, spring elements, or both. A mounting system will generally consist of four or more mounts with supporting structures above and below the mounts.

3.4 ***Leader* Causes of Noise**

The underwater radiated noise levels of the *Leader* are controlled primarily by the propulsion engines. At some conditions, secondary contributions from propeller cavitation and blade rate harmonics are present.

Figure 13 and Figure 14 present the *Leader* one-third octave band source level spectra for all transit and STA conditions, respectively. The spectra indicate that total, overall noise levels are typically controlled by noise in the 20-800 Hz range. Engine excitations are prominent in this frequency range and beyond, and control the overall levels of every condition.

Contrary to the other vessels, cavitation noise on the *Leader* only becomes prominent at 10-knot transit, and does not appear to be present at slower speeds. During the STA conditions above 40%, the high frequency levels show signs of light cavitation, though propulsion engine influences remain notable.

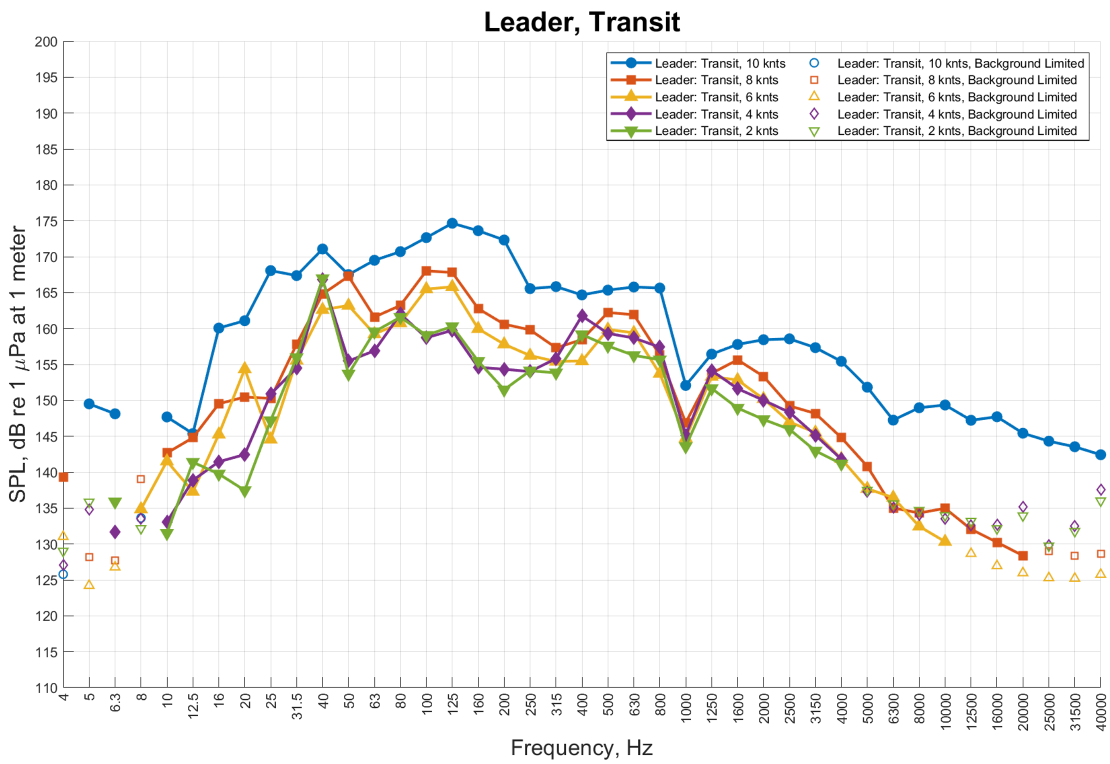


Figure 13: One-Third Octave Band Average Spectra, *Leader* Transit Conditions

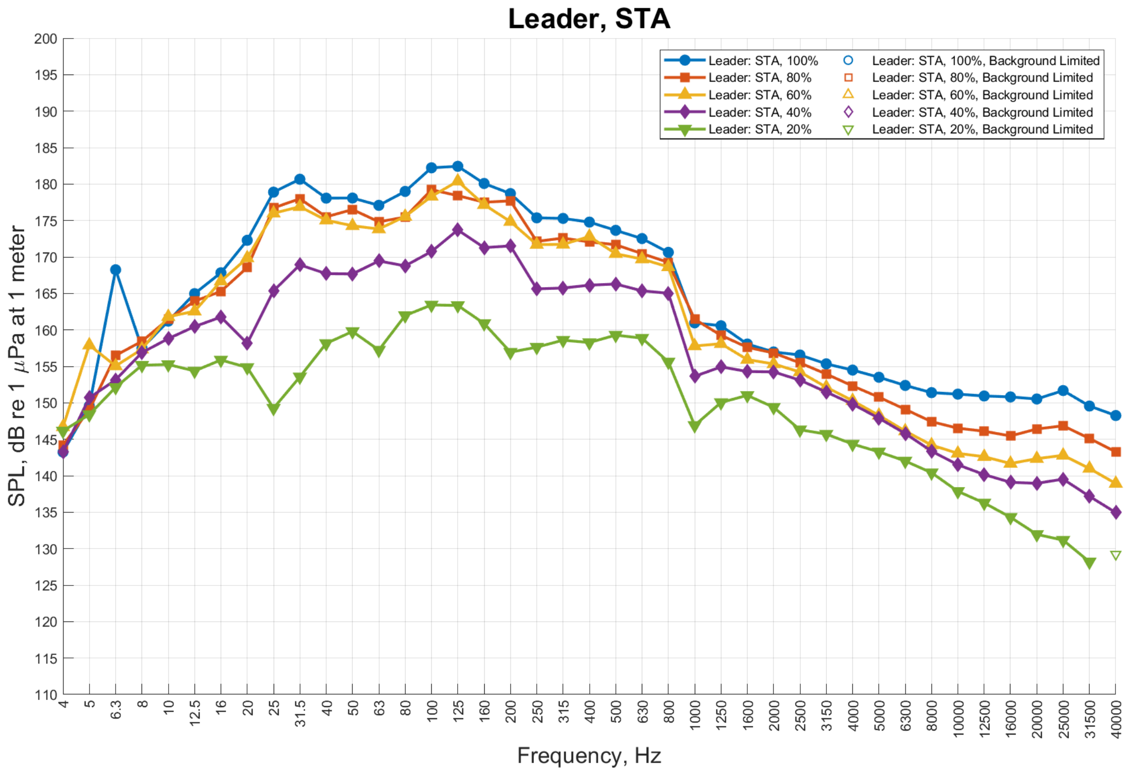


Figure 14: One-Third Octave Band Average Spectra, *Leader*, STA Conditions

The narrowband source level spectrum from a 10-knot transit event is presented in Figure 15. Similar to the *Tioga*, propulsion engine harmonics control the noise below 1 kHz. Broadband cavitation is present at this speed and masks the engine tones that would otherwise be seen above 1 kHz. Where cavitation is present, there is a transition region where both engine harmonics and broadband cavitation contribute to one-third octave band and overall noise levels.

Similar to the *Tioga*, gearmesh tones from the Voith Schneider propulsion were expected, but any such tones seem to be masked by engine excitations. As discussed for the other vessels, a significant dip is present in the spectrum of all *Leader* measurements at 1 kHz due to the location of the hydrophone near the bottom.

It is important to highlight that propeller cavitation produces significantly lower noise levels on the *Leader* as compared to the *Tioga* and *eWOLF*. This will be discussed in more detail in Section 4.5.

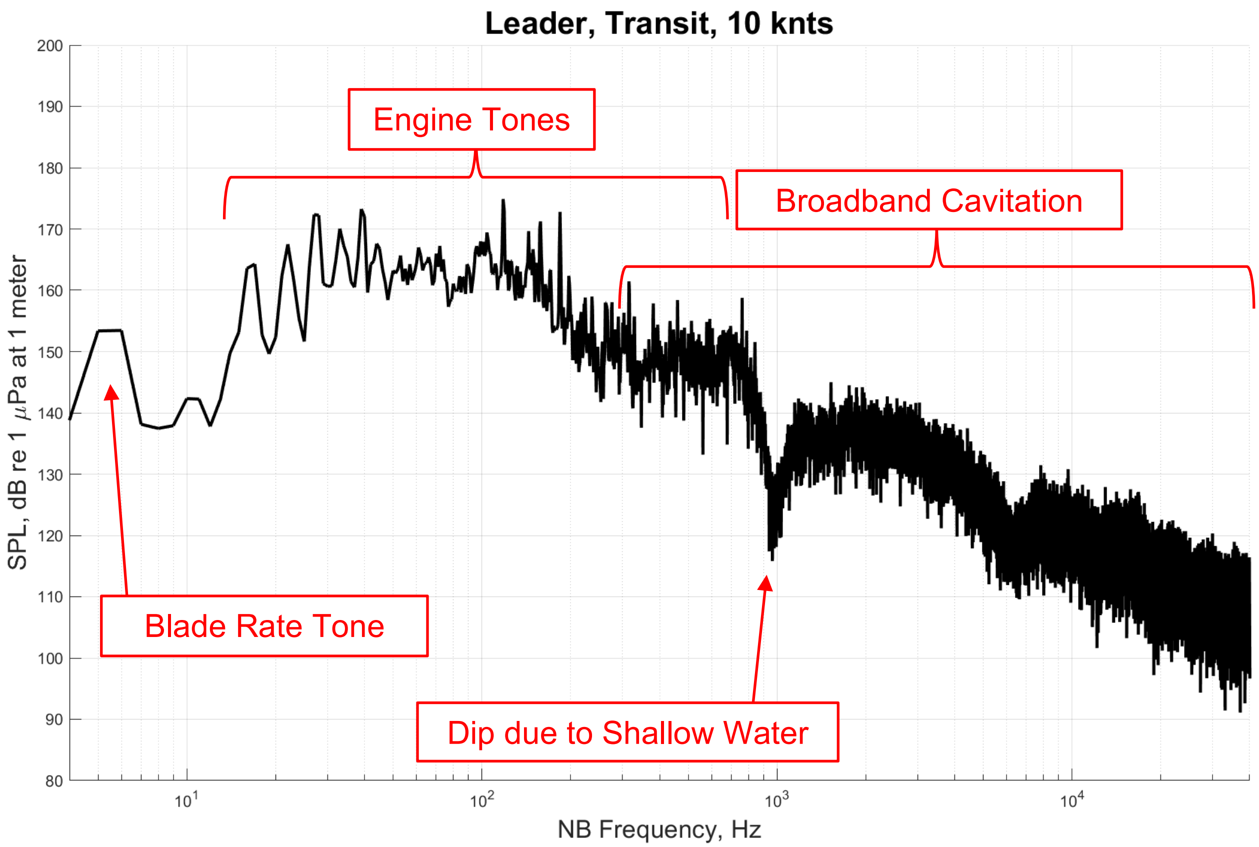


Figure 15: Narrowband Spectrum of *Leader*, 10 knot Transit [Run 67]

3.5 Vessel Comparisons

3.5.1 Transit

Figure 16 and Figure 17 compare the one-third octave source level spectra across the three vessels at 10 knots and 4-5 knots, respectively. Similar plots for all speeds are provided in Appendix D. At frequencies below 1 kHz, the *Tioga* and *Leader* have similar noise levels at all transit speeds because they both have hard-mounted engines. The noise below 1 kHz is primarily responsible for the total noise of the *Tioga* and *Leader* during transit. In comparison, the *eWOLF* has significantly lower noise below 1 kHz because it does not have propulsion engines. Therefore, the primary reason for the differences in overall level between the *eWOLF* and *Tioga*/*Leader* is the hard-mounted propulsion engines.

Above 1 kHz, the *Tioga* and *eWOLF* have similar noise at speeds where cavitation is present. This is seen in the 10-knot data shown here, but can also be seen in the 4- to 8-knot data in Appendix D. This is due to both vessels employing conventional propellers, which appear to have similar cavitation trends. In comparison, the *Leader* uses Voith-Schneider Propellers (VSPs) that produce minimal cavitation at transit conditions up to 10 knots. As a result, the *Leader* has significantly lower levels above 2 kHz in the 8 and 10 knot transit conditions than the other vessels. At slower speeds where no vessels produce cavitation, the *Leader* has higher noise levels above 1 kHz due to machinery influences.

In summary, the *Tioga* and *Leader* propulsion engines control the noise during transit conditions, leading them to have overall noise levels that are 6+ dB louder than the *eWOLF*.

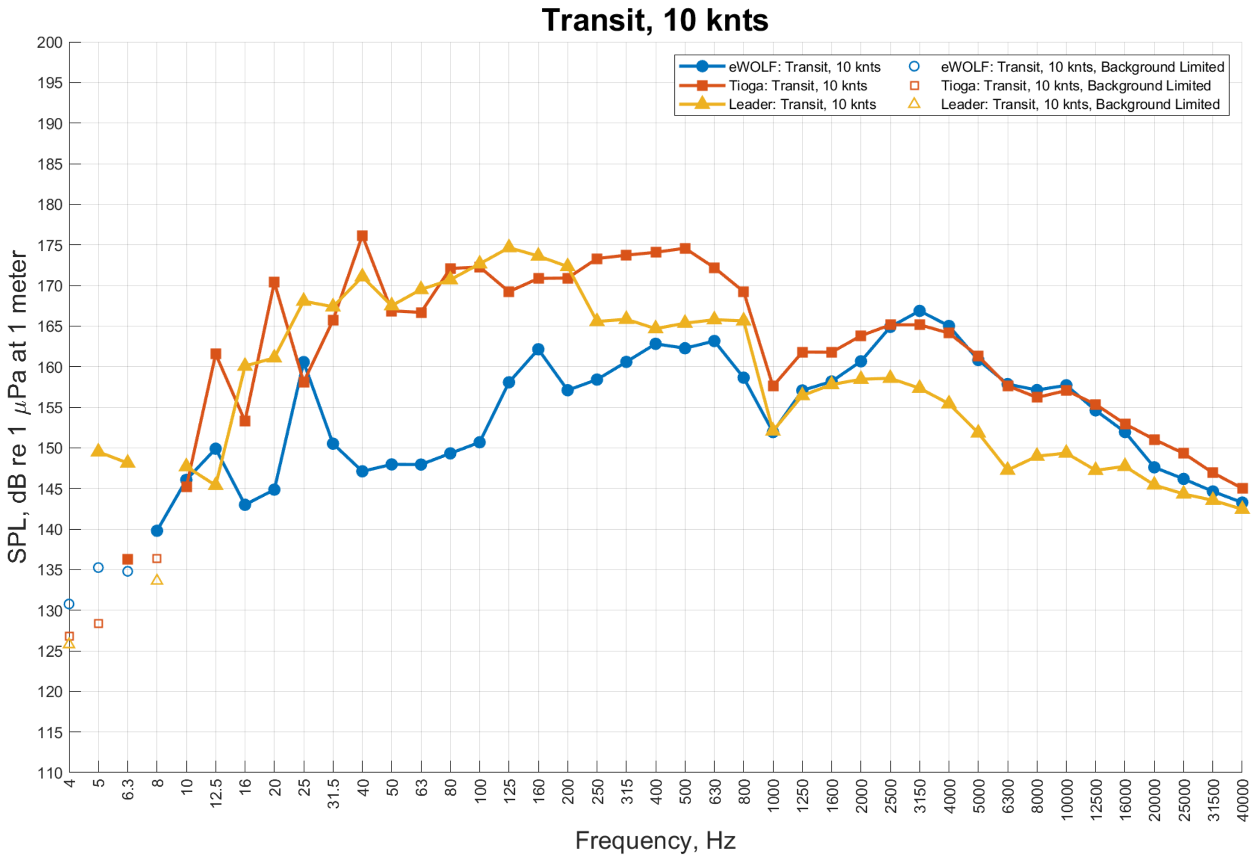


Figure 16: One-Third Octave Band Average Spectra, All Vessels, 10-knot Transit

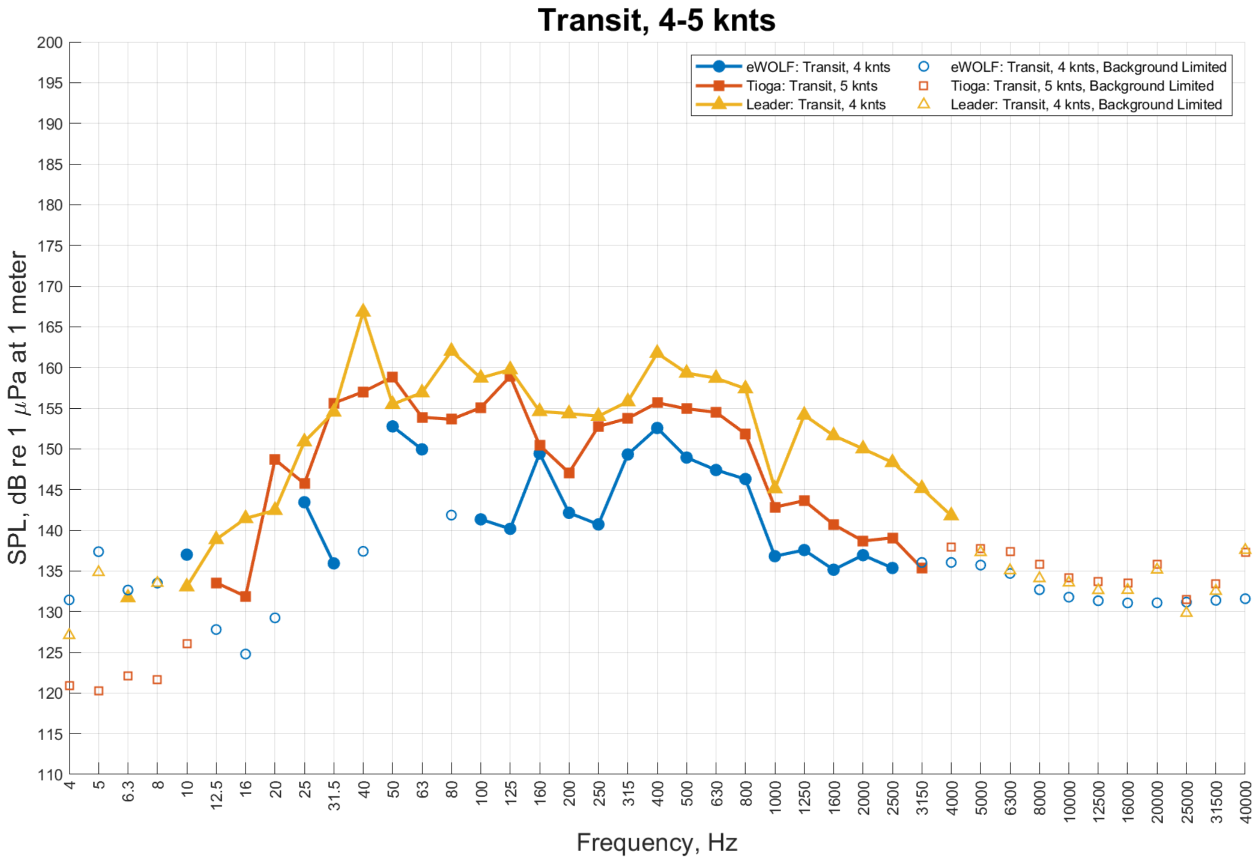


Figure 17: One-Third Octave Band Average Spectra, All Vessels, 4-5 knot Transit

3.5.2 Simulated Tug Assist

Figure 18 and Figure 19 present the one-third octave source level spectra of the three vessels for the 100% and 60% STA conditions, respectively. Similar plots for all STA measurements are provided in Appendix D. As noted previously, the overall levels of the *eWOLF* and *Tioga* are similar; this is also seen in the one-third octave band spectra. Both vessels use conventional propellers, and once cavitation is present it becomes a dominant component of the total noise level. Conversely, the *Leader* does not produce strong cavitation. The noise from the *Leader* is primarily due to the hard mounted propulsion engines, and the rate of increase in noise with STA power is not the same as for propeller cavitation noise on the *eWOLF* and *Tioga*.

As a result, the *Leader* is the quietest vessel at the 100% STA condition, but is the loudest at 80% STA and below. This transition is illustrated by the comparison of the 60% STA conditions in Figure 19. Similar to the 100% STA conditions, stronger cavitation is seen from the *eWOLF* and *Tioga* than the *Leader*. However, at 60% STA, the noise from the hard mounted propulsion engines on the *Leader* is greater than the cavitation noise on the other two vessels.

It is briefly noted that these vessels rarely operate at 100% power when performing tug assist operations. Time spent at worst case conditions can be a factor when assessing impacts of underwater noise, and similarly when designing vessels to have reduced underwater noise.

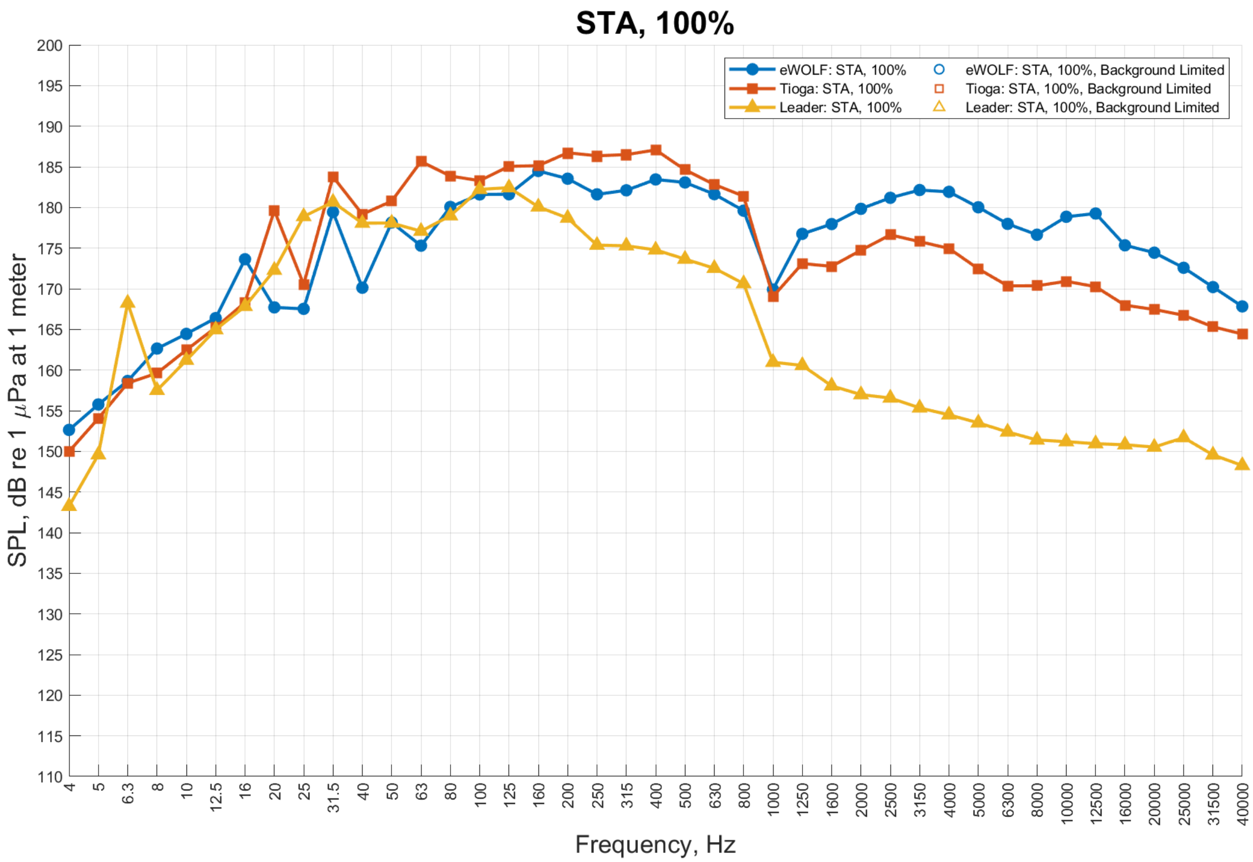


Figure 18: One-Third Octave Band Average Spectra, All Vessels, 100% STA

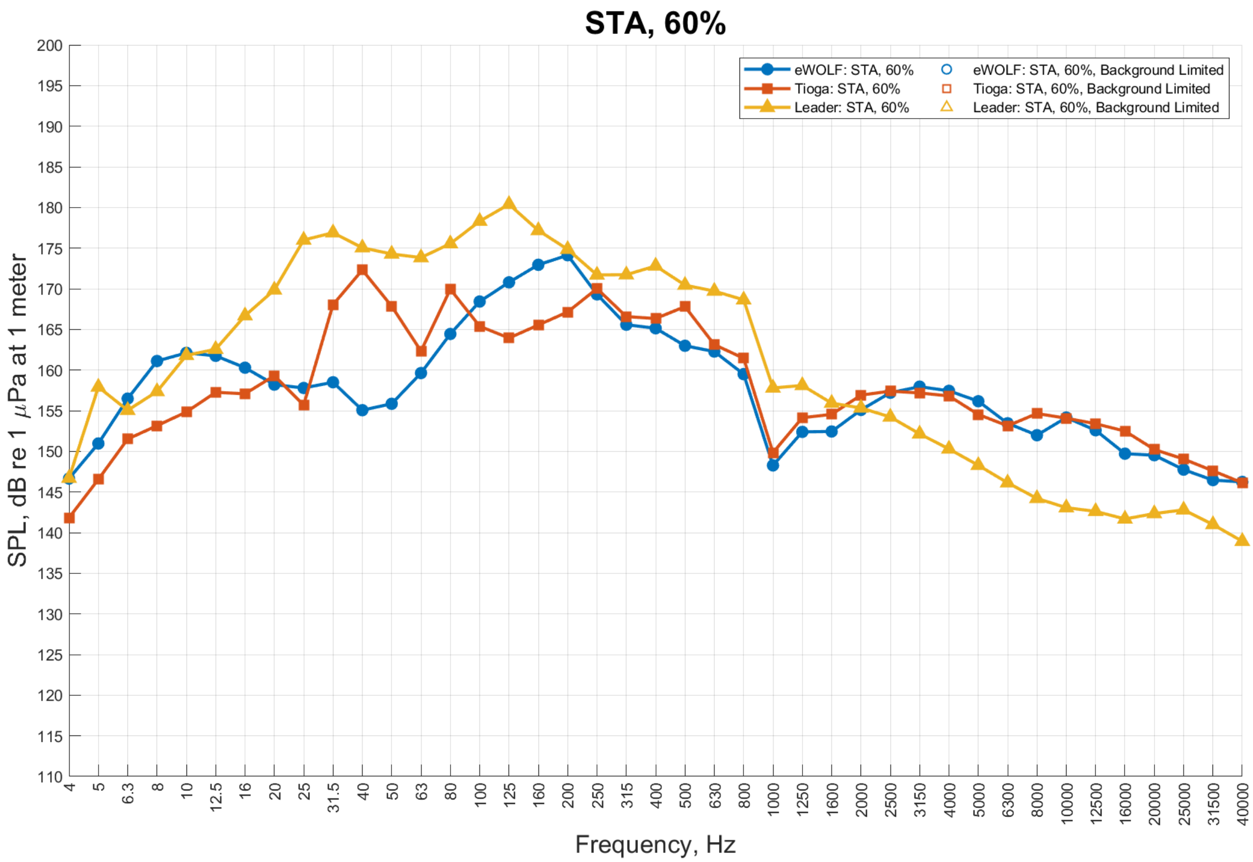


Figure 19: One-Third Octave Band Average Spectra, All Vessels, 60% STA

4.0 BENEFITS OF BATTERY-ELECTRIC PROPULSION

The measurement data indicate underwater noise reductions for tugs are possible by implementing battery-electric propulsion systems. Such systems can also provide a reduction in greenhouse gas emissions. However, these reductions will be largely limited to slower speed operating conditions when propeller cavitation is not present. Cavitation noise typically contributes to or dominates the underwater noise spectra at higher vessel speeds and during tug assist activities when conventional propellers are used.

The *eWOLF* is quieter than the *Tioga* and *Leader* at all transit speeds. This is because the noise produced by the *Tioga* and *Leader* propulsion engines exceeds the *eWOLF* propeller cavitation levels. However, for STA operations at 60% power and above, the *eWOLF* propeller cavitation noise is high enough to equal the overall noise of the *Tioga*, and at 100% STA it exceeds the overall noise of the *Leader*.

It is noted that the *eWOLF* full power rating is somewhat higher than the *Leader* and *Tioga*. The pull forces created by the vessels could not be measured due to logistical issues. It is possible that comparisons using pull force would yield slightly different comparisons than those using percent power, but the overall results presented here relating to the benefits of battery propulsion and overall design considerations are believed to be the same.

Additional improvement of the *eWOLF* underwater noise could be achieved through the design and use of propellers that produce less cavitation. Conventional propeller designs with reduced cavitation may be possible if underwater noise is implemented as a goal at the design stage.

Alternative propulsion systems, such as the Voith Schneider and similar propulsion systems, also present opportunities for reduced underwater noise due to their significant reduction in induced cavitation. Note that this study could not directly assess the fuel efficiency of Voith Schnieder systems, so its impact on greenhouse gas emissions is not known directly.

The design of the *Leader* and *Tioga* could also be modified to lower noise levels by applying noise controls to the propulsion engines. Although this is not likely to reduce low and mid frequency noise levels to the same extent as is achieved through the *eWOLF* battery-electric system, it could significantly reduce the overall measured levels.

5.0 ADDITIONAL INFORMATION AND RESULTS

5.1 Vessel Distance Correction

As discussed in Section 2.5, received levels were corrected on a second-to-second basis using the measured distance between the hydrophone and vessel in accordance with ANSI S12.64 Grade A. This process is illustrated for an example passby of the *eWOLF* in Figure 20. Three plots are provided as a function of time. The top plot shows the overall level received at the hydrophone, which increases while the vessel approaches the CPA and decreases as the vessel departs. The second plot shows the distance from the vessel to the hydrophone, which follows the opposite trend as the received level. The third plot shows the overall level that has been distance corrected on a second-by-second basis.

Each plot shows the CPA at 0 seconds with a dotted vertical line. The beginning and ending of the measurement window is also shown with solid vertical lines (+/- 3 seconds from CPA for this example). All data are presented in 1-second intervals.

It is seen that the distance-corrected level is essentially constant over the measurement window, and even outside of the measurement window. This is generally true of the distance-corrected 1-meter source levels in this study. This result underscores the validity of the spherical spreading ($20*\log_{10}(d)$) distance correction that was used.

Understanding Distance Correction

Distance correction is a requirement of ANSI S12.64 to calculate a vessel's source level. The correction accounts for the change in noise level as the sound propagates from the source to the receiver.

Noise from sources such as cavitating propellers will spread uniformly in all directions unless it encounters a change in the medium (such as the sea floor or surface). The uniform spreading is known as spherical spreading since the sound spreads out spherically from the source.

The distance correction for spherical spreading is mathematically $L_D = 20*\log_{10}(d)$, where L_D is the reduction in level between 1 meter from the source and a distance d from the source. 1 meter is used as the reference distance in accordance with ANSI S12.64.

Spherical spreading is appropriate to use when the sound is free to travel from the source to the receiver. When sound arrives at a receiver from multiple paths, such as multiple reflections off surface and bottom, sound propagation is more complicated and simple spherical spreading may not apply. The effects of these multiple sound paths increase with greater measurement distance, and can be significant when the measurement distance is much greater than the water depth.

One way to assess the validity of a distance correction formula or model is to compare the levels it produces for a given source measured at multiple distances from a single receiver, such as at multiple locations during a vessel passby. If the distance corrected levels are consistent, then the method is generally valid for that range of distances. Conversely, if the distance corrected levels are not consistent, then a different distance correction method should be considered.

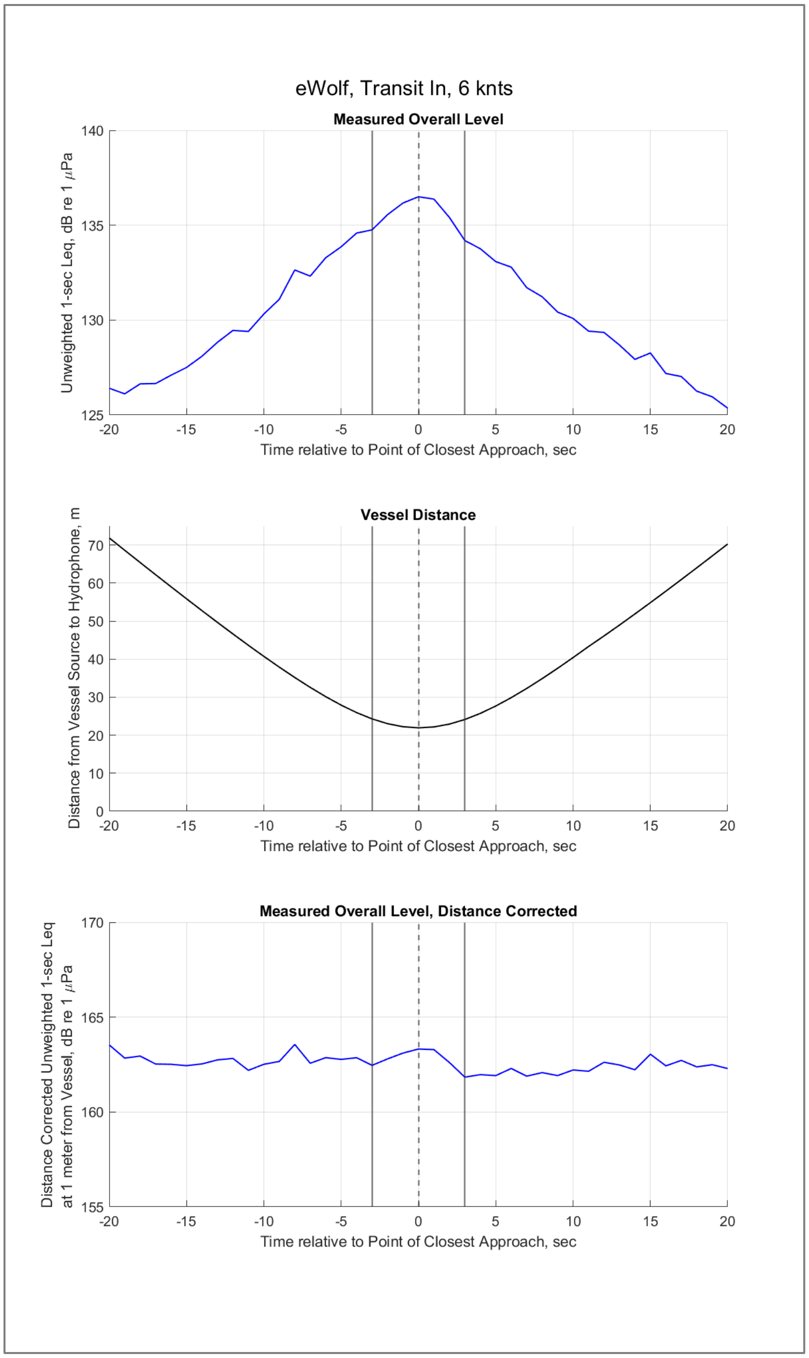


Figure 20: Distance Correction of Vessel Passby [Run 36]

5.2 <u>Example Spectrograms</u>

Spectrograms present time, frequency, and sound pressure level data within a single plot. They are useful in evaluating changes in level over time at specific frequencies and frequency ranges. Figure 21 presents a spectrogram for an example vessel pass of the *eWOLF*. Time is represented on the x-axis, frequency on the y-axis, and the received sound pressure level at the hydrophone as a function of color, with warmer colors indicating higher levels and cooler colors indicating lower levels. In Figure 21, the x-axis is centered on the CPA and extends 20 seconds before and afterwards. Similar to Figure 20, dashed and solid vertical lines indicate the CPA and measurement window. All data are presented in 1-second intervals and 1-Hz frequency bands.

Noise levels increase over a broad range of frequencies as the vessel approaches CPA, and decrease as the vessel departs. Below 200 Hz, a few distinct tones are visible as red horizontal lines, increasing and decreasing in a similar manner to the broadband noise. The relative levels at different frequencies remain similar throughout the vessel pass, particularly during the measurement window.

Figure 22 presents a representative background measurement taken close to the time of the vessel passby shown in Figure 21. The background levels are relatively constant over the measurement window, and are lower than the vessel pass throughout most of the frequency range. Generally, all vessel passes and background measurements within this study follow similar patterns as the data shown here.

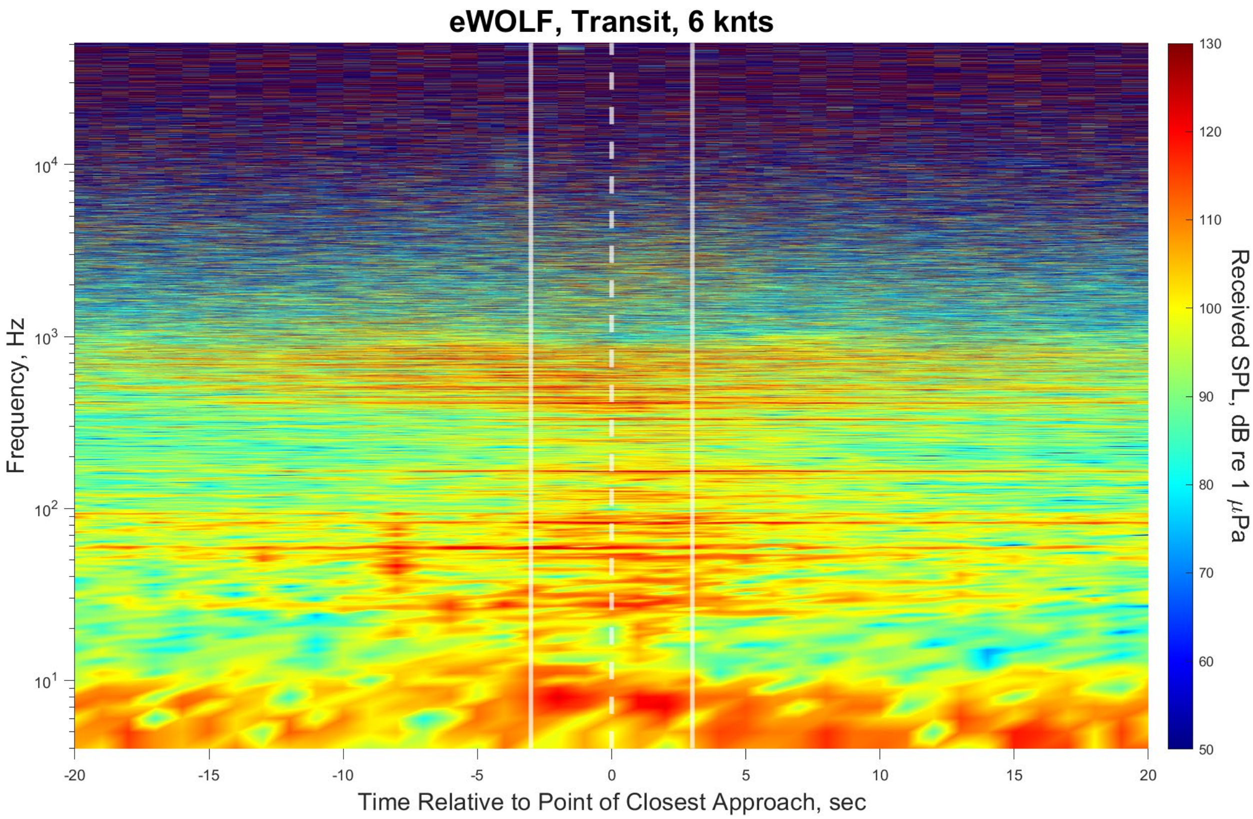


Figure 21: Spectrogram of Vessel Passby [Run 36]

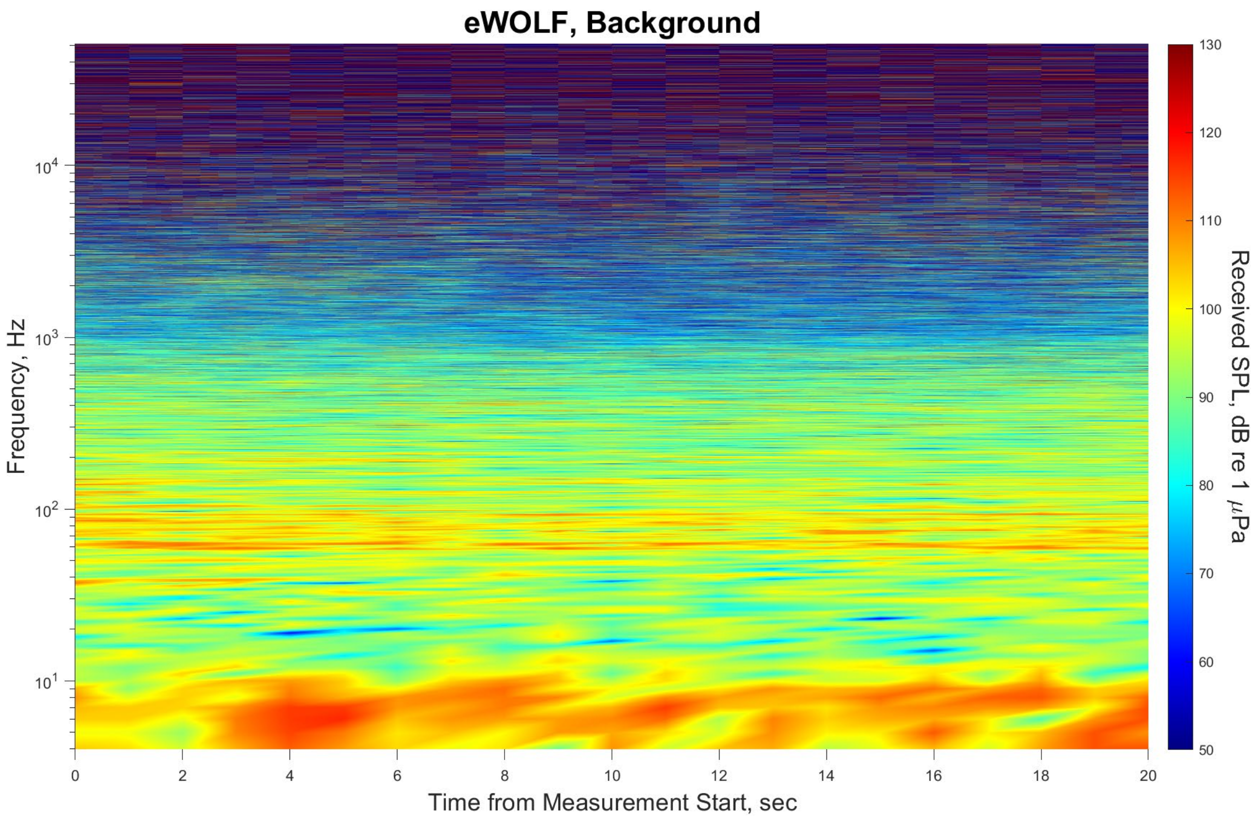


Figure 22: Spectrogram of Background Measurement [Run 24]

5.3 Note on Low Frequency Noise for STA Conditions

During the STA conditions, nearly all measurements captured with the primary measurement system exhibited notable increases in noise below 16 Hz. This appears to be driven by flow-induced noise, which is noise that is generated due to flow over the hydrophone itself, rather than noise generated by the source. The flow at the hydrophone for the STA conditions is a consequence of the stationary vessel testing arrangement, with the flow being driven by the propellers. The presence of this noise in the measurements obscures actual vessel noise below about 10 Hz.

This low frequency flow-induced noise was generally not present in the measurements simultaneously taken with the backup hydrophone system. Figure 23 compares the narrowband low frequency source level spectra from the two measurement systems for the *eWOLF* 80% power STA condition. The spectrum of the primary system is shown in black and the backup in green. Above 20 Hz, the levels measured by the two systems are very close. Below this range, the primary system exhibits levels up to 20 dB higher than the backup system, peaking at 10 Hz. This means the 1x blade rate tone can only be seen in the backup system data.

This result was considered when developing the conclusions regarding sources of noise and potential low-noise design approaches. However, for simplicity, the data presented in the rest of this report is from the primary measurement system only.

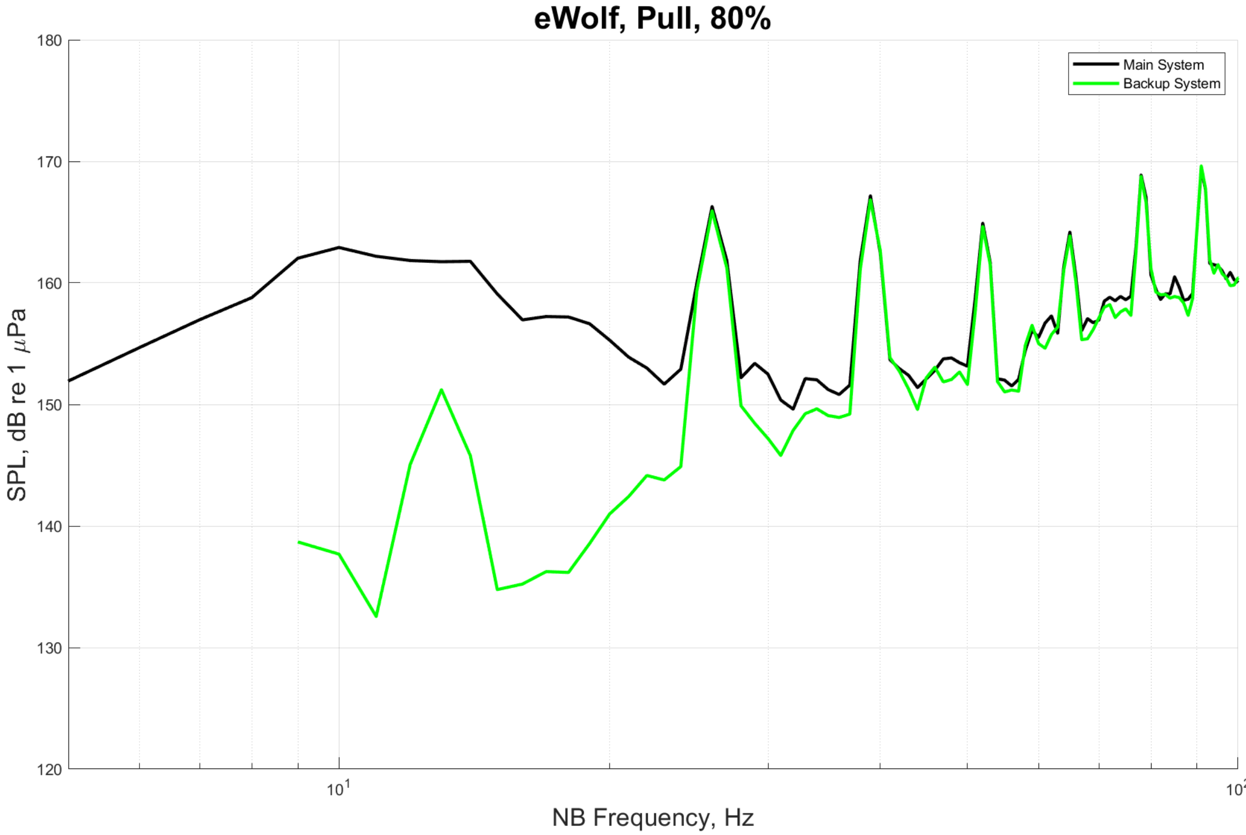


Figure 23: Narrowband Spectra, Primary & Secondary Hydrophone Systems, *eWOLF*, 80% STA [Run 20]

5.4 Estimation of Deep Water Spectra

As discussed above in Section 3.0, a significant dip at 1 kHz is present in all noise spectra measured for this study. This is a consequence of the hydrophone being close to the seafloor, and would not be present if the measurements were taken in deep water. By considering the constructive/destructive interference effects of reflections off the seafloor combined with reflection-free sound paths, estimations of one-third octave band deep water spectra can be created for each measurement. These estimations also incorporate low frequency data from the secondary system to remove the flow-induced noise effects discussed in Section 5.3, which would not be present in deep water.

Figure 24 presents an example estimated deep water one-third octave band source level spectrum for the 80% STA condition, compared against the original shallow water spectrum. Average deep-water spectra for each vessel and condition are presented in Appendix C.

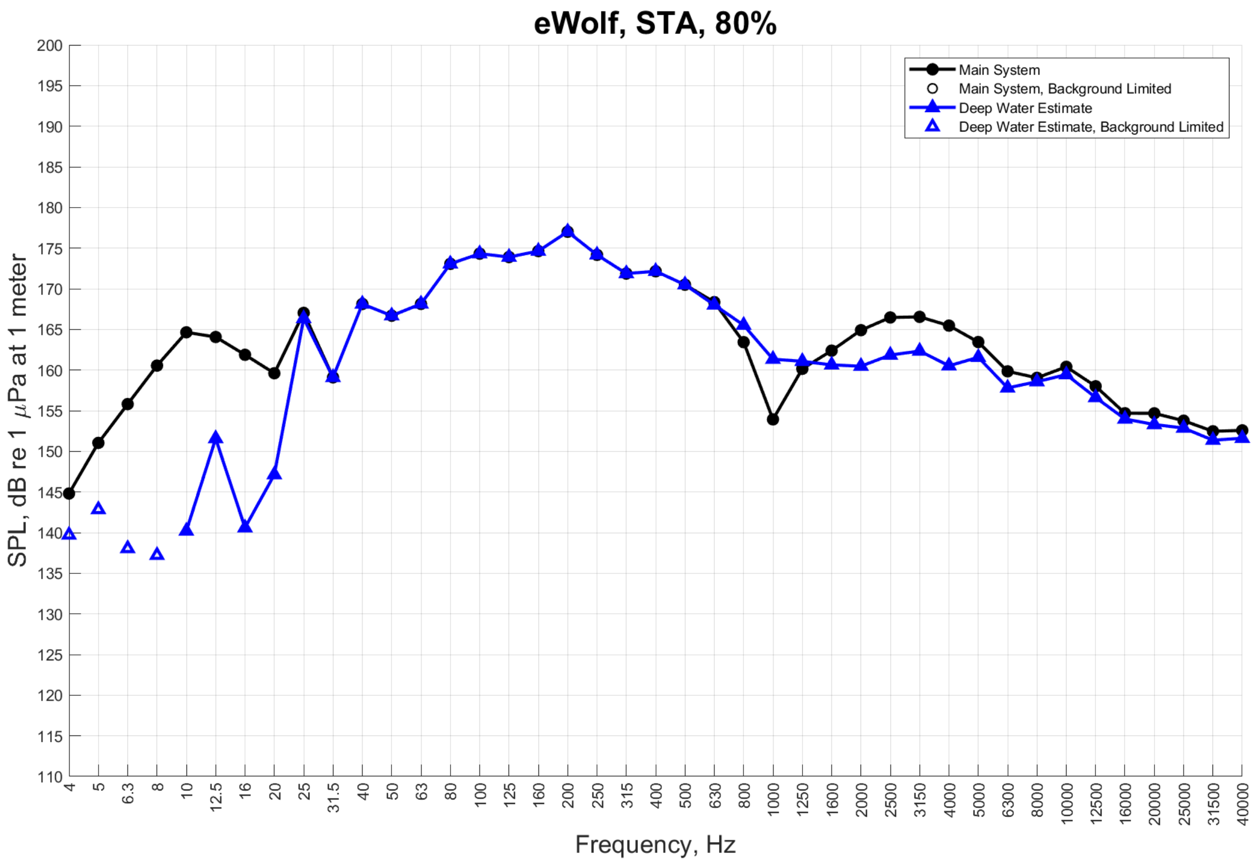


Figure 24: One-Third Octave Band Spectra, Estimated Deep Water, Primary & Backup Hydrophone Systems, *eWOLF*, 80% STA [Run 20]

6.0 CONCLUSION

NCE measured underwater radiated noise from three Crowley tugs, the *eWOLF, Tioga,* and *Leader.* Source level spectra for each vessel were calculated from the measurement data for a range of transit and STA operating conditions. These data were used to identify potential vessel designs that can reduce both underwater noise and greenhouse gas emissions.

At all transit speeds, the *eWOLF* overall noise level is at least 6 dB lower than those of the *Tioga* and *Leader* at comparable speeds. The primary design advantage of the *eWOLF* is the use of battery power instead of diesel engines, which leads to reduced greenhouse conditions as well as lower underwater noise for transit operating conditions. The *Tioga* and *Leader* both have "hard mounted" propulsion diesel engines that create significant noise levels at all operating conditions. This is the primary reason why overall noise levels for the *eWOLF* are lower than the other two vessels for transit conditions.

However, *eWOLF* noise is similar to or louder than the other vessels during STA conditions. *eWOLF* propeller cavitation noise is similar to the *Tioga* because the propeller designs have overarching similarities. Propeller noise from the *Leader* is lower than the *eWOLF* and *Tioga* because the Voith Schneider propulsion system produces minimal cavitation except during higher power STA conditions. However, this reduced cavitation noise is negated due to the noise from the propulsion engines, leading to generally higher noise levels from the *Leader*. If the *Leader* and *Tioga* applied noise controls to the propulsion engines via resilient mounting and/or other treatment approaches, the overall levels from these vessels would generally be lower and the *eWOLF* would be among the loudest vessels for all but the slowest transit speeds and STA powers.

Taken together, the measurement data indicate underwater noise reductions for tugs are possible by implementing battery-electric propulsion systems. However, these reductions will be limited to slower speed operating conditions when propeller cavitation is not present. Cavitation noise typically dominates the underwater noise spectra at higher vessel speeds and during tug assist activities when conventional propellers are used.

Conventional propeller designs with reduced cavitation may be possible if underwater noise is implemented as a goal at the design stage. Alternative propulsion systems, such as the Voith Schneider system, also present opportunities for reduced underwater noise due to the reduced levels of induced cavitation.

7.0 REFERENCES

1. J. Spence, B. Bonnice, “Crowley Tug Underwater Radiated Noise Test and Analysis Plan,” Revision 0, April 26 2024.
2. ANSI/ASA S12.64-2009, “Quantities and Procedures for Description and Measurement of Underwater Sound from Ships – Part 1: General Requirements,” September 30, 2009.
3. VOITH, “Precise and safe manuevering: Voith Schneider Propeller”
4. J. Spence and Z. Weiss, “Directivity of Underwater Radiated Noise from Commercial Ferries and Implications for Measurement Approaches,” Proceedings of the Institute of Acoustics, Vol.46, Pt.1 2024.
5. U.S. Department of Commerce National Oceanic and Atmospheric Administration National Marine Fisheries Service, “2024 Update to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 3.0), Underwater and In-Air Criteria for Onset of Auditory Injury and Temporary Threshold Shifts,” NOAA Technical Memorandum NMFS-OPR-71, October 2024.

APPENDIX A:

VESSEL OPERATIONAL CONDITIONS

Table 4: Operational Parameters during Transit Conditions

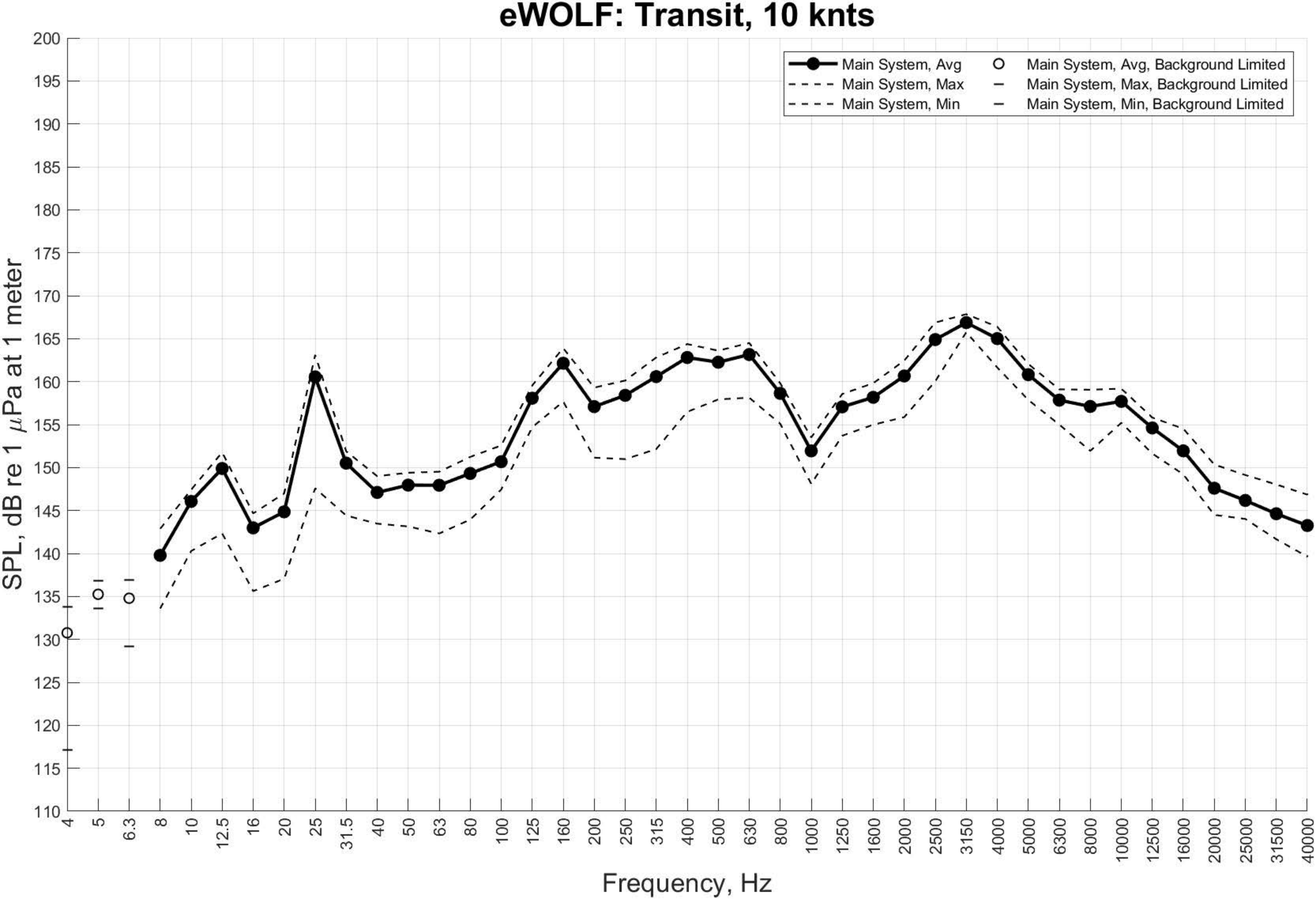
Vessel	Speed, knots	Engine/Motor RPM	Pitch
eWOLF	10	575	--
	8	460	--
	6	330	--
	4	220	--
	2	105	--
Tioga	10	1250	--
	8	1000	--
	6	740	--
	3	610	--
Leader	10	1570	80%
	8	1160	85%
	6	1160	65%
	4	800	70%
	2	800	35%

Table 5: Operational Parameters during STA Conditions

Vessel	Power, %	Engine/Motor RPM	Pitch
eWOLF	100%	715	--
	80%	620	--
	60%	500	--
	40%	510	--
	20%	320	--
Tioga	100%	1800	--
	80%	1415	--
	60%	1080	--
	40%	720	--
	30%	600	--
Leader	100%	1800	80%
	80%	1830	65%
	60%	1570	85%
	40%	1570	60%
	20%	1170	55%

APPENDIX B:

ONE-THIRD OCTAVE BAND SOURCE LEVEL SPECTRA


eWOLF: Transit, 10 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
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630
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20000
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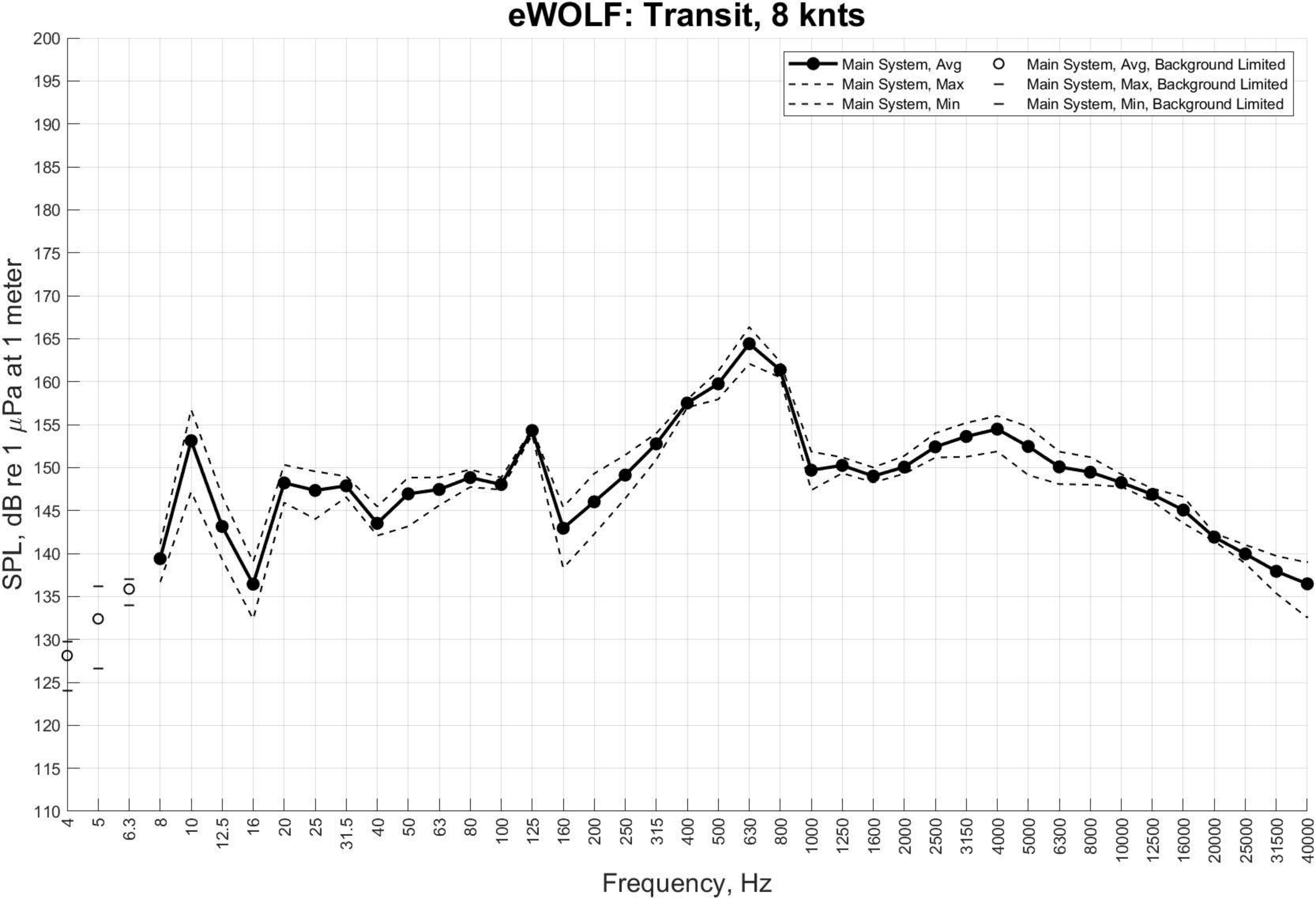
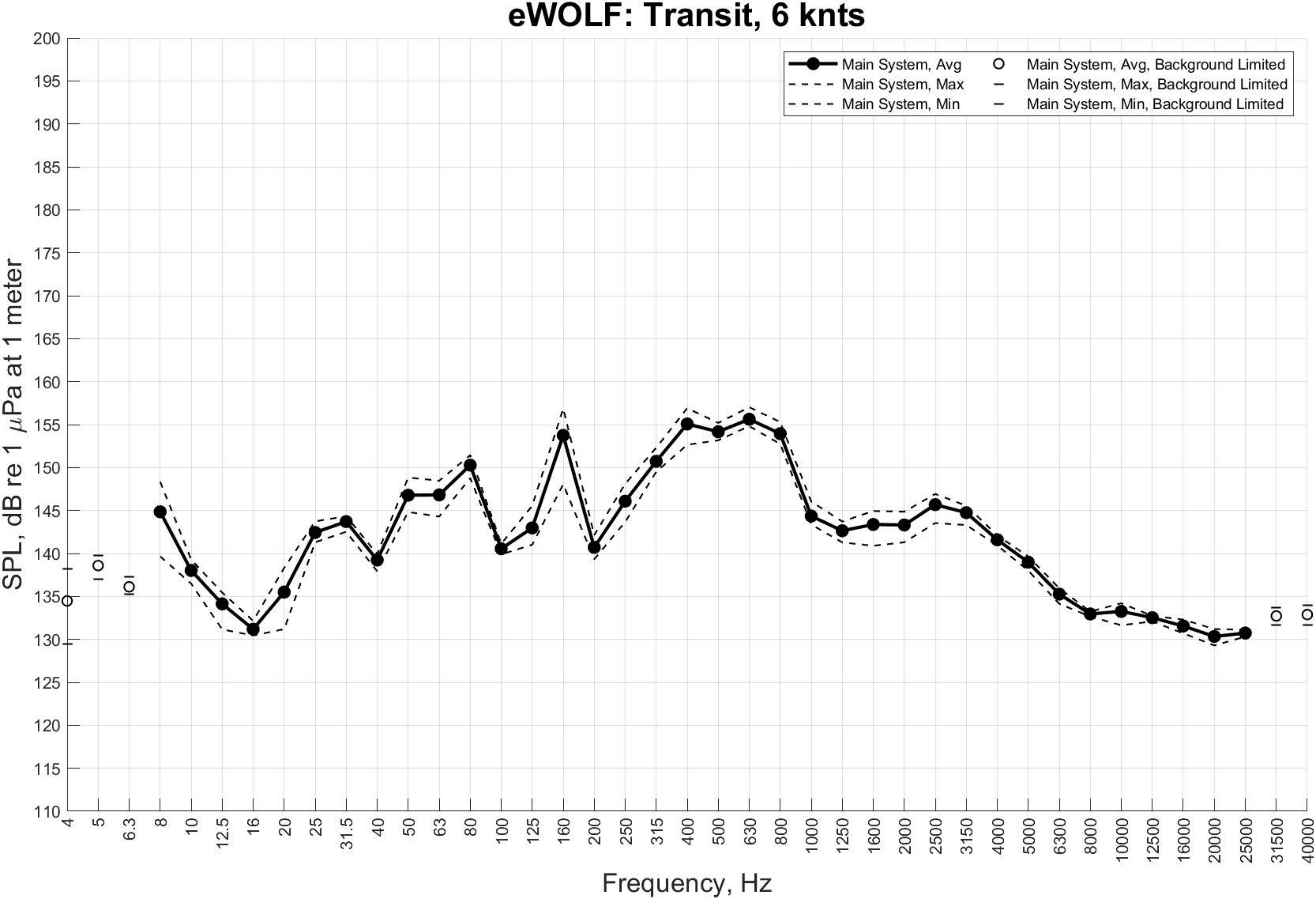


eWOLF: Transit, 8 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz



eWOLF: Transit, 6 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
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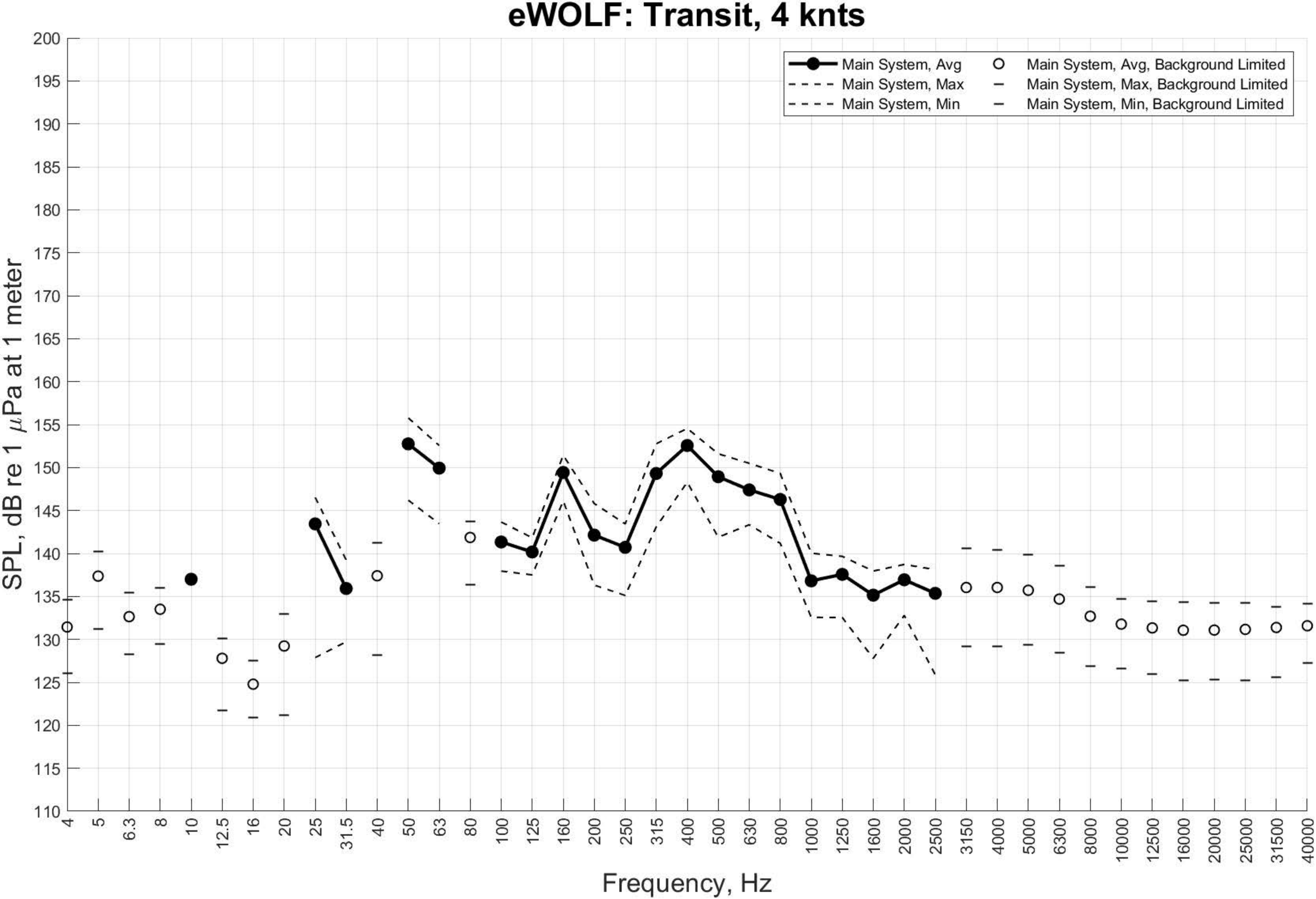

eWOLF: Transit, 4 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
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165
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155
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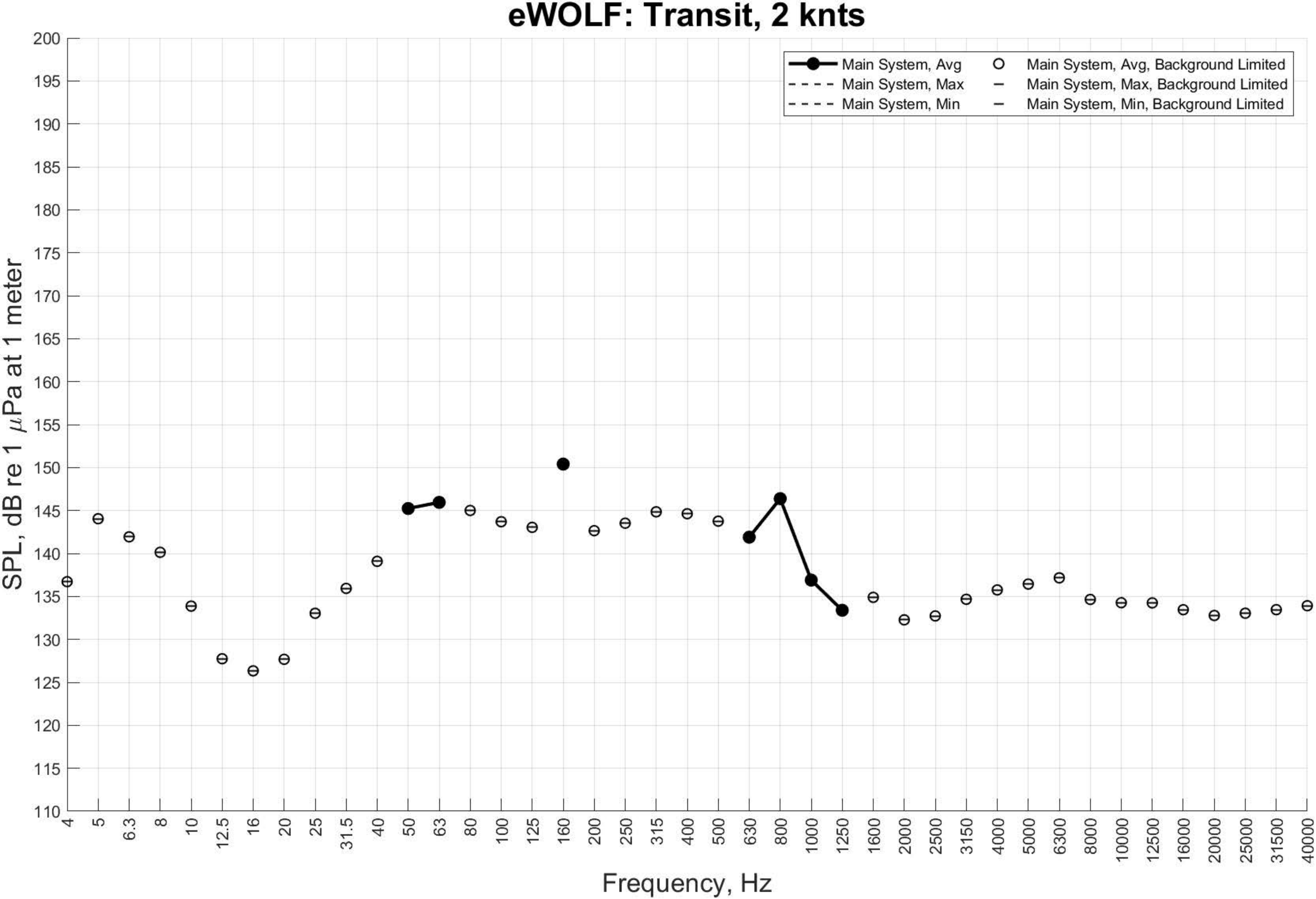
eWOLF: Transit, 2 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
110
115
120
125
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145
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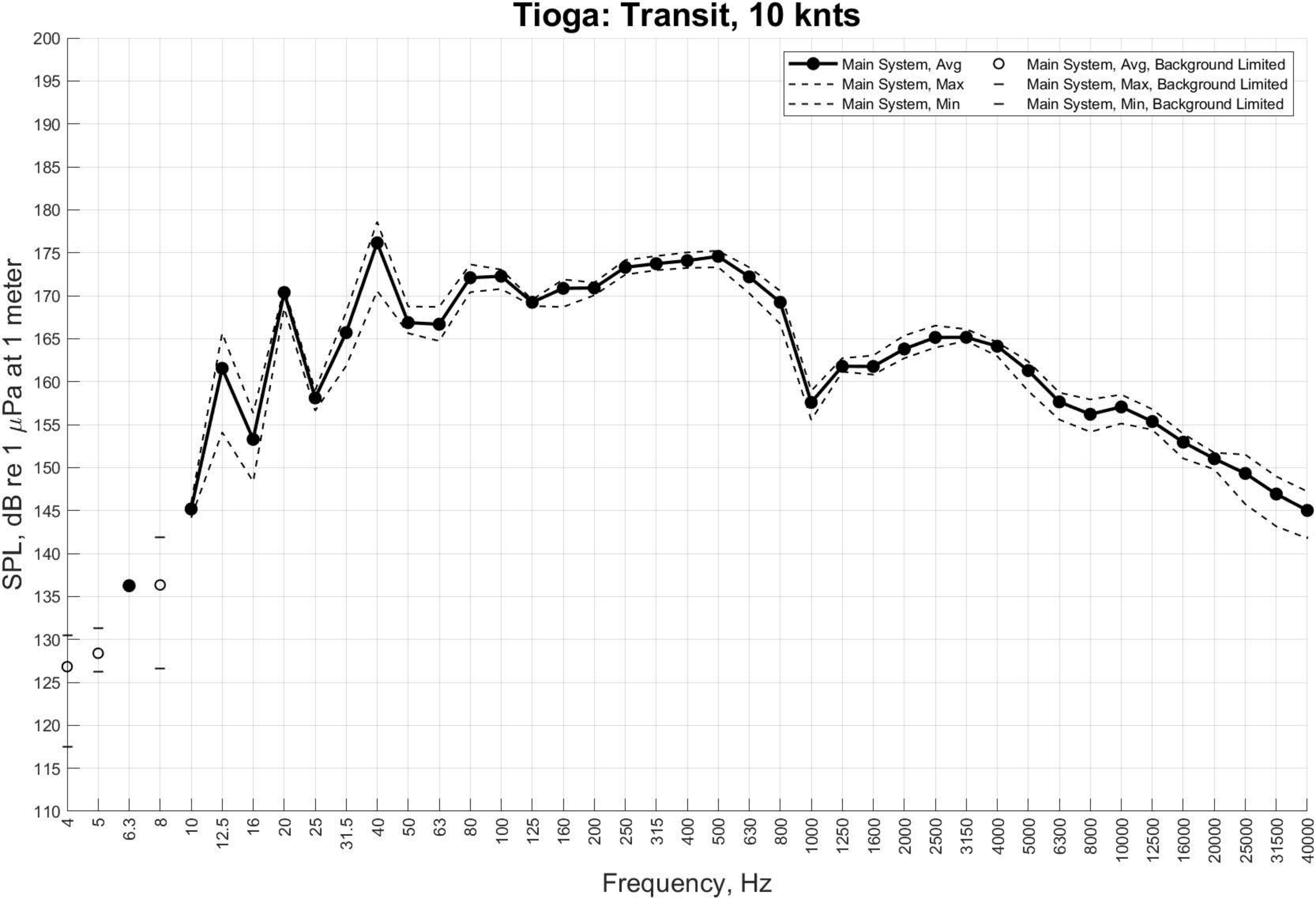

Tioga: Transit, 10 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
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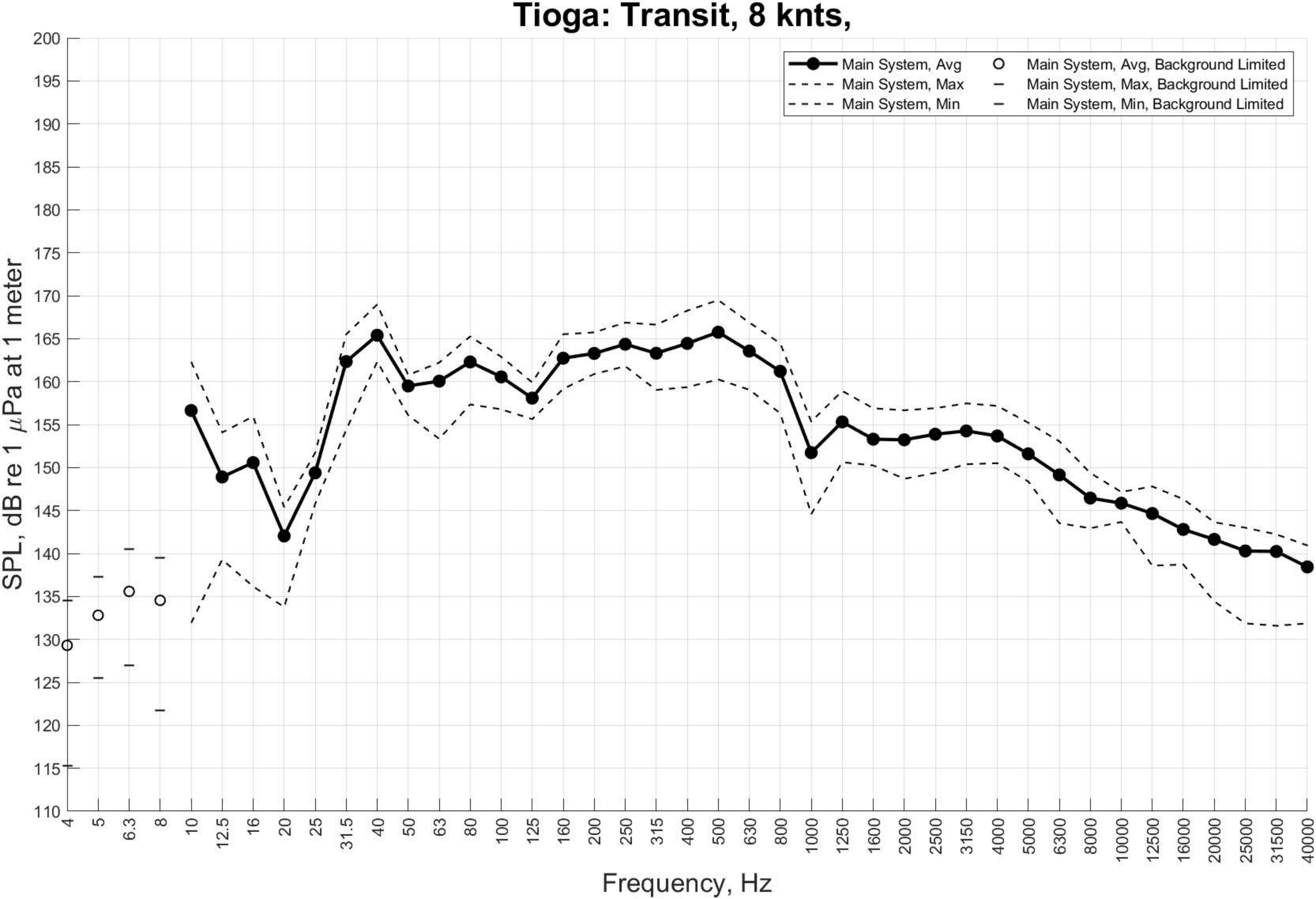

Tioga: Transit, 8 knts,
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
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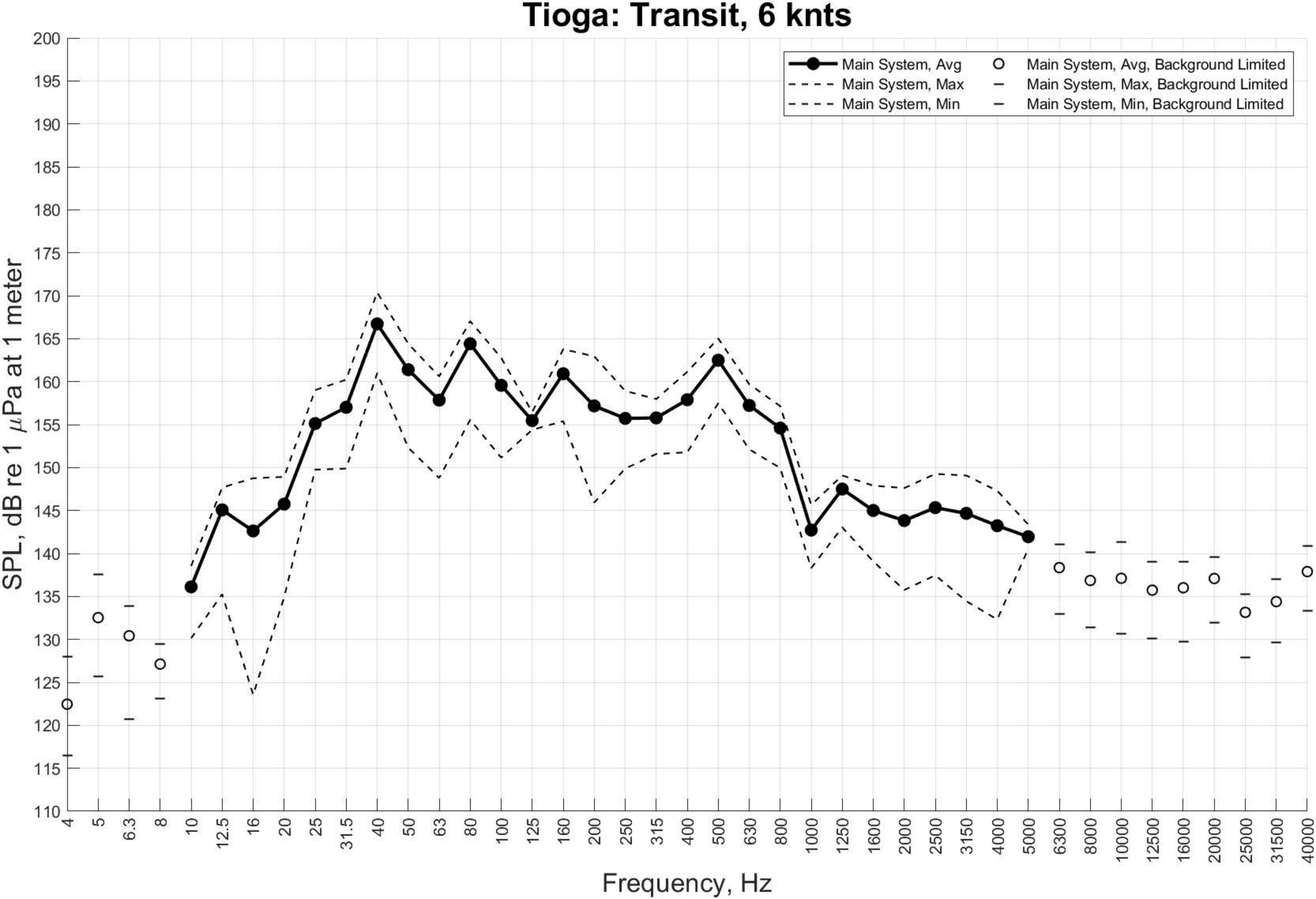

Tioga: Transit, 6 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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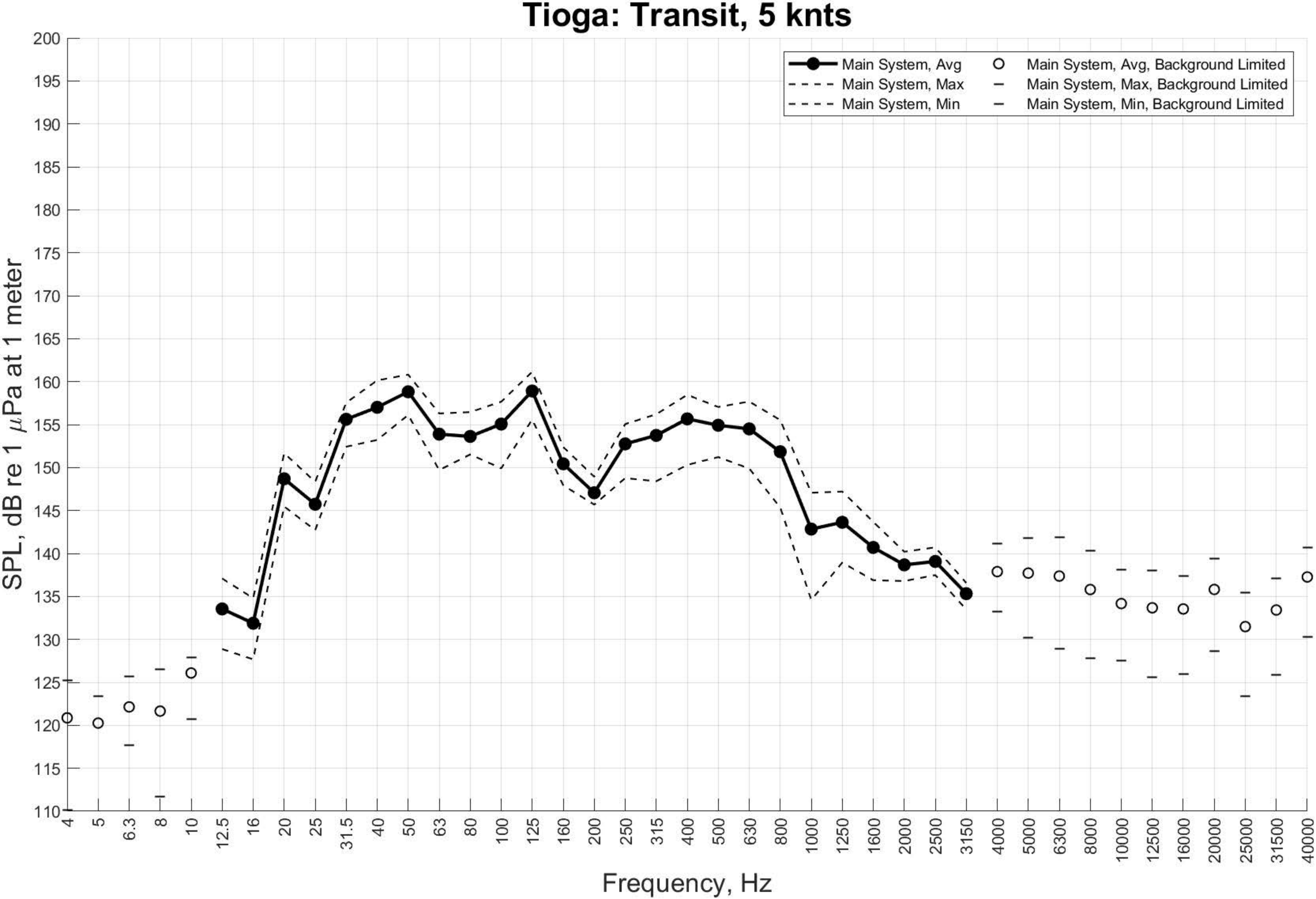

Tioga: Transit, 5 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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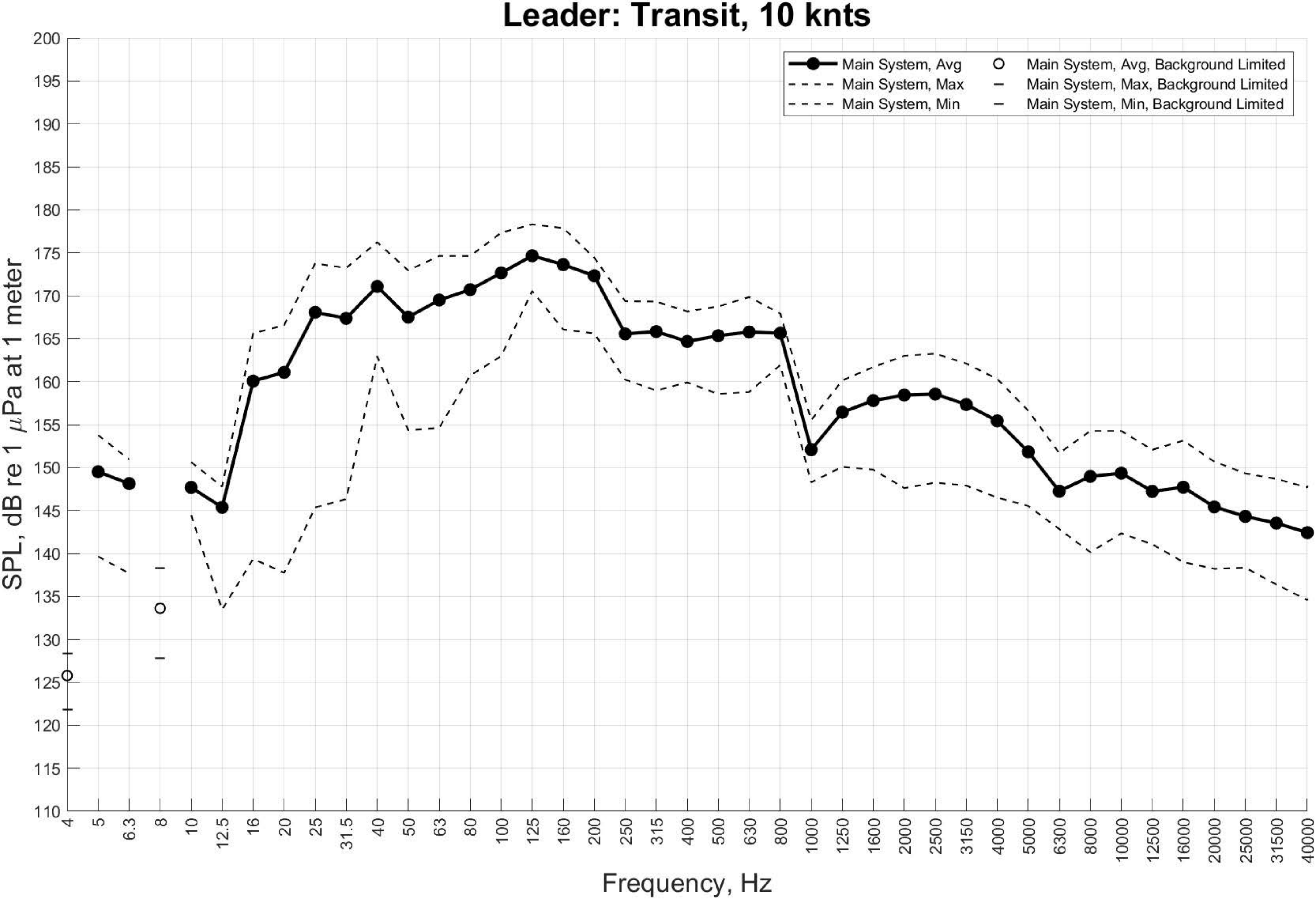
Leader: Transit, 10 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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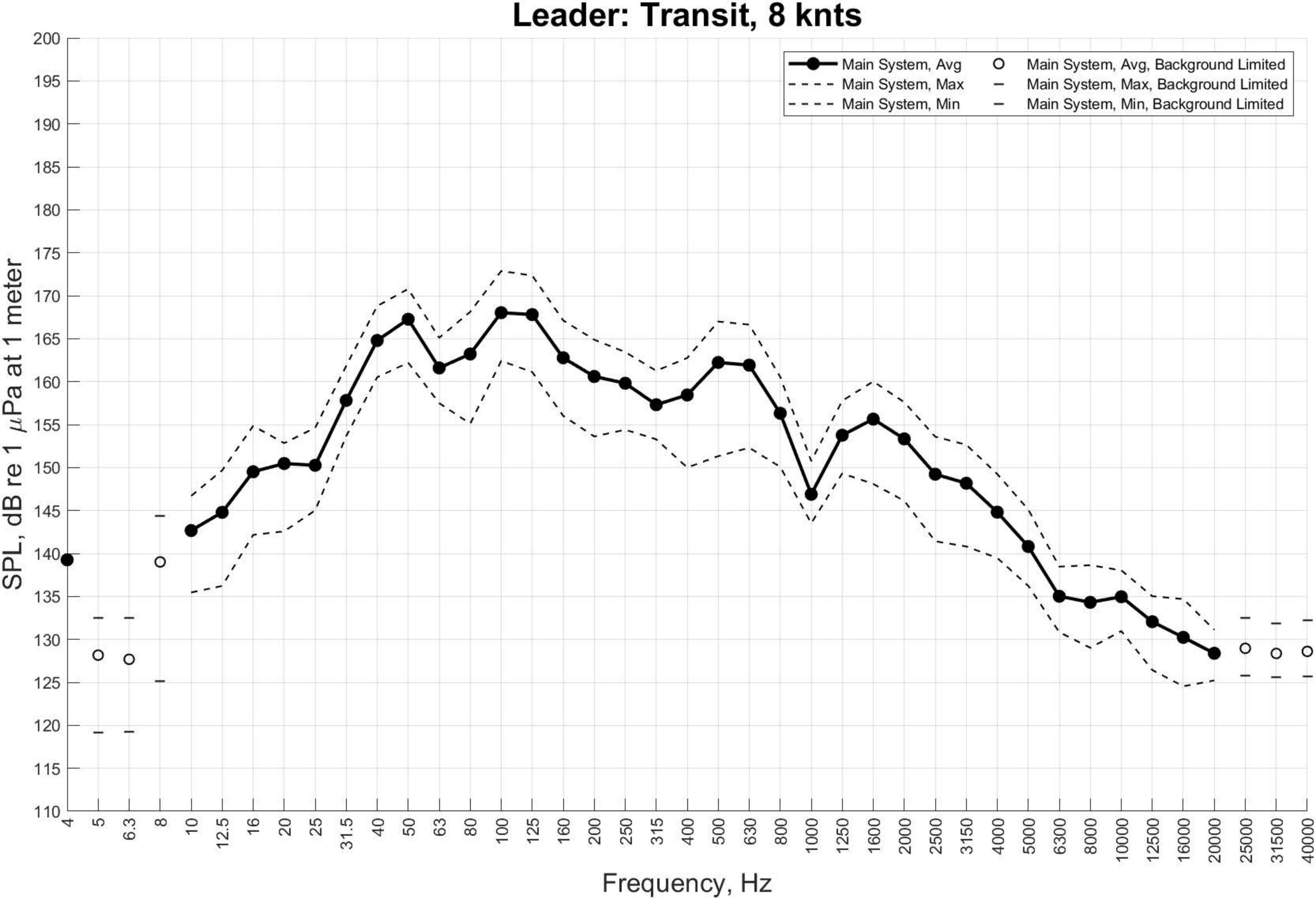

Leader: Transit, 8 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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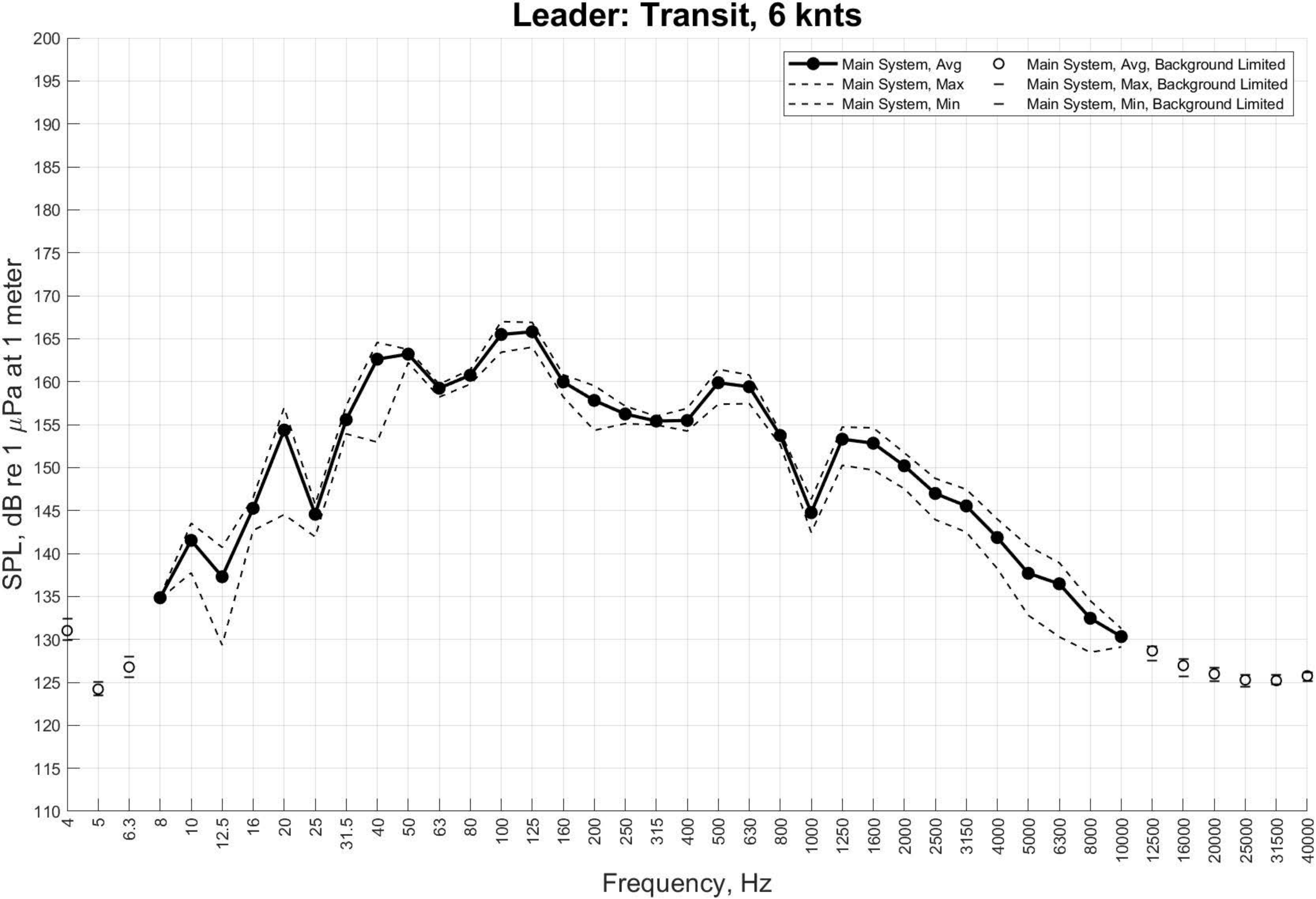

Leader: Transit, 6 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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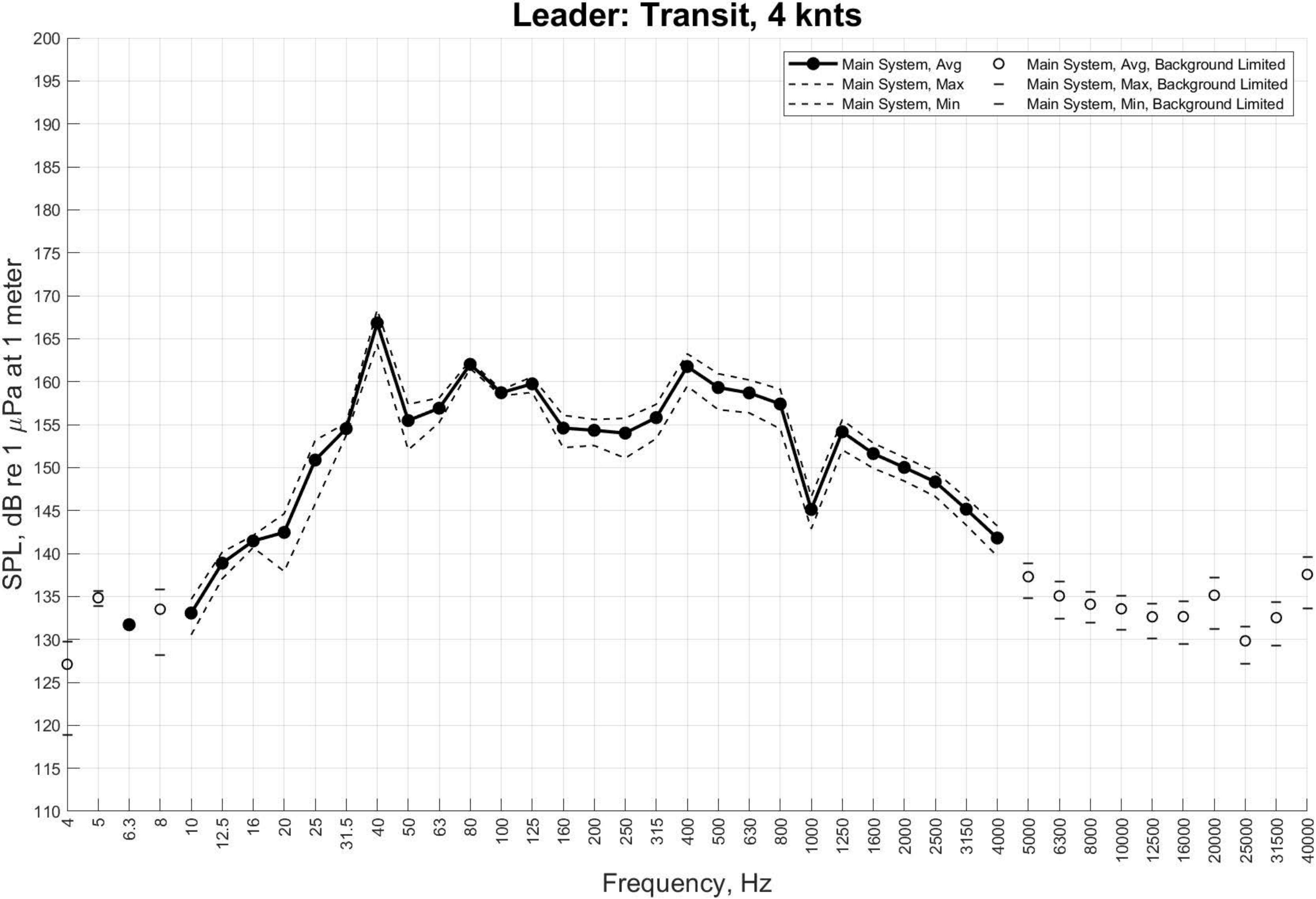

Leader: Transit, 4 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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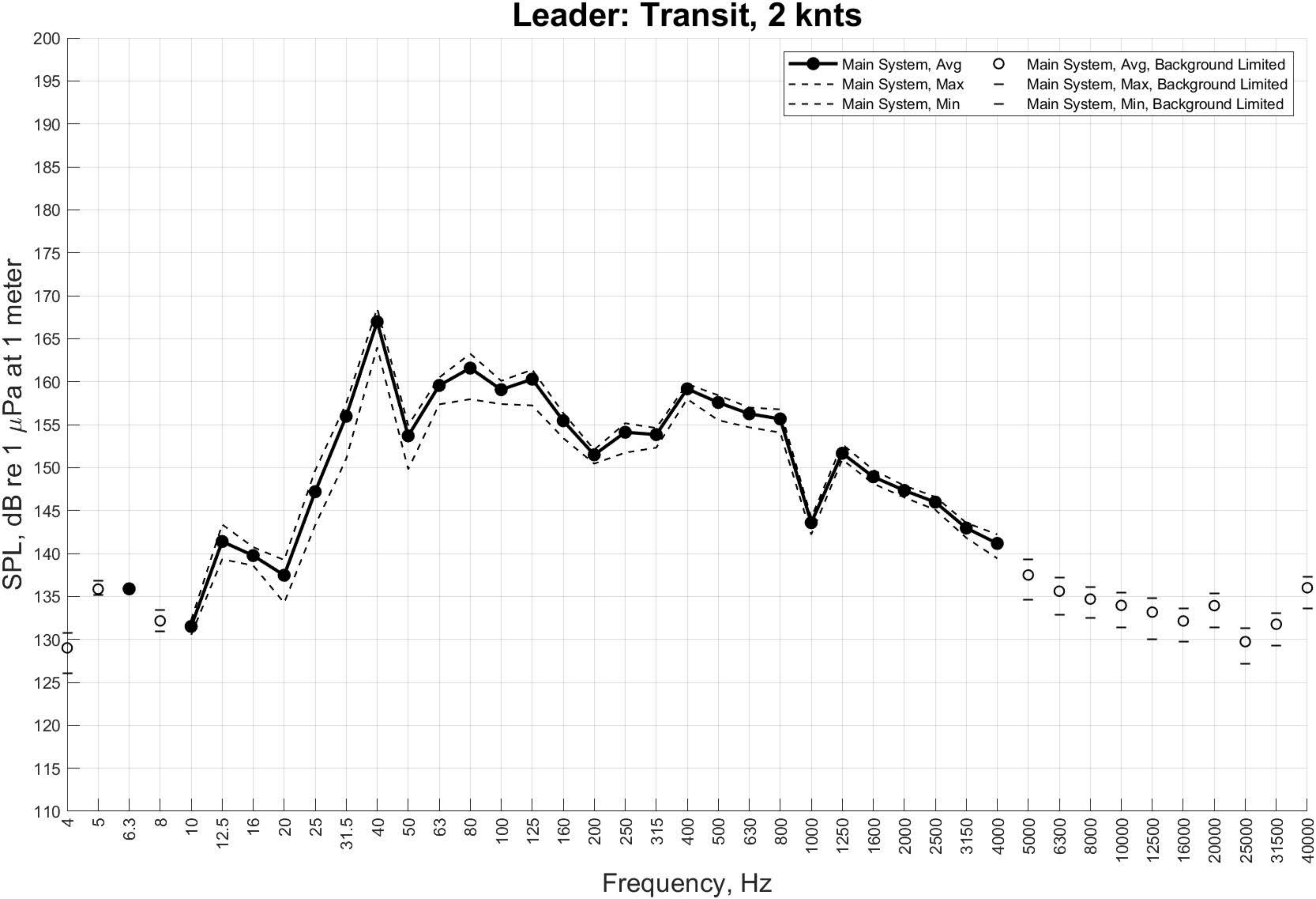
Leader: Transit, 2 knts
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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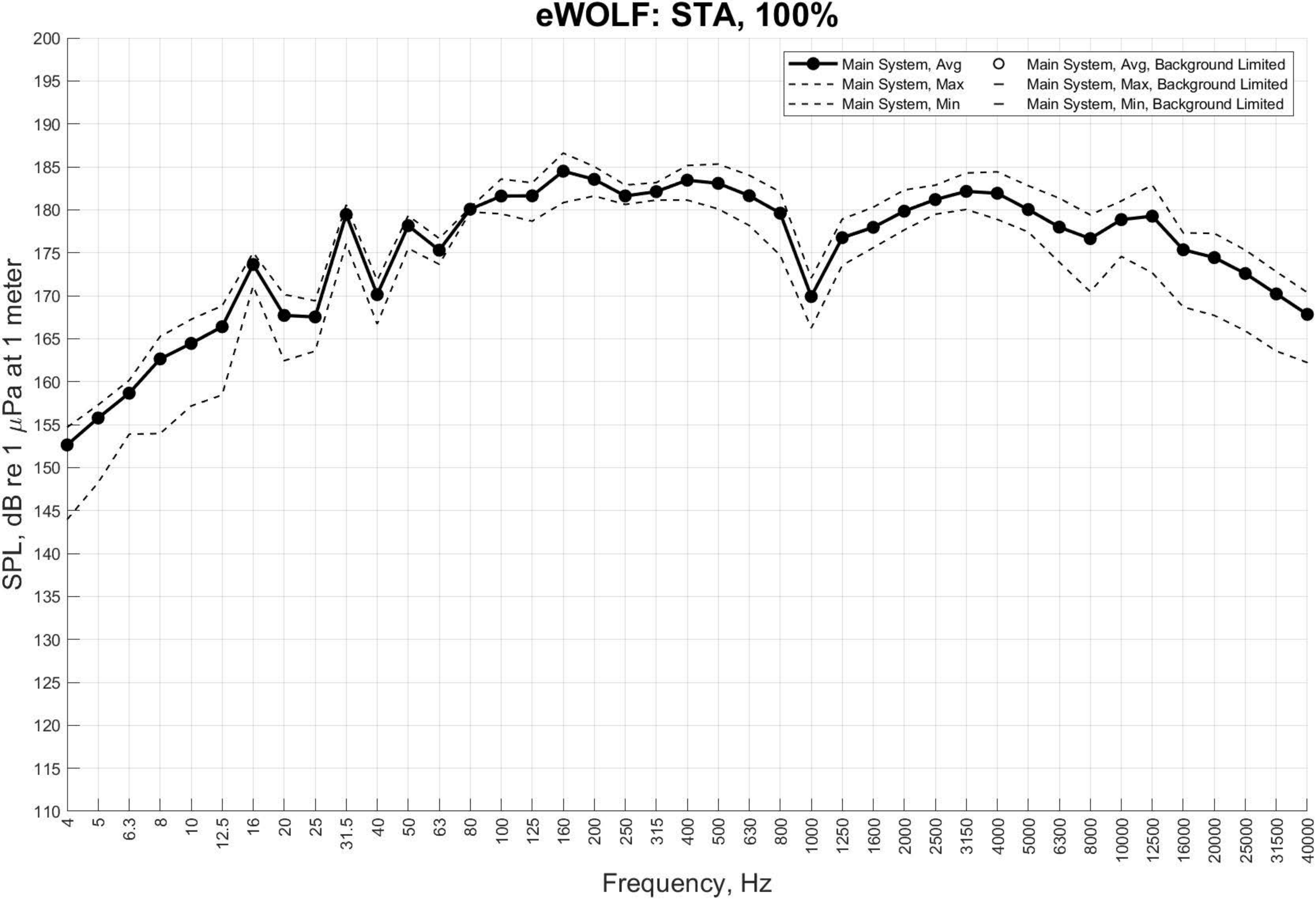
eWOLF: STA, 100%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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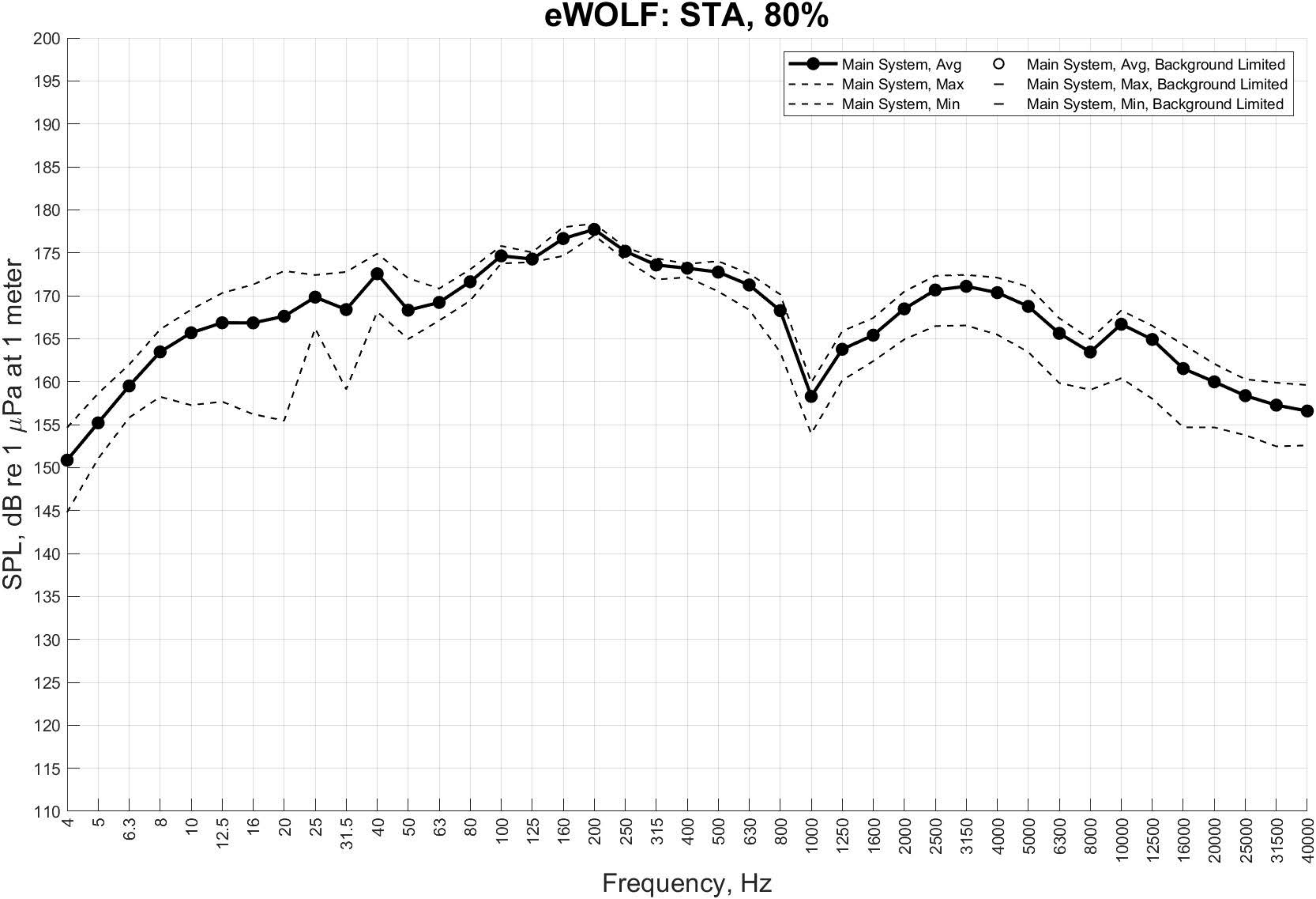
eWOLF: STA, 80%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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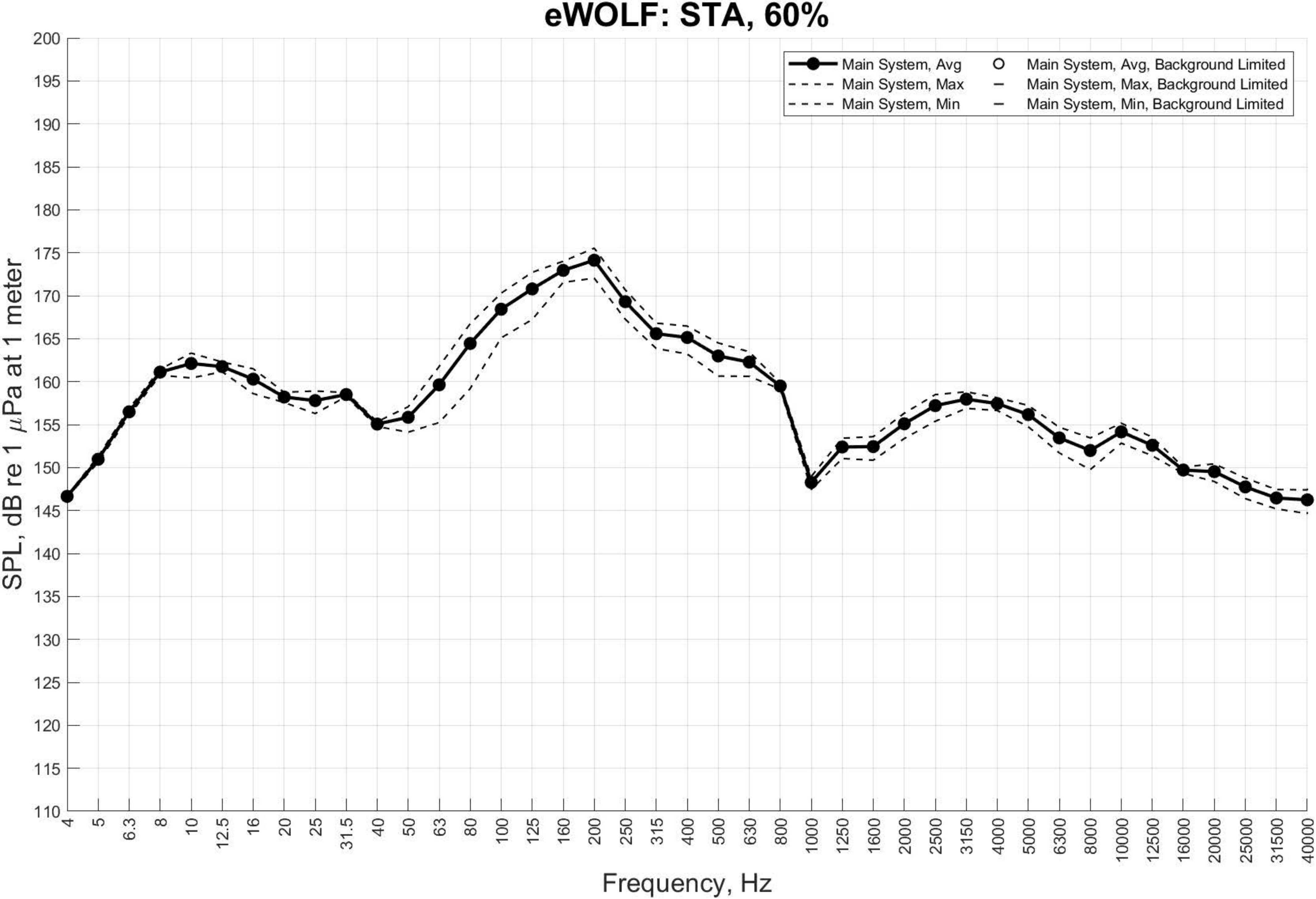
eWOLF: STA, 60%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
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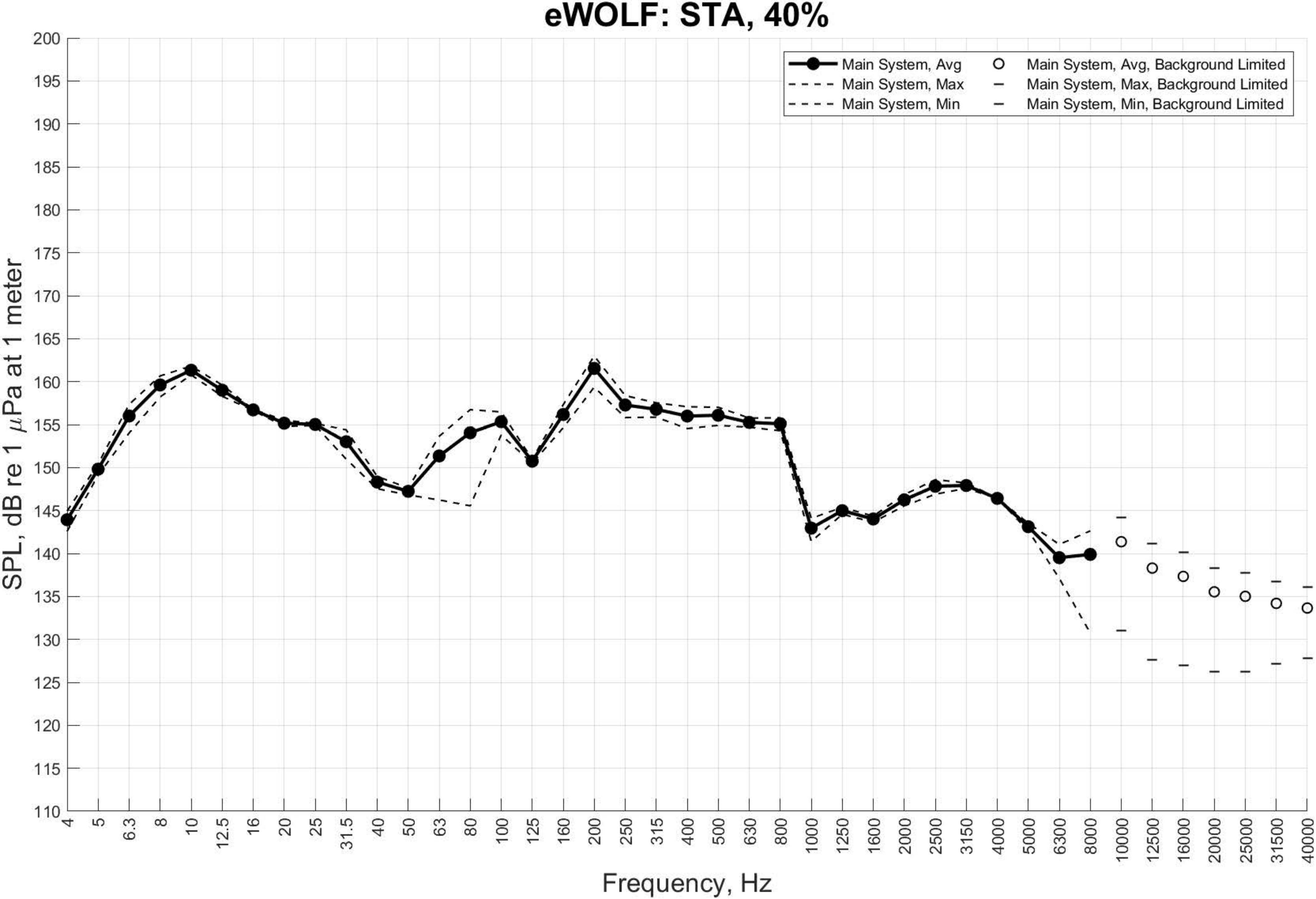
Frequency, Hz


eWOLF: STA, 40%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
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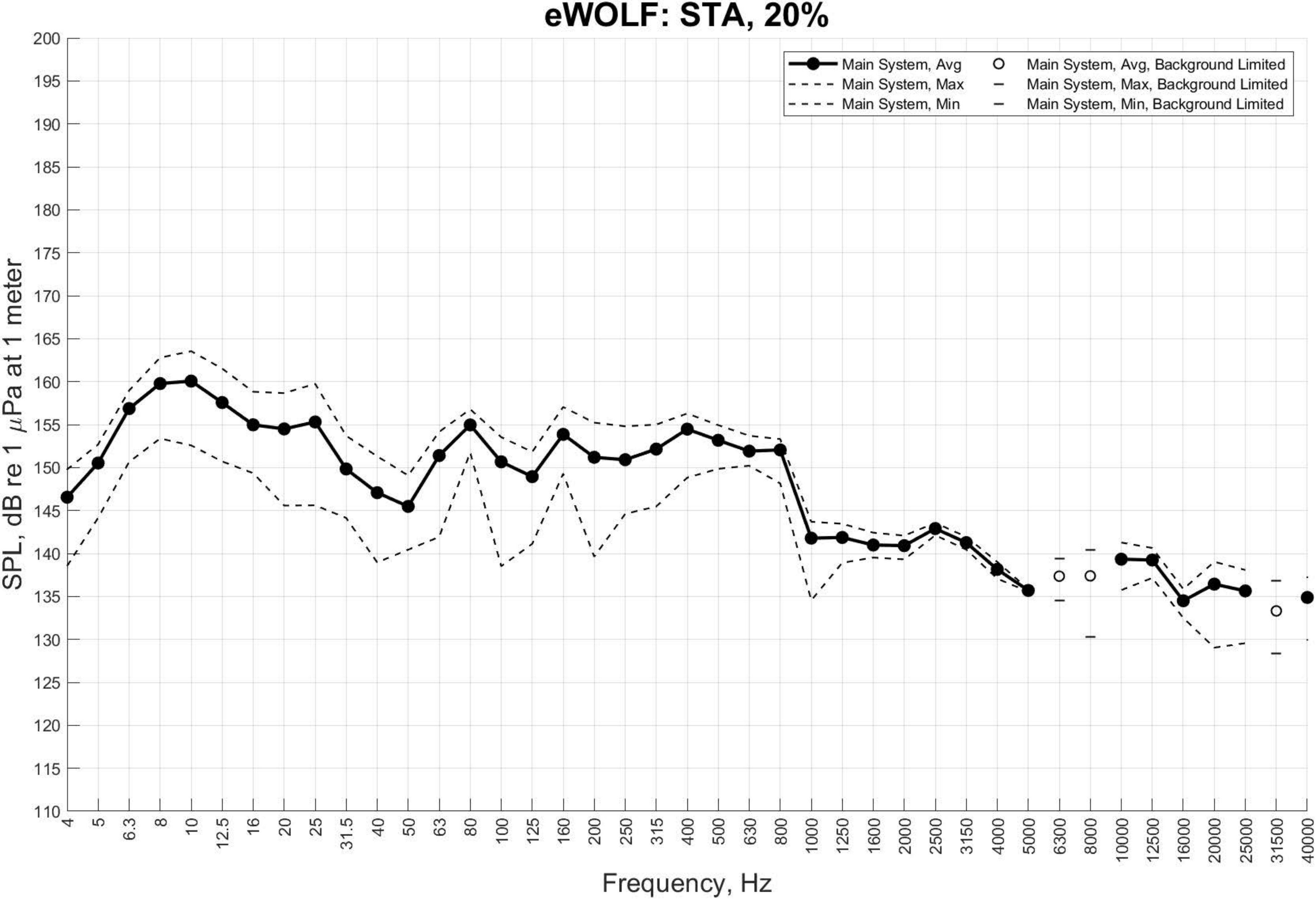
Frequency, Hz


eWOLF: STA, 20%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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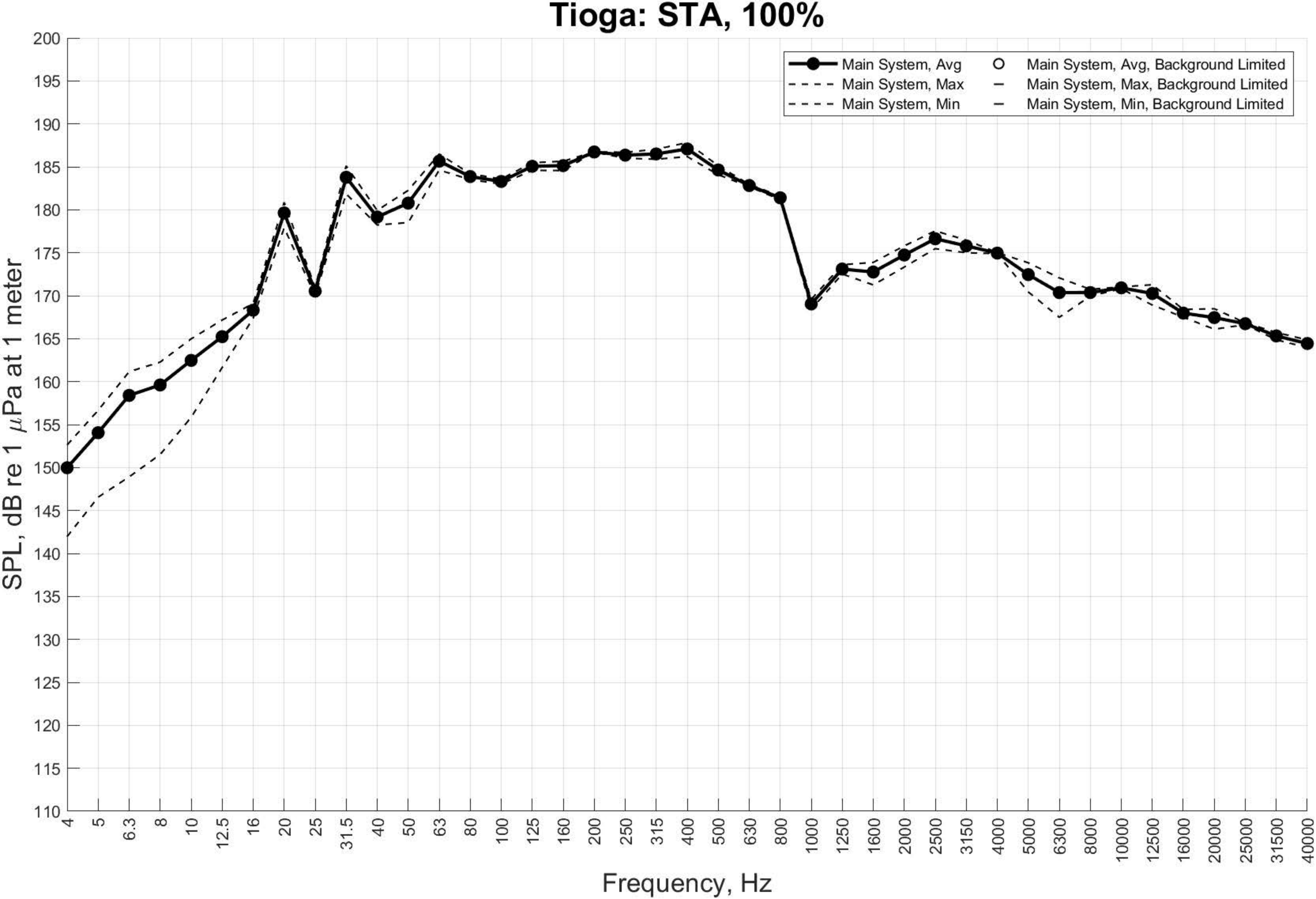
Tioga: STA, 100%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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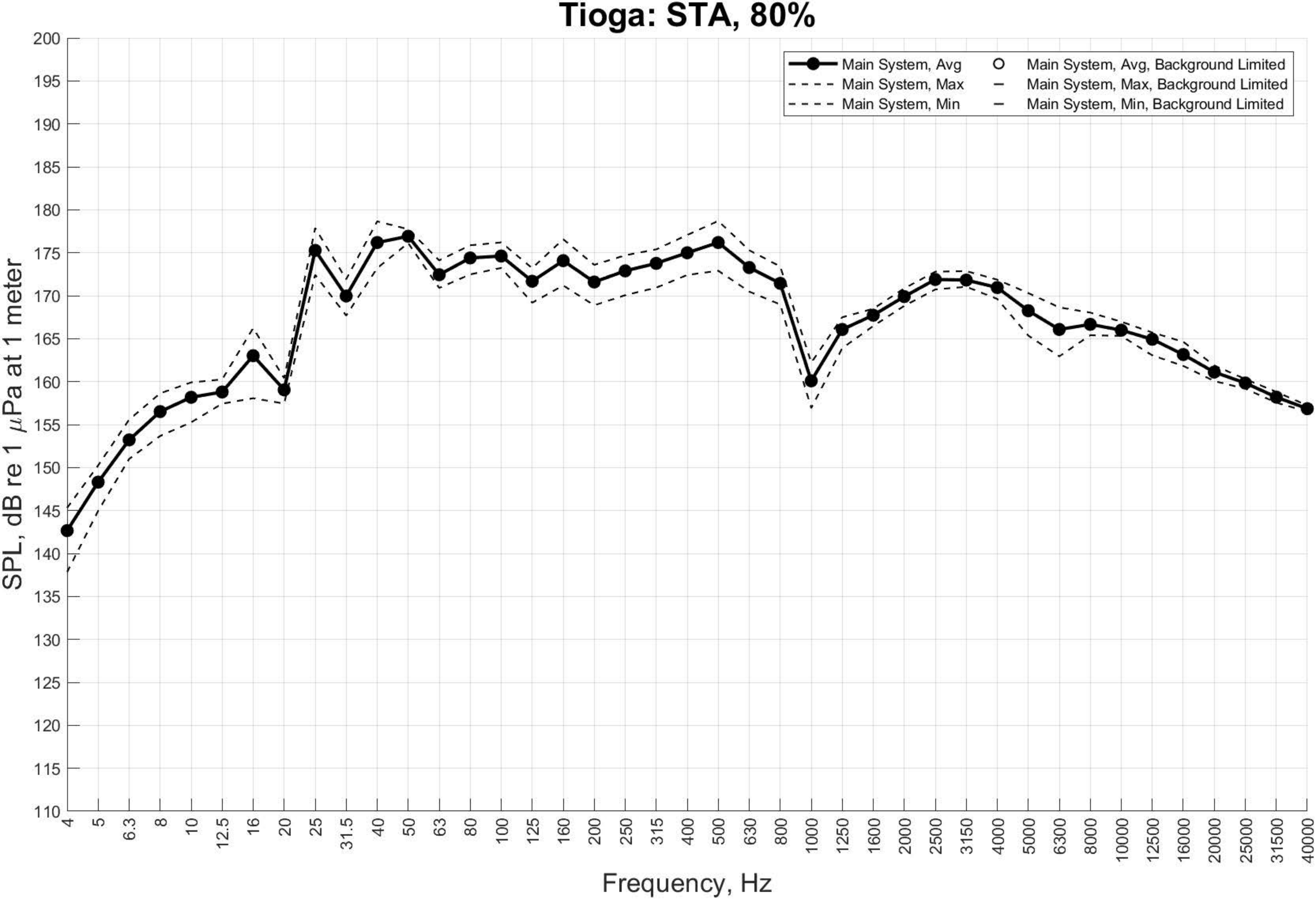

Tioga: STA, 80%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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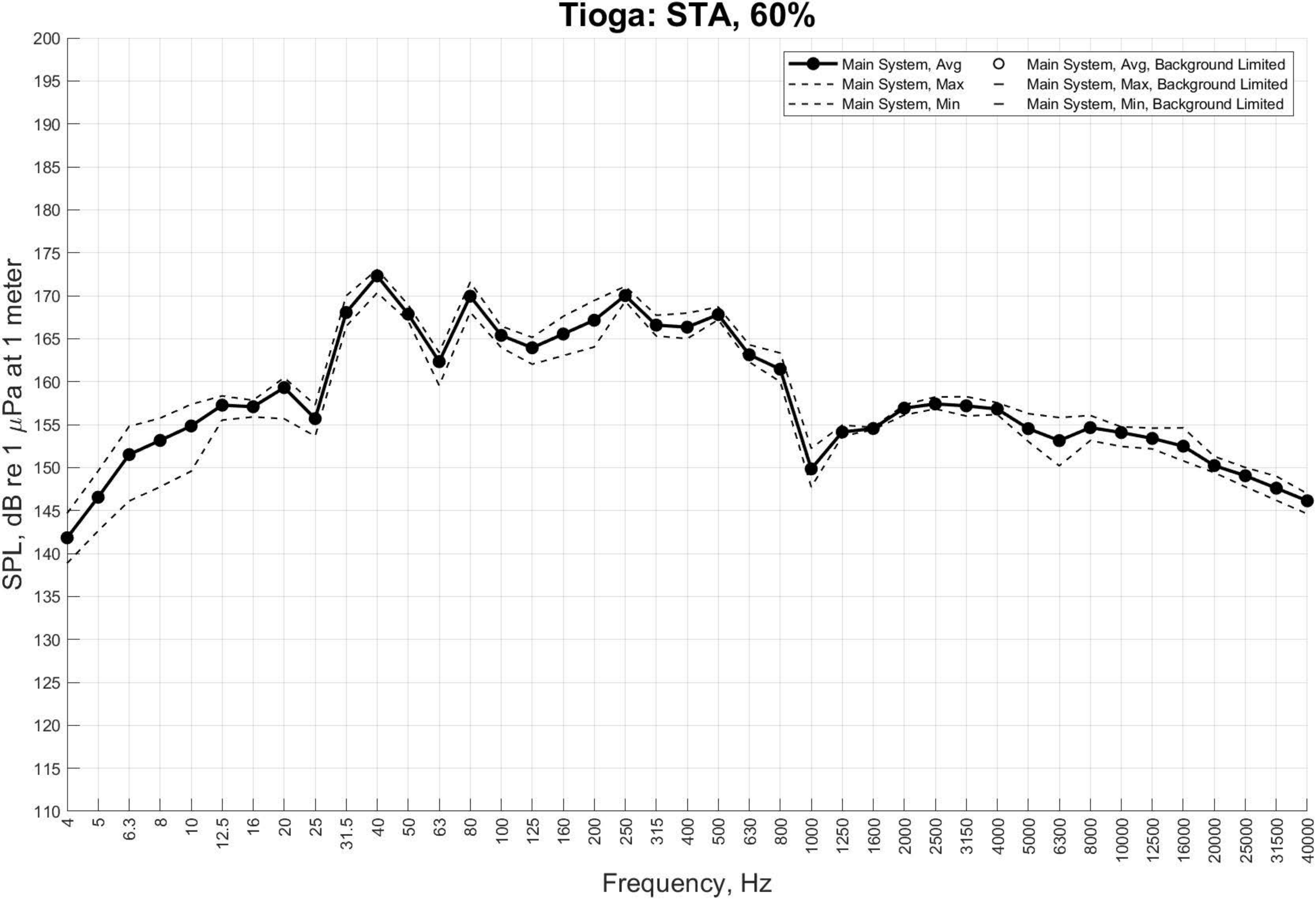
Tioga: STA, 60%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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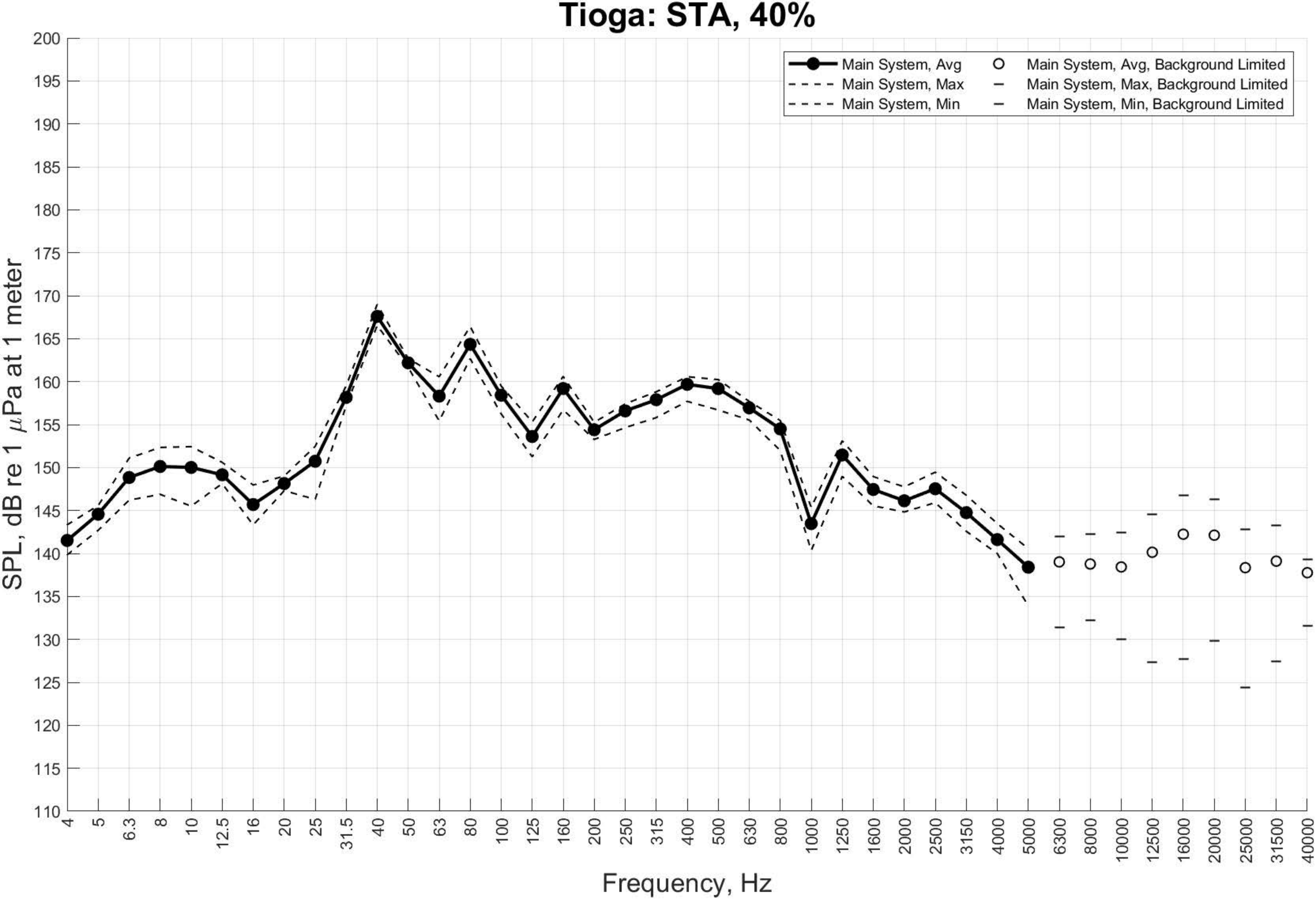

Tioga: STA, 40%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
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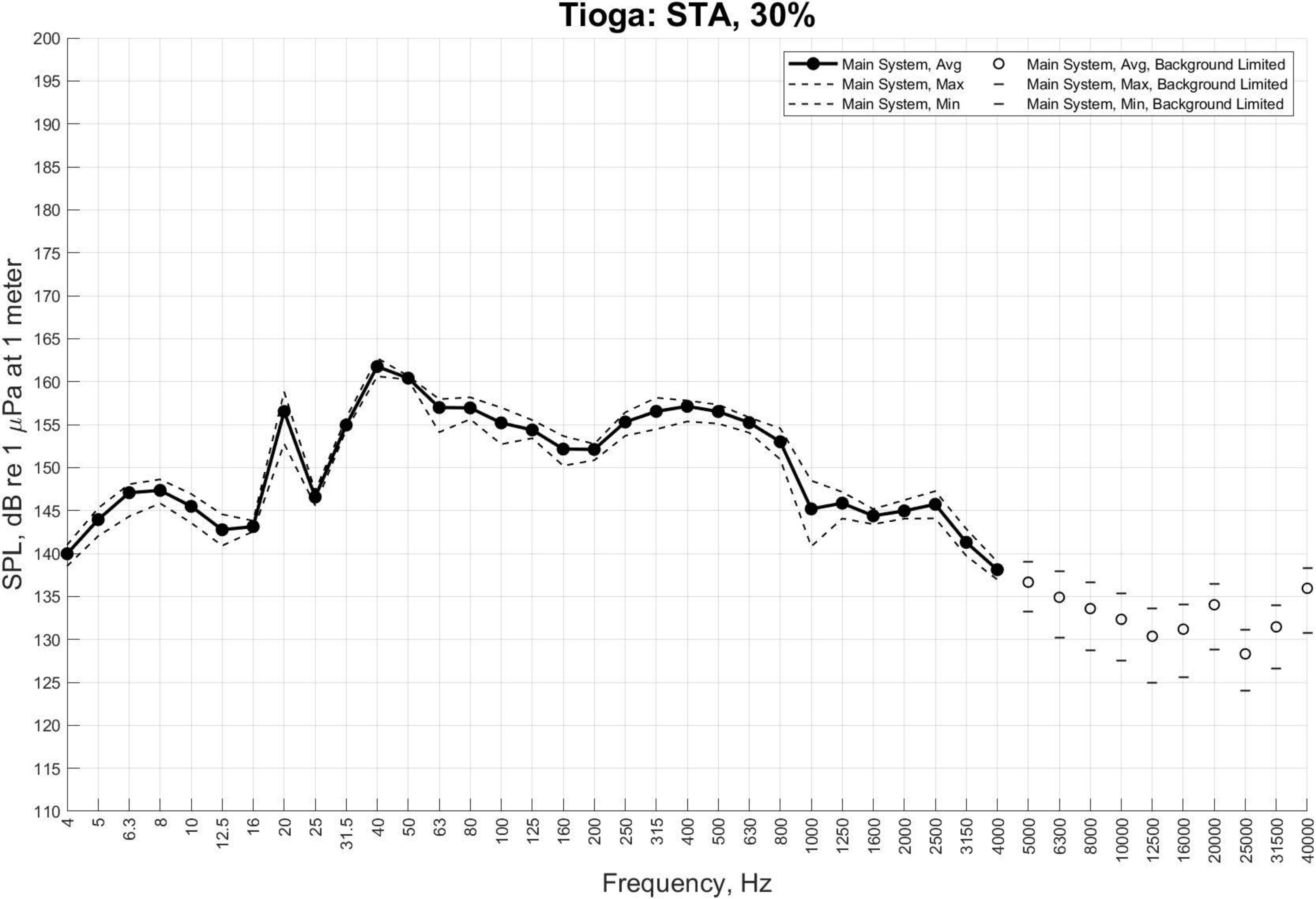
Frequency, Hz



Tioga: STA, 30%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
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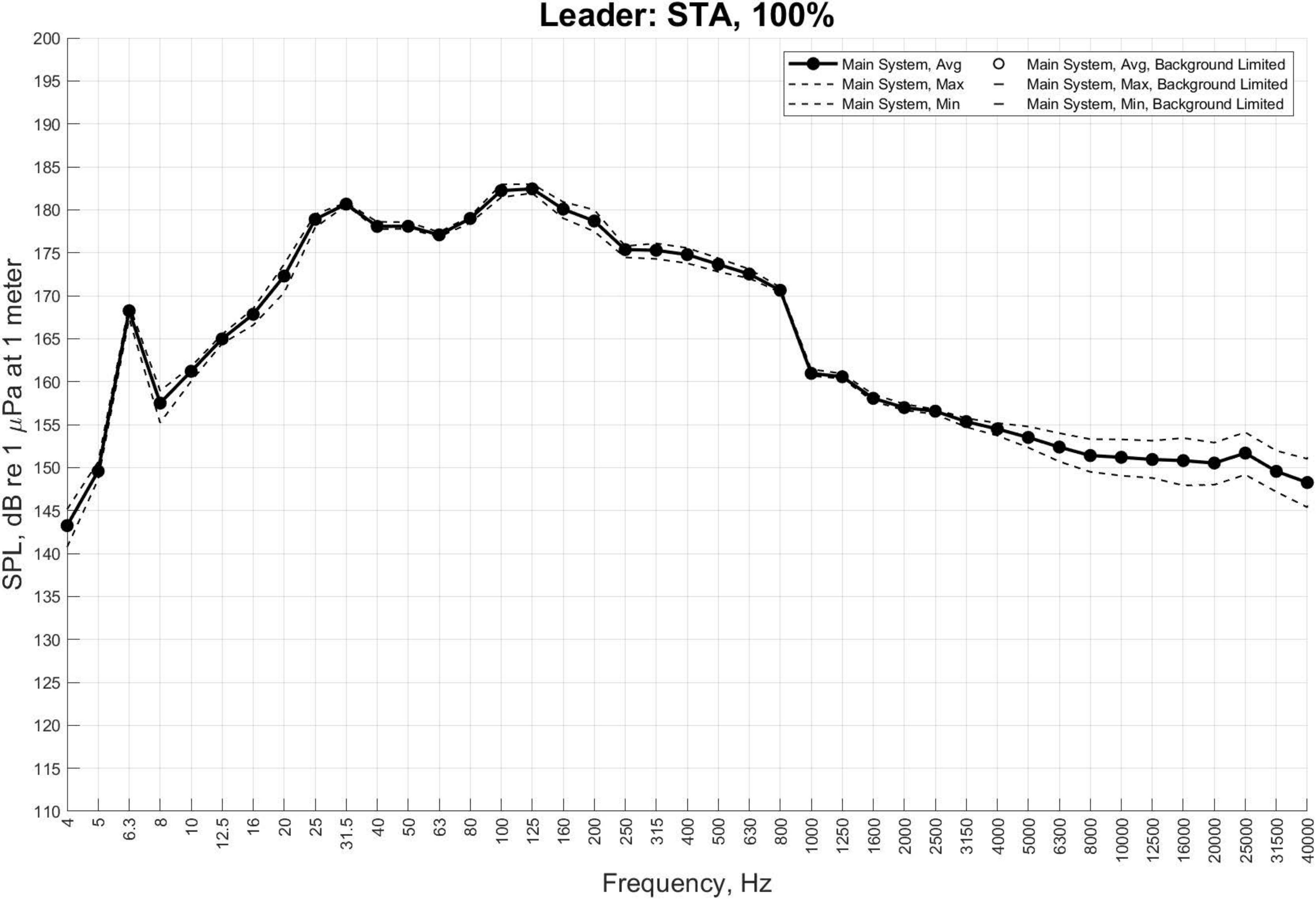
Leader: STA, 100%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
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140
135
130
125
120
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250
315
400
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1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000

Leader: STA, 80%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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12.5
16
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31.5
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63
80
100
125
160
200
250
315
400
500
630
800
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1250
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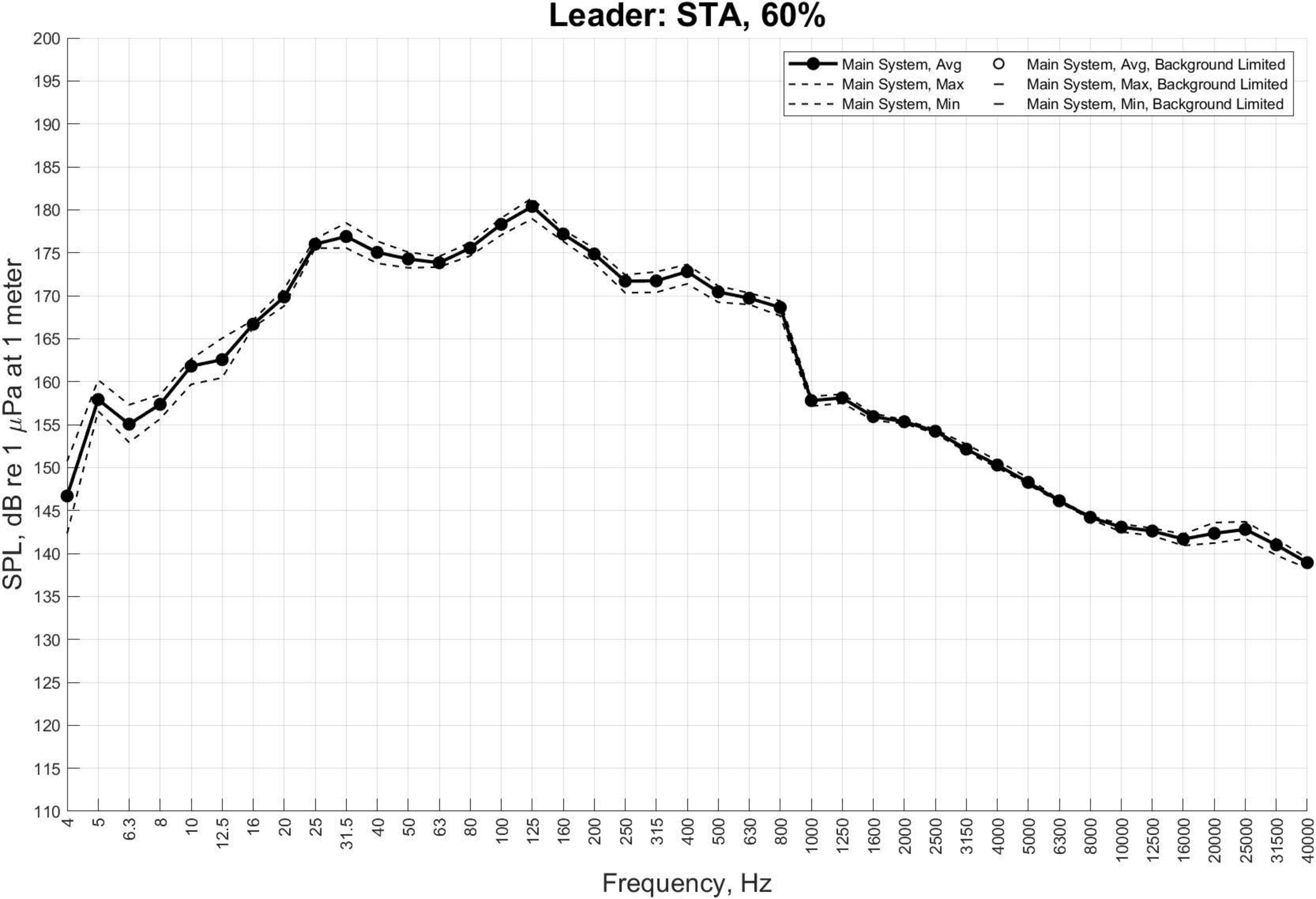
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000



Leader: STA, 60%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
5
6.3
8
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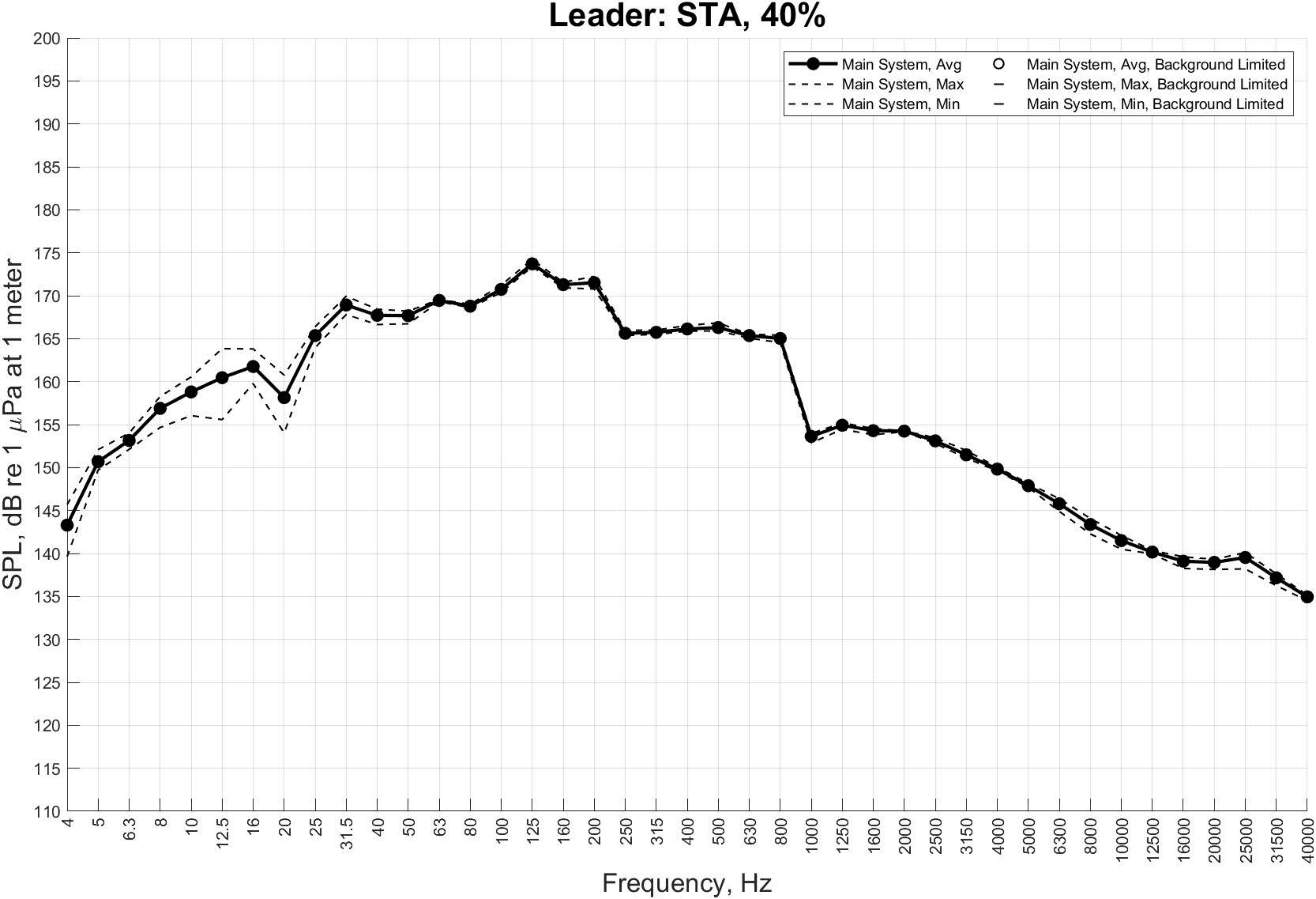
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
Frequency, Hz



Leader: STA, 40%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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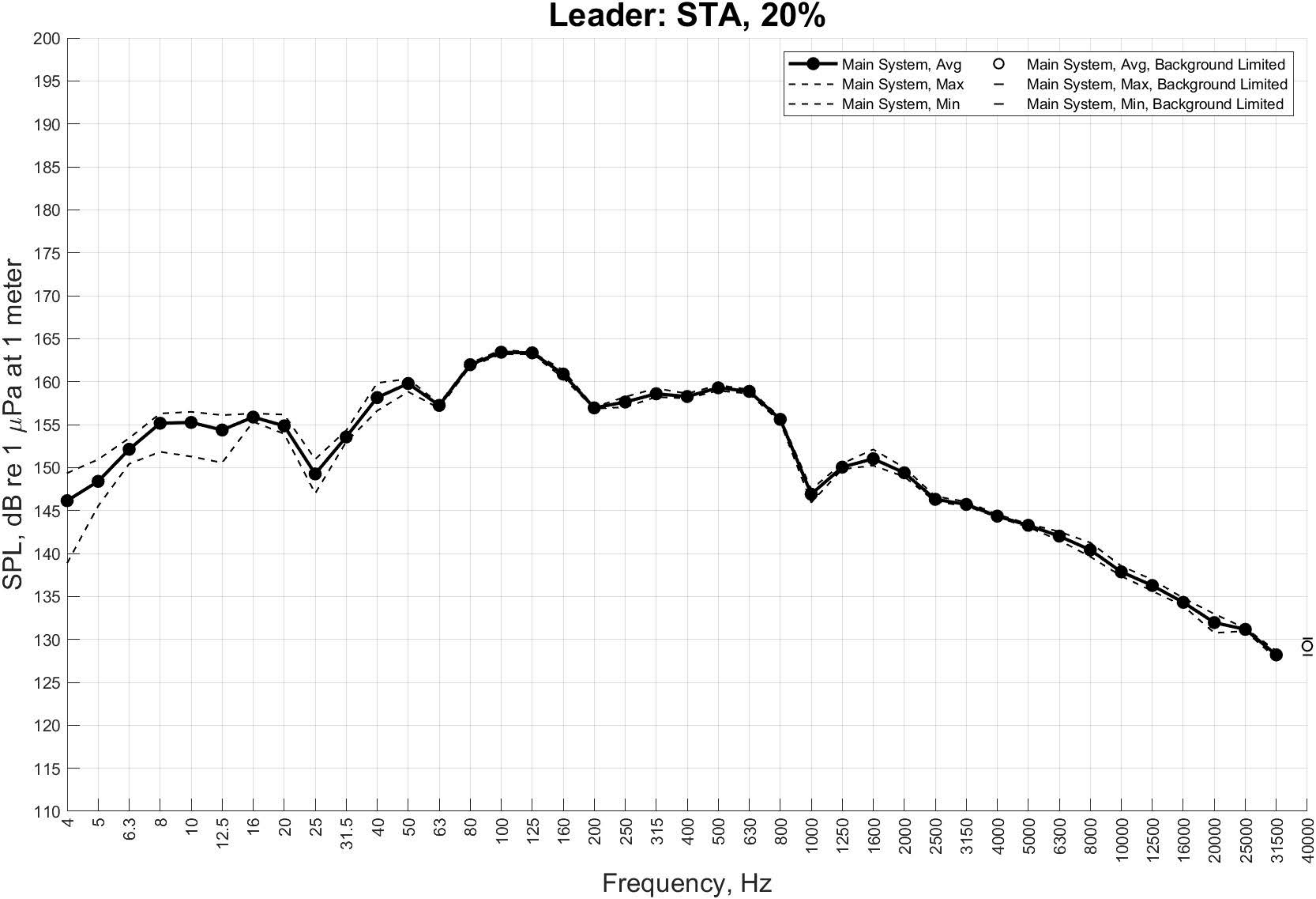
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000



Leader: STA, 20%
Main System, Avg
Main System, Max
Main System, Min
Main System, Avg, Background Limited
Main System, Max, Background Limited
Main System, Min, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
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5000
6300
8000
10000
12500
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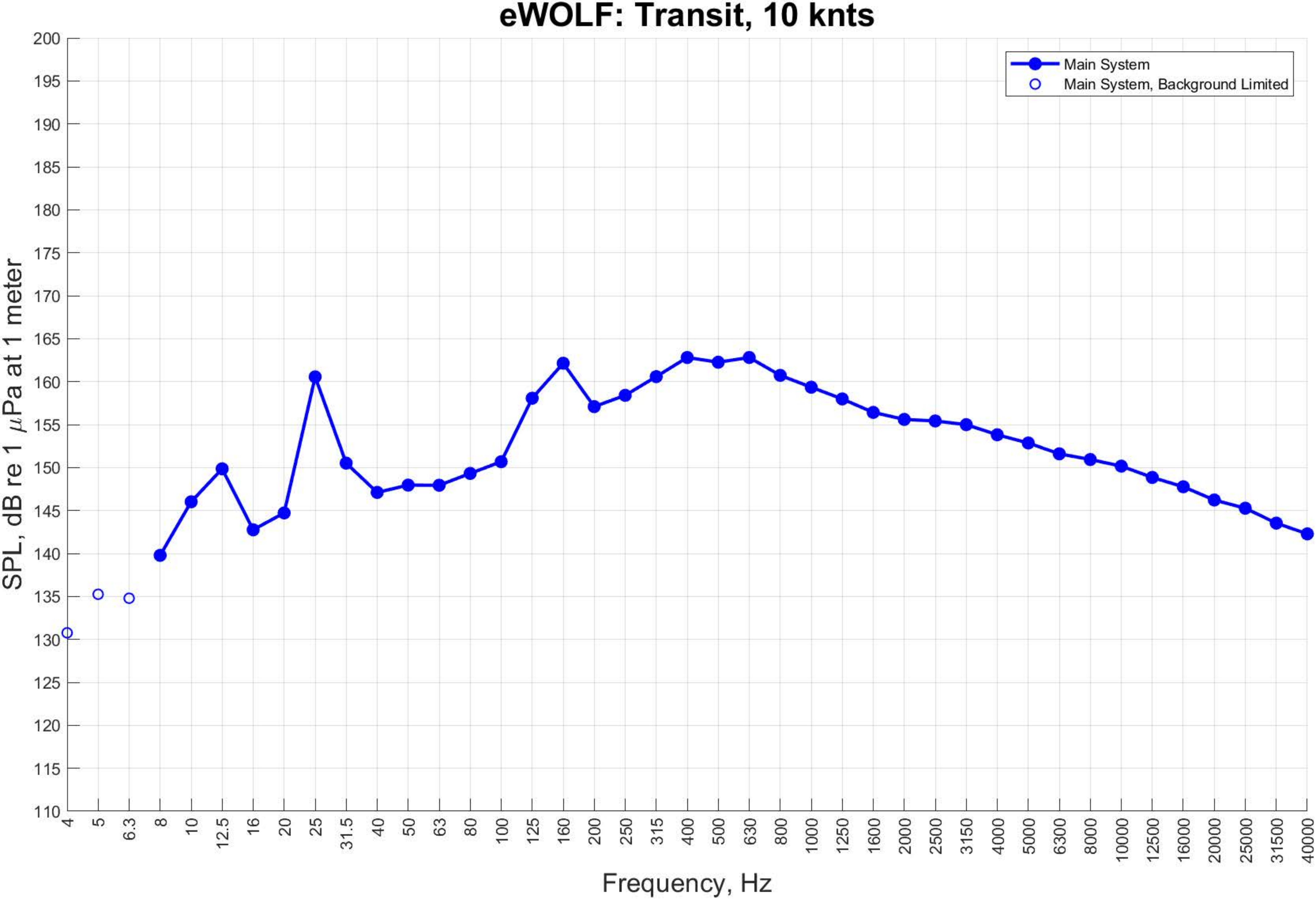
25000
31500
40000

APPENDIX C:

ONE-THIRD OCTAVE BAND SOURCE LEVEL SPECTRA, SIMULATED DEEP WATER



eWOLF: Transit, 10 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
8
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12.5
16
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31.5
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630
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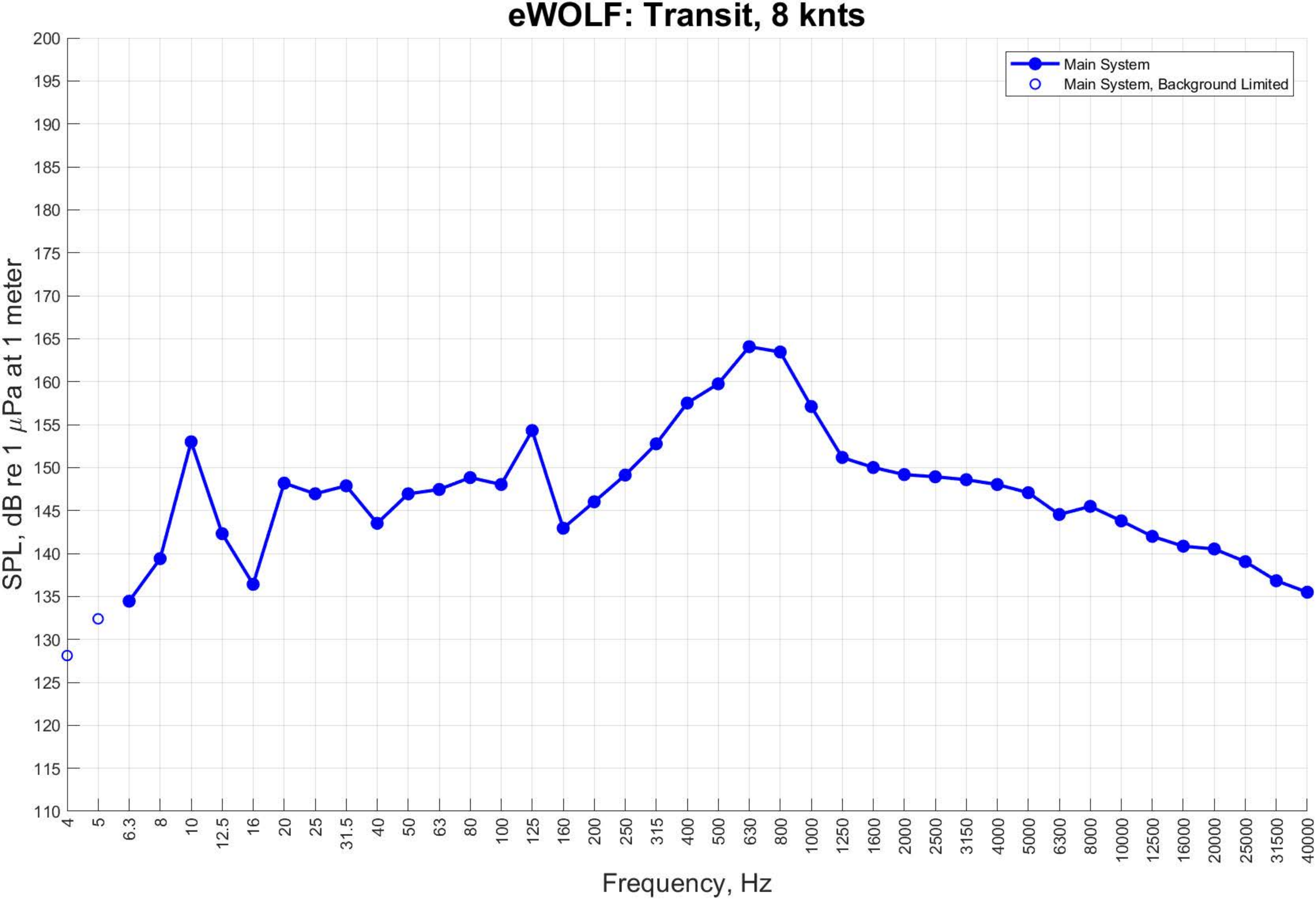
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000



eWOLF: Transit, 8 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
5
6.3
8
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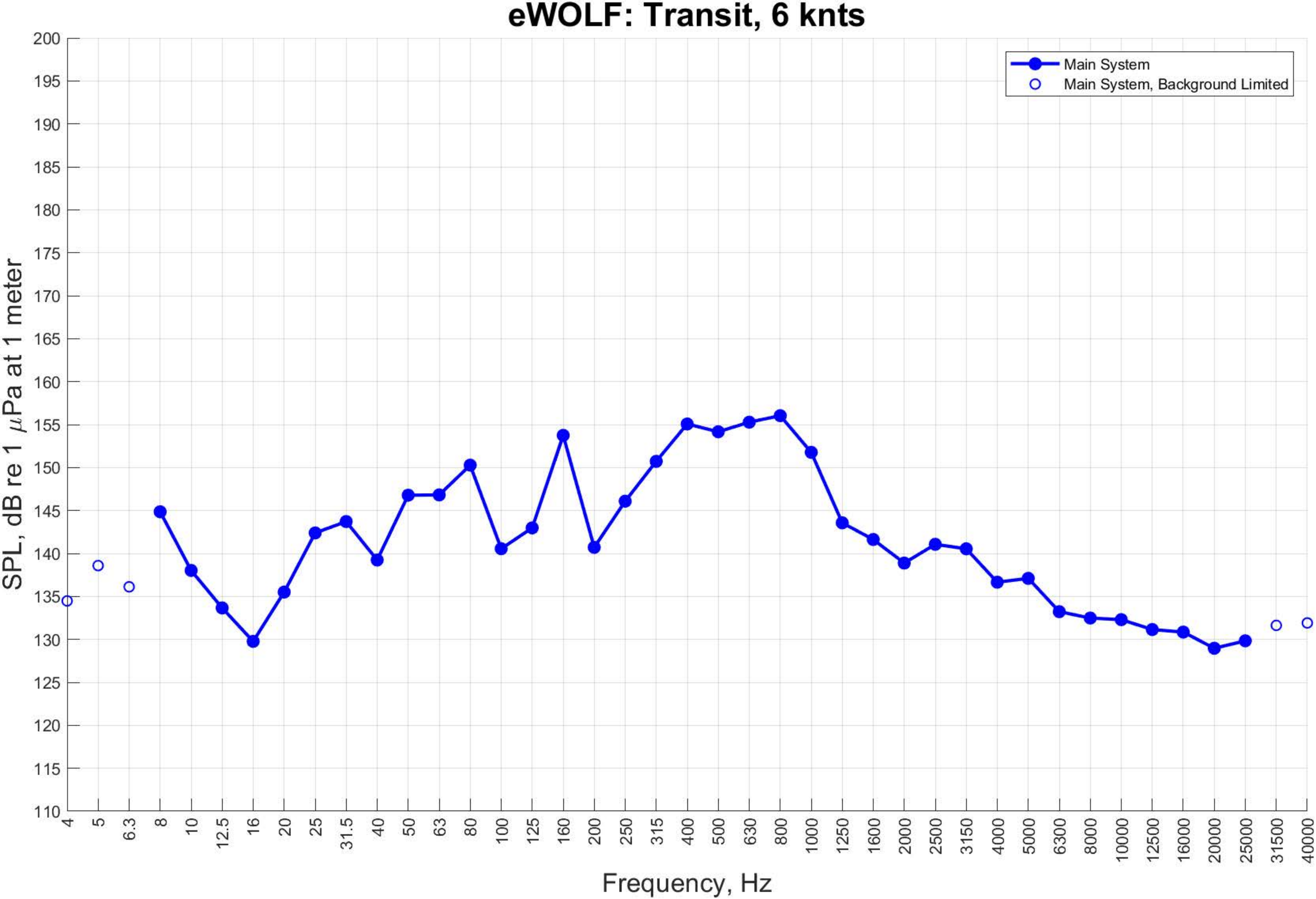
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000



eWOLF: Transit, 6 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
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6.3
8
10
12.5
16
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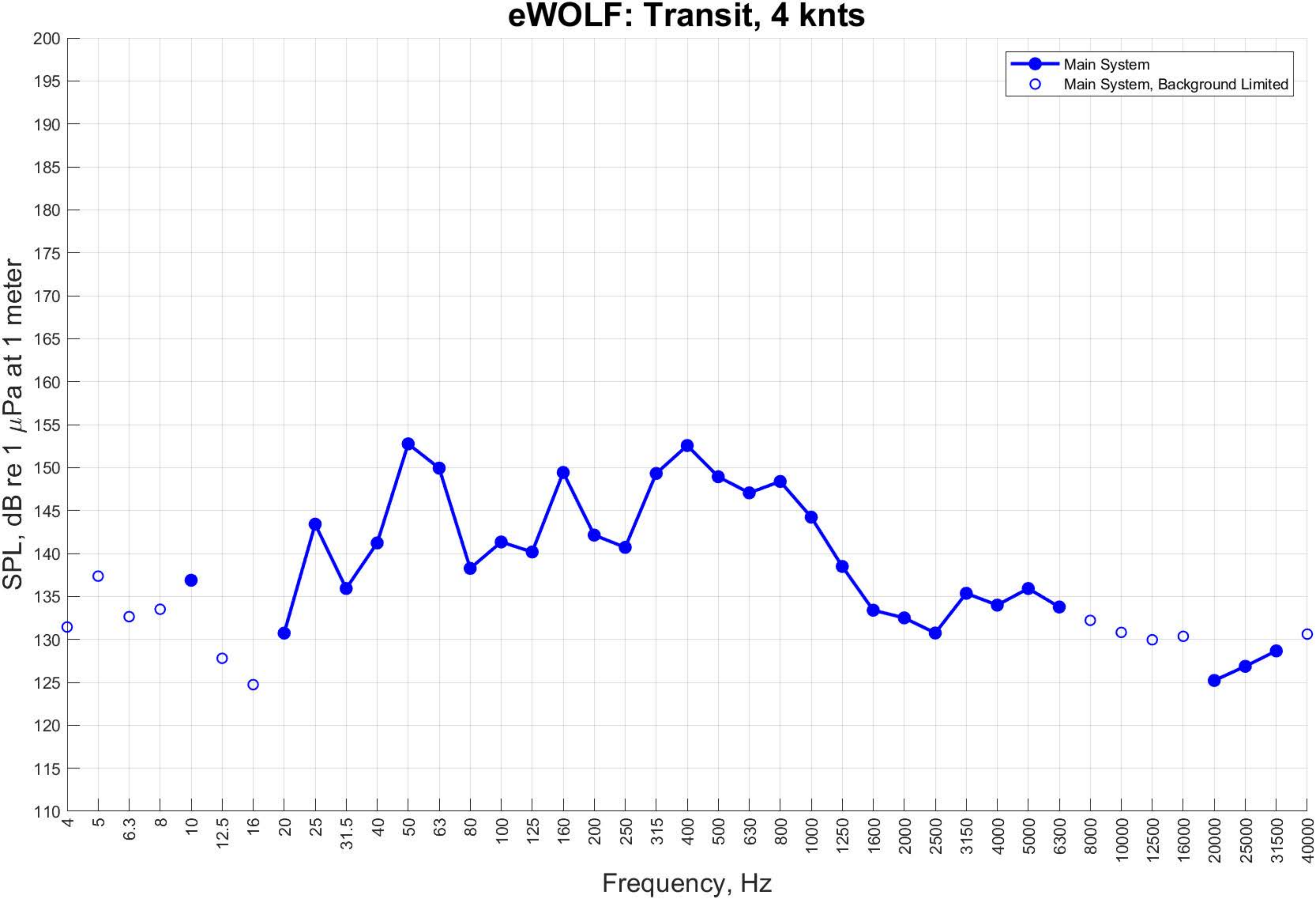
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
Frequency, Hz



eWOLF: Transit, 4 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
8
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12.5
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31.5
40
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63
80
100
125
160
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315
400
500
630
800
1000
1250
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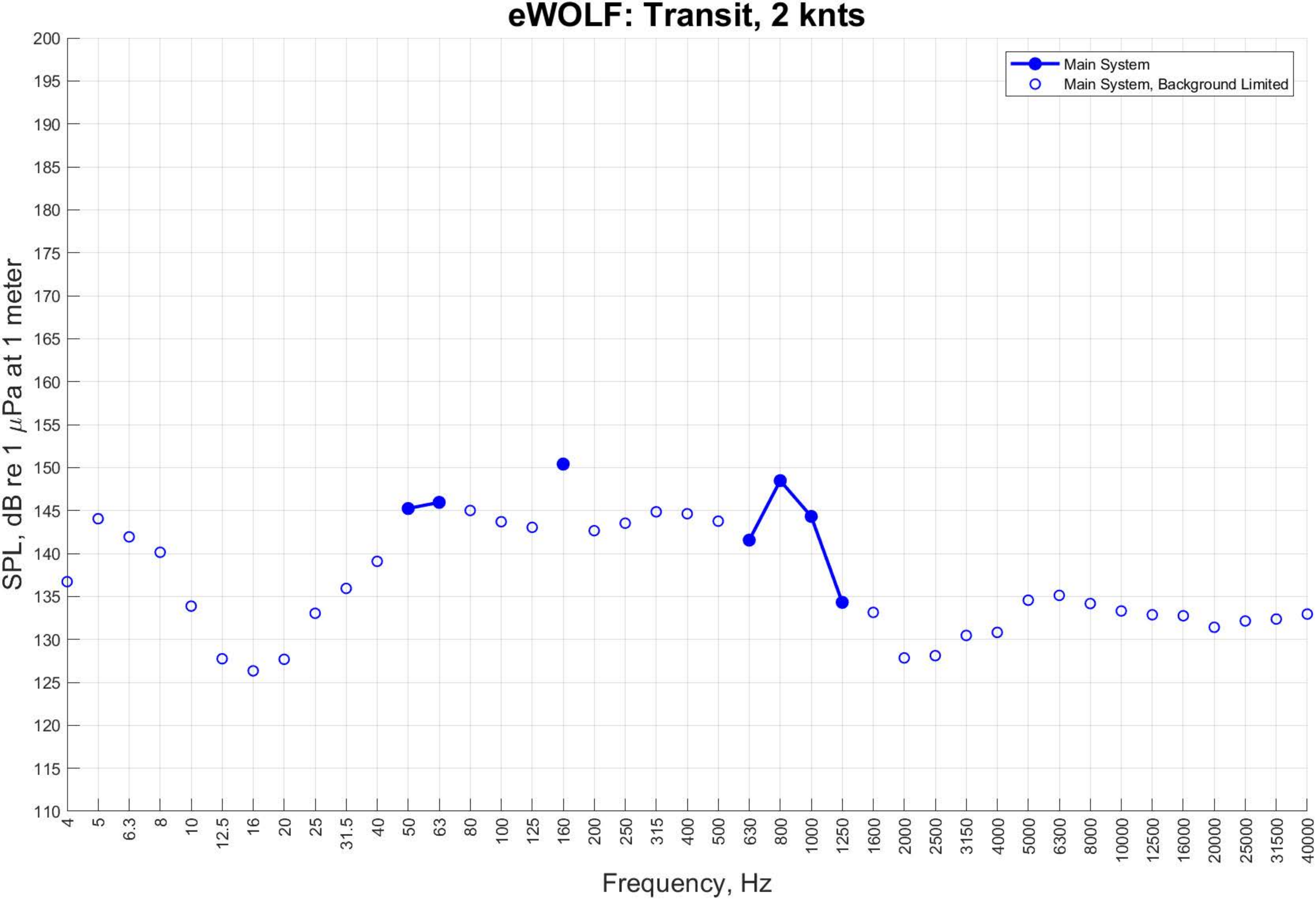
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000


eWOLF: Transit, 2 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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12.5
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31.5
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50
63
80
100
125
160
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1250
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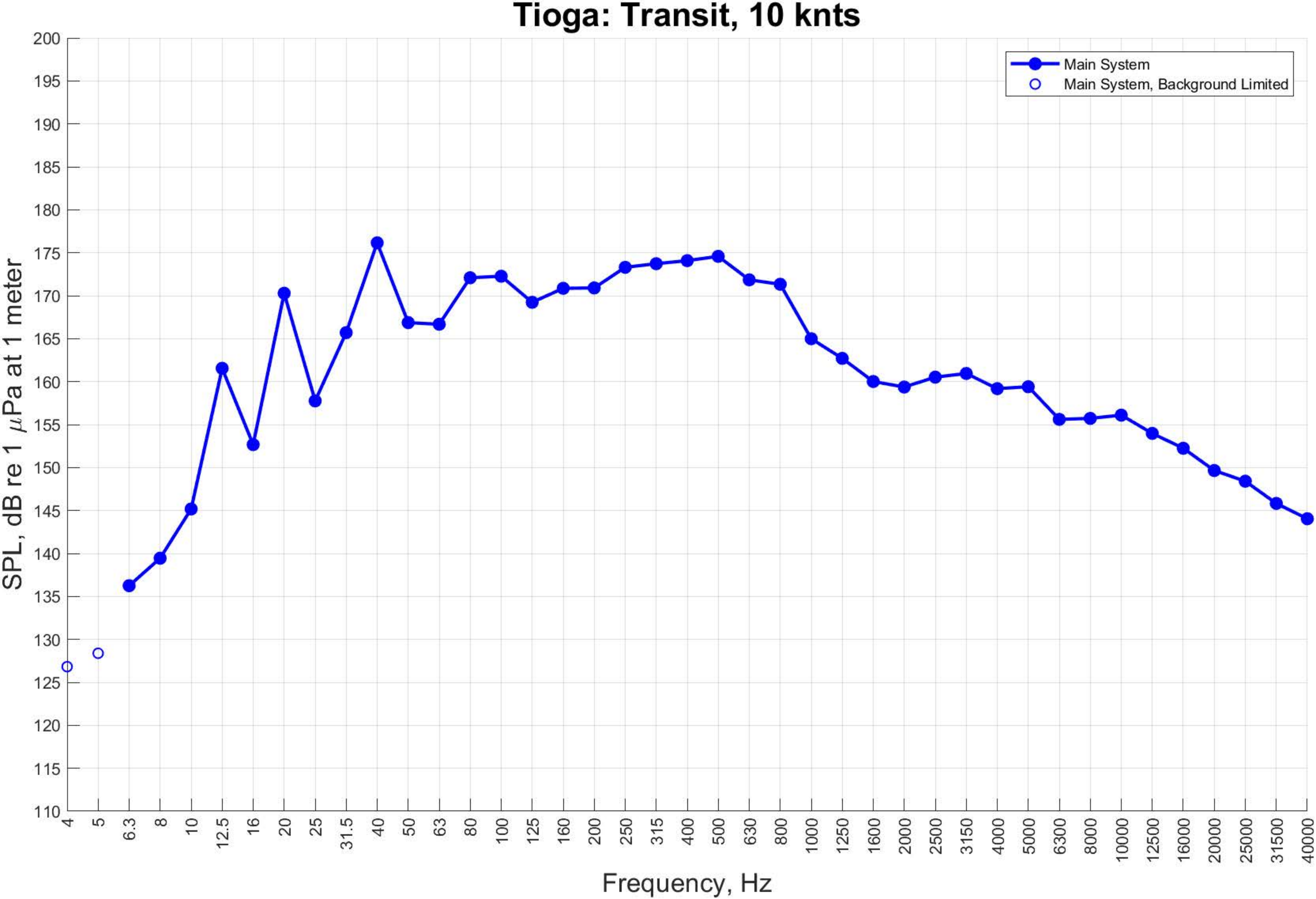
6300
8000
10000
12500
16000
20000
25000
31500
40000


Tioga: Transit, 10 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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12.5
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31.5
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100
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3150
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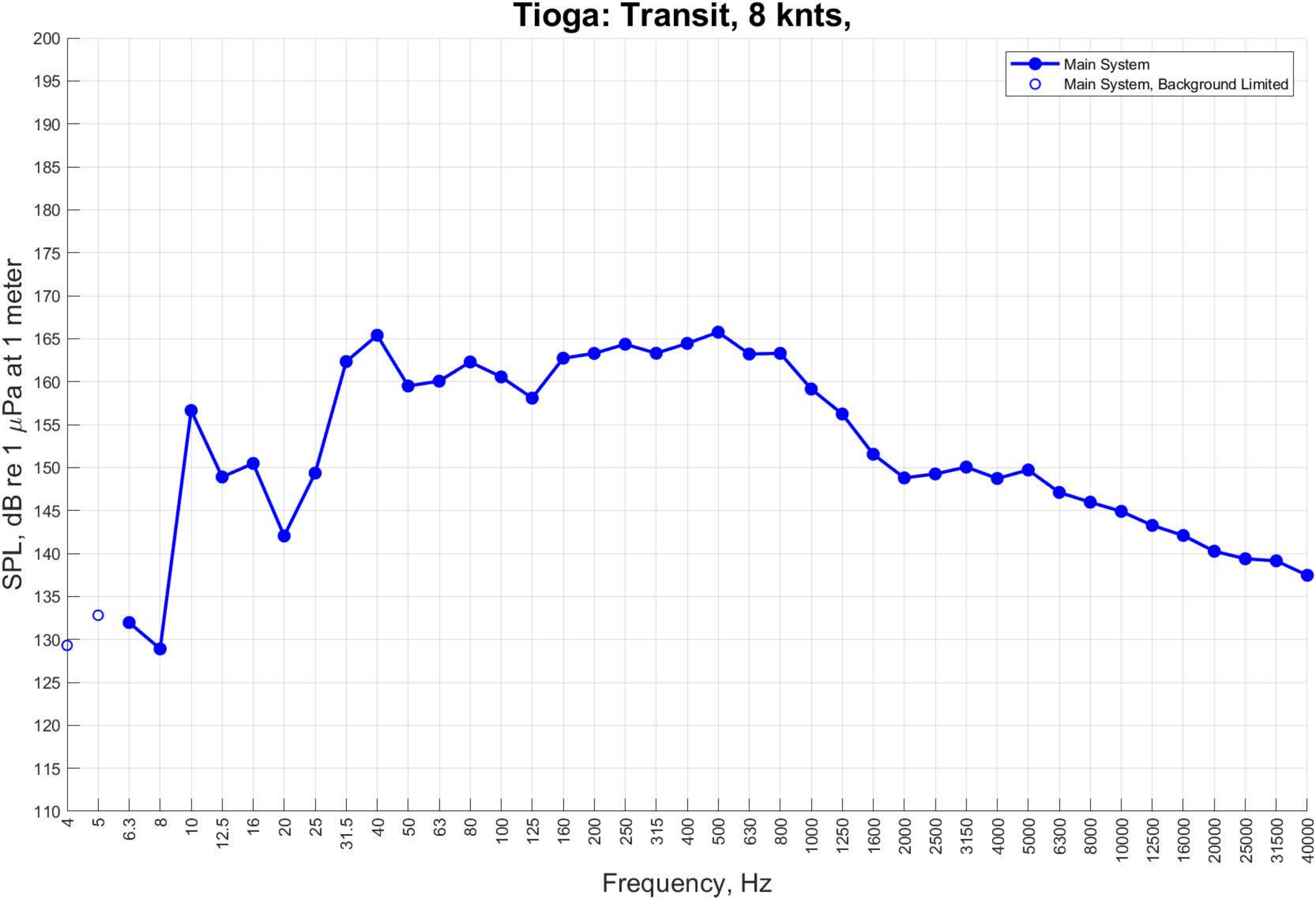
12500
16000
20000
25000
31500
40000



Tioga: Transit, 8 knts,
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
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4
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6.3
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2500
3150
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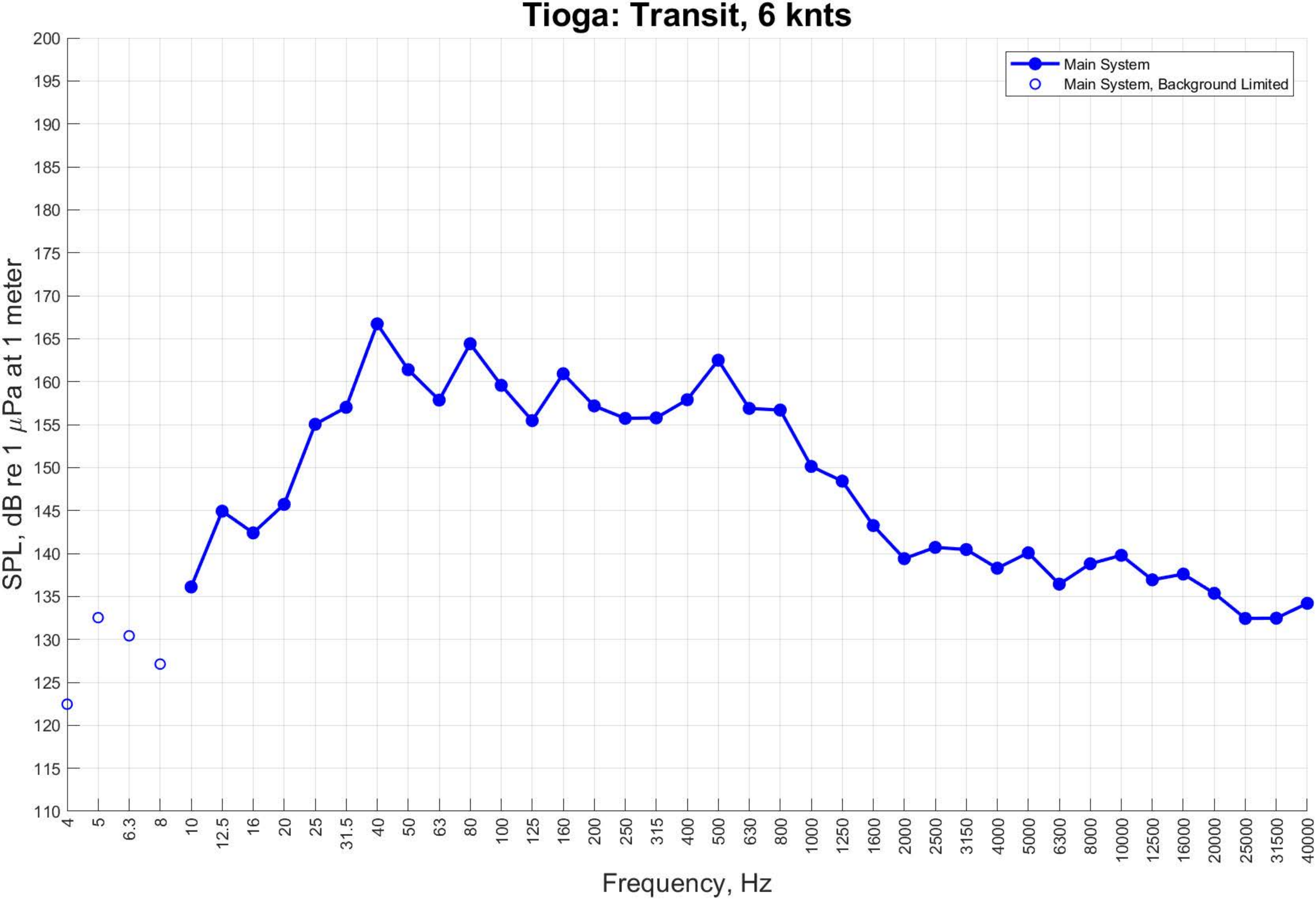
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000



Tioga: Transit, 6 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
8
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12.5
16
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31.5
40
50
63
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100
125
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630
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2500
3150
4000
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6300
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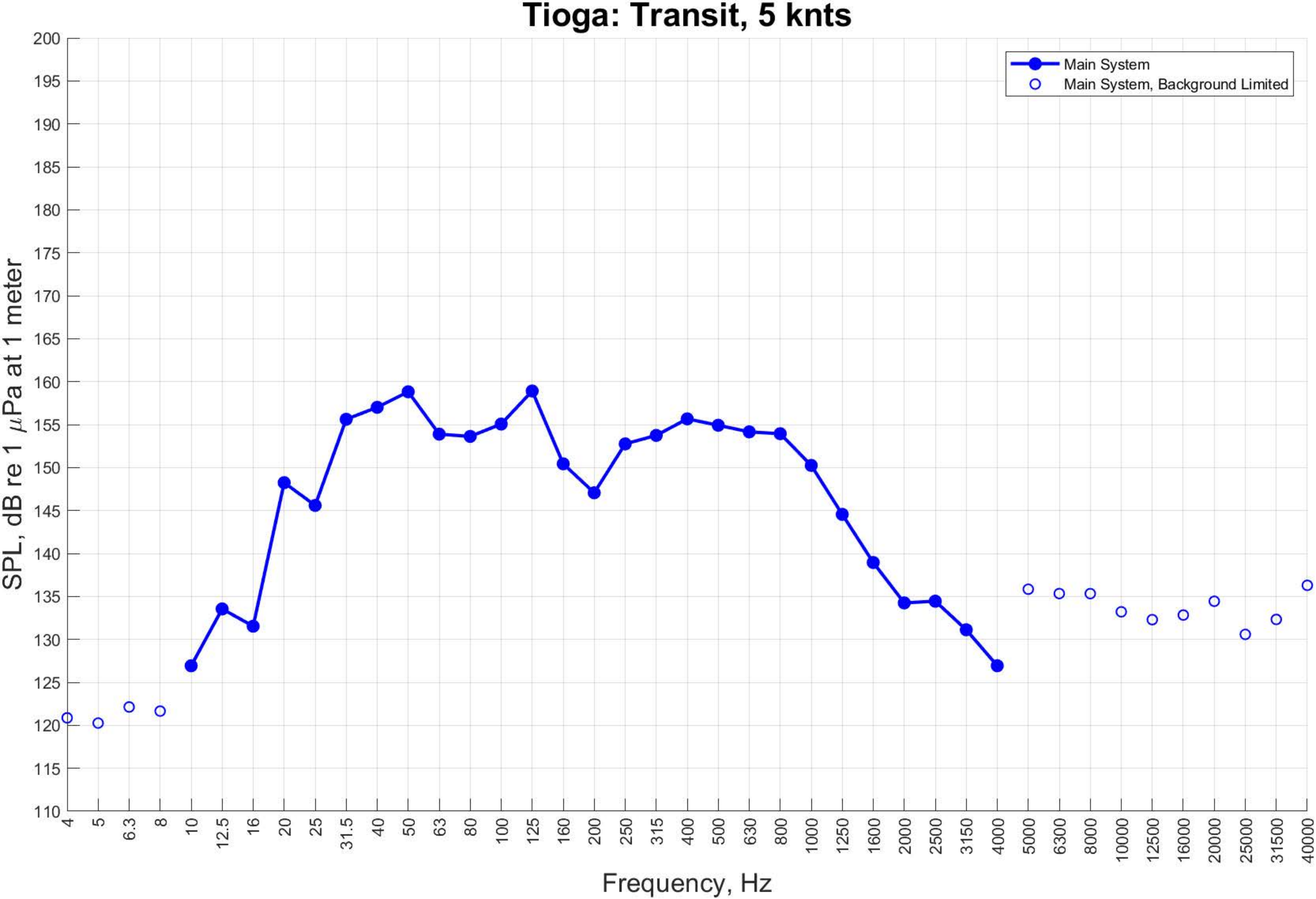
10000
12500
16000
20000
25000
31500
40000



Tioga: Transit, 5 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
8
10
12.5
16
20
25
31.5
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50
63
80
100
125
160
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250
315
400
500
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1250
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3150
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5000
6300
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12500
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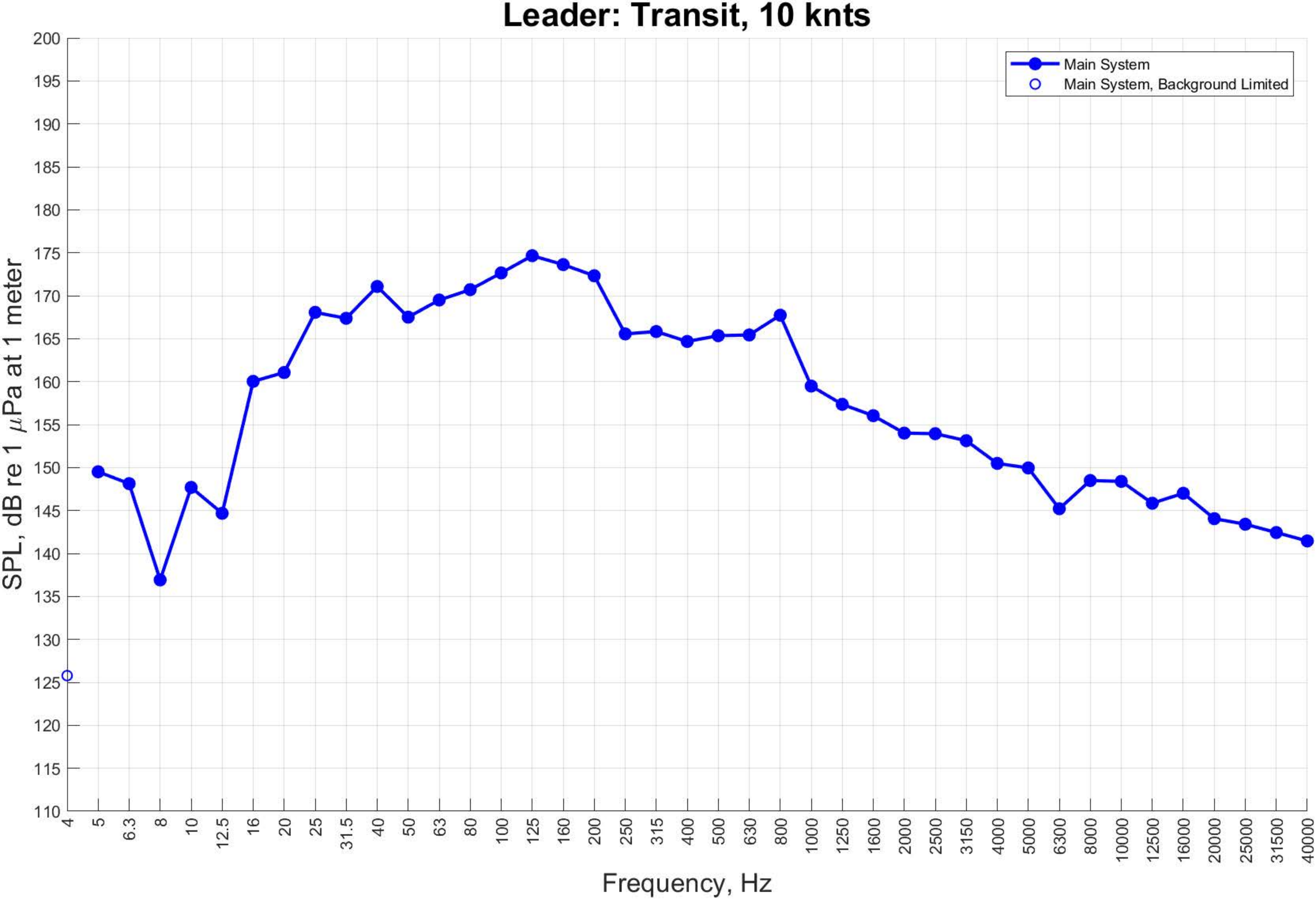
20000
25000
31500
40000


Leader: Transit, 10 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
4
5
6.3
8
10
12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
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1250
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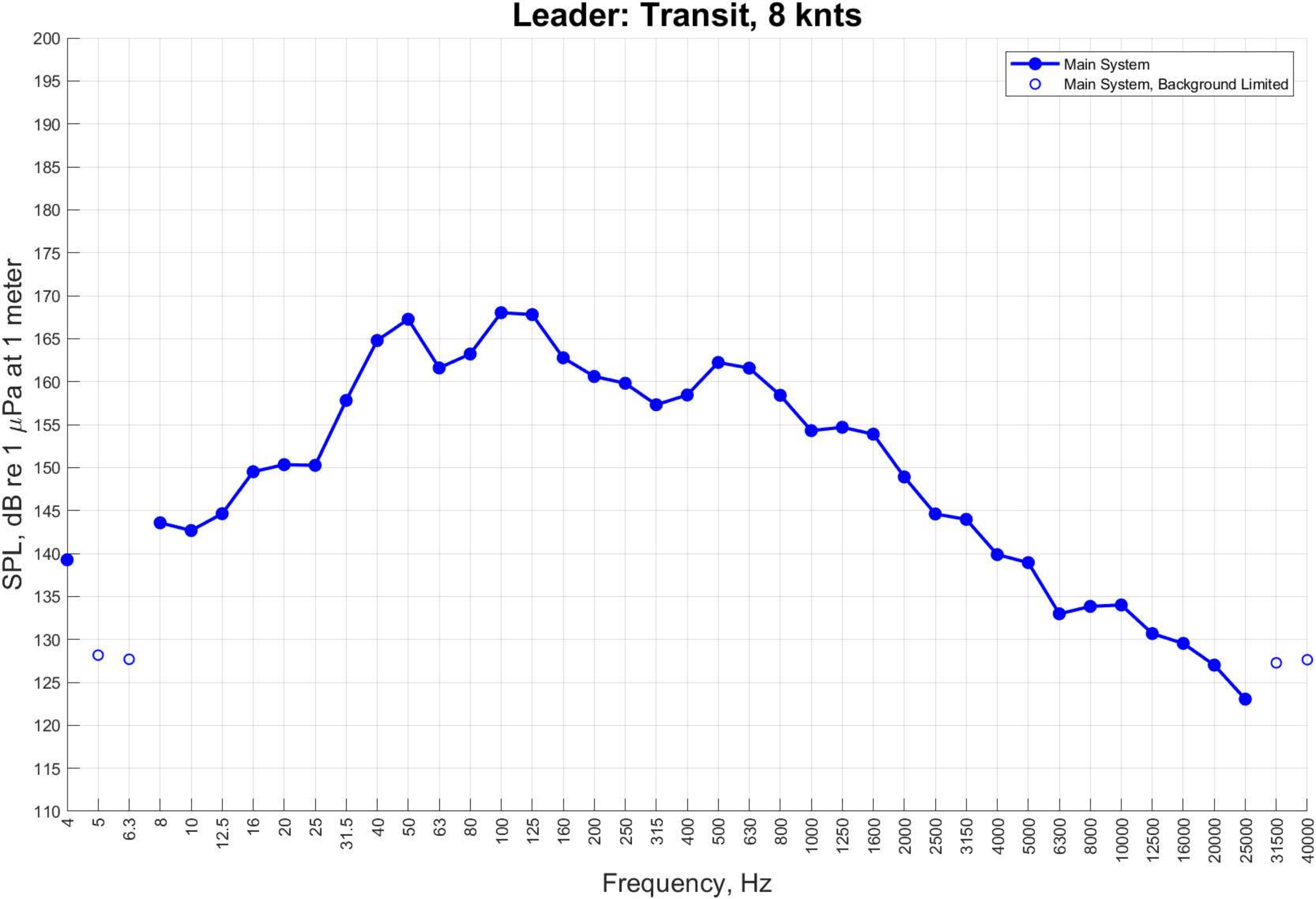
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000


Leader: Transit, 8 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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12.5
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25
31.5
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50
63
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100
125
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200
250
315
400
500
630
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1250
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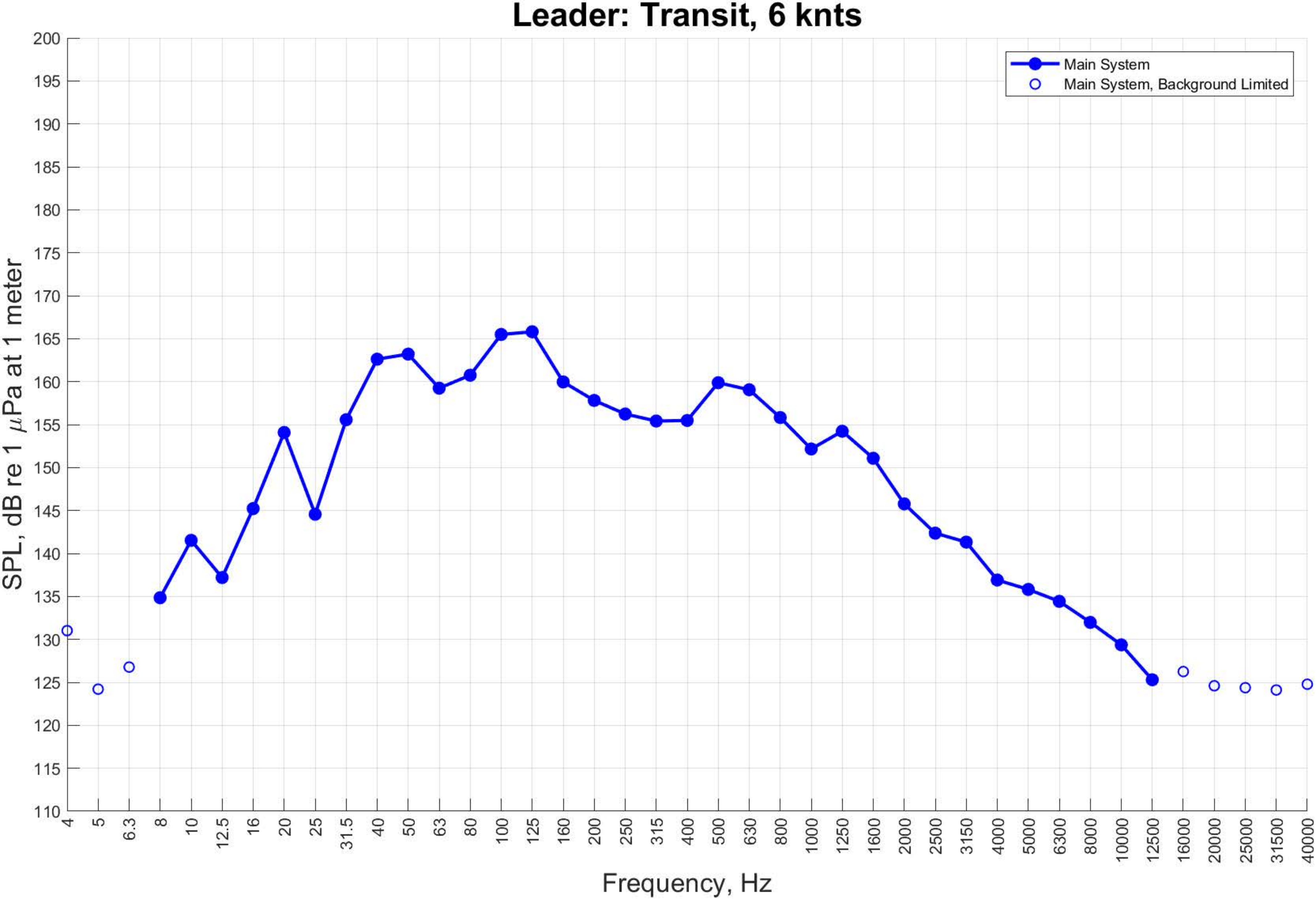
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000



Leader: Transit, 6 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
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140
135
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125
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4
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6.3
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31.5
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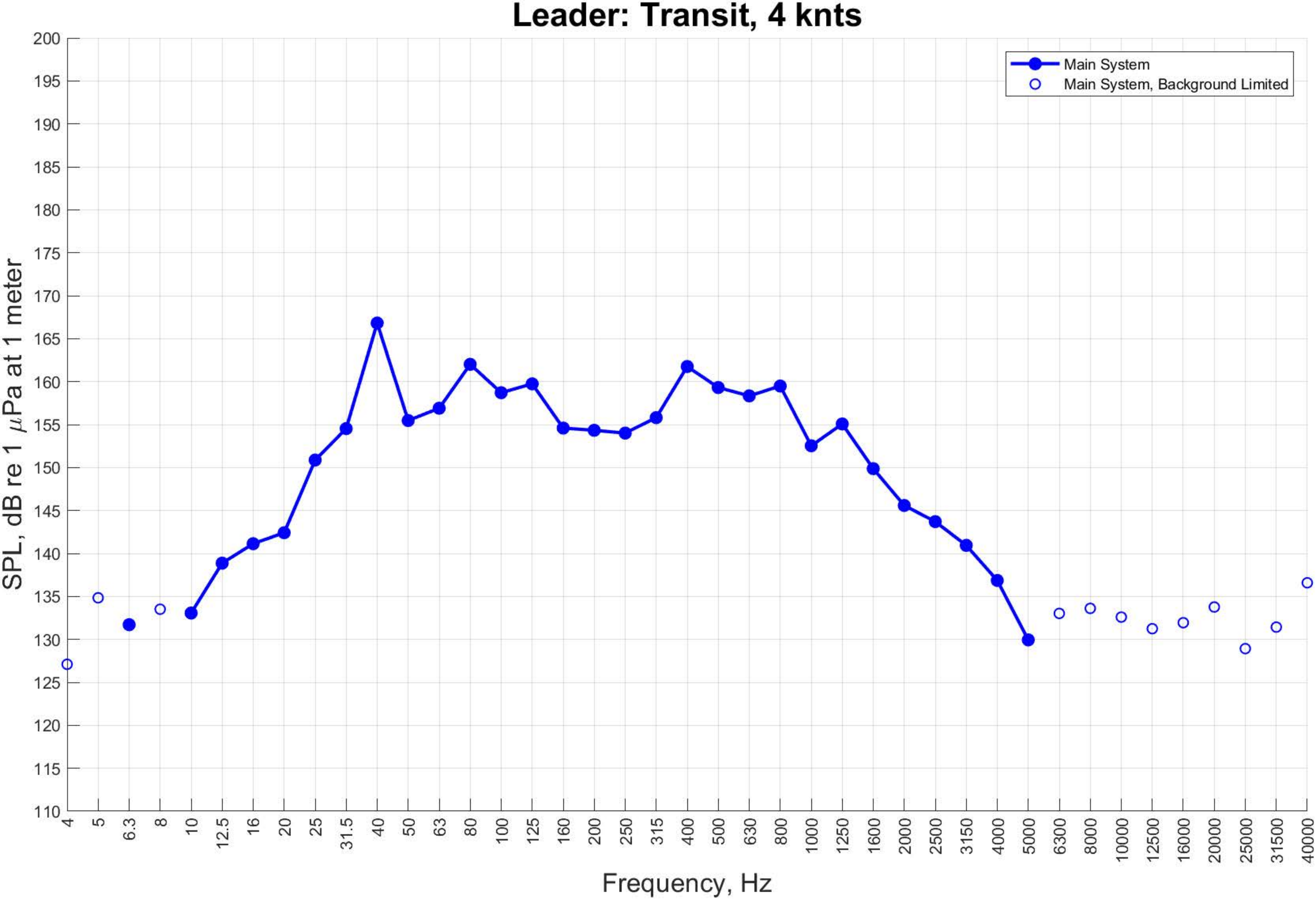
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
Frequency, Hz



Leader: Transit, 4 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
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4
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6.3
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12.5
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31.5
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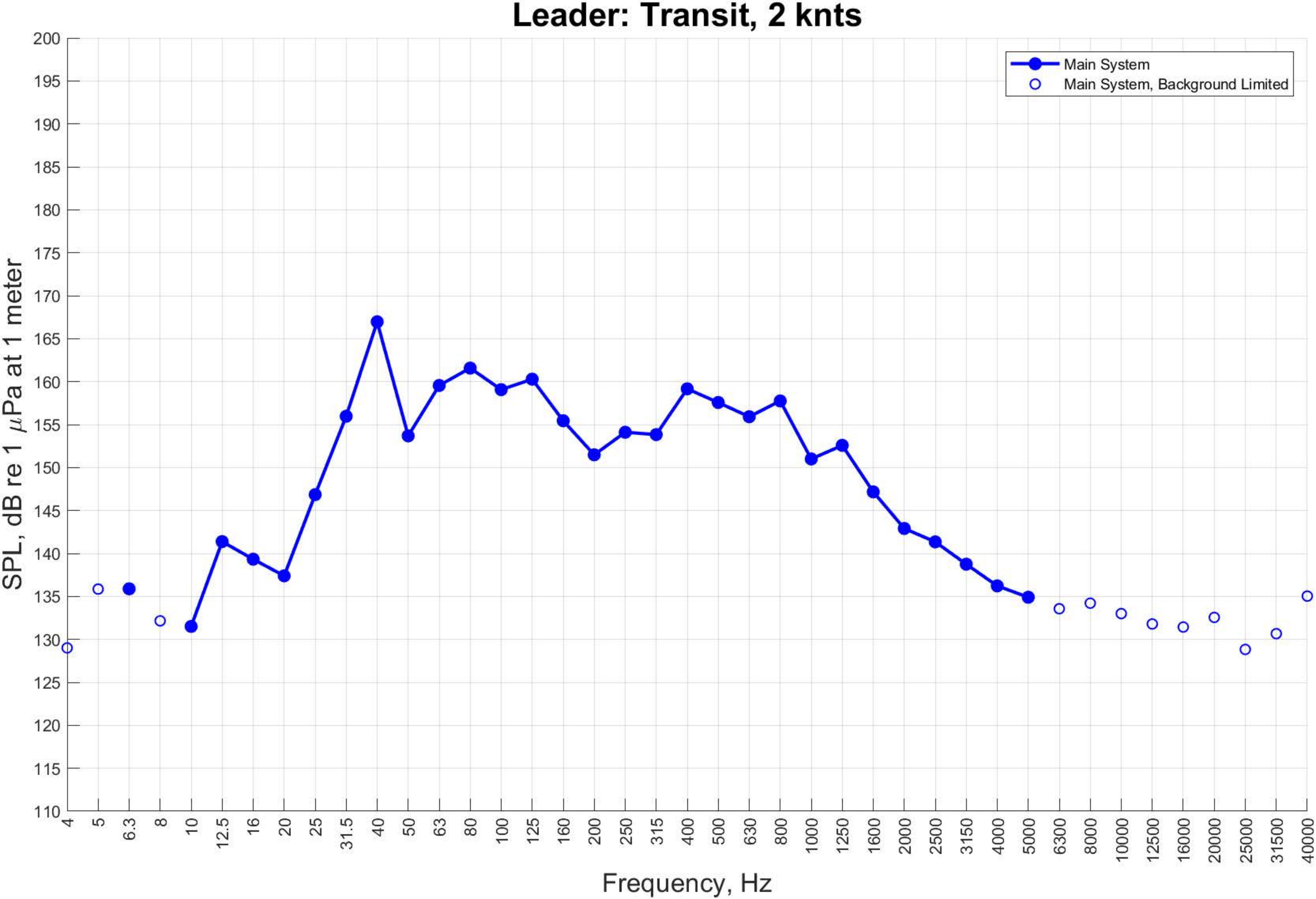
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000


Leader: Transit, 2 knts
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
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115
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4
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6.3
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12.5
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31.5
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3150
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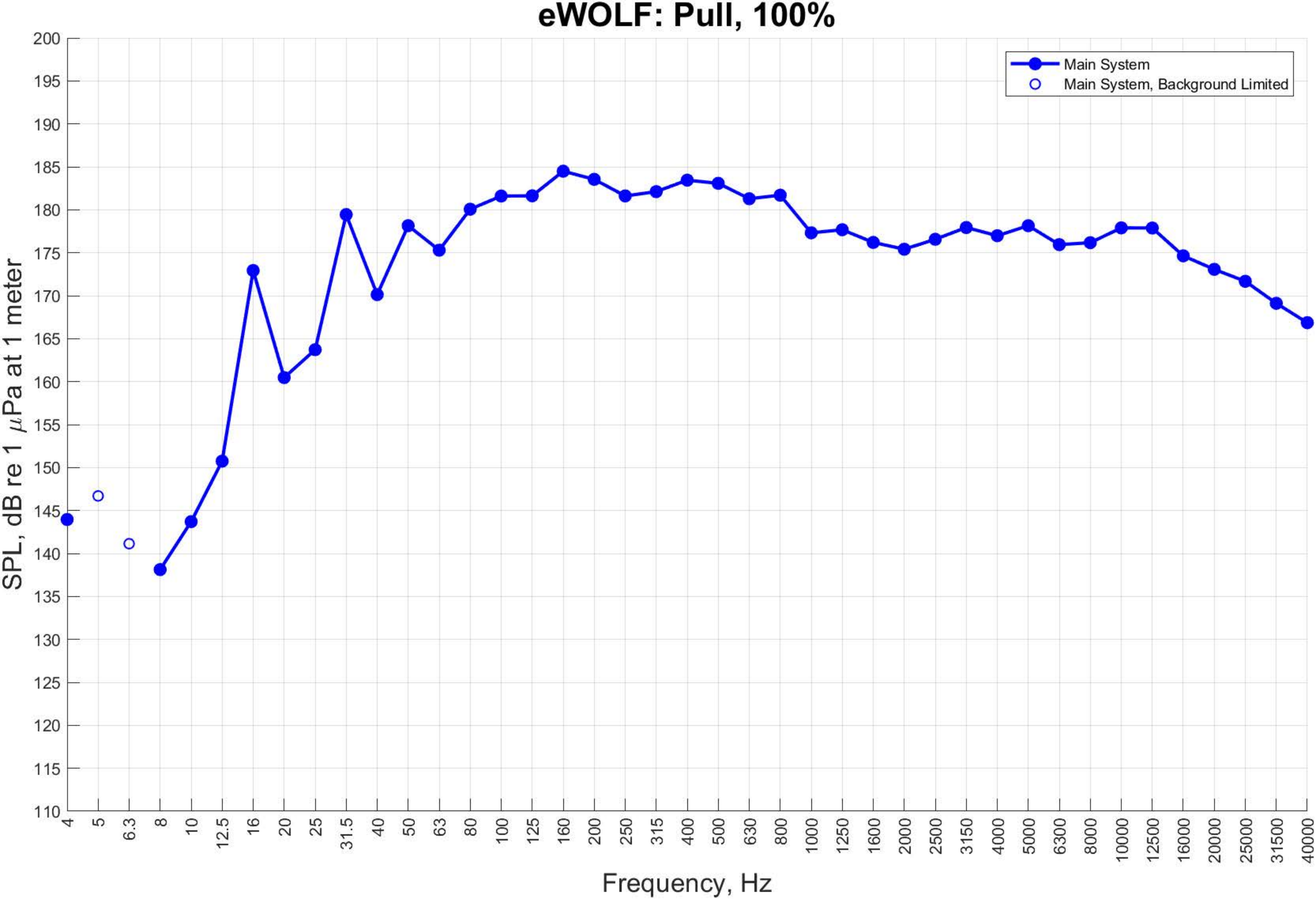
6300
8000
10000
12500
16000
20000
25000
31500
40000



eWOLF: Pull, 100%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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12.5
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31.5
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200
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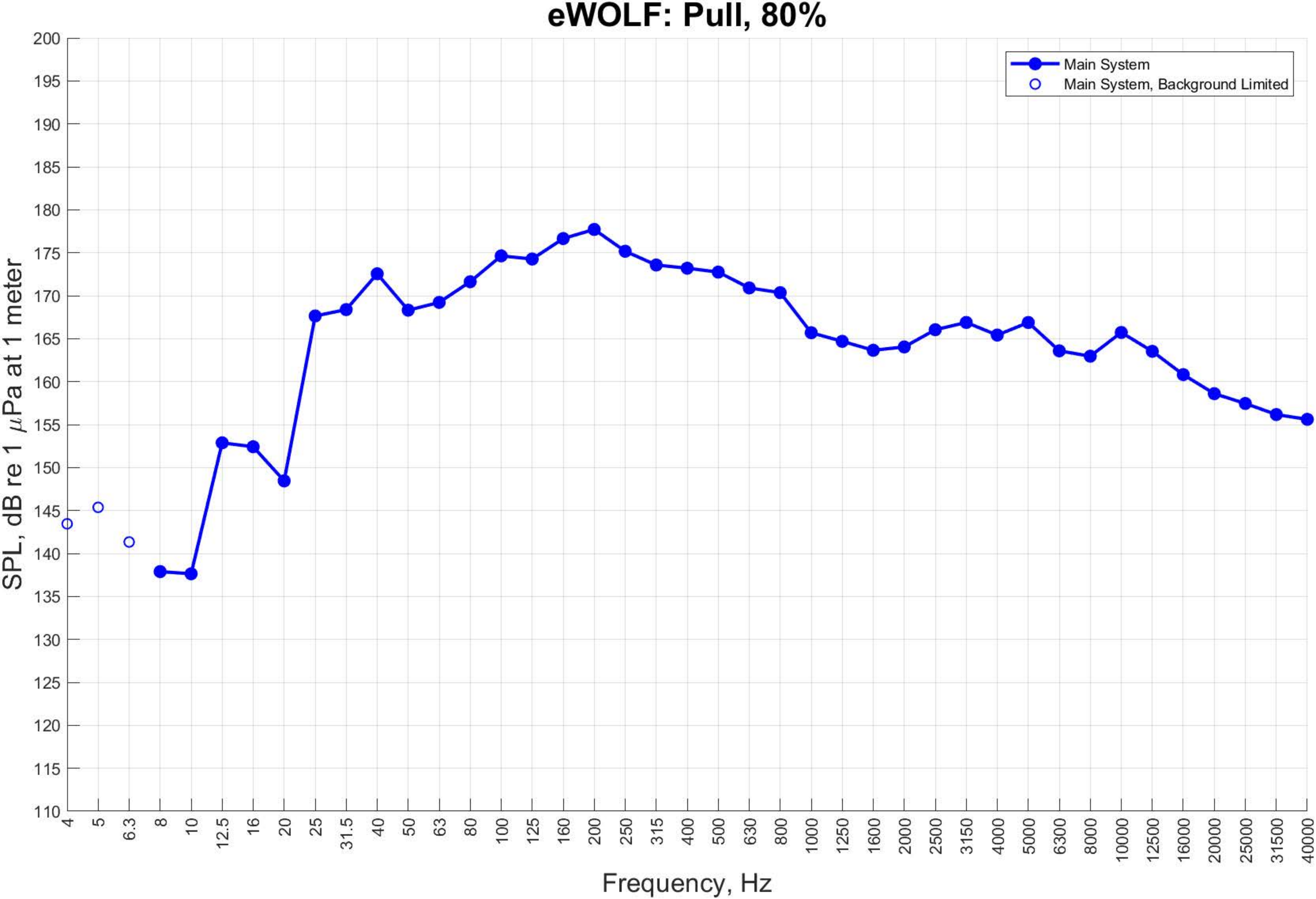
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
Frequency, Hz


eWOLF: Pull, 80%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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12.5
16
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31.5
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63
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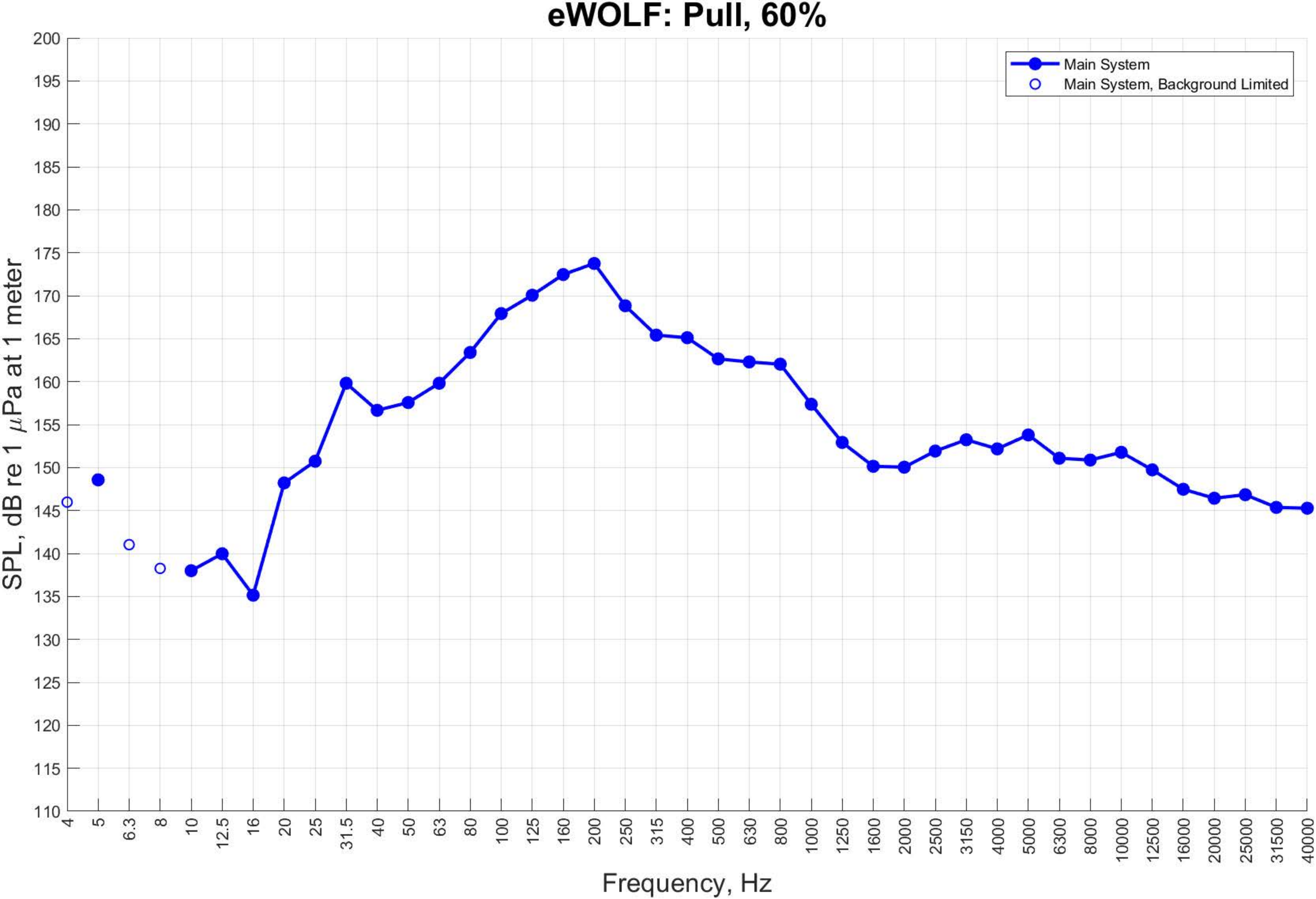
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
25000
31500
40000
Frequency, Hz


eWOLF: Pull, 60%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
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6.3
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12.5
16
20
25
31.5
40
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63
80
100
125
160
200
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315
400
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3150
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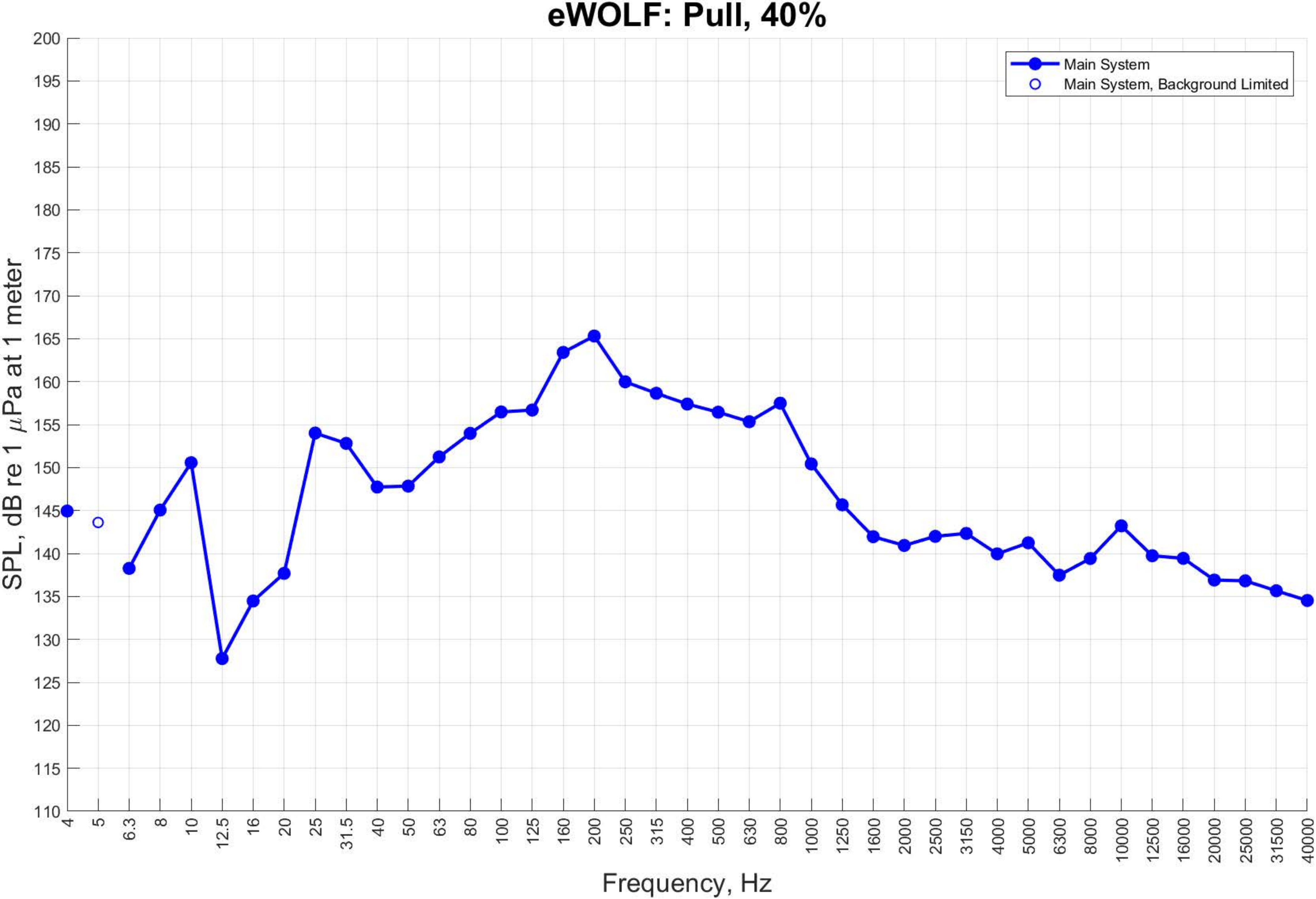
6300
8000
10000
12500
16000
20000
25000
31500
40000



eWOLF: Pull, 40%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
4
5
6.3
8
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12.5
16
20
25
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
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1250
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2000
2500
3150
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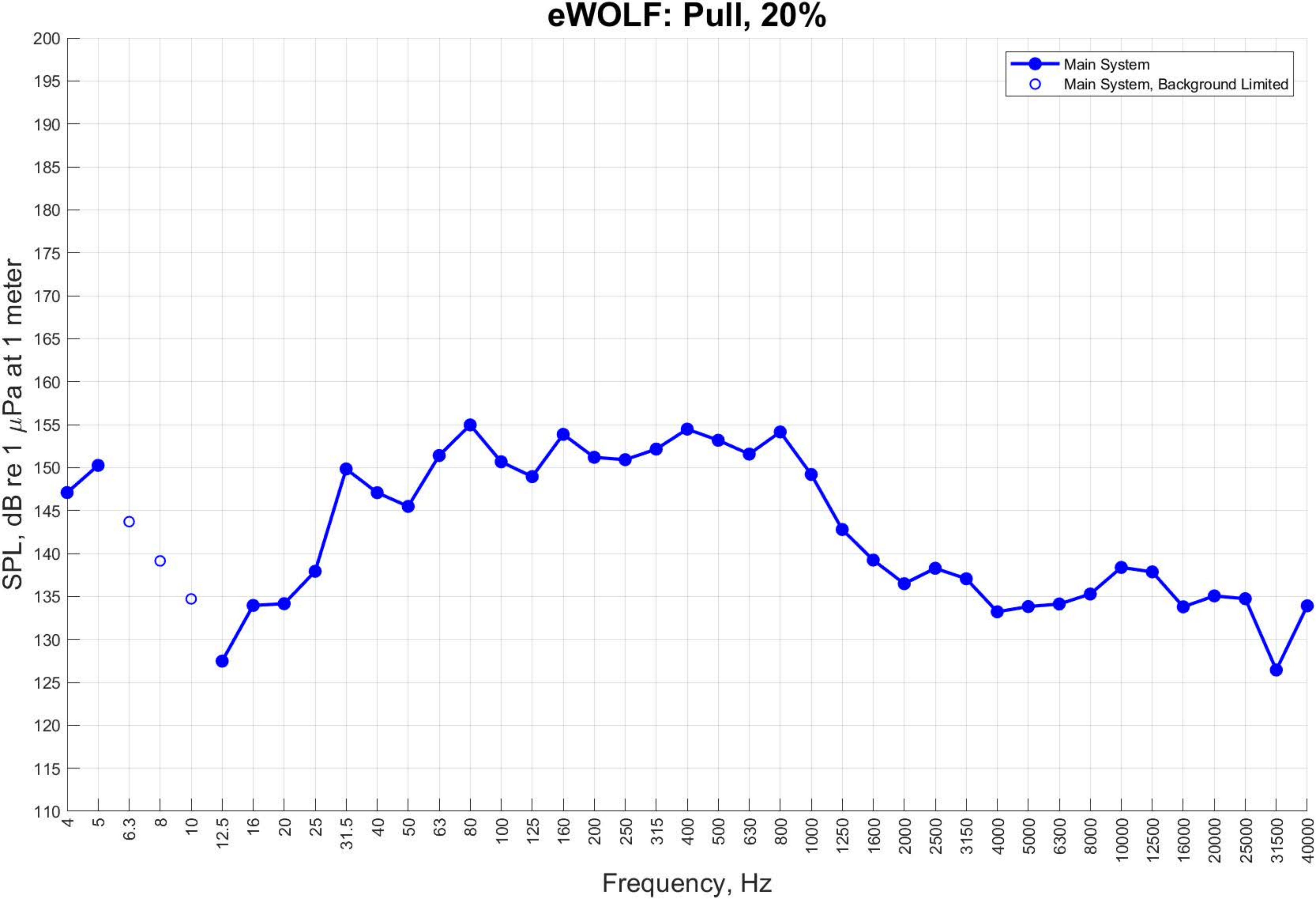
6300
8000
10000
12500
16000
20000
25000
31500
40000


eWOLF: Pull, 20%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
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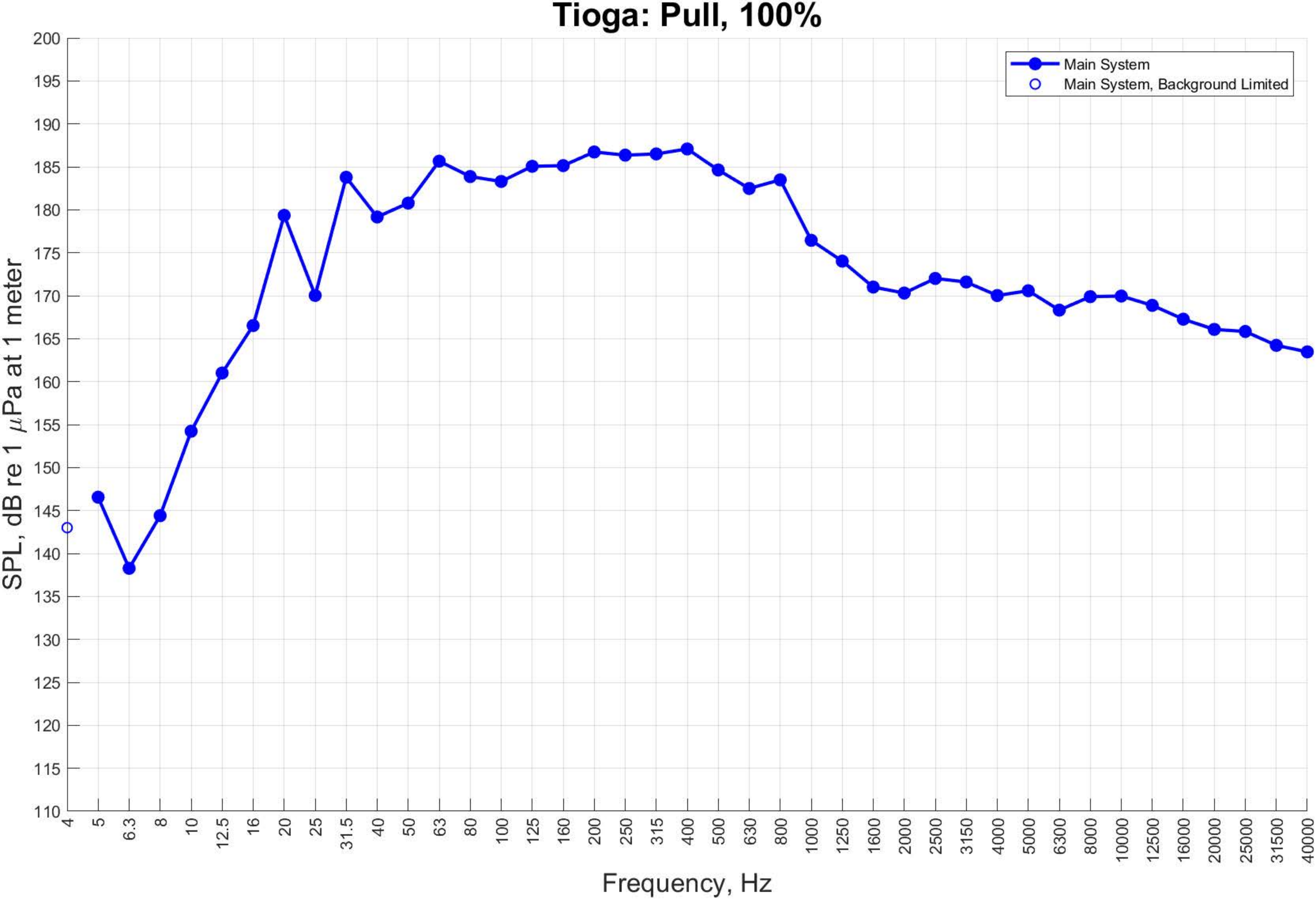
12500
16000
20000
25000
31500
40000



Tioga: Pull, 100%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
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160
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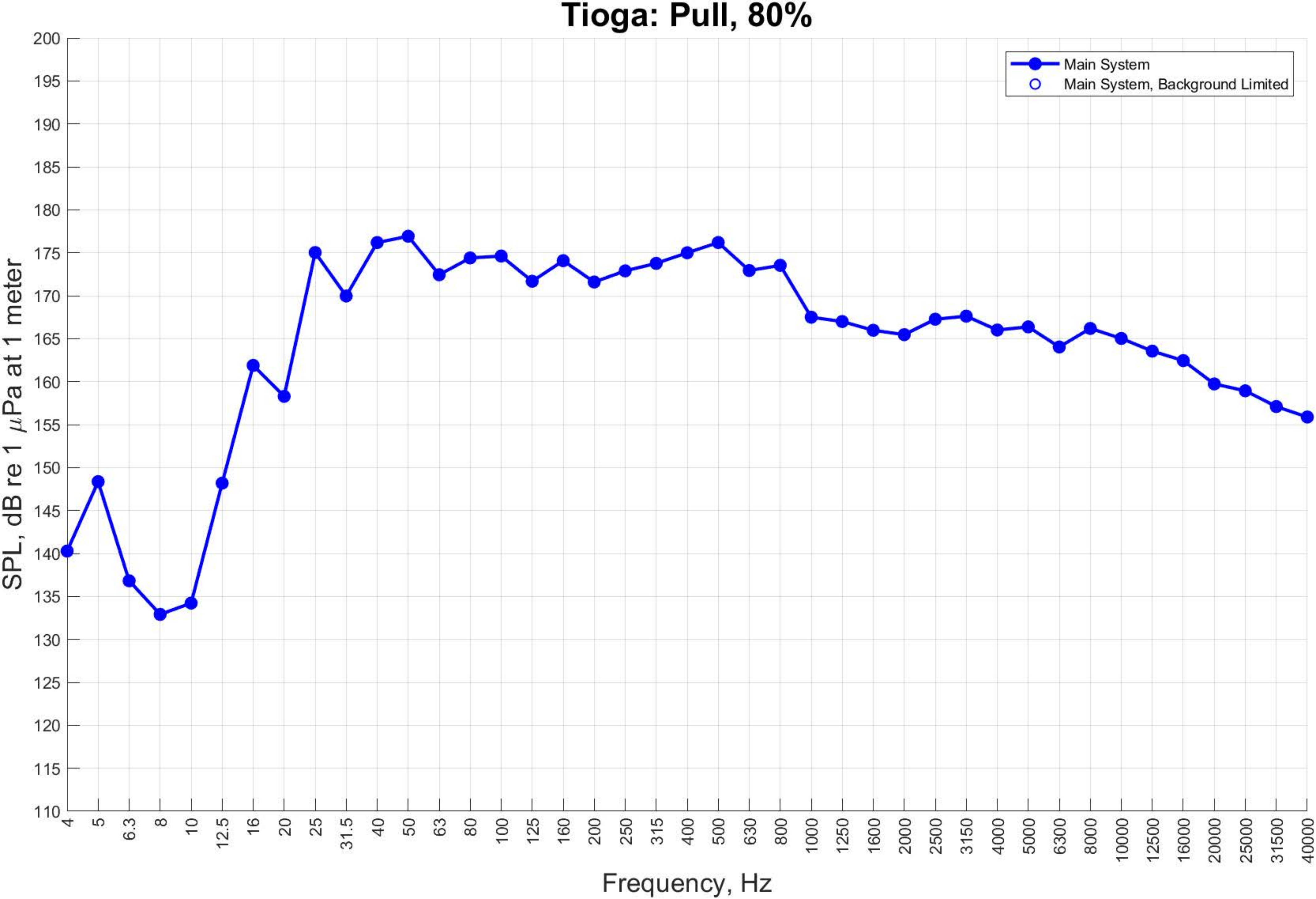

Tioga: Pull, 80%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
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140
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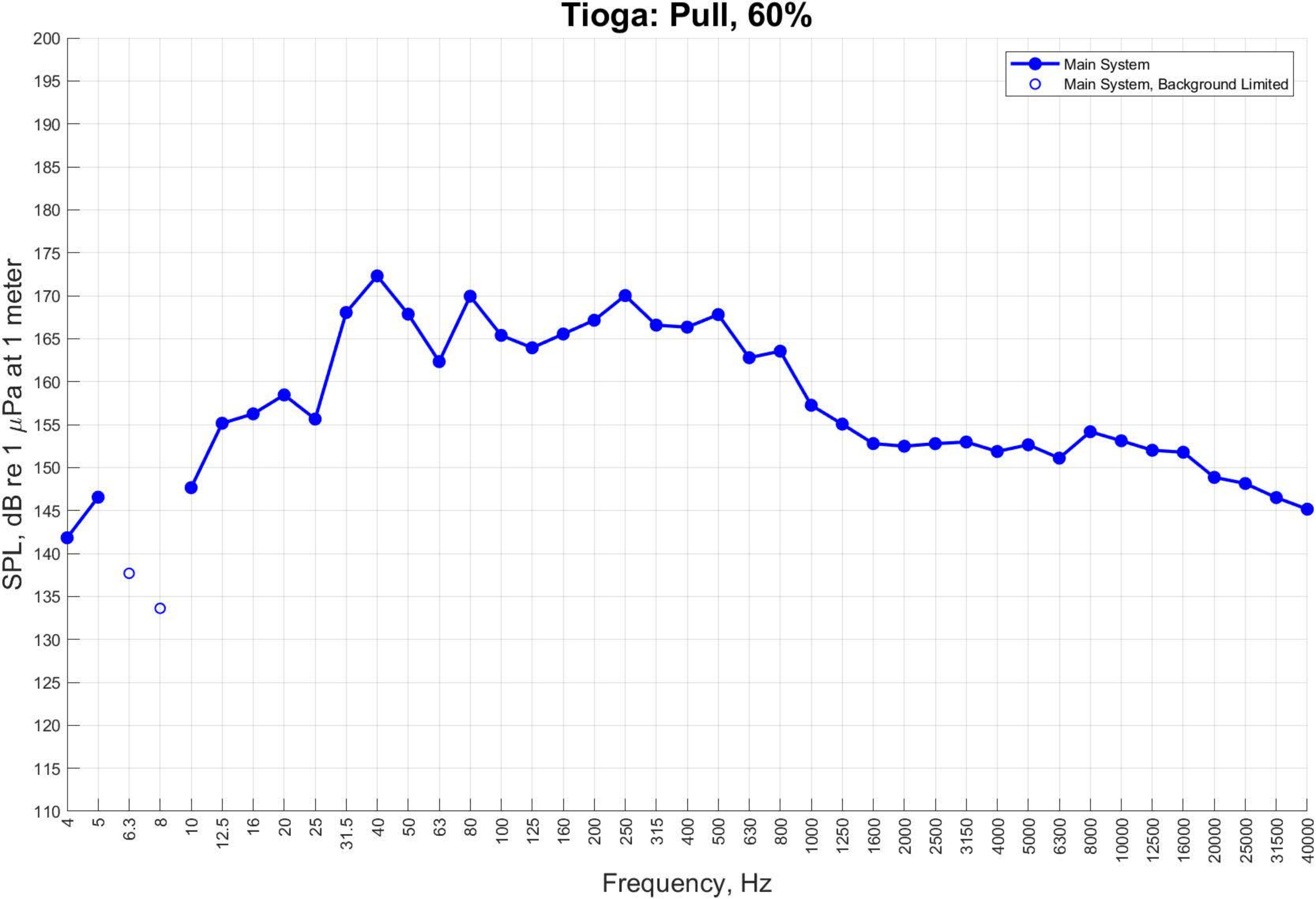
Tioga: Pull, 60%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
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170
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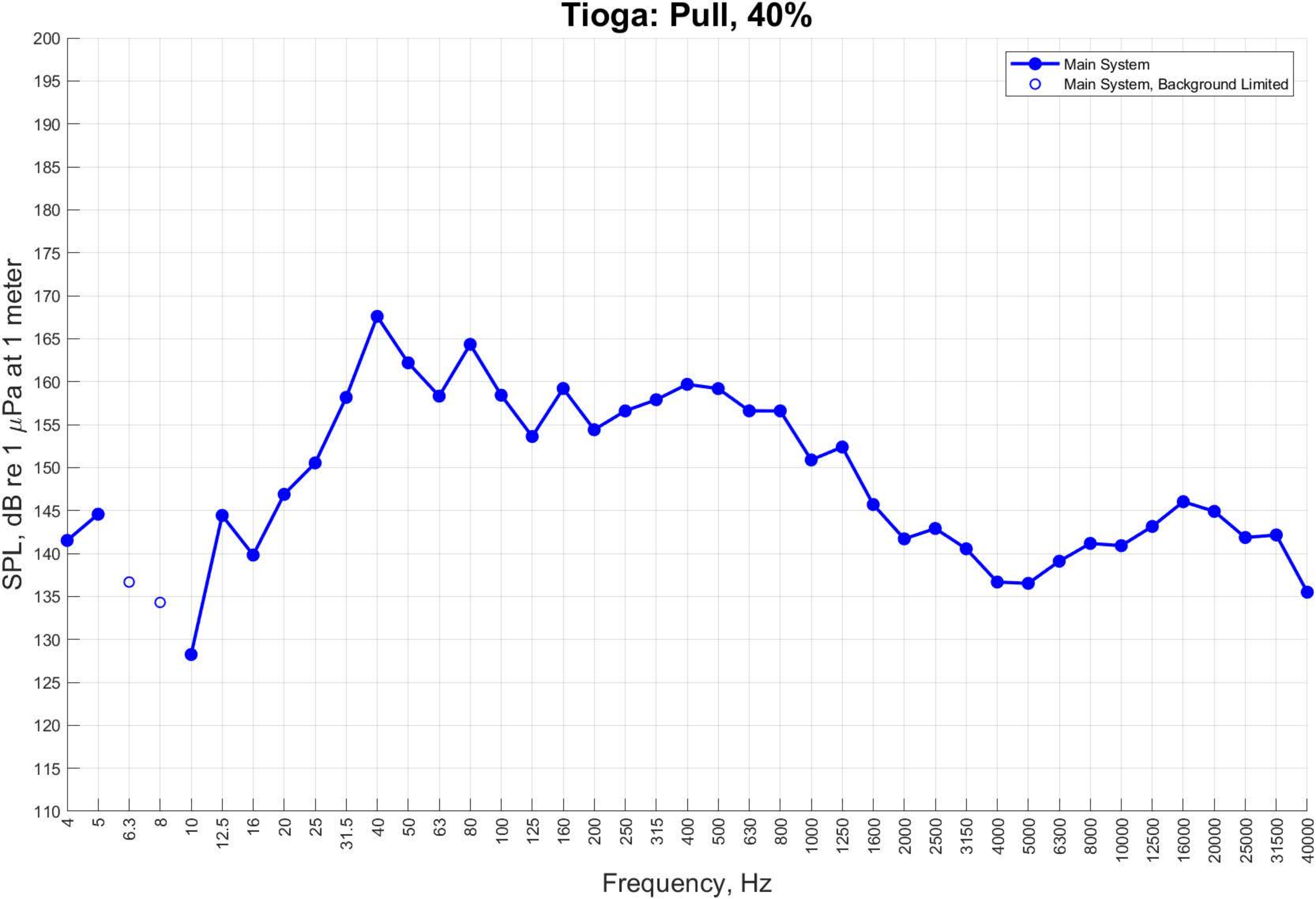
Tioga: Pull, 40%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
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180
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170
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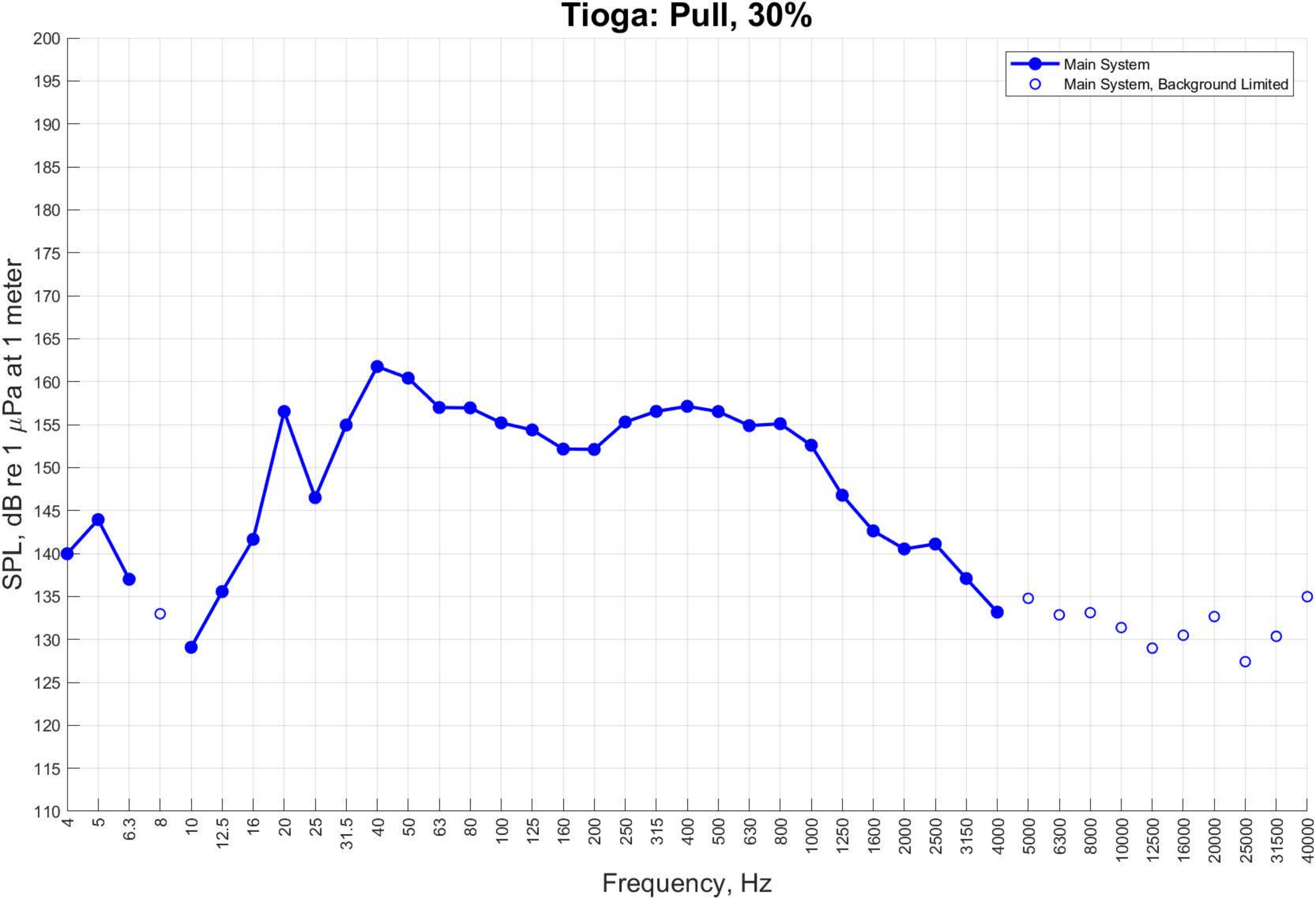

Tioga: Pull, 30%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
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12500
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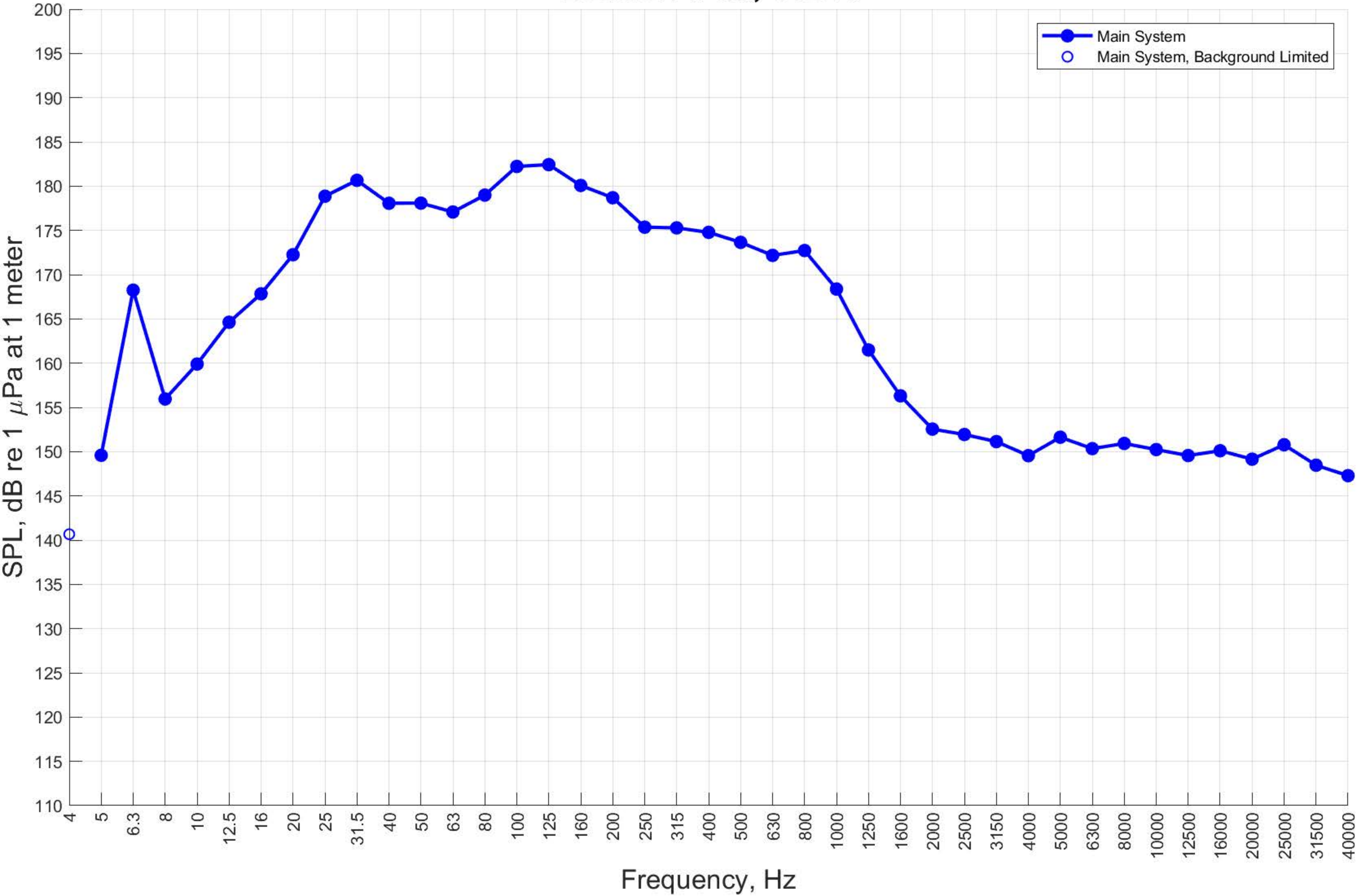
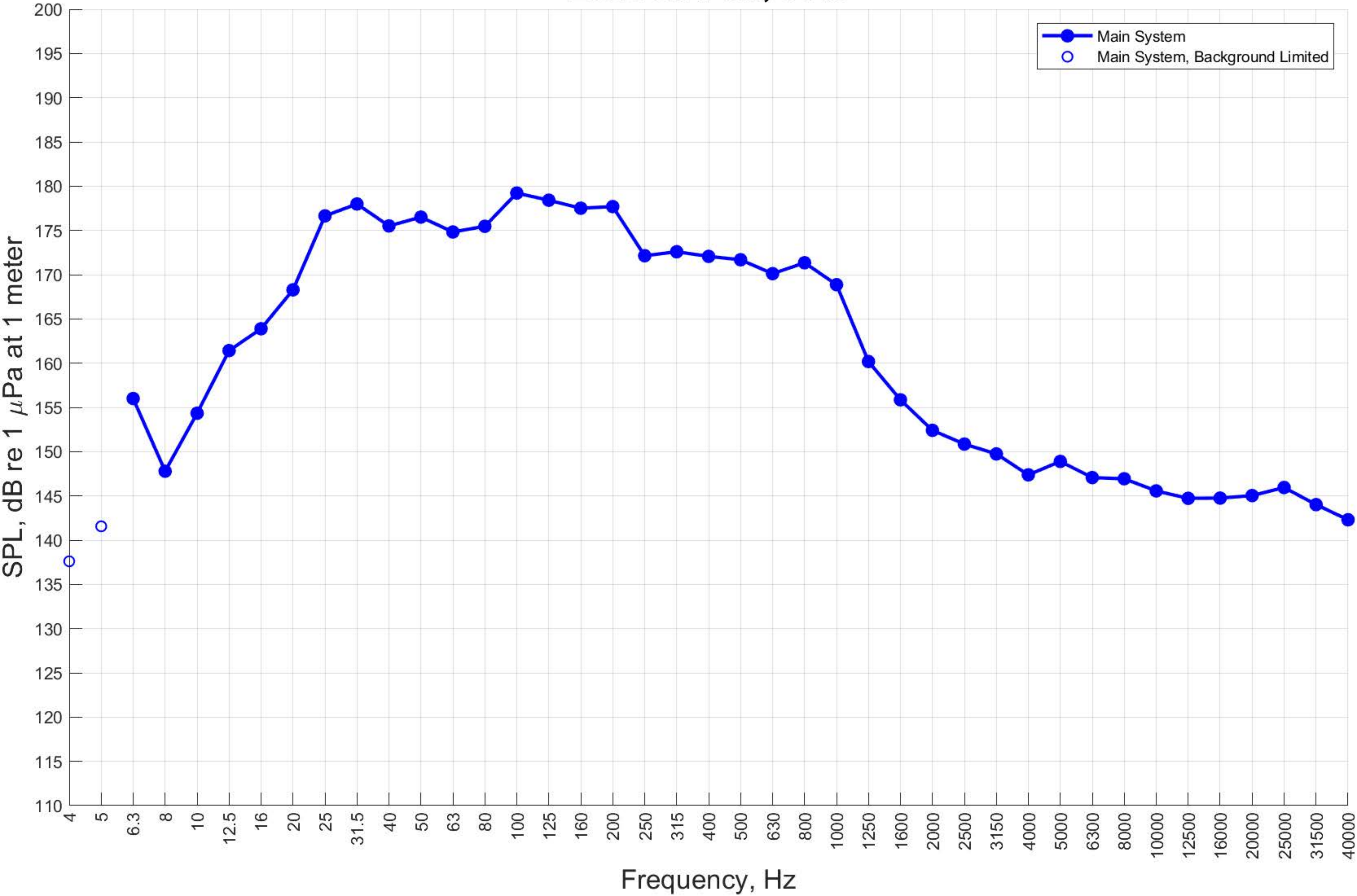
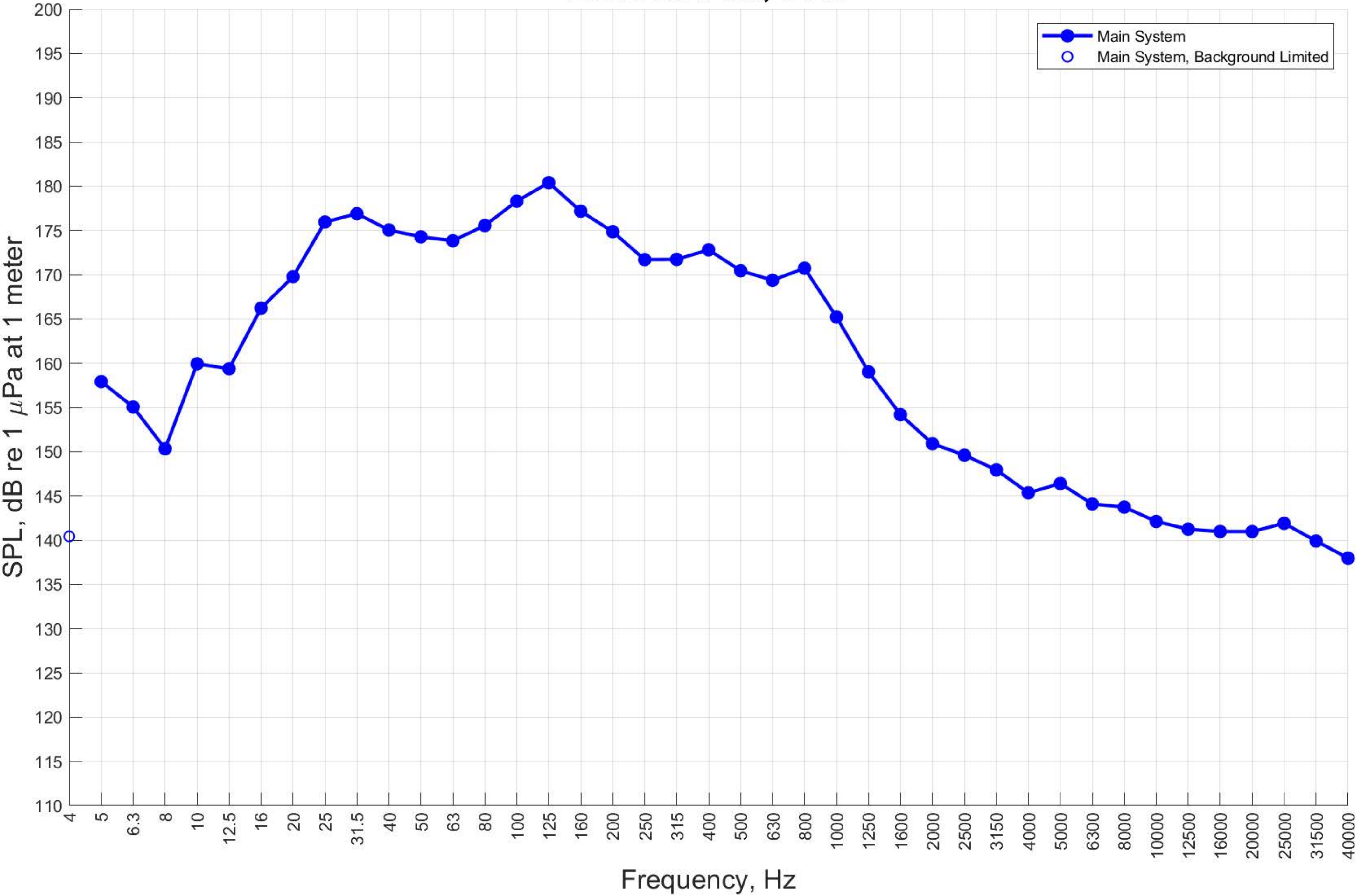
Leader: Pull, 100%

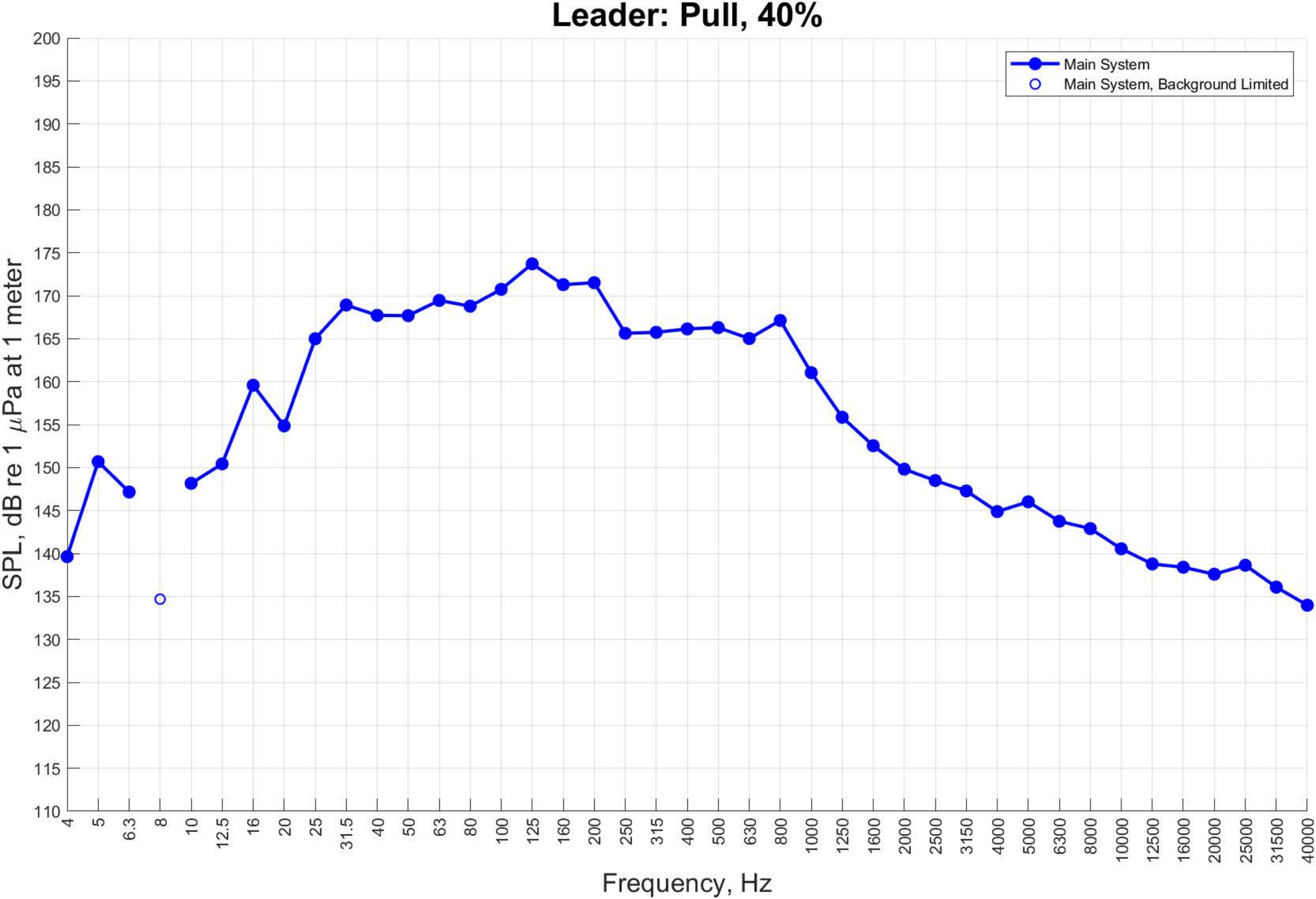


Leader: Pull, 80%



Leader: Pull, 60%




Leader: Pull, 40%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
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170
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160
155
150
145
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12500
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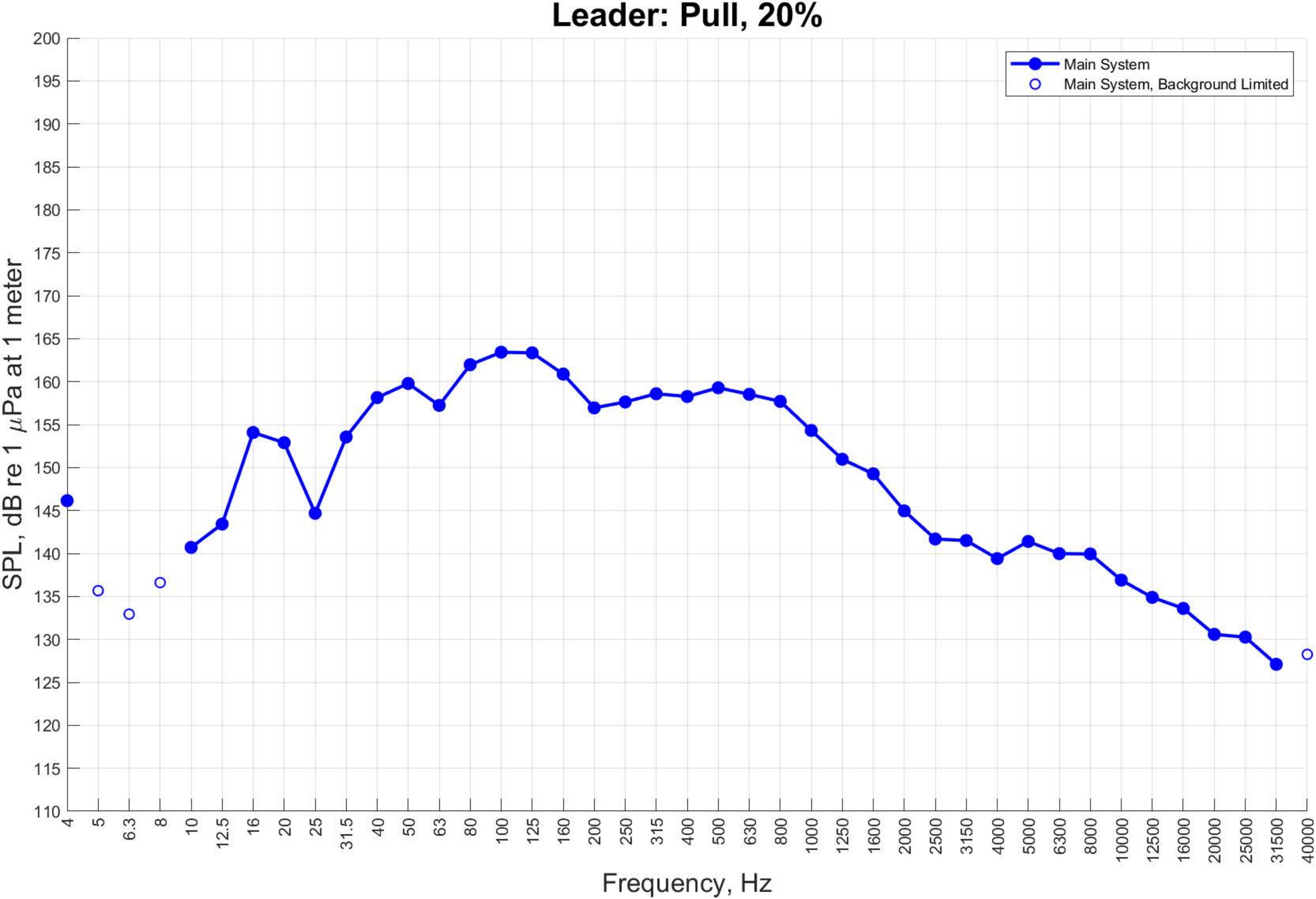
31500
40000


Leader: Pull, 20%
Main System
Main System, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
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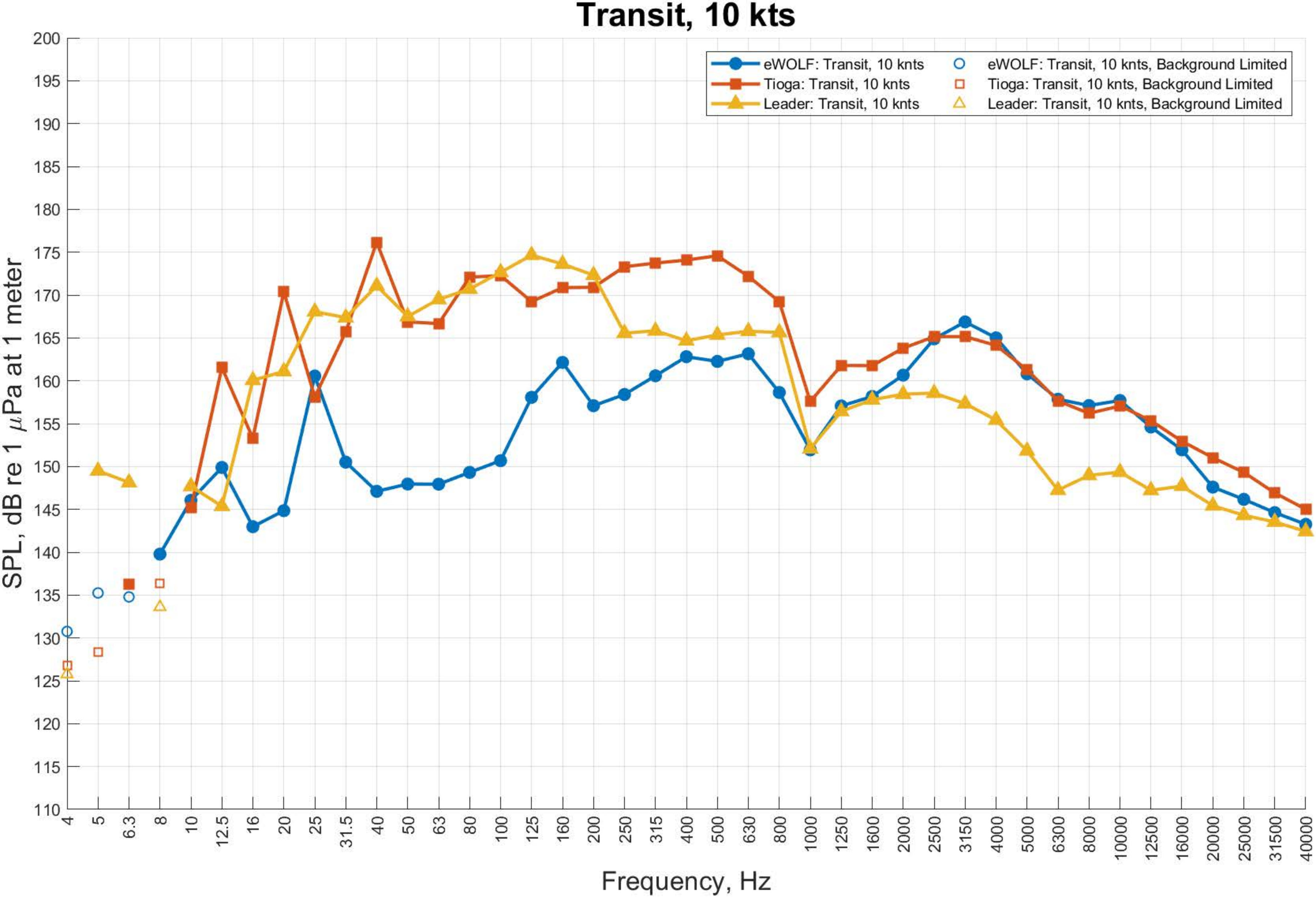
APPENDIX D:

COMPARISON OF ONE-THIRD OCTAVE BAND SOURCE LEVEL SPECTRA BETWEEN VESSELS


Transit, 10 kts
eWOLF: Transit, 10 knts
Tioga: Transit, 10 knts
Leader: Transit, 10 knts
eWOLF: Transit, 10 knts, Background Limited
Tioga: Transit, 10 knts, Background Limited
Leader: Transit, 10 knts, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
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160
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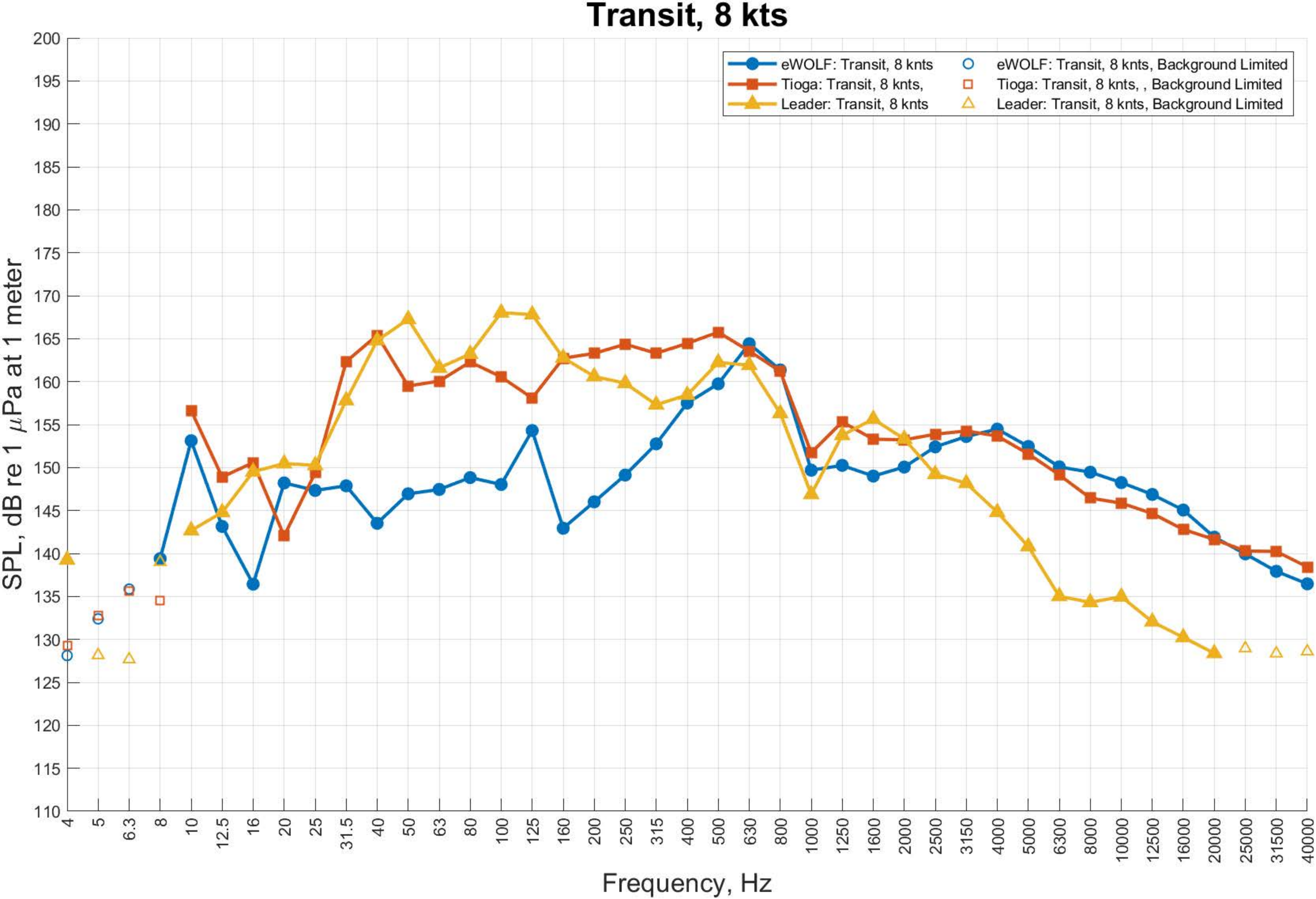

Transit, 8 kts
eWOLF: Transit, 8 knts
Tioga: Transit, 8 knts,
Leader: Transit, 8 knts
eWOLF: Transit, 8 knts, Background Limited
Tioga: Transit, 8 knts, , Background Limited
Leader: Transit, 8 knts, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
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10000
12500
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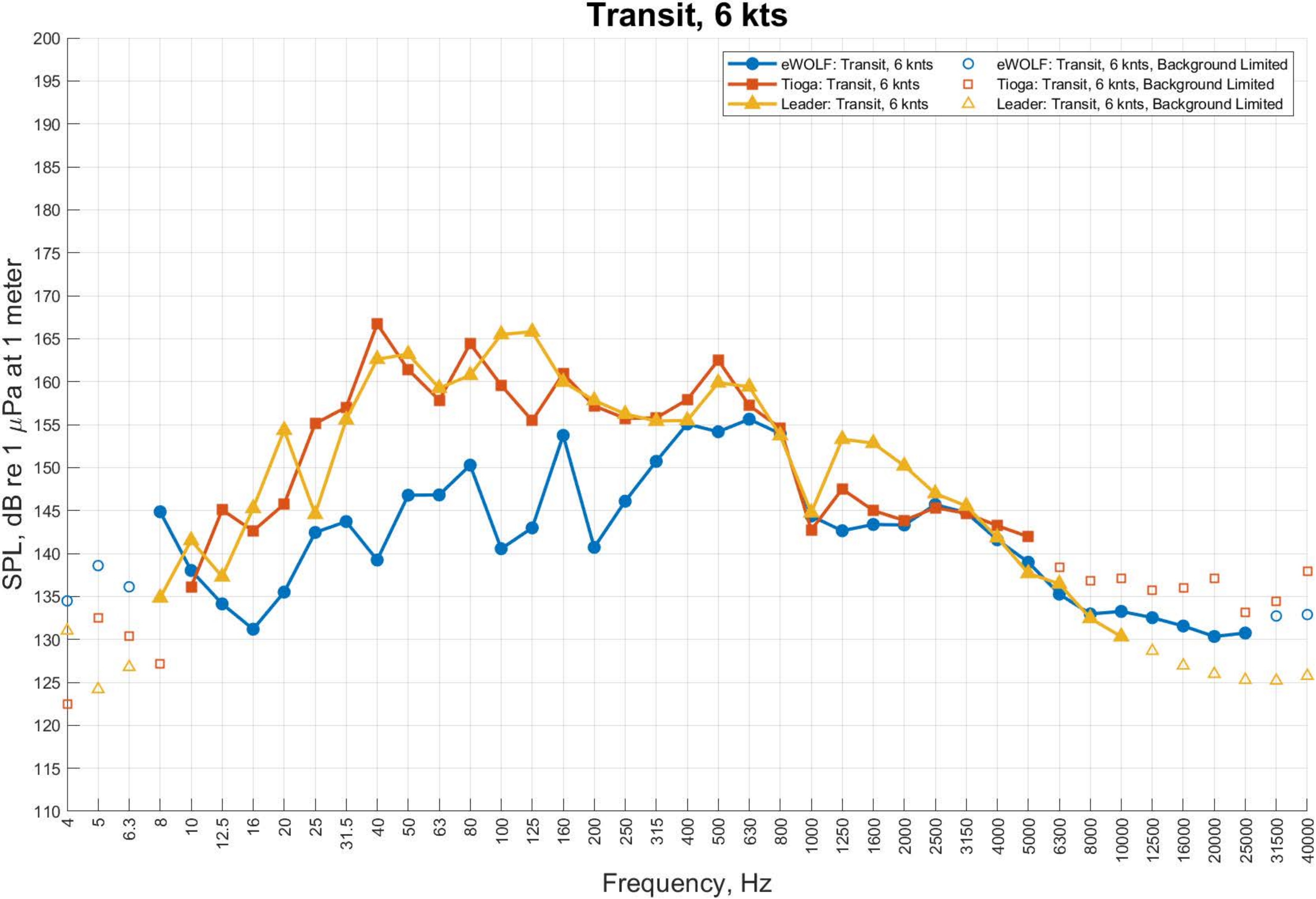
20000
25000
31500
40000
Frequency, Hz


Transit, 6 kts
eWOLF: Transit, 6 knts
Tioga: Transit, 6 knts
Leader: Transit, 6 knts
eWOLF: Transit, 6 knts, Background Limited
Tioga: Transit, 6 knts, Background Limited
Leader: Transit, 6 knts, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
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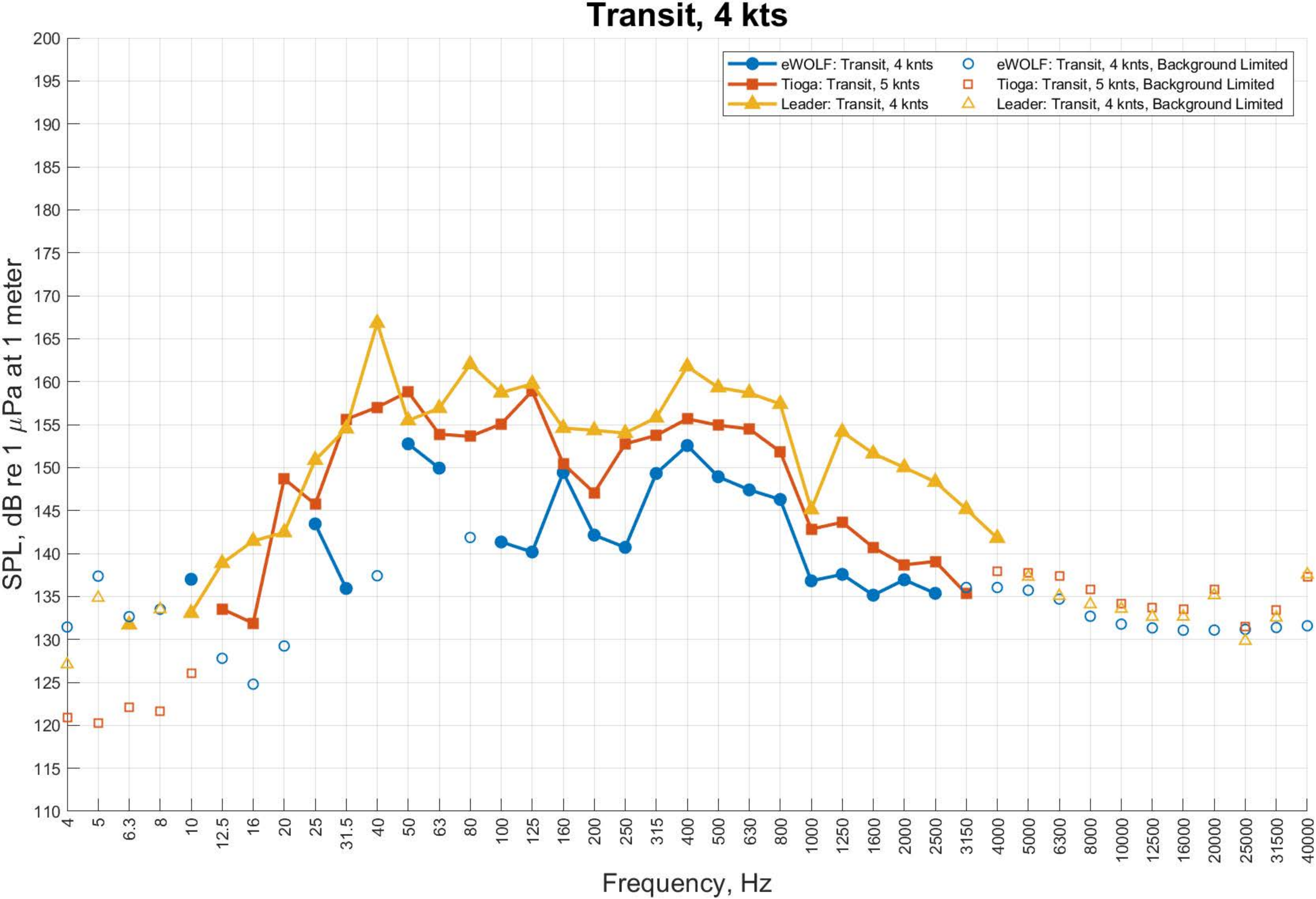

Transit, 4 kts
eWOLF: Transit, 4 knts
Tioga: Transit, 5 knts
Leader: Transit, 4 knts
eWOLF: Transit, 4 knts, Background Limited
Tioga: Transit, 5 knts, Background Limited
Leader: Transit, 4 knts, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
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180
175
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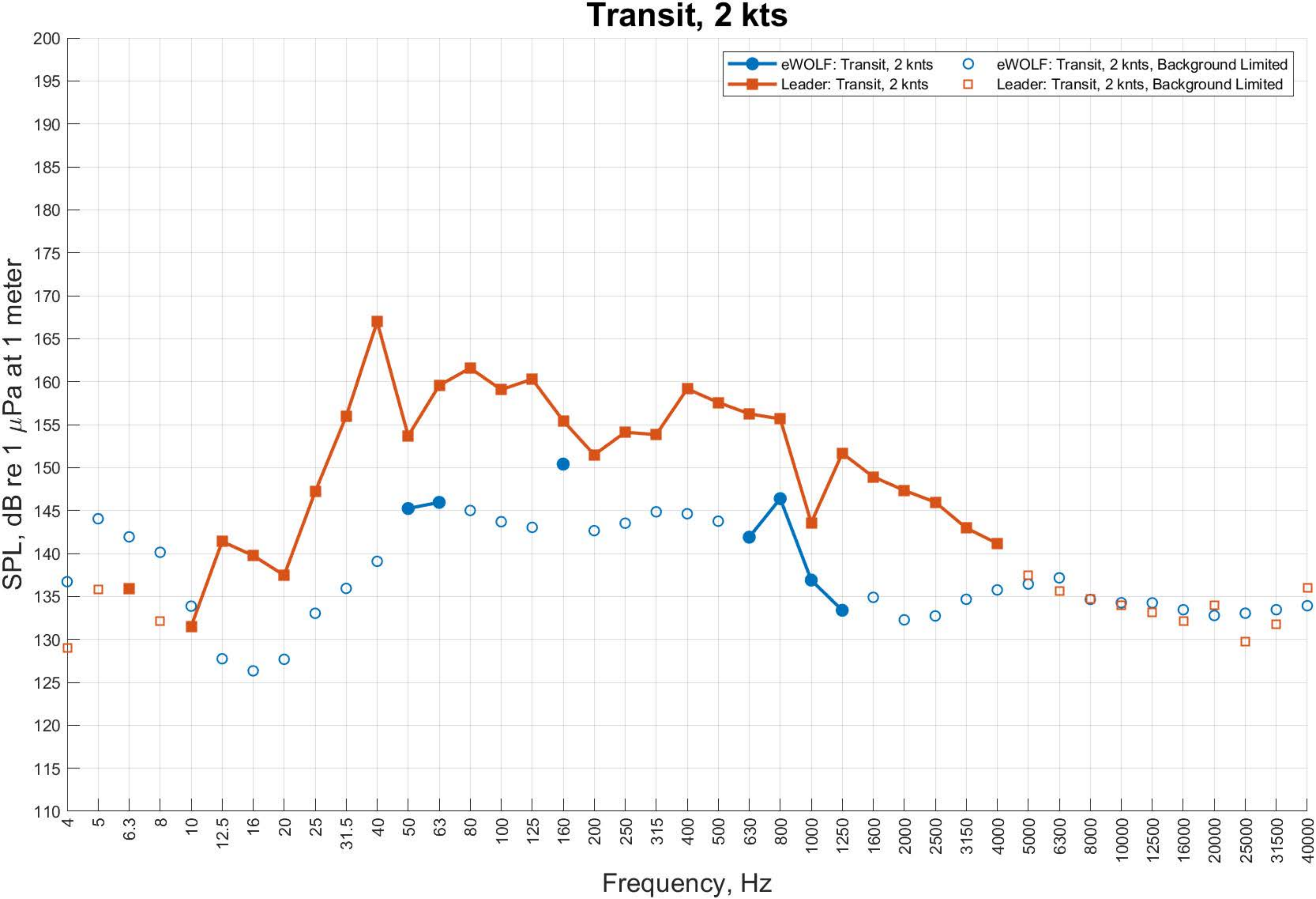

Transit, 2 kts
eWOLF: Transit, 2 knts
Leader: Transit, 2 knts
eWOLF: Transit, 2 knts, Background Limited
Leader: Transit, 2 knts, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
165
160
155
150
145
140
135
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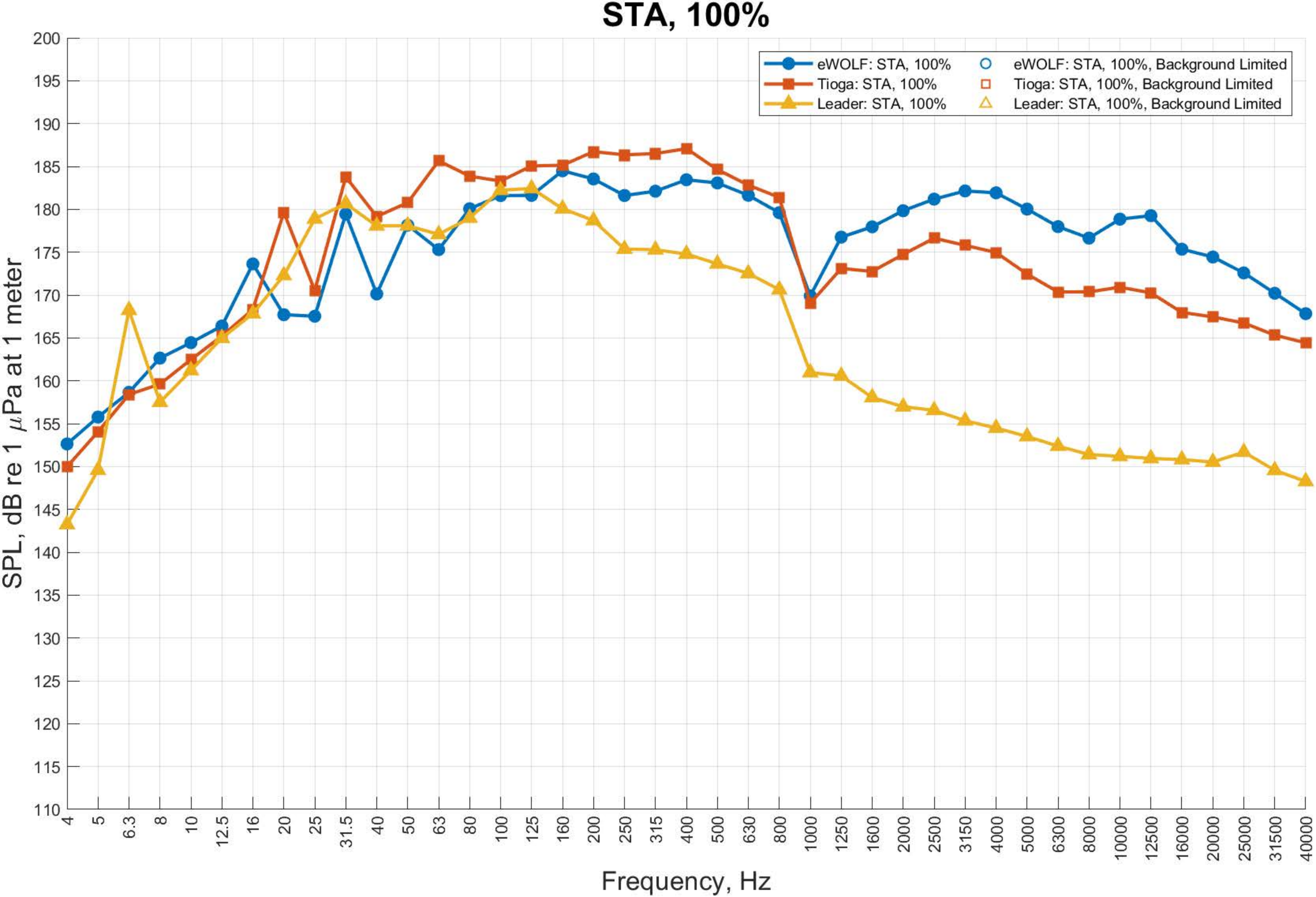
40000



STA, 100%
eWOLF: STA, 100%
Tioga: STA, 100%
Leader: STA, 100%
eWOLF: STA, 100%, Background Limited
Tioga: STA, 100%, Background Limited
Leader: STA, 100%, Background Limited
SPL, dB re 1 μPa at 1 meter
200
195
190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
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3150
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10000
12500
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20000
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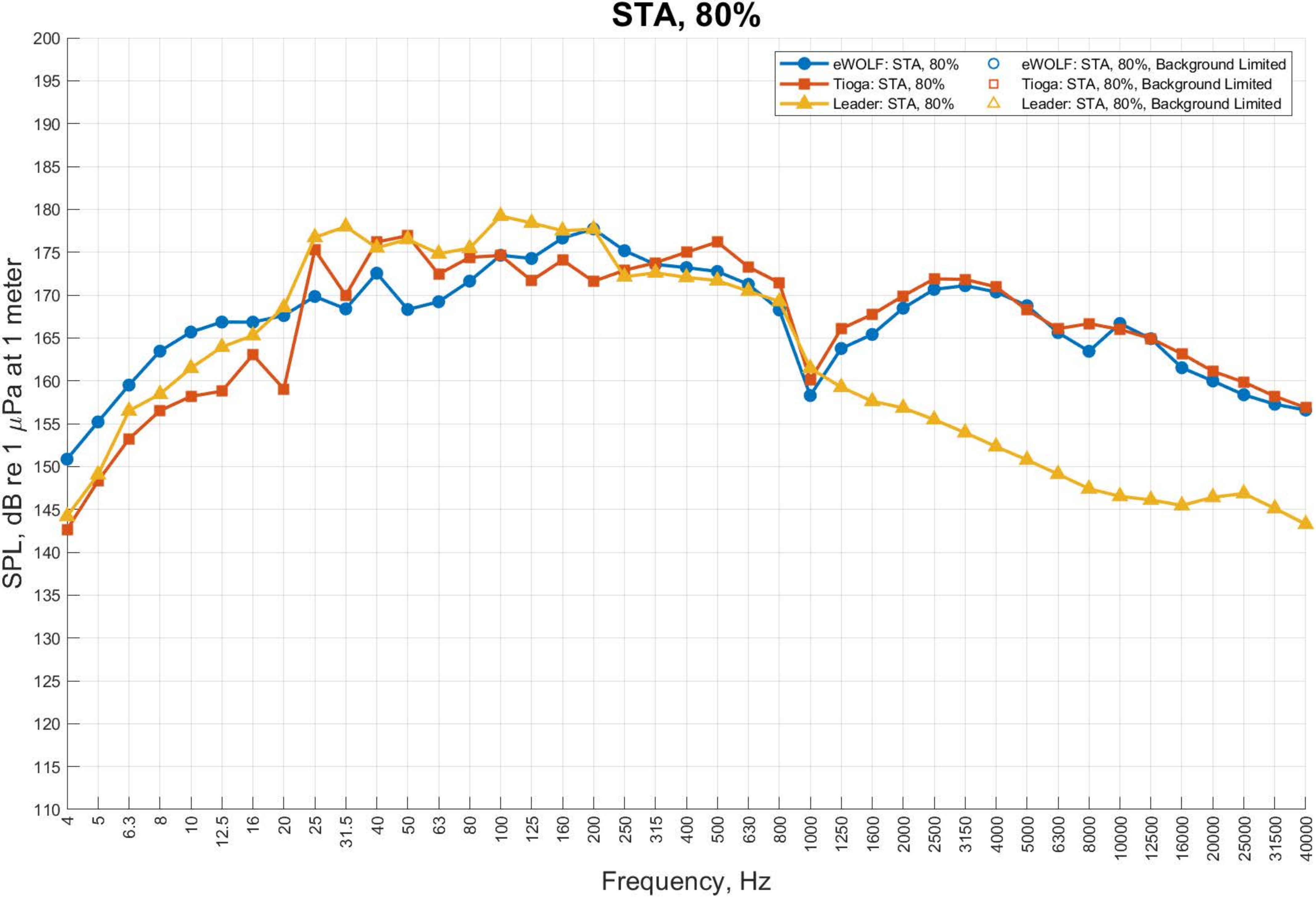
31500
40000
Frequency, Hz


STA, 80%
eWOLF: STA, 80%
Tioga: STA, 80%
Leader: STA, 80%
eWOLF: STA, 80%, Background Limited
Tioga: STA, 80%, Background Limited
Leader: STA, 80%, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
110
115
120
125
130
135
140
145
150
155
160
165
170
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185
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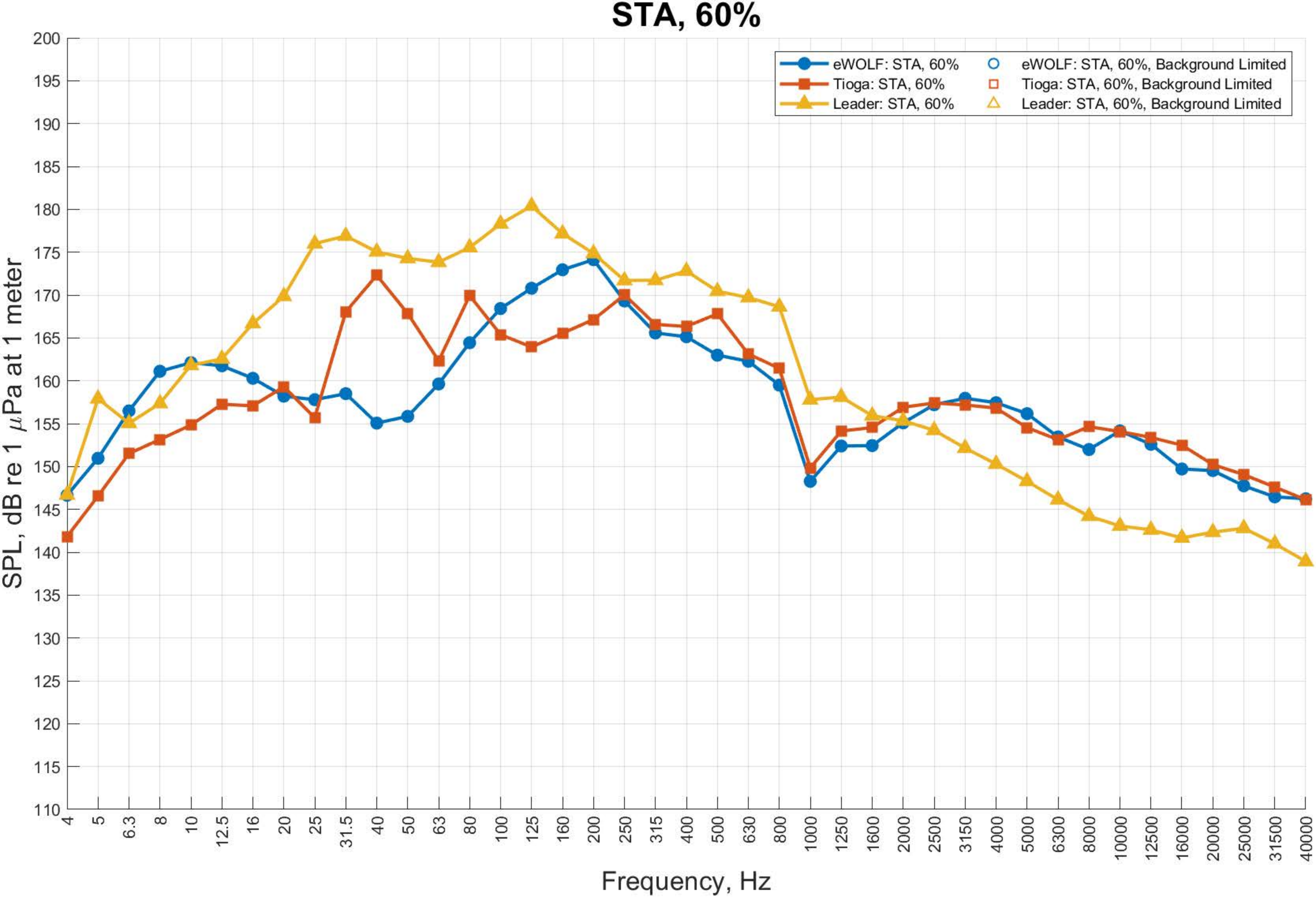

STA, 60%
eWOLF: STA, 60%
Tioga: STA, 60%
Leader: STA, 60%
eWOLF: STA, 60%, Background Limited
Tioga: STA, 60%, Background Limited
Leader: STA, 60%, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
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180
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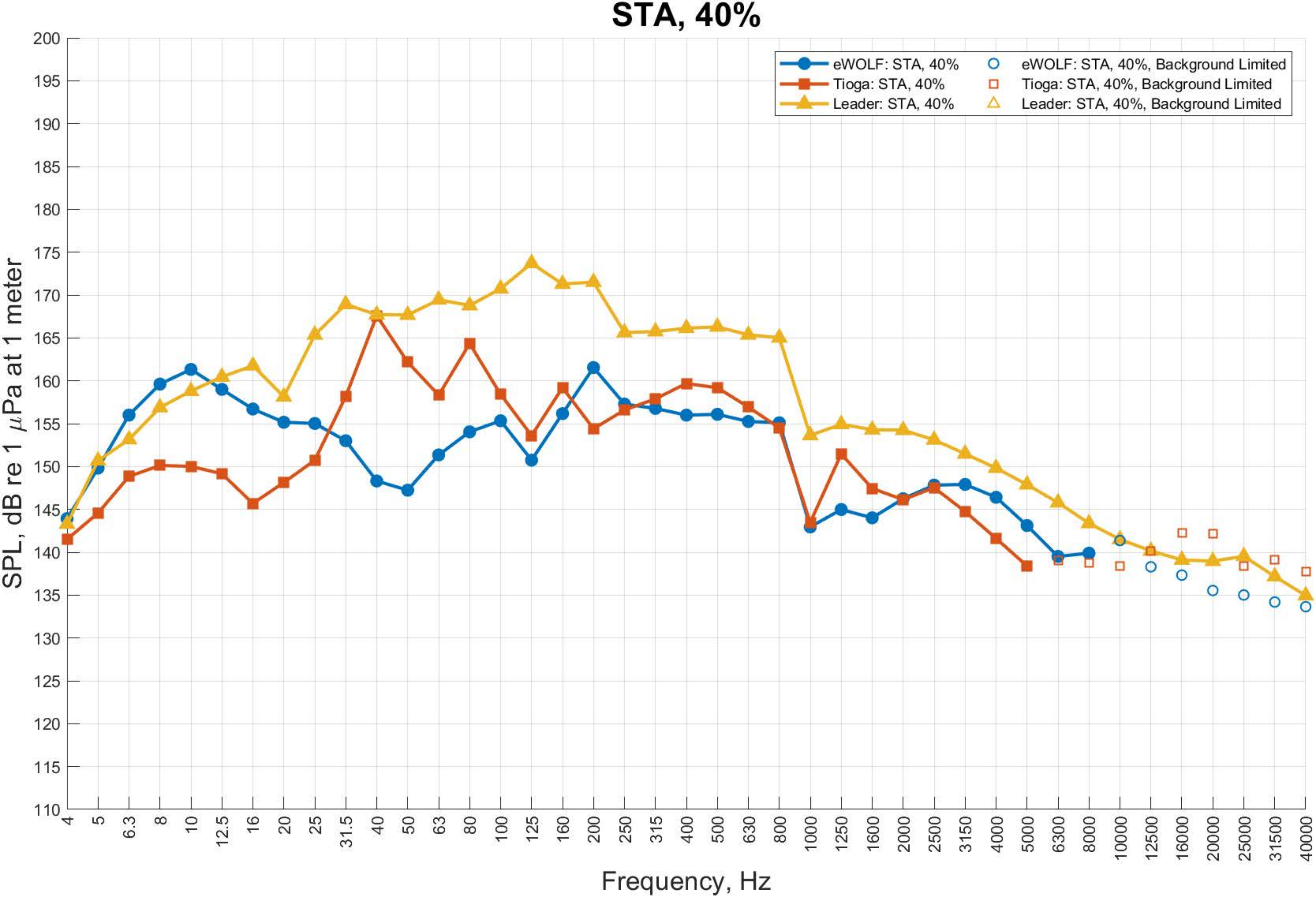
STA, 40%
eWOLF: STA, 40%
Tioga: STA, 40%
Leader: STA, 40%
eWOLF: STA, 40%, Background Limited
Tioga: STA, 40%, Background Limited
Leader: STA, 40%, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
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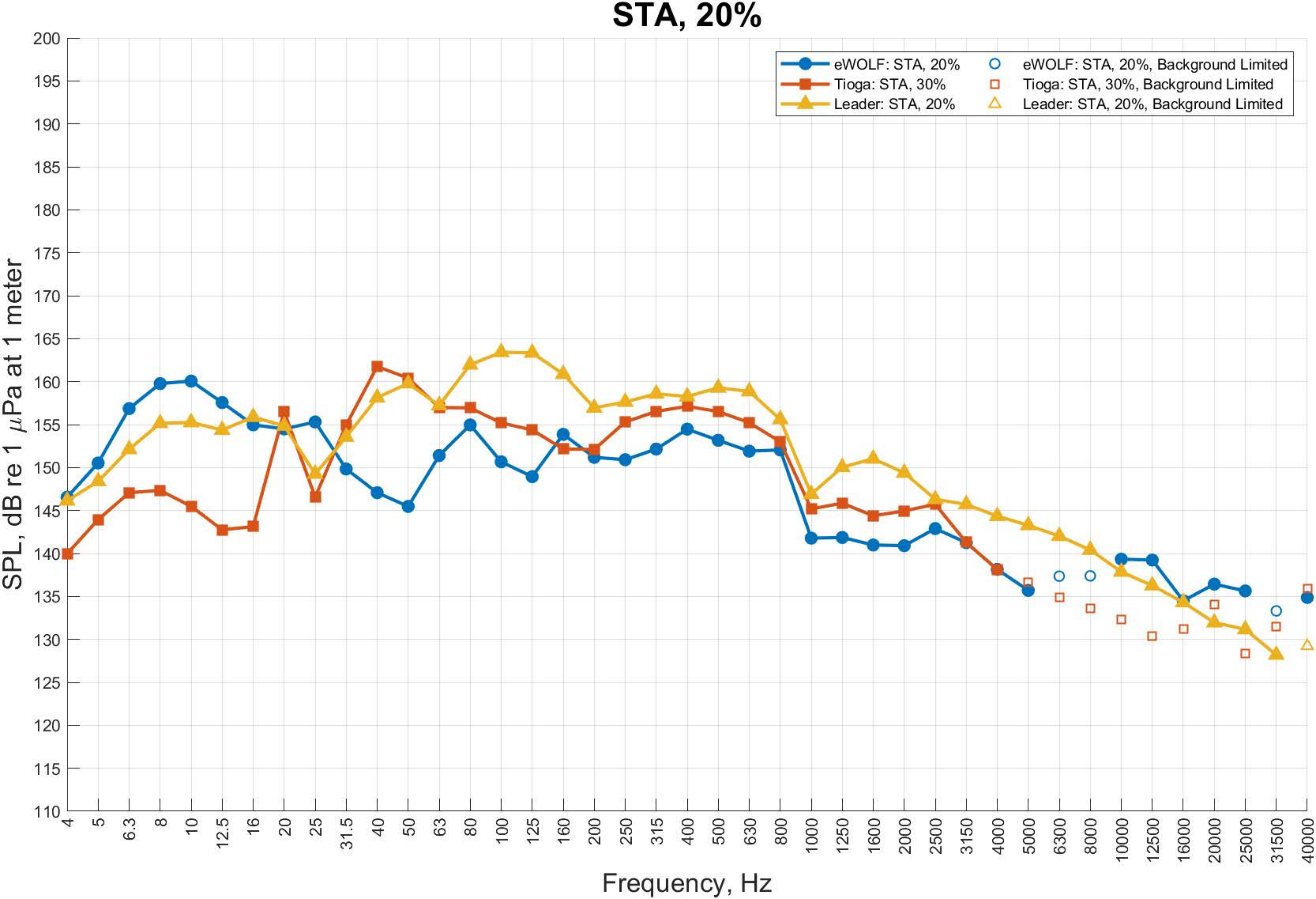

STA, 20%
eWOLF: STA, 20%
Tioga: STA, 30%
Leader: STA, 20%
eWOLF: STA, 20%, Background Limited
Tioga: STA, 30%, Background Limited
Leader: STA, 20%, Background Limited
SPL, dB re 1 μPa at 1 meter
Frequency, Hz
200
195
190
185
180
175
170
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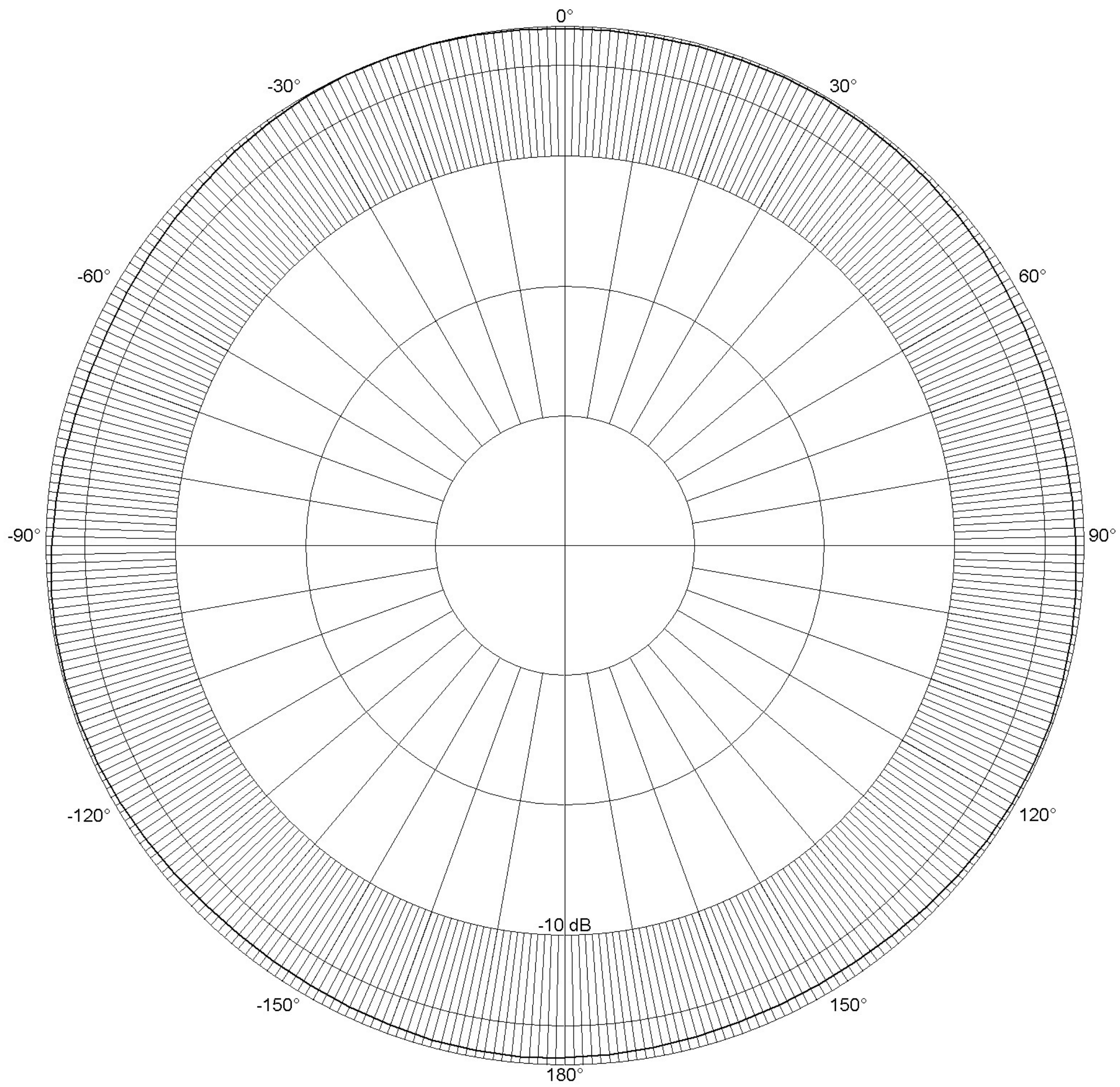
APPENDIX E:

INSTRUMENT CALIBRATION CERTIFICATES

HYDROPHONE DIRECTIVITY

RESON

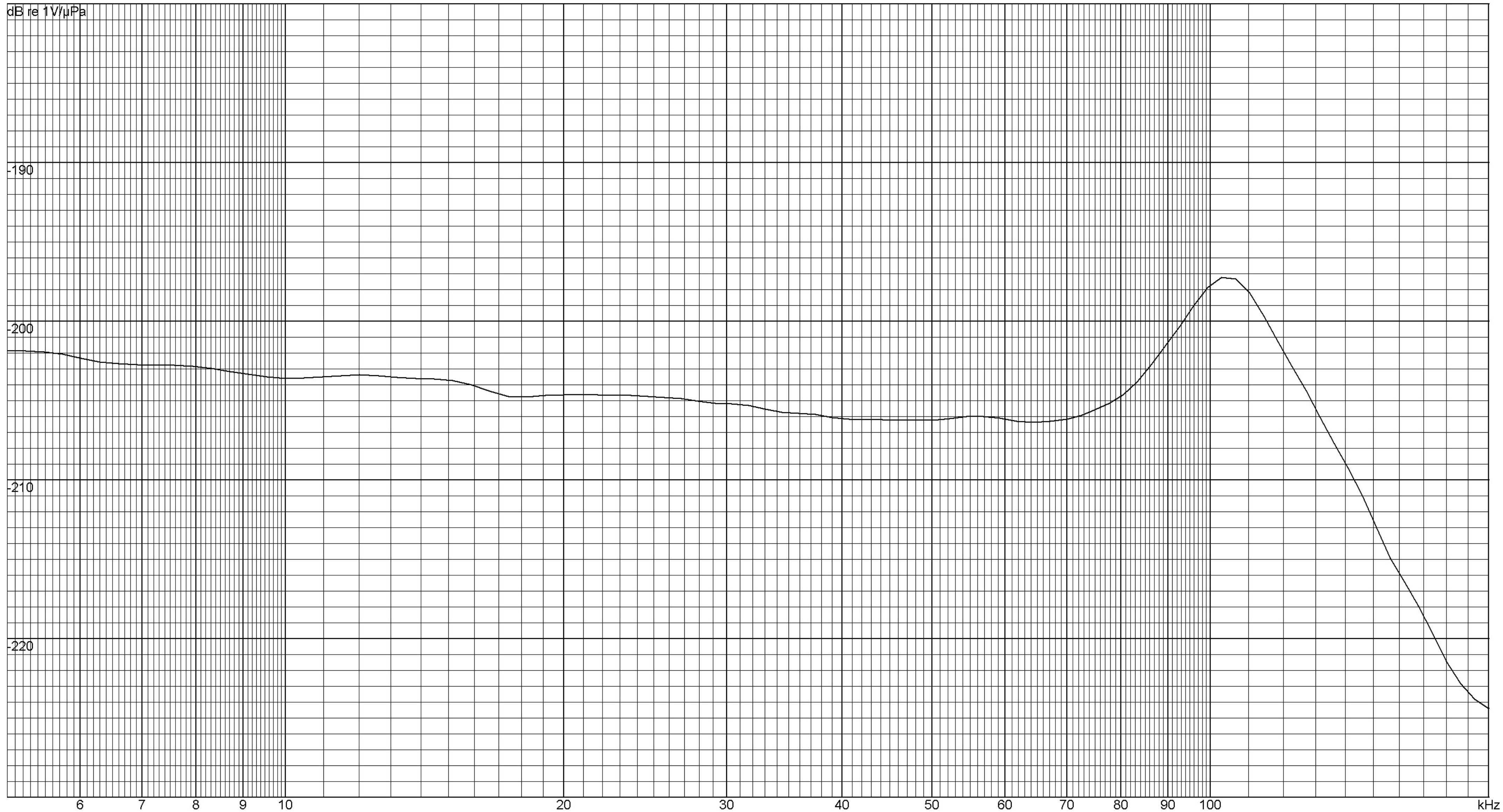
Under Test:	TC4033-1	Amplitude:	9.0 Vrms	Temperature:	19.21°C
S/N:	4715075	Pulse Width:	150.0 µs	Depth:	1.2 m
Reference:	TC4033	Angle:	-180.0° to 180.0°	Distance:	0.65 m
Date:	2024-01-12	Frequency:	100.00 kHz	Tested by:	PRA
Session, Run:	38792, 11				
Max RR:	-196.5 dB re 1µPa/V at 1m				
Comment:	Horizontal.				



HYDROPHONE SENSITIVITY

RESON

Under Test:	TC4033-1	Amplitude:	25.0 Vrms	Temperature:	°C
S/N:	4715075	Pulse Width:	1400.0 µs	Depth:	0.0 m
Reference:		Rep Rate:	66.7 ms	Distance:	0.00 m
Date:	2024-01-12	Averages:	4	Tested by:	PRA
Session, Run:	38792, 12				
Comment:	PHO @ 250 Hz: NA				



HIGH TECH, INC.

21120 Johnson Road
Long Beach, MS 39560

Tel. (228) 868-6632
Fax (228) 868-6645
hightechinc@att.net

785/1/113 Hydrophone Information 01/30/24

Model# HTI-99-HF / 3V / -210dB

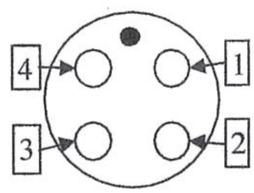
Connector: Subconn MCIL4M/MCDLSF

Cable Length: 2 meters

Connector Pinout

Pin 1	+3.3VDC
Pin 2	3.3VDC Return / Signal Gnd
Pin 3	Signal Output
Pin 4	N/C

Face View



Caution: DO NOT apply voltage to signal output.
This will permanently damage hydrophone.

Test Data

Serial Number	Hydrophone Sensitivity dB re: 1V/uPa	Current mA
785720	-209.9	0.74
785721	-210.6	0.69
AVG	**-210.3**	**0.72**
VAR	**0.2**	**0.00**
STD	**0.5**	**0.04**
MAX	**-209.9**	**0.74**
MIN	**-210.6**	**0.69**
DIF	**0.7**	**0.05**
+/-	**0.35**	**0.025**
Hydrophone Count:	**2**	

Sensitivity was measured using the comparison method
Reference hydrophone = 999902
Measurements traceable to USRD Newport, RI

Hydrophones listed on this page:

- Leaked less than 0.1uA @ 27VDC after 1hr @ 100PSI hydrostatic pressure
- Passed shield integrity test
- Has the same Polarity Response