

The development of robust TWS earphones with premium sound is possible with Knowles' new waterproof balanced armature tweeter. Design, performance, and implementation are discussed.

TWS earphones are by nature intended for use in daily life, exposing them to water in various forms. Audio brands are increasingly applying IP ratings to assure end-users of their robustness. Models with high IP ratings include:

- JBL Reflect Flow IPx7
- Jaybird Vista IP67
- Jabra Elite (Sport and Active 75t) IP67
- Under Armor True Wireless Flash IPx7
- Plantronics BackBeat Fit 3100 IP57

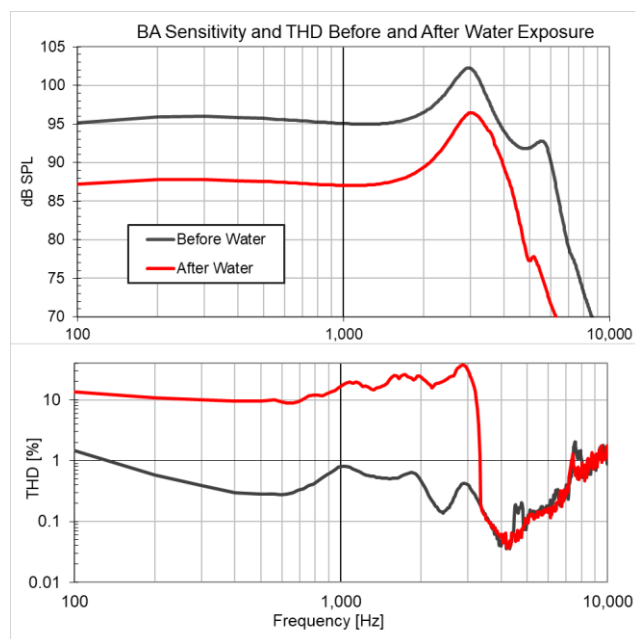
An explanation of IP ratings can be found in Appendix B

The demand for premium sound is increasing, resulting in greater adoption of balanced armature (BA) tweeters in a hybrid configuration. While an ordinary BA tweeter used for hybrids cannot offer meaningful water resistance, Knowles' new waterproof tweeter meets the need for both robustness and fidelity.

Test	Standard BA	Knowles Lifeproof BA
30 Meter Submersion	Fail	100% Pass
Water Thermal Shock	Fail	100% Pass
IPx5 Water Jet	Fail	100% Pass
Soapy Water	Fail	100% Pass
Jacuzzi (Warm Chlorinated)	Marginal Pass	100% Pass
Hard Water	Fail	100% Pass
Condensation	100% Pass	100% Pass
Salt Water	Fail	Pass with water flush

Ordinary BA tweeter robustness

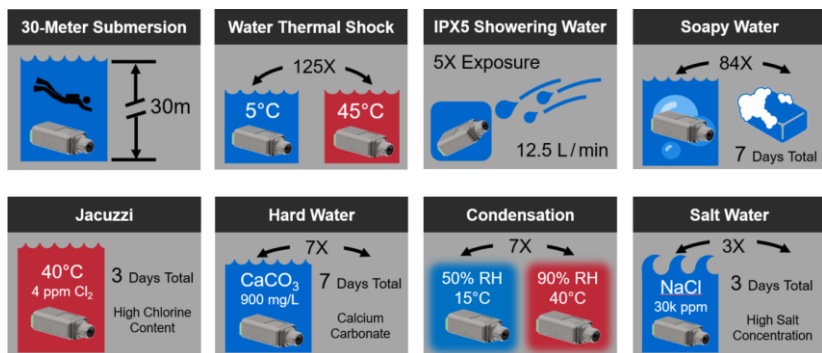
Ordinary BAs tend to fail dramatically after exposure to water, exhibiting a severe loss of sensitivity and increase in THD.



Waterproof tweeter testing and performance

Knowles created specific test methods for eight measures of water exposure robustness. Pass criteria includes the normal test limits for the specific BA model plus two additional limits on allowed change before and after exposure:

- ±3dB max sensitivity change at 500Hz and 1 kHz
- ±3dB max amplitude change at first peak

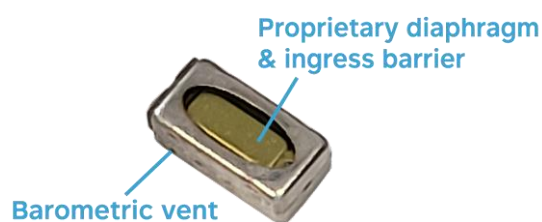


Summary of Knowles test methods for evaluating BA tweeter water resistance. Detailed test procedures are described in Appendix A.

Waterproof tweeter construction

Knowles' first waterproof BA is the new tweeter model WBFK-34053-000. The diaphragm structure utilizes proprietary design features and materials that also serves as an ingress barrier even in extreme situations such as direct spray or deep submersion. The large opening offers two advantages:

- Less constriction in the acoustic path between the diaphragm and ear canal maximizes high frequency output
- Water can drain and dry faster from the large opening

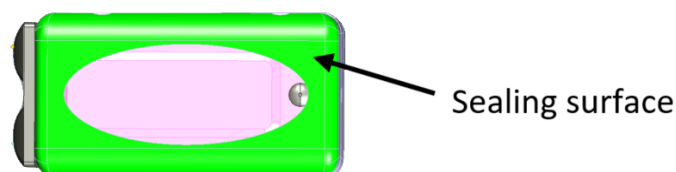


Implementation

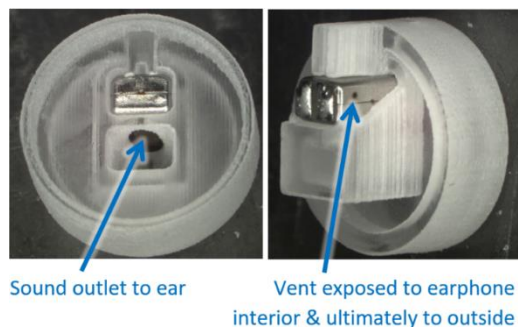
The sound port opening should be fully sealed to the exit tube of the earphone so that water cannot bypass the tweeter.

The seal may be created in several ways:

- Adhesive manually applied
- Die-cut gasket with 2-sided PSA (pressure-sensitive adhesive) rated for water resistance
- Flat rubber gasket in compression



Since the diaphragm is fully sealed, a pressure relief must be provided for the BA back side air volume. This is accomplished with a small vent hole in the case. This vent must ultimately lead to ambient air outside the earphone. (Other venting options are also being considered.)



More information on Knowles balanced armature drivers for hearables & music earphones can be found at www.KnowlesPremiumSound.com

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Appendix A: Test Methods for BA Water Resistance

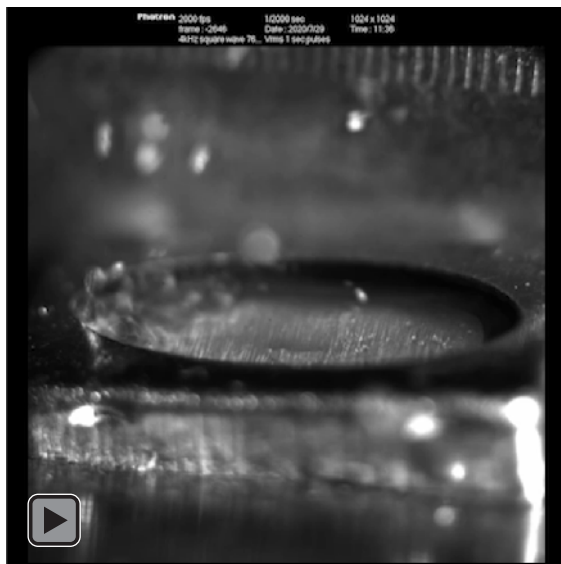
The tests described in this appendix are a combination of those specified by customers and those developed by Knowles. In total, they provide a comprehensive verification of performance in all forms of water exposure one might reasonably expect an earphone to experience in typical outdoor use.

Many of the tests were performed on the balanced armatures themselves. The IPx5 and salt water tests were performed with the BA mounted in earphone housings as being better representative of real-world results. Results in any particular earphone (especially dryout time) will be dependent on the overall mechanical design.

Using acoustic water ejection to speed dryout time.

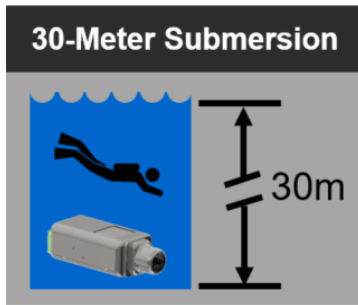
Knowles has demonstrated that water can be ejected from the front volume of the BA using an acoustic signal. The results shown here were obtained by applying a square wave signal of amplitude 700mV and frequency 4.5kHz (the resonant frequency of the tweeter).

A completely full BA facing upward (the worst condition) was substantially emptied after 40s using this method. Results in an earphone will be dependent on the overall mechanical design. Shaking water out of the earphone before signal application is recommended.



Press the Play button to view the video
(8s in the middle of the water ejection)





30 Meter Submersion

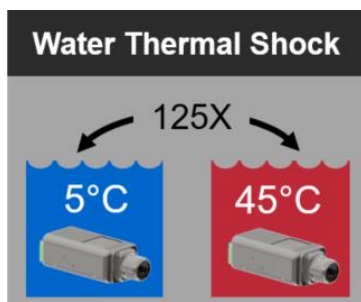
- The BA driver submerged in the equivalent of 30m of room temperature tap water for 10 minutes.
- Test performed at driver component level

Equipment and preparation

- Pressure cooker fitted for compressed air supply, including pressure. Must be rated to handle rated pressure safely
- Beaker to fit within pressure cooker
- Tap water
- Thermometer

Test procedures

1. Perform initial performance measurements.
2. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
3. Submerge units in beaker of water – temperature between 18°C and 25°C.
4. Place beaker into pressure cooker.
5. Raise air pressure gradually over 1 minute to target of 43 psi.
6. Maintain pressure for 10 minutes.
7. Reduce air pressure gradually over 1 minute to ambient.
8. Remove units and remove tape.
9. Dry-out 24 hours 20°C to 25°C, 40 to 60%RH.
10. Measure units subject to criteria above.



Water Thermal Shock ISO 22810

- Driver submerged in 10 cm of tap water cycled 125 times from 45°C to -5°C and back to 40°C.
- Dwell time of 5 minutes at each temperature
- Test performed at driver component level

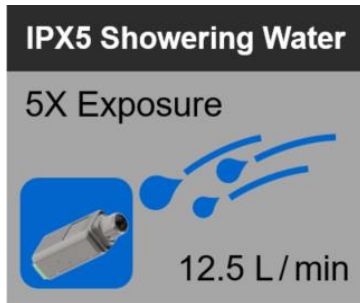
Equipment and preparation

- Poly Science hot and cold chambers
- Drainage hoses
- Drainage bucket, 5 gallon

Test procedures

1. Perform initial performance measurements.
2. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
3. Immerse the receiver (port facing up) in 10cm tap water for 5 minutes at each temperature successively. Transfer time less than 1 minute.
 - a. L₀: 40°C → 20°C → 40°C for 1 cycle.
 - b. L₁: 45°C → 25°C → 45°C for 125 cycles.
 - i. Check points: 25, 50, 75, 100, 125 cycles (dry out before retest at each interval).
4. Remove units and remove tape.
5. Dry-out 24 hours 20°C to 25°C, 40 to 60%RH.
6. Measure units subject to criteria above.





Water Spray IEC-60529-IPX5

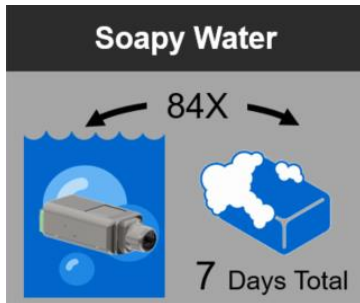
- Water directed at BA within earphone exit tube
- 12.5 litres per minute
- Pressure: 0.5MPa at distance of 3 meters (9.8 ft)
- Nozzle diameter: 6.3mm
- Circle of approximately 40mm dia. at 2.5m distance from nozzle
- Minimum test duration: 3 minutes
- Distance from Nozzle to DUT: 2.5m
- Test performed on driver in simulated earphone housing. Two driver orientations, perpendicular and parallel to sound port.

Equipment and preparation

- Nozzle/flow and setup validated for IPx5 above

Test procedures

1. Perform initial performance measurements.
2. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
3. IPx5 exposure.
4. Remove and dry-out 48 hours 20°C to 25°C, 40 to 60%RH.
5. Remove tape.
6. Measure units subject to criteria above.
7. Repeat test 7 times.



Warm Soapy Water

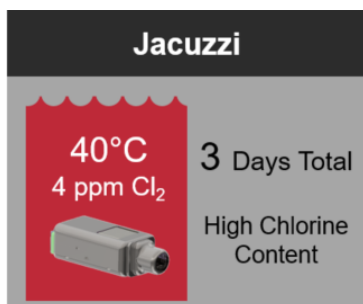
- Soapy water at temperature 38°C.
- 12 cycles of immersion and rinse, followed by 24 hour dwell, then acoustic test.
- Repeat exposure 5 times.
- Test performed at driver component level

Equipment and preparation

- Water immersion tube with heating element
- 1,349 ml (45.6 fluid ounces) of Method Gel Hand Soap with fragrance Sweet Water (available at Target in USA)
- DI water
- Submersion fixture

Test procedures

1. Perform initial performance measurements.
2. Prepare soapy solution in bucket (5400 ml total).
 - a. Place 1,349 ml of Method Sweet Water Soap in a bucket.
 - b. Next add 4,052 ml of distilled water. Mix solution well to make sure the soap is evenly distributed in the distilled water. (25% soap solution).
3. Pour soapy water solution into the heated submersion tube.
4. Adjust the heater to maintain 38°C temperature.
5. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
6. Immerse to 25cm +/-2cm, duration 30 seconds.
7. Tap water rinse, duration 30 seconds.
8. Repeat 6-7 12 cycles.
9. Dry using dry towel.
10. Dry-out 24 hours 20°C to 25°C, 40 to 60%RH.
11. Remove tape.
12. Measure units subject to criteria above.
13. Repeat steps 5 through 12 a total of 5 times.



Hot Tub (Jacuzzi)

- Submerge in 100cm of 40°C Jacuzzi water (chlorinated) for 10 minutes followed by 24 hour dwell, then acoustic test.
- Repeat exposure/dwell/test 3 times.
- Test performed at driver component level

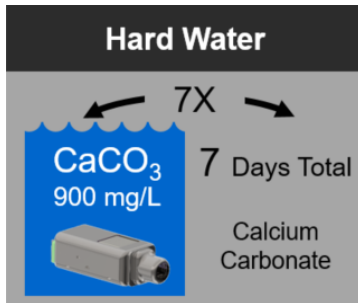
Equipment and preparation

- Heated submersion tube with extension tube
- AquaChek Chlorine meter and strips
- DI water
- Sodium Hypochlorate Solution, 2.5%
- Submersion fixture
- Prepare chlorinated solution in bucket
 - Use the meter to read Cl level, 3-5ppm is acceptable with 4ppm as target.
 - Stir in chlorine and wait 0.5 hours before dipping strip for measurement
 - Amount of Sodium Hypochlorite Solution needed is dependent on cleanliness of equipment, UV rays, initial tap water, and other factors. Use pipette to dispense 200uL of Sodium Hypochlorite Solution.
 - Pour chlorinated water into heated submersion tube and then verify Cl levels.
 - Typically will measure 0.5 to 1 ppm lower than in the bucket.
 - Solution must maintain 40°C for test. Heater Dial set to approximately 6.5, than adjust the dial to achieve temperature within +/- 5°C.
- Place components so that the port is facing up in the submersion fixture.

Test procedures

1. Perform initial performance measurements.
2. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
3. Lower the components in submersion fixture to the specified depth of 100cm.
4. Allow components to dwell 10 minutes at depth.
5. Slowly remove fixture from water.
6. Orient the components so that the fluid can drain from the ports onto a lint-free cloth.
7. 24 hour dwell at 20 to 25°C and 40 to 60%RH.
8. Repeat steps 3-7 a total of 3 times.
9. Remove tape.
10. Measure units subject to criteria above.





Hard Water

- Submerge in 25cm of room temperature hard water (dissolved salt, baking soda, calcium chloride) for 30 seconds, followed by 24 hour dwell, and then acoustic test
- Repeat exposure/dwell/test 7 times
- Test performed at driver component level

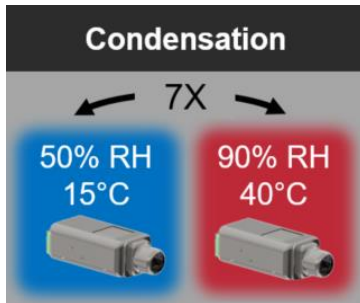
Equipment and preparation

- Heated submersion tube with extension tube
- 1000 ml beaker
- 500mg TUMS
- DI water 5400ml
- Submersion fixture
- Prepare 5400ml precipitation solution.
 - Crush TUMS, 10 tablets.
 - Mix TUMS with 5400ml DI water until dissolved.
- Add solution to tube, no heat required.

Test procedures

1. Perform initial performance measurements.
2. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
3. Place components in the submersion fixture with the ports facing up.
4. Lower the submersion fixture to the depth of 9.8 inches or 0.25 m.
5. Allow the components to dwell at the specified depth for 30 seconds.
6. Slowly remove the submersion fixture from the water solution.
7. Remove components from the submersion fixture and orient the components so the port is facing down to allow water to drain from the port and dwell for 24 hrs in 25°C and 40 to 60%RH.
8. Repeat steps 3-7 for 7 cycles.
9. After the seventh cycle remove the tape.
10. Measure units subject to criteria above.





Condensation

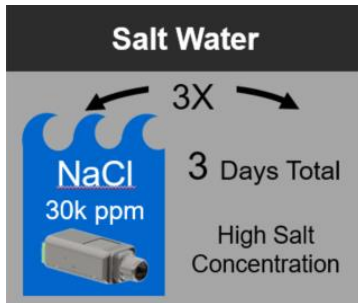
- Expose driver to 40°C / 90%RH for 15 minutes
- Move to 15°C / 60%RH
- Perform acoustic test, dwell 24 hours
- Repeat exposure/dwell/test 7 times
- Test performed at driver component level

Equipment and preparation

- Heat and humidity chambers

Test procedures

1. Perform initial performance measurements.
2. Cover vent and/or cup/cover seam with 3M 853 (low residue) tape.
3. Place units in chamber at 15°C, 40 - 60%RH, dwell 15 minutes.
4. Remove the components from the lower temperature chamber and place into 2nd chamber at 40°C, 90%RH for 15 minutes with transfer time of less than 1 minute.
5. Place components in the low temperature chamber for 15 minutes with transfer time of less than 1 minute.
6. Remove components from chamber and dry with cloth.
7. Dwell 24 hours 20 to 25°C and 40 to 60%RH.
8. Repeat steps 3-7 for 7 cycles.
9. After the seventh cycle, remove the tape.
10. Measure units subject to criteria above.



Salt Water

- The BA driver submerged in the equivalent of 30m of room temperature 36,000ppm salt concentration water for 10 minutes
- Water pressure ramped up and down gradually to avoid impact effects
- Flush port with fresh water after exposure to remove crystals
- Test performed on driver in simulated earphone housing. Two driver orientations, perpendicular and parallel to sound port.

Equipment and preparation

- 1000ml beaker
- Table salt (example Morton Culinox 999 Salt)
- Submersion Fixture
- Extech EC210 salinity meter
- Test samples in simulated earphone housing
- Prepare salt solution up to 1000 ml batches (5400 ml total) Place 35 g of salt in the 1000 ml beaker and then add distilled water until water level is at 1000 ml. Mix solution well to make sure the salt is evenly distributed in the distilled water. (36,000 ppm±500 ppm)
- Place the receiver components in the submersion fixture so that the port is facing up.

Test procedures

1. Perform initial performance measurements.
2. Lower the submersion fixture to the depth of 9.8 inches or 0.25 m.
3. Allow the components to dwell at the specified depth for 30 seconds.
4. Slowly remove the submersion fixture from the salt water solution, then remove components and orient so the port is facing down to allow water to drain from the port. Dwell 24 hrs 20 to 25°C, 40 to 60% RH.
 - a. Thoroughly rinse the submersion basket after each salt water exposure, approximately 30 seconds.
5. After the 24 hours room ambient dwell, thoroughly rinse the components in tap water.
6. Repeat steps 2 through 5 for a total of 5 cycles.
7. Remove the tape.
8. Measure units subject to criteria above.



Appendix B: IP Ratings for Water Ingress

IP_{yz} **y** Ingress rating for solids
 z Ingress rating for water

For example **IP67**

A product is sometimes rated for water ingress only. In that case an “x” is often used as a placeholder for the solid rating, for example IPx7. The table below describes the tests for various levels of water ingress protection.

Level	Protected against	Testing for water ingress level	Details
0	Not protected	—	—
1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect.	Test duration: 10 minutes Water equivalent to 1 mm rainfall per minute
2	Dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle up to 15° from its normal position.	Test duration: 10 minutes Water equivalent to 3 mm rainfall per minute
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect.	Test duration: 5 minutes Water volume: 0.7 litres per minute Pressure: 80–100 kPa
4	Splashing of water	Water splashing against the enclosure from any direction shall have no harmful effect.	Test duration: 5 minutes Water volume: 10 litres per minute Pressure: 80–100 kPa
5	Water jets	Water projected by a nozzle (6.3 mm) against enclosure from any direction shall have no harmful effects.	Test duration: at least 3 minutes Water volume: 12.5 litres per minute Pressure: 30 kPa at distance of 3 m
6	Powerful water jets	Water projected in powerful jets (12.5 mm nozzle) against the enclosure from any direction shall have no harmful effects.	Test duration: at least 3 minutes Water volume: 100 litres per minute Pressure: 100 kPa at distance of 3 m
7	Immersion up to 1 m	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).	Test duration: 30 minutes Immersion at depth of at least 1 m measured at bottom of device, and at least 15 cm measured at top of device
8	Immersion beyond 1 m	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. Normally, this will mean that the equipment is hermetically sealed. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects.	Test duration: continuous Immersion in water Depth specified by manufacturer

