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I. Converting from "EOC" Sensitivity to Amplifier-loaded Sensitivity

HMA and HMB hydrophones are sold with a standard 1-20 MHz calibration into a 50-ohm load. HGL, HNP (formerly HNV), HNC (formerly HNZ), and HNR hydrophones are modular—i.e., they allow the user to choose different amplifiers or no amplifier at all. Because a hydrophone's sensitivity depends on the electrical impedance of the detector or amplifier it is attached to, modular hydrophones are sold with an open-circuit calibration, called formally the "End-of-cable Open Circuit Sensitivity", or EOC sensitivity for short, and designated as $M_c(f)$ [1,2]. $M_c(f)$ is determined by measuring the sensitivity of the hydrophone with a laboratory amplifier, and then subtracting the effect of that amplifier's gain, as well as that of its finite (i.e., non-infinite load). Note that the HGL, HNP, and HNC hydrophones may be connected directly to an amplifier without any cable, so the EOC sensitivity is defined as the sensitivity that would be measured at the hydrophone's connector into an infinite load.

Of course, actual hydrophone usage is made with the customer's choice of amplifier and/or other form of detector. In such cases, the customer may calculate the effect of the amplifier/detector configuration on the hydrophone sensitivity, by mathematically combining hydrophone calibration data and amplifier data, as described below:

Obtaining amplifier-loaded sensitivity from EOC data

The sensitivity of the hydrophone/preamp combination ($M_L(f)$) can be determined using the following formula [1]:

$$M_L(f) = G(f) M_c(f) \left[\frac{\mathrm{Re}(Z_A)^2 + \mathrm{Im}(Z_A)^2}{\{\mathrm{Re}(Z_A) + \mathrm{Re}(Z_H)\}^2 + \{\mathrm{Im}(Z_A) + \mathrm{Im}(Z_H)\}^2} \right]^{1/2} \quad (1)$$

where

$G(f) =$ amplifier gain (as a function of frequency)
$Z_A =$ input impedance of amplifier
$Z_H =$ impedance of hydrophone
$\mathrm{Re}(Z)$ indicates the real part of a complex number Z

$\mathrm{Im}(Z)$ indicates the imaginary part of a complex number Z

If the hydrophone and amplifier impedances are primarily capacitive (as is the case with all Onda hydrophones and amplifiers), Eq. (1) can be approximated:

$$M_L(f) = G(f)\, M_c(f)\, \frac{C_H}{C_H + C_A} \tag{2a}$$

where C_A and C_H and are the capacitance of the amplifier and hydrophone , respectively. C_H is provided with the EOC calibration data shipped with each modular hydrophone. Onda provides C_A with the calibration sheets for all AH2010 and AH2020 amplifiers, and can be purchased for an additional price for other Onda amplifiers.

Note that in some cases, adaptors or short cables may be used between the hydrophone connector and the amplifier. This additional connection length may have an effect which can be approximated by a connection capacitance, designated C_C, which can be accounted for by the following modification to Eq. (2):

$$M_L(f) = G(f)\, M_c(f)\, \frac{C_H}{C_H + C_C + C_A} \tag{2b}$$

A common example of such a connector is the right angle SMA connector (Onda part number AR-AMAF) which is used to connect an Onda HGL hydrophone to an AH2010 or AH2020 in a right-angle configuration; C_C *= 1.6 pF for this case.*

Note: Customers are advised to perform their own assessment of the accuracy of Eqs. (2a-b) for their configuration. In particular, customers should be aware that extension cables connecting the hydrophone to the preamplifier or detector may not be accurately modeled as purely capacitive at higher frequencies; in such cases, customers are advised to consider purchasing a separate calibration which includes the use of their extension cables.

II. Other Common Calibration Units

$M_L(f)$ is in units of voltage divided by pressure and is typically expressed in V/Pa. Alternatively, it can be expressed in units of dB re 1V/µPa using Eq. (3):

$$dB_{re\,1V/\mu Pa}[M_L(f)] = 20 * \log_{10}[M_L(f)] - 120 \qquad (3)$$

It is also common to express the calibration in terms of acoustic intensity. Strictly speaking, a simple calibration factor exists only under conditions of a sinusoidal signal and under the assumption that intensity is equal to the time-averaged value of the pressure squared divided by the acoustic impedance of the medium. Under these conditions the following relation applies:

$$I = V_{RMS}{}^2 / K \qquad (4)$$

where I is the acoustic intensity, and V_{RMS} is the root-mean-square voltage of the sinusoidal signal. The calibration factor K is given by

$$K = z_a[M_L(f)]^2 \qquad (5)$$

where z_a is the acoustic impedance of the medium (1.5 MRayls for water). Because it is common to express I in units of W/cm^2,

$$K\{volts^2 cm^2 / Watt\} = 1.5x10^{10}[M_L(f)\{volts/Pa\}]^2 \quad \textbf{\textit{for water}} \qquad (6)$$

III. Examples

Example I. An HNV-0400 is supplied by Onda with an EOC calibration:

$M_c(f)$ = 50 nV/Pa at 5 MHz, and C_H = 80 pF

We now wish to determine the sensitivity for this hydrophone connected to an AH-2010 preamplifier.

As determined from the datasheet for the AH-2010, the amplifier impedance is capacitive with C_A = 7 pF, and the gain is 20 dB ($G(f)$ = 10). Application of Eqs. (2a) and 3 shows that $M_L(5MHz) =$ 460 nV/Pa, or –246.7. dB re 1V/µPa. Application of Eq. (6) yields K (5 MHz) = 3.17 x 10^{-3} V^2 cm^2/W.

Example II. An HGL-0200 is supplied by Onda with an EOC calibration:

$M_c(f)$ = 45 nV/Pa at 5 MHz, and C_H = 13 pF

We now wish to determine the sensitivity for this hydrophone connected to an AH-2010 preamplifier through an AR-AMAF connector:

As determined from the datasheet for the AH-2010, the amplifier impedance is capacitive with C_A = 7 pF, and the gain is 20 dB ($G(f)$ = 10). Application of Eqs. (2b) and 3 shows that $M_L(5MHz) =$ 271 nV/Pa, or –251.3dB re 1V/μPa. Application of Eq. (6) yields K (5 MHz) = 1.10 x 10^{-3} V^2 cm^2/W.

References

[1] ALUM/NEMA: Acoustic Output Measurement Standard for Diagnostic Ultrasound Equipment. American Institute of Ultrasound in Medicine, 14750 Sweitzer Lane, Suite 100, Laurel MD 20707-5906; National Electrical Manufacturers Association, 1300 North 17thStreet, Suite 1847, Rosslyn VA 22209, 1998.

[2] IEC 61102 Measurement and characterisation of ultrasonic fields using hydrophones in the frequency range 0,5 MHz to 15 MHz.