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A Correction to the Calibration Technique
Used with the WOTAN (Weather Observation
Through Ambient Noise) Instruments.

by

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Abstract

A calibration technique and theoretical aspects in which it is based is discussed.

The technique proposed by Sue Bourassa at University of Rhode Island [1] and used by the WOTAN users community [3] assumes the electronics bandwidth as the determining factor in the calculation of the overall instrument bandwidth.

A major correction coefficient is obtained when transducer bandwidth is taken into account in the calculations.

Instrument.

Fig 1. shows a diagram of the WOTAN instrument [3], where:

"NSL" is the Noise Spectrum Level defined as the amount of noise pressure variance in a 1 Hz bandwidth in units of dB relative to $(\text{micropascal})^{*2}$.

"b" is the transducer sensitivity, defined as the dB-Log-relation between the voltage signal at the transducer output and the pressure signal measured at the transducer face when applying a sinusoidal pressure signal of a given frequency called central frequency.

"BW" is the equivalent bandwidth of the amplification stages (electronics) as defined in Appendix I [8].

"(Vrms)B" is the root-mean-square voltage signal measured prior to the RMS and V/F stage.

"CNT" are the counts accumulated after a prefixed period of time is elapsed. During such time a true RMS conversion and a Voltage to Frequency conversion is performed on the (Vrms)B voltage. This frequency signal is fed to a counter whose output, CNT, is finally stored on magnetic tape and used to calculate the wind speed.

Figure 1:

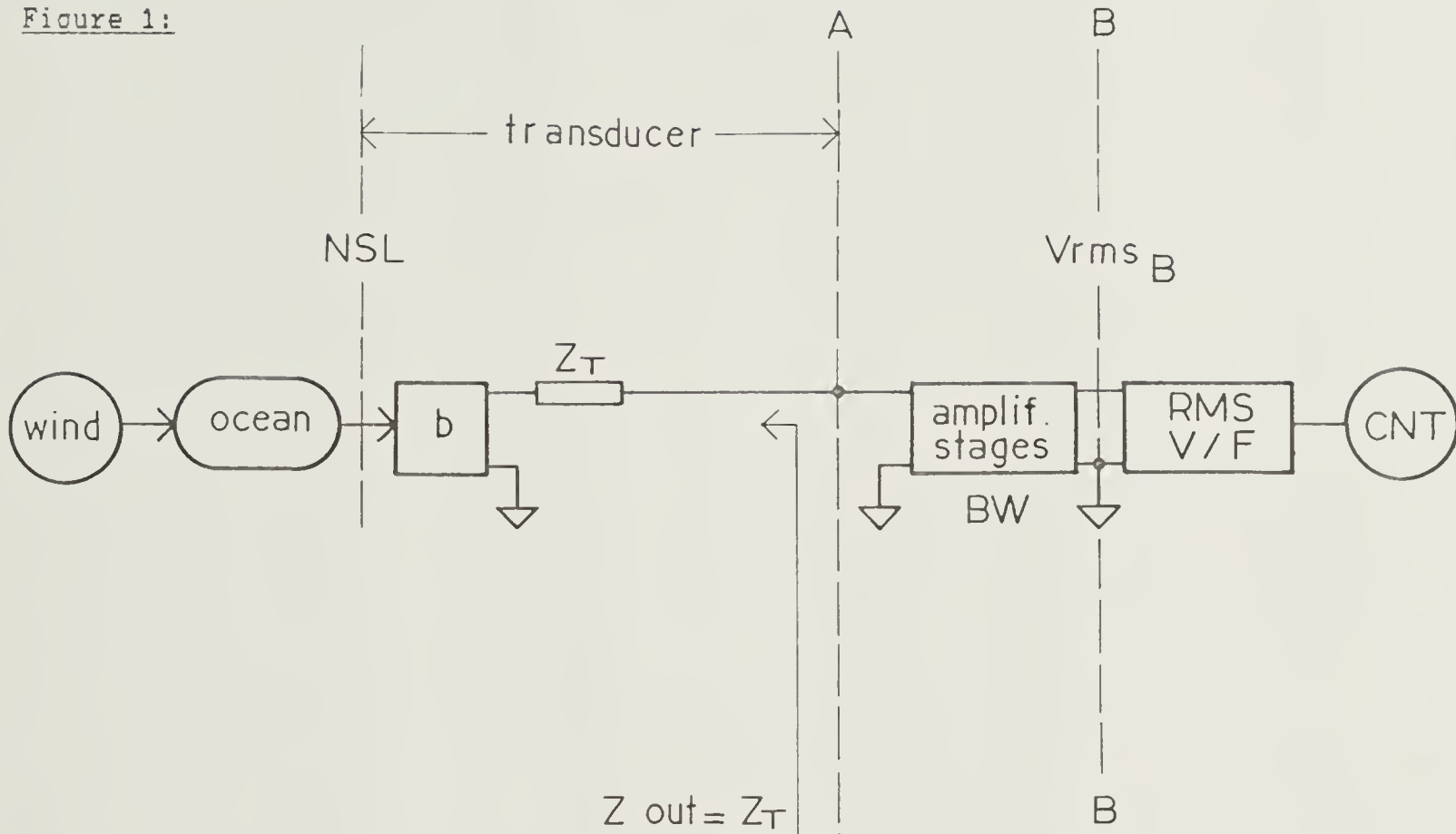
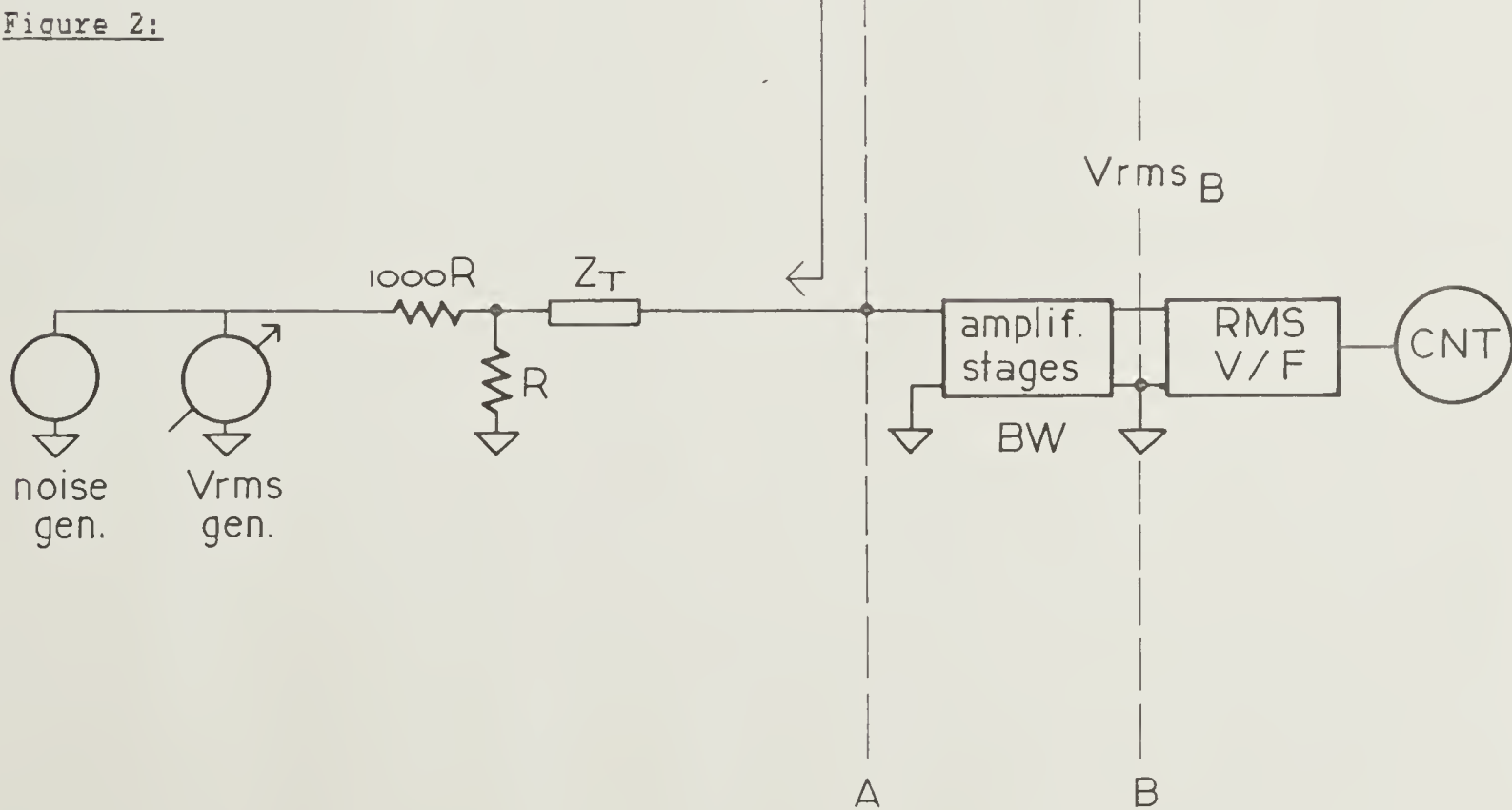


Figure 2:



The wind speed on the sea surface is reflected on a certain value of NSL, which is the parameter measured by the instrument [2].

The relationship between wind speed and NSL is an ocean-dependent problem and does not involve instrument performance [4].

The instrument calibration technique consists in finding an accurate relationship (either tabular or by the use of equations describing the instrument behavior) between the CNT and the NSL. Finally, the wind speed is calculated using an empirical formula relating NSL and Wind.

The NSL vs. CNT relationship can be described by linear equations. It ranges from a minimum NSL below which the signal is obscured by the instrument self-noise, to a maximum at which the circuits saturate and is no longer linear.

The technique proposed calibrates the instrument while working in this linear region.

Original Calibration Technique.

Fig. 2. shows a diagram for the laboratory setup to obtain the calibration coefficients [1].

Using a Gaussian noise generator plus an attenuator, both in series with the transducer (to have the same output impedance), the acoustic pressure noise produced by the wind force is simulated and, once a relationship between NSL and the $(V_{rms})_{gen}$ (measured at the output of the generator) is found, it is straightforward to construct a set of pairs (NSL, CNT). Finally, NSL is linearly regressed on CNT and the calibration coefficients are obtained.

In order to obtain the mentioned relationship between NSL and $(V_{rms})_{gen}$, the original technique compares Fig.1 and Fig.2, and, assuming the CNT's are the same at both outputs, it follows that at point B the $(V_{rms})_B$'s have to be equal. Therefore:

From Fig.1.

$$\text{Eq.1: } \underline{20\log((V_{rms})_B) = 10\log(BW) + NSL + b}$$

From Fig.2.

$$\text{Eq.2: } \underline{20\log((V_{rms})_B) = 10\log(BW) + 20\log((V_{rms})_{gen}/1000) - 10\log(GBW)}$$

where GBW is the equivalent bandwidth of the true r.m.s. voltmeter used in Fig.2.

Solving for NSL:

$$\text{Eq.3: } \underline{NSL = -b + 20\log((V_{rms})_{gen}/1000) - 10\log(GBW)}$$

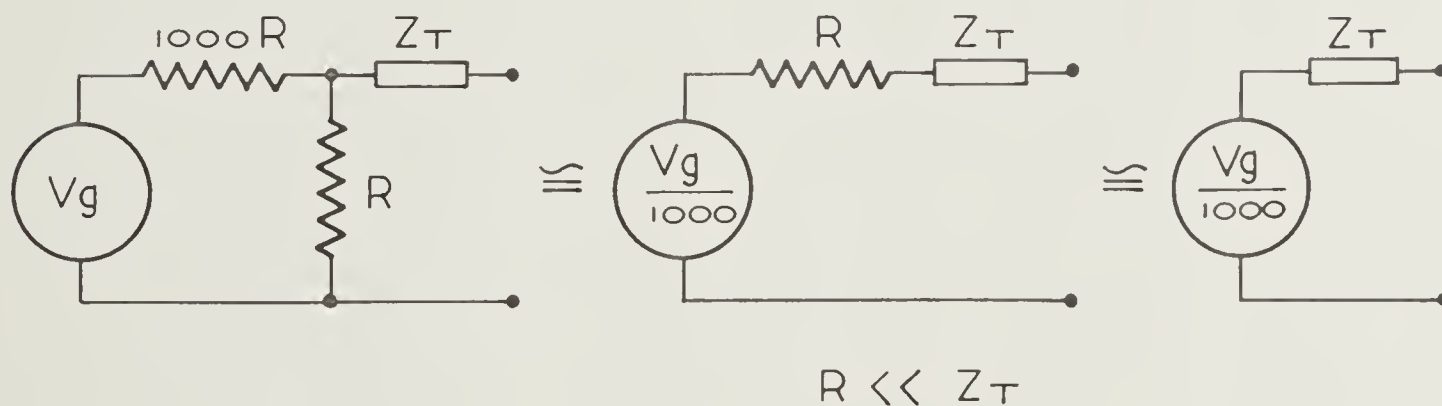
From here on, the technique continues by solving the linear regression using the NSL values obtained with the above equation for given $(V_{rms})_{gen}$ readings and the correspondent CNT's.

Correction to the proposed technique.

The above equations are valid if the following conditions occur:

a) The output impedances seen to the left of point A of the circuitry are the same for both circuits of Fig. 1 and Fig. 2. This is approximately true because R is selected such that $R \ll Z_T$ (Z_T : impedance of transducer), and therefore the Thevenin equivalent circuits for both left-side part circuits are the same. See Fig. 3.

Figure 3



b) The voltage transfer function between NSL and point A in Fig.1 and between $(V_{rms})_{gen}$ and point A in Fig. 2 have to have the same values for any frequency.

This means that the gains between the mentioned points in both circuits should be the same at a given frequency. This is assured, in part, by the fact that both circuits have the same output impedance (See section 3.a above).

However, and here is the problem to be corrected, a detailed observation of the transducer characteristics shows that its open-loop voltage is frequency dependent, while the open-loop voltage of the generator is almost uniform in the frequency range in question (approximately flat up to 20kHz).

Equations 1 and 2 will then become valid if transducer frequency dependence is taken into account. In order to do so, Eq.1 has to contain the frequency dependence of the transducer and electronics transfer function. That is, in Eq.1, the term BW should be replaced by BWT, which is the overall equivalent bandwidth of the total transfer function when transducer and the electronics are put in series. Eq. 2 remains unchanged.

After the above modifications are performed, a new "NSL vs. (Vrms)gen" equation is obtained:

$$\text{Eq. 4: } \underline{\text{NSL} = -b + 20\log((V_{\text{rms}})_{\text{gen}}/1000) - 10\log(\text{GEW}) + e}$$

where "e" is the correction to Eq. 3 and is given by:

$$\text{Eq. 5: } \underline{e = 10\log(\text{BW}/\text{BWT})}$$

where:

BW is the electronics equivalent bandwidth.

BWT is the transducer plus electronics equivalent bandwidth.

Conclusions.

A detailed theoretical discussion on the WOTAN calibration technique is presented. From there, a correction that takes into account the transducer characteristics is presented and a correction factor obtained.

The value of that factor depends on how the transducer transfer function varies with frequency with respect to the electronics bandwidth. That is, if the electronics has a very narrow bandwidth with respect to the transducer, then the error is very small.

Appendix II shows calculations made for a given pair of transducer-electronics [7] used in an Inverted Echo Sounder (IES) [5],[6] at Lamont-Doherty Geological Observatory (LDGO).

For that pair, the error found was approximately +5.48 dB. This is a large value compared to the variations of the expected NSL and therefore the correction factor was included in the calibration of this particular instrument at LDGO.

Acknowledgments.

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Appendix I:

Given $u(t)$ with characteristics of noise, then the autocorrelation of $u(t)$ is:

$$R(z) = E[u(t).u(t+z)]$$

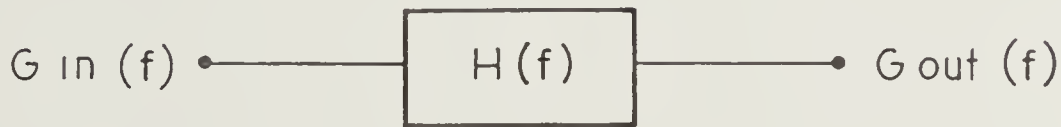
and the density power spectrum of $u(t)$ is defined as:

$$G(f) = \int_{-\infty}^{\infty} R(z).exp(-jwz)dz \quad \text{where } w = 2 \text{ Pi } f$$

for a Gaussian noise signal:

$$Rg(z) = V_{rms}^2(z) .exp(-jwz) = V_{rms}^2 \text{ [Volts/Hz]}$$

Let's input the Gaussian noise to a filter whose transfer function is $H(f)$.



It is well known that:

$$G_{out}(f) = |H(f)|^2 G_{in}(f)$$

and if $G_{in}(f) = V_{rms}^2$ then $G_{out}(f) = |H(f)|^2 V_{rms}^2 \text{ [Volts /Hz]}$

therefore:

$$V_{rms,out}^2 = \int_{-\infty}^{\infty} G(f)_{out} df = V_{rms,in}^2 \int_{-\infty}^{\infty} |H(f)|^2 df.$$

Equivalent Bandwidth BW

Finally:

$$V_{rms,out}^2 = BW . V_{rms,in}^2 \text{ [Volts /Hz]}.$$

Appendix II

Error Correction Factor Calculation

Given the following transducer and electronics transfer functions, where:

- F: Frequency
- TG: Transducer gain at a given frequency
- TGn: Transducer gain normalized (TGn = TG/TGo) TGo gain at 10 khz.
- EG: Electronics gain
- EGn: Electronics gain normalized (EGn = EG/EGo) EGo: gain at 10 khz.
- ETn: Electronics plus TRansducer gain normalized.

BW is calculated as $BW = \text{SUM}(\text{SQUARE}(\text{EGn}_i))$ where "i" indicates frequency, for i = 1 kHz to 20 kHz)

BWT is calculated as $BWT = \text{SUM}(\text{SQUARE}(\text{ETn}_i))$, "i" is the same as above.

F Khz	EG dB	EGn dB	EGn 1	TG dB	TGn dB	TGn 1	ETn 1
2	54	-10.50	0.29	114	-35	0.017	0.005
3	58	-6.5	0.47	114	-35	0.017	0.008
4	60	-4.5	0.59	114	-35	0.017	0.01
5	62	-2.5	0.75	122	-27	0.044	0.033
6	63	-1.5	0.84	130	-19	0.112	0.094
7	63.5	-1	0.89	136	-13	0.223	0.198
8	64	-0.5	0.94	139	-10	0.316	0.297
9	64.3	-0.2	0.97	144	-5	0.562	0.545
10	64.5	0	1.0	149	0	1.0	1.0
11	64.5	0	1.0	148	-1	0.89	0.89
12	64.3	-.2	0.97	146	-3	0.707	0.685
13	64	-.5	0.94	143	-6	0.5	0.47
14	64	-.5	0.94	135	-14	0.199	0.187
15	63.8	-0.7	0.92	143	-6	0.5	0.46
16	63.5	-1	0.89	143	-6	0.5	0.445
17	63	-1.5	0.84	142	-7	0.446	0.374
18	62.8	-1.7	0.82	141.7	-7.3	0.43	0.352
19	62.5	-2	0.79	141.2	-7.8	0.4	0.316
20	62.2	-2.3	0.76	141	-8	0.39	0.296

From the above tables:

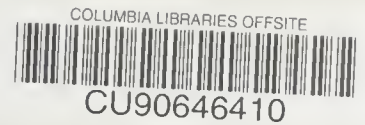
$$BWT = 3.812 \text{ Khz}$$

$$BW = 13.464 \text{ Khz}$$

From Eq.5

$$e = 10 \log(BW/BWT)$$

$$e = \underline{+5.48 \text{ dB.}}$$



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