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Expectative Noise-Immunity of Combined Receiver

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Simplified estimation of signal-to-noise ratio of combined receiver involving pressure receiver (scalar receiver) and particle velocity receiver (vector receiver) was performed. Combined receiver gain in SNR was introduced in much the same way as antenna array gain. It was shown that this quantity may be used to estimate expectative noise-immunity of combined receiver in actual noise fields.

1. Directional characteristic of combined receiver

Combined receiver is a prime element of devices used in our acoustic intensity measurements. Combined receiver consists of pressure receiver (scalar receiver) and three-component receiver of either particle velocity or particle acceleration (vector receiver).

Spherical vector receivers (D≈0.2 m) cast from syntactic foam each with 6 piezoelectric transducers mounted within its body are used in our experiments. Three pairs of transducers are symmetrically mounted to three axes in Cartesian coordinate system with the origin coinciding with geometrical center of the vector receiver. Six hydrophones are symmetrically mounted closely to vector receiver at points $(\pm x_0;0;0)$, $(0;\pm y_0;0)$, $(0;0;\pm z_0)$, $x_0=y_0=z_0$. Electrical signals from all hydrophones are summarized. Symmetrical arrangement of hydrophones around vector receiver is necessary for coincidence of points symbolizing phase center, mass center and buoyancy center of combined receiver with geometric center of vector receiver (0;0;0).

Transducers used in vector receiver are mounted to orthogonal axes in Cartesian coordinate system and possess the following spatial directional characteristics:

$$R_x = \sin\theta \cdot \cos\varphi$$
$$R_y = \sin\theta \cdot \sin\varphi \qquad (1)$$
$$R_z = \cos\theta$$

where φ is azimuth angle counted from *x* axis, θ is elevation angle counted from *z* axis. It is evident three-component vector receiver has spherical directional characteristic:

$$R_x^2 + R_y^2 + R_z^2 = 1 \qquad (2)$$

Hence, four-component combined receiver consisting of pressure receiver and three-component vector receiver has spherical directional characteristic. Combined receiver may be supposed as a point-like receiving system if its diameter $D \le (\lambda_H/2)$ where λ_H corresponds to the upper limit of the operating range f_H .

2. Combined receiver gain in SNR in a frequency band

«An antenna array gain» characterizes enhancing in signal-to-noise ratio (SNR) achieving by a hydrophone array in comparison with that of nondirective hydrophone in the field of isotropic noise and signal describing by plane sinusoidal wave [1, 2].

If hydrophones in antenna array are separated by λ/2, then SNR of this array at distinct f_0 will be given by:

$$SNR = 10lg\left(\sigma_S^2/\sigma_N^2\right)+10lg\,N \qquad (3)$$

σ_S^2, σ_N^2, are the powers of signal and noise respectively, N is number of hydrophones.

Here $10lg\left(\sigma_S^2/\sigma_N^2\right)$ is SNR at output of a single hydrophone and $10lg\,N$ is referred to as antenna array gain. Hence, enhancing in SNR by antenna array is achieved by directional characteristics forming and subsequent spatial filtering. Unlike antenna array a single combined receiver possesses spherical directivity characteristic and is not capable of spatial filtering. But it is capable of measuring angular characteristics of vector quantities of acoustic field and suppressing isotropic part of ambient noise. So it makes sense to compare combined receiver to antenna array.

Consider simplified estimation of a combined receiver SNR(PV) and then compare it with the expression for antenna array SNR (3). A combined receiver SNR may be expressed in terms of the following magnitudes in distinct band around signal frequency f_0 [3, 4]:

$$SNR(PV) = 10lg\left\{\frac{\left|S_{PV,S}(f_0)\right|}{\left|S_{PV,N}(f_0)\right|}\right\} \qquad (4)$$

where $S_{PV,S}(f_0)$, $S_{PV,N}(f_0)$ are cross-spectral densities. After substitution

$S_{PV,S}(f_0)=\gamma^2_{PV,S}(f_0)\,S_{P^2,S}(f_0)$ and $S_{PV,N}(f_0)=\gamma^2_{PV,N}(f_0)\,S_{P^2,N}(f_0)$ into (4):

$$SNR(PV) = 10lg\left\{\frac{\gamma^2_{PV,S}(f_0)S_{P^2,S}(f_0)}{\gamma^2_{PV,N}(f_0)S_{P^2,N}(f_0)}\right\} =$$
$$= 10lg\{S_{P^2,S}(f_0)\,/\,S_{P^2,N}(f_0)\} +$$
$$+10lg\{\gamma^2{}_{PV,S}(f_0)\,/\,\gamma^2{}_{PV,N}(f_0)\} \qquad (5)$$

where $\gamma^2_{PV,S}(f_0)$, $\gamma^2_{PV,N}(f_0)$ are one-point coherence functions of signal and noise, $S_{P^2,S}(f_0)$, $S_{P^2,N}(f_0)$ are spectral energy densities of signal and noise.

The expression $10\,lg\{S_{P^2,S}(f_0)/S_{P^2,N}(f_0)\}$ in (5) is SNR(P^2) at the output of hydrophone being incorporated into combined receiver. It is physically equal to $10lg(\sigma_S^2/\sigma_N^2)$ in (3). The term $10\,lg\{\gamma^2_{PV,S}(f_0)/\gamma^2_{PV,N}(f_0)\}$ is equal to $10\,lgN$ (3) and further will be referred to as combined receiver gain.

In the case of perfectly coherent signal $(\gamma^2_{PV,S}(f_0)\to 1)$ and purely isotropic noise $(\gamma^2_{PV,N}(f_0)\to 0)$ combined receiver gain would tend to infinity. In fact ambient noise acoustic field is a superimposing of anisotropic (coherent) and isotropic (diffusive) fields and hence coherence of actual ambient noise $\gamma^2_{PV,N}(f)$ differs from zero and depends on frequency. In 200-1000 Hz band attributed to dynamic noise it may be as low as 0.01÷0.001. Hence, a single combined receiver gain $10\,lg(1/\gamma^2_{PV,N}(f_0))$ may ran as high as 20÷30 dB as signal is perfectly coherent.

3. Coherent properties of both signal and noise energy fluxes

Consider how coherent properties of signal and noise depend on averaging time T_0 at 150 m depth. Use data sample of 1800 s duration. Exponent averaging was done over different T_0: 3; 5; 15; 30; 45; 60; 75; 90; 100; 150; 192; 200; 250; 300; 320 s. In accordance to (5) a combined receiver gain may be expressed directly in terms of coherence functions.

Fig.1 illustrates T_0-dependence of both noise coherence function $\gamma^2_{PV_y,N}(f_0)$ and standard deviation $\sigma_N(f_0)$, as well as corresponding signal characteristics $\gamma^2_{PV_y,S}(f_0)$ and $\sigma_S(f_0)$. All data sample of 1800 s duration was used to calculate $\gamma^2_{PV_y,N}(f_0)$ and $\sigma_N(f_0)$ (Fig 1a). Data obtained in two intervals 700≤t≤800 s and 1200≤t≤1500 s of the period under exploring 0≤t≤1800 s were used to calculate signal coherence function $\gamma^2_{PV_y,S}(f_0)$ and $\sigma_S(f_0)$ shown in Figs. 1b, 1c, respectively. Noise coherence decreases with increasing T_0 (Fig. 1a). Comparing $\gamma^2_{PV_y,N}(f_0)\pm\sigma_N(f_0)$=0.415±0.021 obtained by averaging over T_0=3 s with $\gamma^2_{PV_y,N}(f_0)\pm\sigma_N(f_0)$=0.008±0.003 obtained by averaging over T_0=320 s it is easy to see

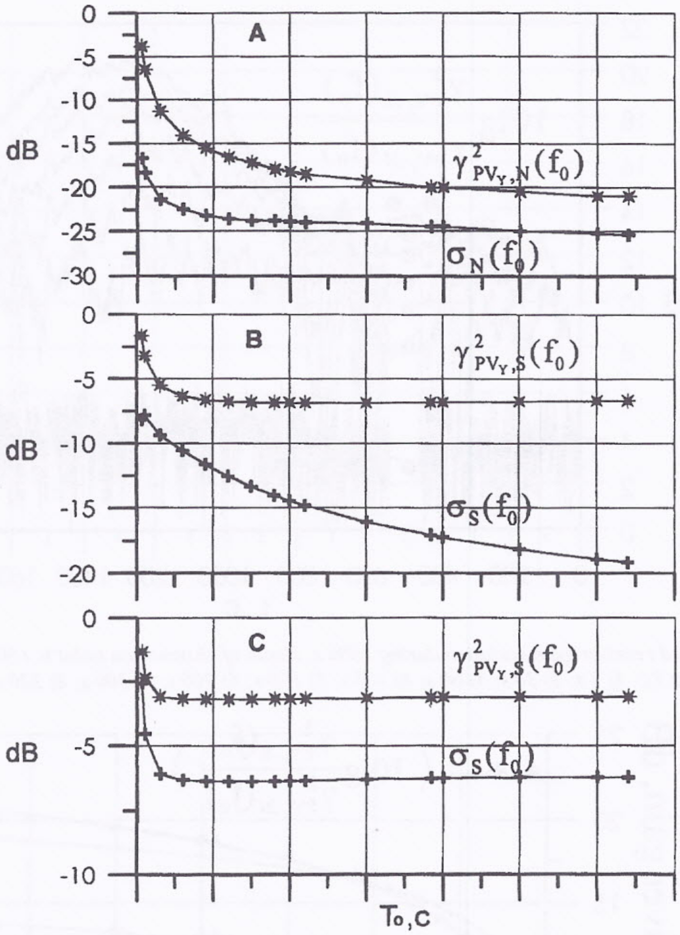

Fig. 1. Dependence of $\gamma^2_{PV_y,N}(f_0)$, $\sigma_N(f_0)$; $\gamma^2_{PV_y,S}(f_0)$, $\sigma_S(f_0)$ on averaging time. 0-dB level corresponds to unite value of coherence function

the coherence level drops by 17 dB. At the same time standard deviation $\sigma_N(f_0)$ decreases by approximately 7.5 dB (from 0.021 to 0.003). So diffusive component of the noise field dominates along *y* direction.

Signal coherence (Figs. 1b, c) decreases with increasing T_0 and tends to finite constant value ($T_0 \leq 320$ s). Low signal coherence decreases until $T_0=30$ s (Fig. 1b) as well as corresponding $\sigma_S(f_0)$. More strong signal coherence decreases until $T_0=15$ s (Fig. 1c) and also tends to constant value as well as corresponding standard deviation.

Fig. 1 clearly shows that at averaging times greater than 30 s signal coherence will tend to constant value, noise coherence will decrease as well as its standard deviation.

Combined receiver gain given by $10lg\{\gamma^2_{PV,S}(f_0)/\gamma^2_{PV,N}(f_0)\}$ grows with increasing averaging time. For the same data sample of 1800 s duration and eight different T_0 eight curves illustrating time-dependence of combined receiver gain are presented in Fig. 2. As may be seen the gain varies with time since the signal f_0=622 Hz fluctuates. Fig. 3 shows T_0-dependence of a combined receiver gain. Results computed from $700 \leq t \leq 800$ s data interval of 1800 s recording are marked by crosses. That computed from $1200 \leq t \leq 1500$ s interval are marked by triangles.

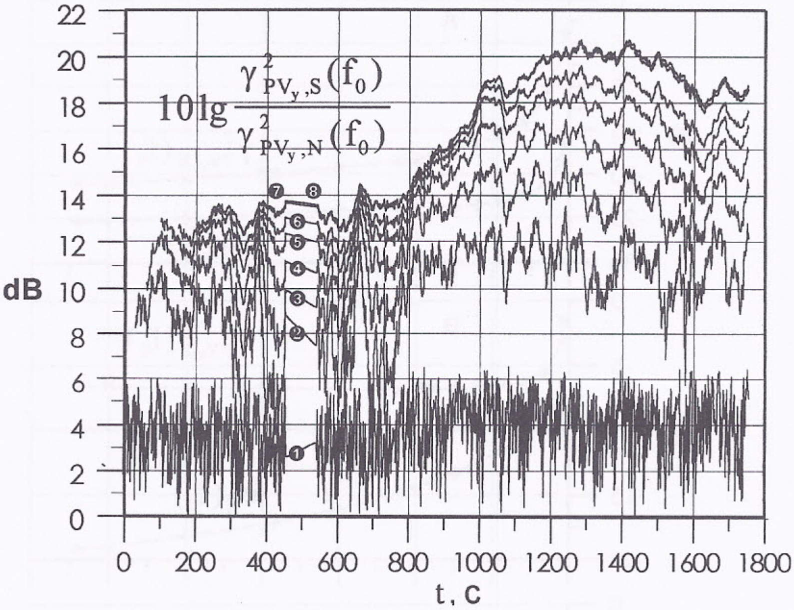

Fig. 2. Combined receiver gain variation during 1800 s. Depth of observation point is 150 m. Averaging times T_0: 1) 5 s; 2) 30 s; 3) 60 s; 4) 100 s; 5) 150 s; 6) 200 s; 7) 300 s; 8) 320 s

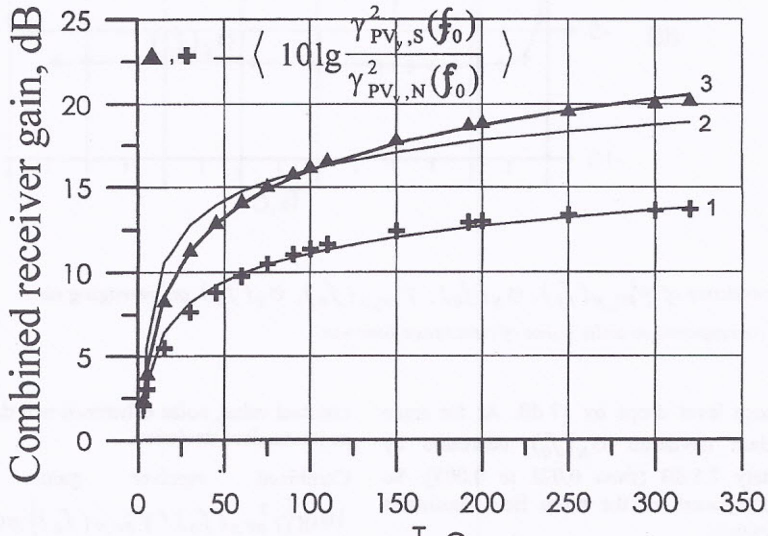

Fig. 3. T_0-dependence of combined receiver gain. Depth of observation point is 150 m. Crosses: $700 \leq t \leq 800$ s; triangles: $1200 \leq t \leq 1500$ s (see Fig. 2). Approximation by solid lines ($a+b \cdot \sqrt{t}$): the 1st curve: $a_1=-1.0$; $b_1=1.4$; the 2nd curve: $a_2=-7.0$; $b_2=8.0$; The 3rd curve: ($a+b \cdot t^c$); $a=0$; $b=0.6$; $c=0.9$

Hence, in this report combined receiver gain in SNR has been defined in much the same way as antenna array gain. Its dependence on averaging time (in particular its rise with increasing averaging time) has been examined. It has been proposed to use this quantity to estimate expectative noise-immunity of combined receiver in acoustic noise fields.

Reference

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