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On the generation of bionic pulses with conventional piezoelectric transducers by proper design of the input driving function

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Abstract: This paper concerns with the capacity of piezoelectric transducers to generate bionic pulses, by proper design of the input driving function which equalizes their transfer function. Firstly, the transfer function is measured by performing the transducer in the pinger mode. The measured transfer function, together with the parameters of the desired bionic pulse (i.e. central frequency, stretching and chirp), are the inputs to a program to calculate the voltage function which should drive the transducer. Finally, the transducer is driven with the calculated voltage function, synthesized by an arbitrary waveform generator, and the transmitted acoustic pulse is measured. Theoretical bionic pulses and experimental pulses synthesized by this method show an excellent agreement.

1. INTRODUCTION

We are acquainted with the use of pulsed transducers for active sonar systems. These kinds of systems radiate to the water a repetitive train of pulsed tones and measure the range and bearing between the source and the target. Since the transducer is characterized by a given impulse response, fixing the input driving function also fix the pulse waveform transmitted to the water. Hence, this driving way to perform a transducer is non versatile.

The animal echolocation systems, however, are versatile. This means that they adapt the transmitted acoustic pulse to the particular location problem at hand. When the target is far away they emit a low-rate train of long FM pulses. When they approach the target, they increase the rate and decrease the length of the pulse train.

Signal processing provides a tool to design more versatile sonar pulses. Holly [1] reported a Wiener filtering method to generate broadband acoustic transmissions. Cobo and Carbó [2] showed that inverse filtering can be used to design the input voltage which equalizes the transfer function of the transducer. They reported a drastic reduction of the Q factor of a conventional 106 kHz piezoelectric transducer from $Q=14.7$, in pinger mode, to $Q=1.65$, in equalized mode, with the cost of an amplitude loss amounting 33 %. Piquette [3-4] used the equivalent circuit of the transducer to design the input driving voltage that cancels out the turnon and turnoff transients of the transmitted pulse.

This paper concerns with the generation of bionic pulses with conventional transducers. According to Altes [5] bionic pulses have the following properties :

1. They simulate closely the sonar pulses emitted by dolphins.
2. They provide a constant TW which simplifies the design of matched filters to analyze generalized targets.
3. They are free of range-doppler coupling.
4. They are optimally tolerant to doppler.

2. METHODS

2.1. Design of the driving function

In conventional performance, a transducer driven with a burst-type voltage, $x_c(t)$, transmits to the load an acoustic pulse, $y_c(t)$, given by

$$y_c(t) = h(t) * x_c(t) \quad (1a)$$

where $h(t)$ is the impulse response of the transducer and $*$ denotes convolution. In the frequency domain, the transfer function, $H(f)$, is

$$H(f) = \frac{Y_c(f)}{X_c(f)} \quad (1b)$$

where $X_c(f)$ and $Y_c(f)$, the Fourier transforms of $x_c(t)$ and $y_c(t)$, respectively, are the input and output spectra. Now, instead of fixing the input voltage, let us prescribe the output waveform, $y_p(t)$. The necessary input spectrum to obtain such an acoustic spectrum, $X_p(f)$, should be

$$X_p(f) = \frac{Y_p(f)}{H(f)} \quad (2a)$$

and, including eq. (1b) for the transfer function

$$X_p(f) = Y_p(f) \frac{X_c(f)}{Y_c(f)} \quad (2b)$$

Therefore, to determine the necessary input voltage, we only need:

1. The direct Fourier transform of the easily measured input voltage and output acoustic pulse, in conventional performance.
2. To choose the spectrum of the desired pulse.
3. The inverse Fourier transform of the necessary voltage spectrum, calculated according to eq. (2b).

Then, this voltage function should be implemented either by suitably driving a digital filter, as made by Holly [1], or by sending this function to the bank memory of an arbitrary waveform generator, as made by Cobo and Carbó [2].

If $Y_p(f) = 1$, the spectrum for a spike, $X_p(f) = 1 / H(f)$, the inverse of the transfer function. Thus, ideal equalization is equivalent to inverse filtering (or spiking deconvolution). In this case, we shape a bionic spectrum, as given in the next Section.

2.2. Bionic pulses

According to Altes [5], the spectrum of the bionic pulse can be given by

$$Y_p = \begin{cases} cte & e^{-[\ln(f/f_0)]^2/2 \ln k} & e^{-j2\pi a \ln(f/f_0)/\ln k} & f \geq 0 \\ 0 & & & f < 0 \end{cases} \quad (3)$$

where f_0 is the central frequency of the magnitude spectrum, k is the stretching parameter governing the bandwidth of the pulse, and a is the chirp parameter giving the sweeping of the phase spectrum. The waveform of the corresponding pulse is calculated from $y_p(t) = \text{Real}\{\mathcal{F}^{-1}[Y_p(f)]\}$. The effective duration of the pulse depends on the combination of k and a parameters. Greater values of k afford wider frequency bands and therefore shorter pulses. However, greater values of a provide larger pulses with more zero crossings and higher frequency modulation.

3. RESULTS

Figure 1 shows the results of applying this technique to the generation of bionic pulses with a 106 kHz sandwich transducer. Figures 1a and 1b are the driving voltage input and the transmitted acoustic pulse, respectively, in pinger mode. The f_0 and k parameters of the corresponding bionic pulse were chosen according with the amplitude spectrum of the ping in Figure 1b. The bionic pulse for the parameter series $\{f_0, k, a\} = \{106 \text{ kHz}, 1.02, -0.5\}$ is shown in Figure 1d. The sandwich transducer should be driven with the voltage function shown in Figure 1c. This driving function was synthesized with a programmable arbitrary waveform generator.

4. CONCLUSIONS

We have presented a method to enforce a conventional sandwich transducer to generate bionic pulses. Instead of driving the transducer with a conventional gated-sine function, we prescribe the desired acoustic waveform and we synthesize the necessary voltage function, provided that we previously measure the transfer function of the transducer. Bionic waveforms depend on three parameters: f_0 , the central frequency of the spectrum, k , which determines the spectral bandwidth, and a , that determines the slope of the spectral phase function and is related to the chirp in the time waveform.

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Figure 1. Input driving voltage (left) and transmitted acoustic pulse (right) in pinger mode (above) and bionic mode (below) for the parameter series $\{f_0, k, a\} = \{106 \text{ kHz}, 1.02, -0.5\}$

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