Time-frequency analysis in sonar transducer design and characterization

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Time resolution is essential to many applications of sonar systems (especially for imaging): estimation of the time of flight, measurement of attenuation coefficient and acoustical impedance of nondispersive or dispersive media, definition of the time-frequency structure of echoes, etc.

However, sonar transducers are essentially designed to convert the energy of an electric source into the acoustic energy of a travelling wave without paying much attention to time signal. In the sonar equation, transducers or arrays are described by a « source level » term representing the average acoustic power radiated in all directions, and a « directivity index » term representing the concentration of the power along transducer axis. Sonar transducer calibration is given the Transmitting Voltage Response (TVR) which represents the power spectrum of the acoustic pressure radiated in the far field, in the axis, at a reference distance when submitted to a unit drive voltage. TVR amplitude spectrum is usually widely discussed and optimized but TVR phase spectrum is most of the time ignored.

To improve time resolution, transducer bandwidth increase is usually achieved in two ways: damping the mechanical system (high frequency dampers) and adding extra mechanical resonances ("camel" type transducers). Both methods increase the effective bandwidth as far as energy is concerned, but also lead to phase distortions. On one hand, absorbing materials are dispersive (causality relation of Kramer Koenig) i.e. they lead to phase spreading. On the other hand, the presence of multiple resonances leads to a complex phase pattern. Thus, although increasing the bandwidth (B) leads to an improvement of time resolution, phase spreading leads to the opposite effect and the expected resolution (1/B) is hardly achieved.

This paper presents two attempts at overcoming this issue. First, the case of a super-wideband tonpilz transducer (500 Hz - 10 kHz i.e. about 4.5 octaves) specifically developed for sea sub-bottom imaging and characterization is presented to illustrate the importance of time-frequency analysis at the design stage. It is also shown that the time-frequency response of this transducer may be improved by adequate modifications of its mechanical structure. Second, the example of an ultrasonic transducer driven with precomputed signals is described. As most transmitters use digitally computed waveforms at present day, precomputed signals are used that integrate pre-accentuated waveforms where both amplitude and phase can be corrected via inverse filtering (or deconvolution). Thus, transducer response may be corrected using deconvolution in the time domain to generate all frequencies with the same amplitude without phase distortion. The effect of deconvolution is also illustrated in both time and frequency as well as in the time-frequency plane (Wigner-Ville Distribution) where the effect of velocity dispersion can be clearly shown (and compensated).