

Delay Axis of Impulse-Response Images in Biosonar

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Abstract: Theoretical and experimental work on echo-delay acuity in bat sonar reveals a unique, previously unknown feature of the bat's internal representation of sonar targets. Big brown bats (*Eptesicus fuscus*) broadcast wideband, frequency-modulated (FM) biosonar sounds containing frequencies of 20-100 kHz and perceive objects from echoes of these sounds that return to their ears.

Echolocating bats determine target distance, or range, from the delay of echoes. These biosonar sounds have high center frequencies (f_c) and wide bandwidths (Δf), which in principle could support very accurate determination of echo delay. Using the auditory system as a sonar receiver, big brown bats are able to achieve this potential. For echoes with relatively unrestricted bandwidths, they can detect changes in echo delay as small as 10 to 40 ns at high echo signal-to-noise ratios. To understand how the wide frequency span of echoes contributes to the bat's delay images, we restricted the frequency content of

echoes by removing progressively greater portions of the low-frequency or the high-frequency end of the broadcast spectrum. We have found that the bat's delay accuracy deteriorates systematically in a manner that depends on the ratio of echo center frequency to bandwidth, which equals the value for Q , the width of the target impulse response in number of cycles.

The decline is not consistently proportional to either the reciprocal of the bandwidth or the reciprocal of the center frequency alone, as would be expected from sonar theory. The bat's internal representation of targets appears to consist of the target impulse response scaled by the number of cycles rather than by units of time. Use of a normalized time axis for impulse responses may facilitate comparison of images for the same target at different aspects and could contribute to the bat's ability to rapidly identify targets from their shape using a small number of pings.