In this study a theoretical framework for calculating the acoustic response of optical fiber-based ultrasound sensors is presented. The acoustic response is evaluated for optical fibers with several layers of coating assuming a harmonic point source with arbitrary position and frequency. First, the fiber is acoustically modeled by a layered cylinder on which spherical waves are impinging. The scattering of the acoustic waves is calculated analytically and used to find the normal components of the strains on the fiber axis. Then, a strain-optic model is used to calculate the phase shift experienced by the guided mode in the fiber owing to the induced strains. The framework is showcased for a silica fiber with two layers of coating for frequencies in the megahertz regime, commonly used in medical imaging applications. The theoretical results are compared to experimental data obtained with a sensing element based on a pi-phase-shifted fiber Bragg grating and with photoacoustically generated ultrasonic signals.