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This Week's Citation Classic

Papadakis E P. Ultrasonic phase velocity by the pulse-echo-overlap method incorporating diffraction phase corrections.
J. Acoust. Soc. Amer. **42:**1045-51, 1967.
[Bell Telephone Laboratories, Allentown, PA]

This paper gives an experimental method and an apparatus for the measurement of the travel time of ultrasonic waves to 50 ppm or better. The accuracy is achieved by (1) the electronics, (2) the calculations of cyclic overlap, and (3) the diffraction phase corrections. The method is versatile as well as accurate. [The *SCI*® indicates that this paper has been cited over 145 times since 1967.]

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"This piece of research is really the happy synthesis of three other research efforts. When I joined Bell Telephone Laboratories in 1962, a system had been built[1] for measuring group delay in ultrasonic delay lines by matching the envelopes of narrow-band bursts of rf ultrasonic waves. I modified it to measure pairs of echoes on specimens with only one transducer. Two years earlier, McSkimin and Andreatch had published papers on the pulse-superposition method[2,3] which gave the correct cycle-for-cycle matching of rf echoes for phase velocity measurements in a pulse-echo single transducer system. McSkimin's calculation was directly applicable to the pairs of echoes in the pulse-echo-overlap method I was assembling. With pairs of echoes, it became possible to measure apparent phase velocity as a function of distance from the transducer. A monotonic trend was apparent and could be explained by a phase shift caused by ultrasonic diffraction. In 1966, I had published a paper[4] on a 3-D calculation of the effects of ultrasonic diffraction upon attenuation and phase velocity measurements. Using this calculation for diffraction phase corrections and the facility of the pulse-echo-overlap method to measure phase delay between pairs of echoes, I successfully eliminated the monotonic trend of velocity vs. distance from pulse-echo phase velocity measurements. Thus, the triplet of factors was complete.

"I believe the wide acceptance of the pulse-echo-overlap method arises from its versatility and its absolute accuracy. The diffraction phase corrections eliminate the last major systematic error in travel time, namely, one-fourth of the period of the ultrasonic frequency in a travel distance from the face of the transducer to 'infinity.' The 'McSkimin criterion' for cyclic echo matching eliminates gross errors of one or more periods of the ultrasonic frequency between echoes. The electronics permits a precision of a few parts per million. The net effect is an absolute accuracy good to about 50 ppm. Versatility is achieved because of the ability to measure between any pair of echoes, between the input pulse and any echo, between the input pulse and a transmitted signal, or between echoes when a buffer rod or other delay medium is interposed between the transducer and the specimen. The pulse-echo-overlap method has been used on moon rock, oriented single crystals, hardened steel, and many more materials. New terminology which this work has helped to introduce into the literature is 'pulse-echo-overlap method' and 'PEO method,' 'McSkimin criterion,' and 'diffraction phase corrections.' The method has been engineered into a commercial instrument by Panametrics, Inc., Waltham, Massachusetts. See my publication in *Physical Acoustics: Principles and Methods* for more recent work in the field."[5]

1. **May J E**. Precise measurement of time delay. *IRE Int. Conv. Rec.* **6** (Pt. 2): 134-42, 1958.
2. **McSkimin H J.** Pulse superposition method for measuring ultrasonic wave velocities in solids. J. *Acoust. Soc. Amer.* **33**:12-16, 1961.
3. **McSkimin H J & Aadreatch P.** Analysis of pulse superposition method for measuring ultrasonic wave velocities as a function of temperature and pressure. J. *Acoust. Soc. Amer.* **34**:609-15, 1962.
4. **Papadakis** E P. Ultrasonic diffraction loss and phase change in anisotropic materials. J. *Acoust. Soc. Amer.* **40**:863-76, 1966.
5. .... Ultrasonic velocity and attenuation: measurement methods with scientific and industrial applications. (Mason W P & Thurston R N, eds.) *Physical acoustics: principles and methods.* New York: Academic Press, 1976. Vol. 12. p. 277-374.