Cement placement is a critical component of a well’s architecture for ensuring mechanical support of the casing, providing protection from fluid corrosion, and, most importantly, isolating permeable zones with different pressure regimes to prevent hydraulic communication.

Conventional cement bond log (CBL) and ultrasonic pulse-echo techniques are sometimes used together to diagnose zonal isolation but encounter difficulties when attempting to evaluate cements with low acoustic impedance or cements contaminated with mud. Ambiguity can result because these tools rely on a significant contrast in acoustic impedance between the cement and displaced fluid to identify solids.

Isolation Scanner cement evaluation service provides more certainty by combining the pulse-echo technique with a new ultrasonic technique that induces a flexural wave in the casing with a transmitter and measures the resulting signals at two receivers. The attenuation calculated between the two receivers provides an independent response that is paired with the pulse-echo measurement and compared with a laboratory-measured database to produce an image of the material immediately behind the casing.

By measuring radially beyond traditional cement evaluation boundaries, Isolation Scanner service confirms zonal isolation, pinpoints any channels in the cement, and ensures confident squeeze or no-squeeze decisions.

The signals following the casing arrivals arising from the interface between the annulus and the borehole or outer casing can be detected and measured. These third-interface echoes (TIEs) provide the position of the casing within the borehole, and if the borehole size is known, the velocity of the annulus material can be determined. This additional information, available only through the flexural measurements, can provide useful information for remedial applications and serve to confirm or determine the correct interpretation for complex evaluations.

**Applications**

- Differentiate high-performance lightweight cements from liquids
- Map annulus material as solid, liquid, or gas
- Assess hydraulic isolation
- Identify channels and defects in annular isolating material
- Determine casing internal diameter and thickness
- Assess annulus beyond the casing/cement interface

Isolation Scanner cement evaluation service integrates the conventional pulse-echo technique with flexural wave propagation to fully characterize the cased hole annular environment while evaluating casing condition.

Identifying and distinguishing various well fluids from cement with low acoustic impedance is difficult for CBL and ultrasonic pulse-echo techniques.
PITCH-CATCH PROPAGATION

The Isolation Scanner pulse-echo acoustic impedance measurement is made with a rotating subassembly containing four transducers. The normal-incidence transducer is oriented 180° from the other three transducers. The three obliquely aligned transducers transmit and receive high-frequency pulsed beams (on the order of 250 kHz) to excite the casing in a flexural mode. Once excited in the casing, the flexural wave propagates while radiating acoustic energy into the annulus and back toward the receiving transducers, resulting in a circumferential scan of the casing, annulus, cement, and near-wellbore formation. The annulus-propagating energy is reflected at interfaces that present an acoustic contrast, such as the cement/formation interface, and propagates back through the casing predominantly as a flexural wave that reradiates energy into the casing fluid.

Geometrical interpretation of signal propagation for the pulse-echo (blue paths) and flexural wave imaging (green paths) techniques shows that the pitch-catch flexural wave signal separates into an early-arriving (or casing) signal and a later-arriving (TIE) signal in reference to the first interface encountered in the annulus (the inner and outer walls of the casing are the first and second interfaces, respectively). The attenuation of the casing arrival amplitude complements the pulse-echo measurement to determine whether the material behind the casing is a fluid or a solid. If TIEs are present in the acquired data, they are used to further enhance the characterization of the cased hole environment in terms of the state and acoustic properties (wave speed) of the material filling the annulus, the position of the casing within the hole, and the geometrical shape of the hole.
INSIGHT THROUGH ATTENUATION

The rate of energy radiation into the annulus depends on the acoustic properties of the annular fill. The attenuation is estimated by capturing the reflected signals at two of the receivers, which are a known distance apart, and calculating the decay rate of the received signal. Attenuation is expressed in decibels per centimeter.

For a fluid filling the annulus, the attenuation is approximately proportional to the acoustic impedance. For cement bonded to the casing, the attenuation exhibits a more complex behavior as a function of the velocities at which the compressional and shear waves propagate in the cement. As shown in the plot of flexural attenuation versus acoustic impedance for a well-bonded cement, below a critical impedance ($Z_c$) of approximately 3.9 Mrayl, the attenuation increases linearly with the impedance of the annular fill, whether the fill is liquid or solid. Beyond 3.9-Mrayl $Z_c$, only the shear waves can propagate in the cement, and the attenuation drops sharply to small values. A high-impedance cement, such as Class G, has an attenuation similar to that of a liquid. This ambiguity in identifying cement is resolved by determining the acoustic impedance of the cement with the pulse-echo technique. However, the distinct attenuation of low-impedance cements, such as lightweight or contaminated cements, is used to differentiate them from fluids.

SOLID-LIQUID-GAS MAPPING

The first goal of Isolation Scanner processing is to provide a robust interpreted image of the material immediately behind the casing. The inputs are cement impedance determined by the pulse-echo measurement and flexural wave attenuation computed from the amplitude of the casing arrivals on the near and far receivers. These two independent measurements are linked to the properties of both the fluid inside the casing and the outside medium through an invertible relation. Combining them accounts for the effect of the inside fluid, which eliminates the need for logging specific fluid-property measurements.

The processing output is a solid-liquid-gas (SLG) map displaying the most likely material behind the casing. The map is computed during an initialization step before logging by using a priori knowledge of the possible materials:

- **Gas** is defined as a very low impedance material, independent of any input.
- **Liquid** is defined as a liquid with the expected acoustic impedance of the mud displaced by the cement, with provisions for possible deviations from this value.
- **Solid** is defined through the expected type of cement. A laboratory-measured database is used to convert the material selection into acoustic properties, again with provisions made for some contamination or incompletely set cement.

Areas corresponding to inconsistencies between the measurements (for example, at collars) are shown in white.

The mapped states are obtained for each azimuth by locating the pulse-echo and flexural attenuation measurements, corrected for the effect of the inside fluid, on the map with the areas encompassed by each state.

Flexural wave attenuation of a well-bonded cement is plotted as a function of acoustic impedance for various materials. The value of $Z_c$ corresponds to the critical compressional wave speed of the cement.

Three clouds of points are generated in SLG mapping of the measurement plane for a Class G cement $Z_{us}$ is the impedance determined by the pulse-echo technique; the attenuation is for the flexural wave technique.
By measuring radially and beyond traditional cement evaluation boundaries, Isolation Scanner service confirms zonal isolation, pinpoints any channels in the cement, and ensures confident squeeze or no-squeeze decisions.

In addition to pulse-echo information on the rugosity, radius, cross section, and thickness of the 7-in [17.8-cm] casing, Isolation Scanner service processed the acoustic impedance and flexural attenuation data to produce an SLG map. Although the cement is heavy Class G, the flexural attenuation map clearly displays low-density material from X330 to X370 m, revealing that the cement is contaminated in that interval. Regardless of the density difference, the material is correctly indicated as solid on the SLG map.
NEW MEASUREMENTS FROM FORMATION-WALL ECHOES

In addition to the SLG map identifying the annular fill immediately behind the casing, a further Isolation Scanner objective is to extract relevant information from the annulus/formation reflection echo or echoes for quantifying the state of the annulus between the casing and formation. First, the echoes following the casing arrival are detected and their time of arrival and amplitude measured. From the time differences between the reflection echoes and the casing arrival—provided sufficient echo azimuthal presence is available in the data—the casing centering within the borehole can be determined. This is conveniently presented as a percentage, with 100% representing perfect centering and 0% for fully eccentered casing, in contact with the formation wall. If the borehole diameter is known, the time-difference processing can be further converted into material wave velocity and is displayed as an annulus velocity map.

Other new measurements possible with the Isolation Scanner TIE reflected from the cement/formation interface are

- estimated wave velocity, which can be used to confirm the SLG map and better understand cement placement
- imaged borehole shape
- imaged outer string to reveal corrosion and damage.

Isolation Scanner imaging of the formation wall through casing and cement reveals hole enlargement (caving) in the reflection echo from the cement/formation interface at two opposite azimuths in the intervals X,673–X,675 m and X,679–X,682 m. The left-side image, displaying the raw data at all azimuths, shows that the formation-wall echo is present at nearly all azimuths. Echo moveout appears sinusoidal because of casing eccentricity. Each cycle represents a tool azimuthal scan.
### Measurement Specifications

<table>
<thead>
<tr>
<th>Output^1</th>
<th>Solid-liquid-gas map of annulus material, hydraulic communication map, acoustic impedance, flexural attenuation, rugosity image, casing thickness image, internal radius image</th>
</tr>
</thead>
</table>
| Max. logging speed | Standard resolution (6 in, 10° sampling): 623 m/h (2,700 ft/h)  
High resolution (0.6 in, 5° sampling): 172 m/h (563 ft/h) |
| Range of measurement | Min. casing thickness: 0.38 cm (0.15 in)  
Max. casing thickness: 7.01 cm (0.275 in) |
| Vertical resolution | High resolution: 1.52 cm (0.6 in)  
High speed: 15.24 cm (6 in) |
| Acoustic impedance^1 | Range: 0 to 10 Mrayl  
Resolution: 0.2 Mrayl  
Accuracy: 0 to 3.3 Mrayl = ±0.5 Mrayl, >3.3 Mrayl = ±15% |
| Flexural attenuation | Range: 0 to 2 dB/cm^4  
Resolution: 0.05 dB/cm^4  
Accuracy: 0.01 dB/cm^4 |
| Min. quantifiable channel width | 30 mm (1.2 in) |
| Depth of investigation^1 | Casing and annulus up to 7.62 cm (3 in) |
| Mud type or weight limitation†† | Conditions simulated before logging |
| Combinability | Bottom only, combinable with most wireline tools  
Telemetry: fast transfer bus (FTB) or enhanced FTB (EFTB) |
| Special applications | H₂S service |

^1 Investigation of annulus width depends on the presence of third-interface echoes. Analysis and processing beyond cement evaluation can yield additional answers through additional outputs, including the Variable Density log (VDL) of the annulus waveform and polar movies in AVI format.

^4 Differentiation of materials by acoustic impedance alone requires a minimum gap of 0.5 Mrayl between the fluid behind the casing and a solid.

^‡ Differentiation of materials by acoustic impedance alone requires a minimum gap of 0.5 Mrayl between the fluid behind the casing and a solid.

| Special applications | H₂S service |

### Mechanical Specifications

<table>
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<tr>
<th>Isolation Scanner Tool</th>
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</thead>
<tbody>
<tr>
<td>Max. temperature</td>
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<tr>
<td>Pressure range</td>
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<tr>
<td>Casing size—min.</td>
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<tr>
<td>Casing size—max.</td>
</tr>
</tbody>
</table>
| Outside diameter | IBCS-A: 8.57 cm (3.375 in)  
IBCS-B: 11.36 cm (4.472 in)  
IBCS-C: 16.91 cm (6.657 in) |
| Length without sub | 6.01 m (19.73 ft) |
| Weight without sub | 151 kg (333 lbm) |
| Sub length, weight | IBCS-A: 61.22 cm (24.10 in), 7.59 kg (16.75 lbm)  
IBCS-B: 60.32 cm (23.75 in), 9.36 kg (20.64 lbm)  
IBCS-C: 60.32 cm (23.75 in), 10.73 kg (23.66 lbm) |
| Sub max. tension | 10,000 N (2,250 lbf) |
| Sub max. compression | 50,000 N (12,250 lbf) |

^† Limits for casing size depend on the sub used. Data can be acquired in casing larger than 9.5 in with low-attenuation mud (e.g., water, brine).

^†† Max. mud weight depends on the mud formulation, sub used, and casing size and weight, which are simulated before logging.