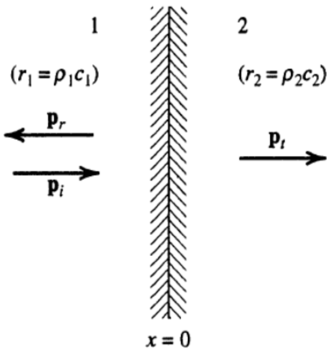
Reflection and transmission



Acoustic impedance r

$$r = \frac{p}{u} = \rho c$$

where

p : pressure
u : particle velocity
ρ : density
c : sound speed

An incident wave traveling in the $+x$ direction is

$$\mathbf{p}_i = \mathbf{P}_i e^{-jk_1 x}$$

It generates a reflected wave $\mathbf{p}_r = \mathbf{P}_r e^{jk_1 x}$ and a transmitted wave $\mathbf{p}_t = \mathbf{P}_t e^{-jk_2 x}$

The sound speed c_1 and c_2 are different, implies the wave numbers are different, that is,

$$k_1 = \frac{\omega}{c_1} \quad \text{and} \quad k_2 = \frac{\omega}{c_2}$$

Two boundary conditions to be satisfied:

(1) the acoustic pressures on both sides of the boundary must be equal
--- *continuity of pressure,* and

(2) the normal components of the particle velocities on both sides of the boundary must be equal
--- *continuity of the normal component of velocity*.

$$\mathbf{p}_i + \mathbf{p}_r = \mathbf{p}_t \quad \text{at} \quad x = 0$$

$$\mathbf{u}_i + \mathbf{u}_r = \mathbf{u}_t \quad \text{at} \quad x = 0$$

Division of the 1st equation by the 2nd equation yields

$$\frac{\mathbf{p}_i + \mathbf{p}_r}{\mathbf{u}_i + \mathbf{u}_r} = \frac{\mathbf{p}_t}{\mathbf{u}_t} \quad \text{at} \quad x = 0$$

--- continuity of normal specific acoustic impedance

A plane wave has $\mathbf{u} = \pm\, \mathbf{p}/r$, the sign depending on the direction of propagation.

It becomes

$$r_1 \frac{\mathbf{p}_i + \mathbf{p}_r}{\mathbf{p}_i - \mathbf{p}_r} = r_2$$

that leads to the *reflection coefficient*

$$\mathbf{R} = \frac{\mathbf{P}_r}{\mathbf{P}_i} = \frac{r_2 - r_1}{r_2 + r_1} = \frac{r_2/r_1 - 1}{r_2/r_1 + 1}$$

that is always real. It is positive when $r_1 < r_2$ and negative when $r_1 > r_2$

The reflected wave is either in phase or 180° out of phase with that of the incident wave.

When $r_1 = r_2$ then $\mathbf{R} = 0$, and there is complete transmission.

The *transmission coefficient* $\mathbf{T}$ is defined as

$$\mathbf{T} = \frac{\mathbf{P}_t}{\mathbf{P}_i}$$

Since

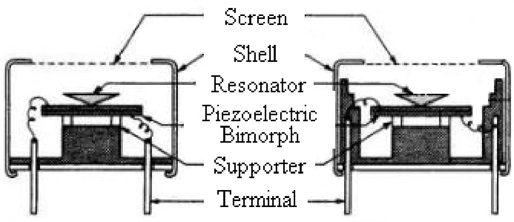
$$1 + \mathbf{R} = \mathbf{T}$$

results in

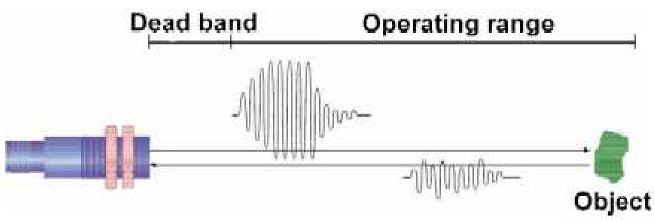
$$\mathbf{T} = \frac{2r_2}{r_2 + r_1} = \frac{2r_2/r_1}{r_2/r_1 + 1}$$

$\mathbf{T}$ is real and positive regardless of the relative magnitudes of r_1 and r_2. The transmitted wave is *always in phase* with that of the incident wave.

Non-Contact Ultrasonic Distance Sensors



Principle of operation



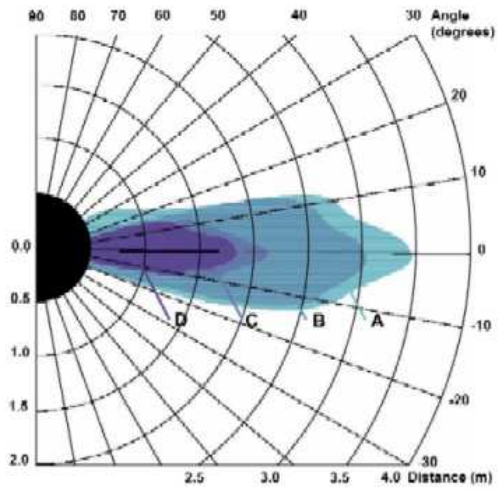
Ultrasonic sensors operate in reflex mode. An ultrasonic transducer emits and receives the ultrasonic signala. Within a stipulated distance range, the incoming echo is checked, the time taken for the sound to travel the distance is determined and a corresponding output signal is emitted. If the distance between the sensor and the objects is too small, the echo arrives before the ultrasonic transducer has reached steady state and is ready to receive. Objects in this dead band cannot be detected reliably.

Sound cone and response curve

Sound cone is a function of response distance to angle.

Different sound cones result for different objects.

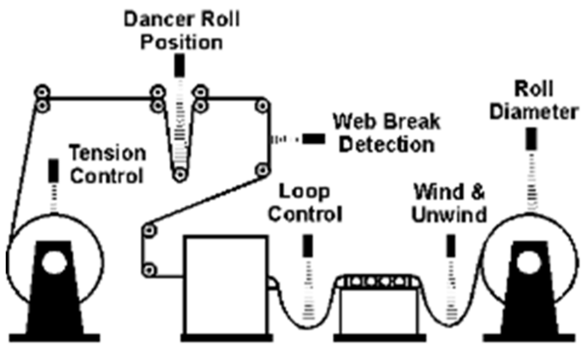
A : level target, 700 x 700 mm
B : level target, 100 x 100 mm
C : felt tube, f 16 mm
D : round bar smooth, f 25 mm



Response curves of the sensor

Motion Control

These applications are common in the converting, pulp and paper, printing, rubber, metal and textile industries. The object being sensed and controlled is usually a web or tube material being manufactured, wound/unwound, processed, positioned or stacked.



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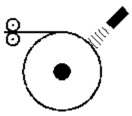
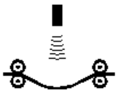
Roll Diameter

The sensor can provide an output proportional to the diameter of a roll of material as it winds or unwinds on a machine.



Loop Control

The sensor can look down and measure the vertical position of a free loop of material as it is being moved from one machine to another, to maintain the material loop in a fixed mid-range position so that it does not break .



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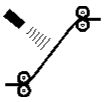
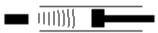
Web Break

The sensor can detect the break and initiate shut-down if the web material moving through a press or other web processing machine breaks, .



Position Feedback

The sensor measures the distance to a remote object to control the positioning of that object.



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Dimension & Level applications

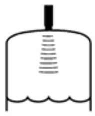
Stack Height

Object Dimensions

Height & Size

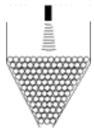
Liquid Level

These applications range from benign open top tanks in clean environments to severe process environments involving high temperature and pressures, caustic or hazardous materials.



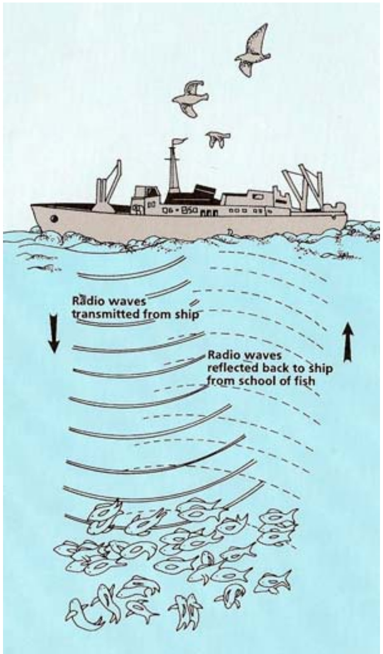
Solids Level

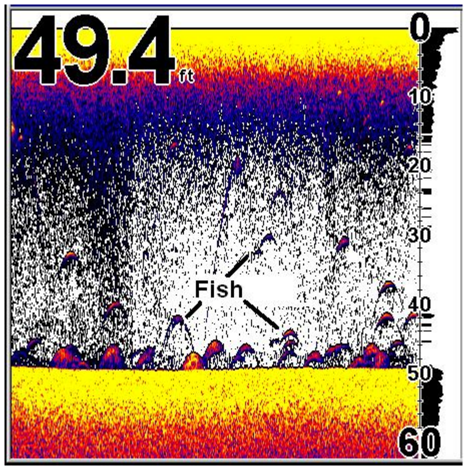
Dry material level in bins or hoppers can be measured if the materials provide sufficient ultrasonic echo for reliable detection.



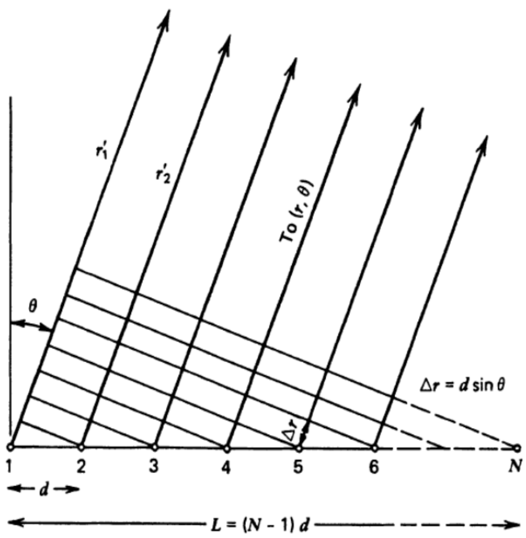
Fishing sonar

Frequency:200kHz
Sensor Beam Angle: 45 Degrees
Depth range: 0.7m to 100m





The line array



A line of N simple sources

d : adjacent elements space

The ith source generates a pressure wave

$$(A/r_i')\exp[j(\omega t - kr_i')].$$

The resultant pressure is

$$\mathbf{p}(r,\theta,t) = \sum_{i=1}^{N} \frac{A}{r_i'} e^{j(\omega t - kr')}$$

The far field $r \gg L,\ L = (N-1)d$

$$r_i = r_1 - (i-1)\Delta r, \quad \Delta r = d\sin\theta$$

The distance to the center of the array

$$r = r_1 - \tfrac{1}{2}(L/d)\,\Delta r$$

$$\mathbf{p}(r,\theta,t) = \frac{A}{r} e^{-j(L/2d)k\Delta r} e^{j(\omega t - kr)} \sum_{i=1}^{N} e^{j(i-1)k\Delta r}$$

or

$$\mathbf{p}(r,\theta,t) = \frac{A}{r} e^{j(\omega t - kr)} \left(\frac{\sin[(N/2)k\Delta r]}{\sin[(1/2)k\Delta r]} \right) = P_{ax}(r) H(\theta) e^{j(\omega t - kr)}$$

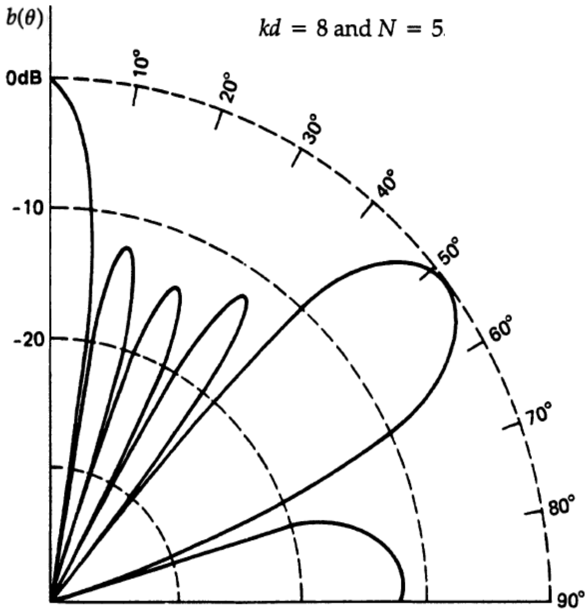
where

$$P_{ax}(r) = NA/r$$

and

$$H(\theta) = \left| \frac{1}{N} \frac{\sin[(N/2)kd\sin\theta]}{\sin[(1/2)kd\sin\theta]} \right|$$

is the directional factor



Electronic steering

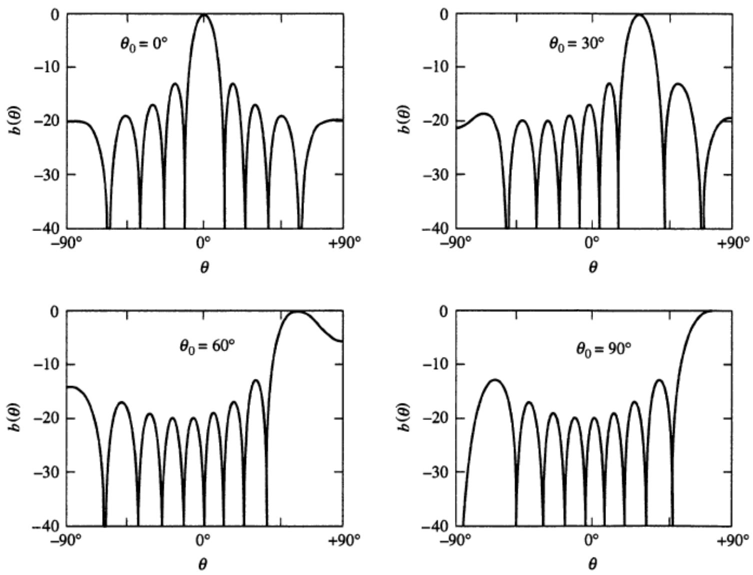
A time delay $i\tau$ is inserted into the signal for the ith element of the array

$$\mathbf{p}(r,\theta,t) = \sum_{i=1}^{N} \frac{A}{r_i'} e^{j[\omega(t+i\tau) - kr_i']}$$

the directional factor becomes

$$H(\theta) = \left| \frac{1}{N} \frac{\sin[(N/2)kd(\sin\theta - \sin\theta_0)]}{\sin[(1/2)kd(\sin\theta - \sin\theta_0)]} \right| \qquad \sin\theta_0 = c\tau/d$$

θ_0 : the direction of the major lobe that is independent of frequency.



$$kd = \pi(N-1)/N$$

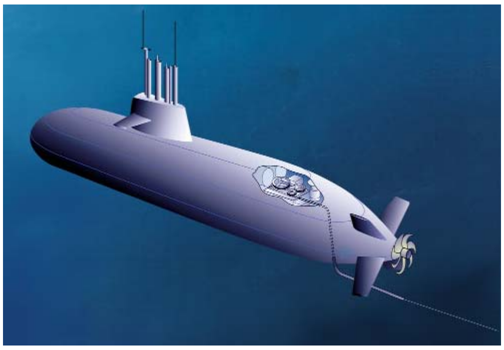
Linear array probe

Ultrasonic scanner

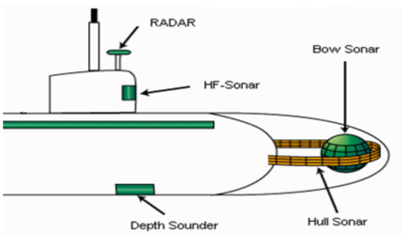
Microphone array

TB-29A thin line towed array sonar

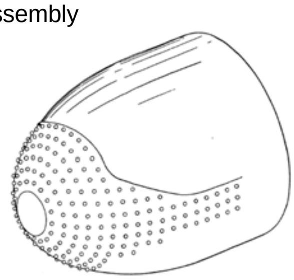
The 3.8 *cm* outside diameter, 1.9 *cm* internal diameter array incorporates 13 × 48.8 *m* long acoustic modules each containing 32 acoustic channels. The array is towed at the end of a 365 *m* long cable.



Bow & Hull Sonar



Homing torpedo nose assembly



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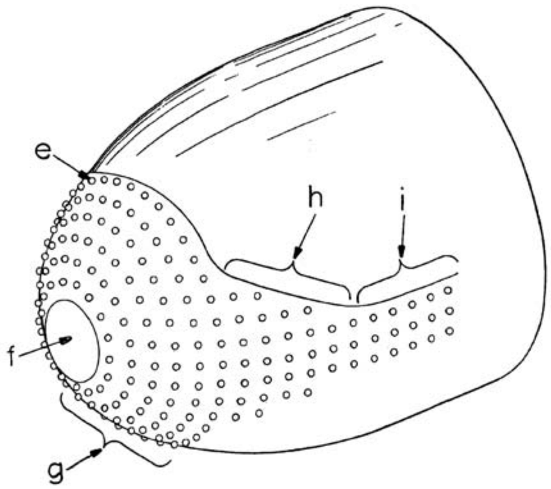

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