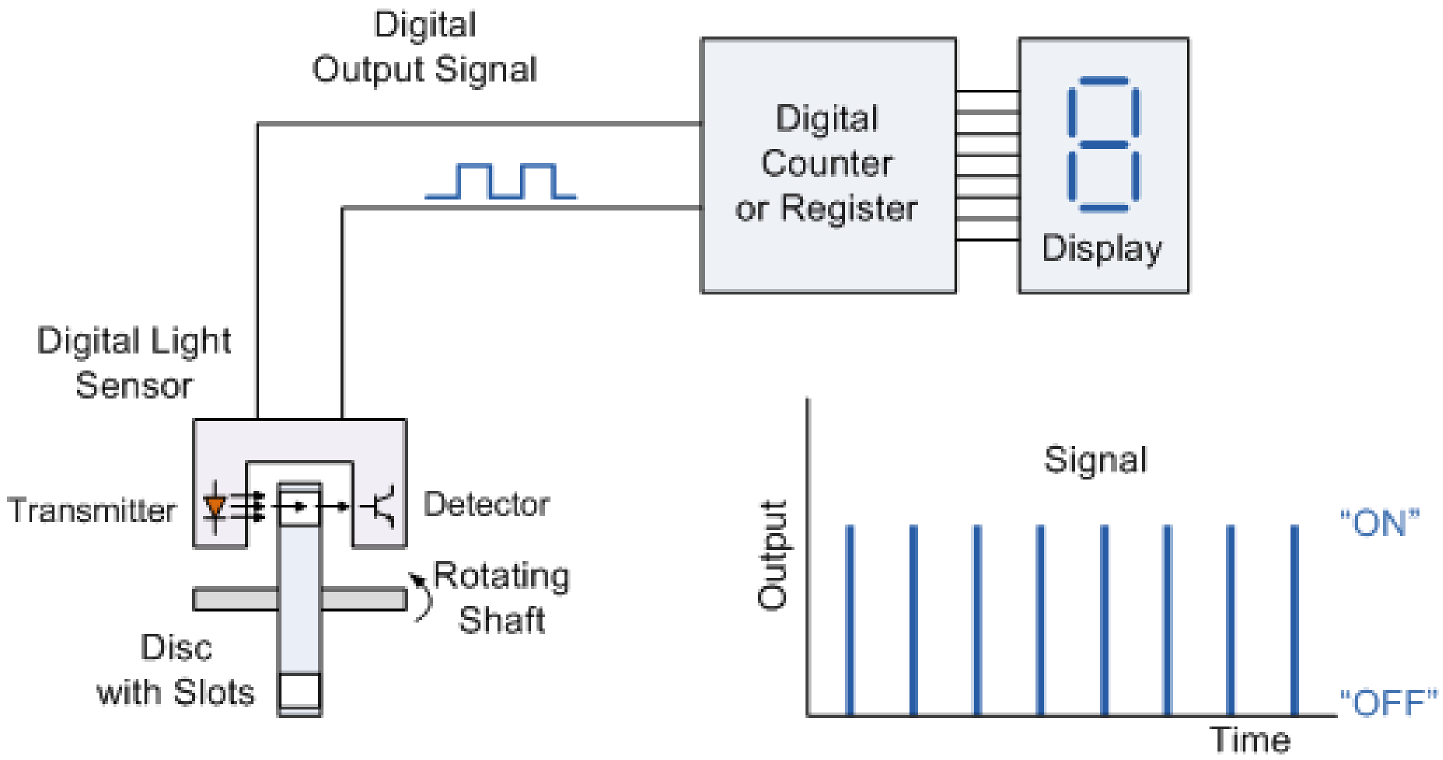
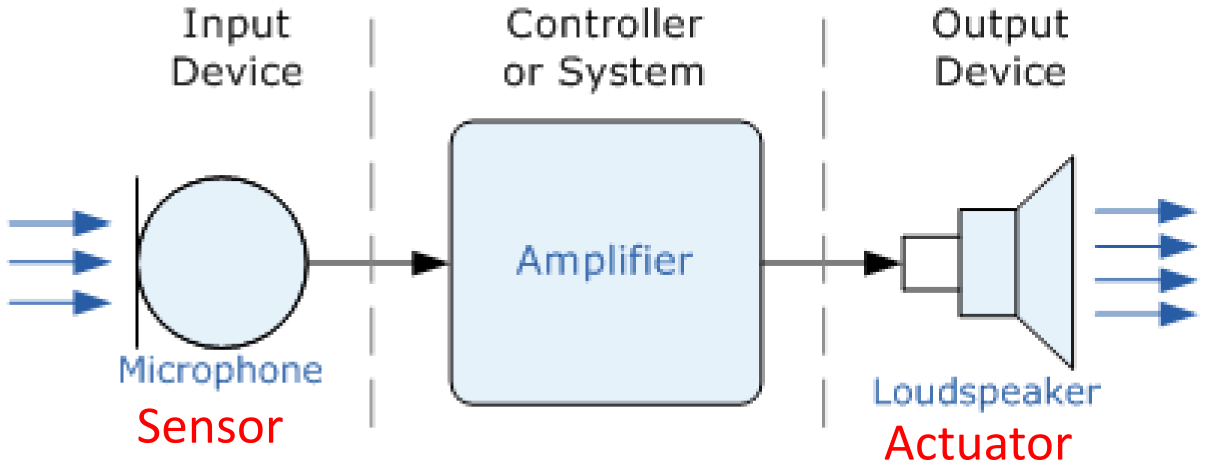


Transducers

Terminology

- Transducers convert one form of energy into another
- Sensors/Actuators are input/output transducers
- Sensors can be *passive* (e.g. change in resistance) or *active* (output is a voltage or current level)
- Sensors can be *analog* (e.g. thermocouples) or *digital* (e.g. digital tachometer)

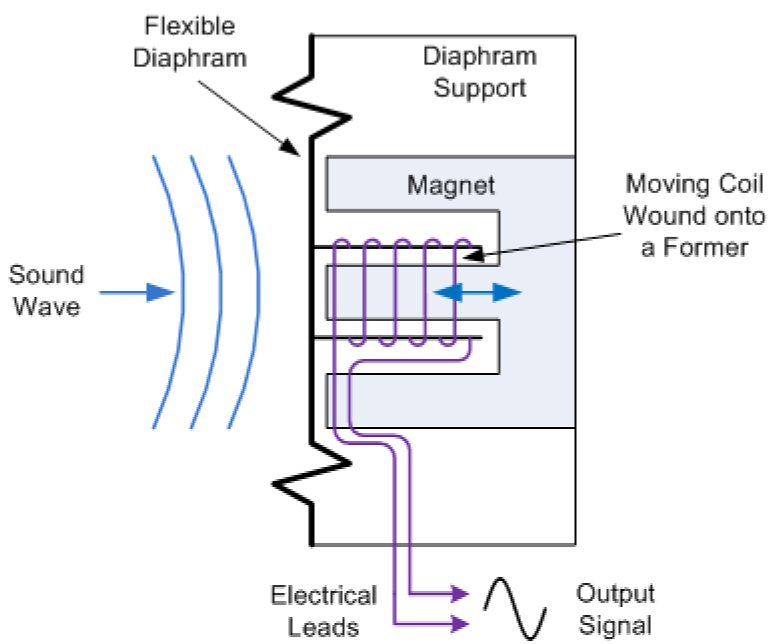


Transducer types

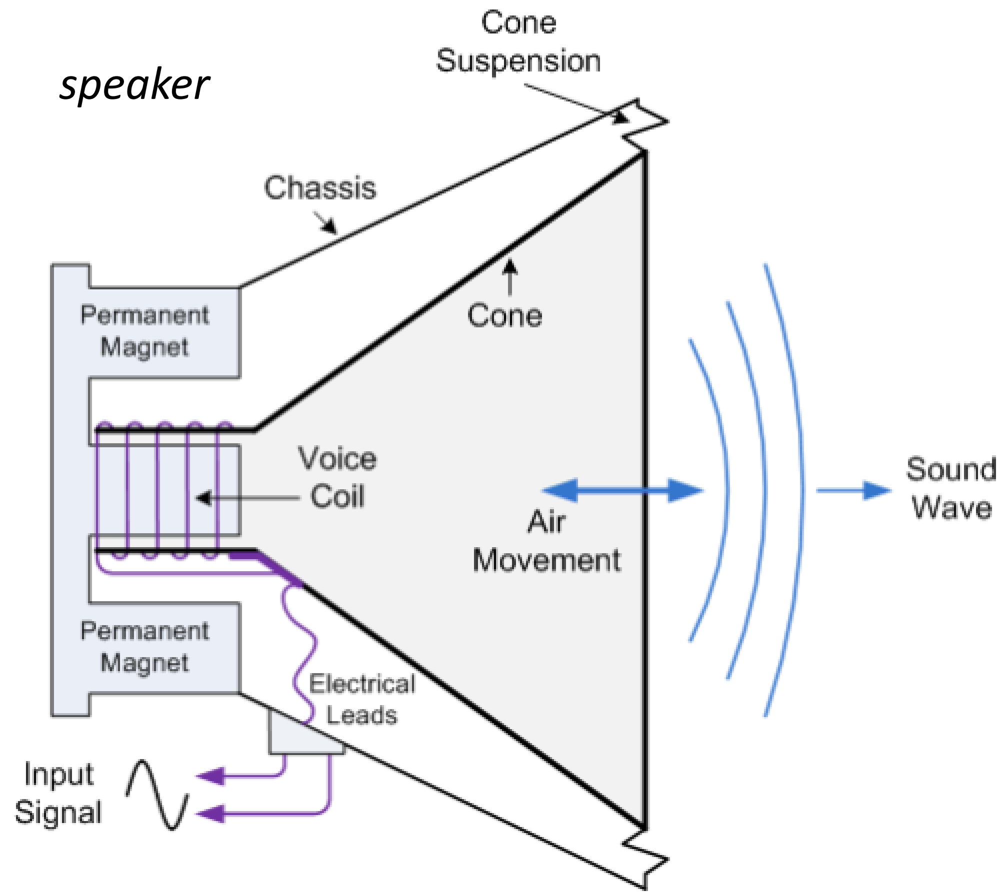
Quantity being Measured	Input Device (Sensor)	Output Device (Actuator)
Light Level	Light Dependant Resistor (LDR), Photodiode, Phototransistor, Solar Cell	Lights & Lamps, LED's & Displays, Fiber Optics
Temperature	Thermocouple, Thermistor, Thermostat, Resistive temperature detectors (RTD)	Heater, Fan, Peltier Elements
Force/Pressure	Strain Gauge, Pressure Switch, Load Cells	Lifts & Jacks, Electromagnetic, Vibration
Position	Potentiometer, Encoders, Reflective/Slotted Opto-switch, LVDT	Motor, Solenoid, Panel Meters
Speed	Tacho-generator, Reflective/Slotted Opto-coupler, Doppler Effect Sensors	AC and DC Motors, Stepper Motor, Brake
Sound	Carbon Microphone, Piezo-electric Crystal	Bell, Buzzer, Loudspeaker

Sound transducers

microphone



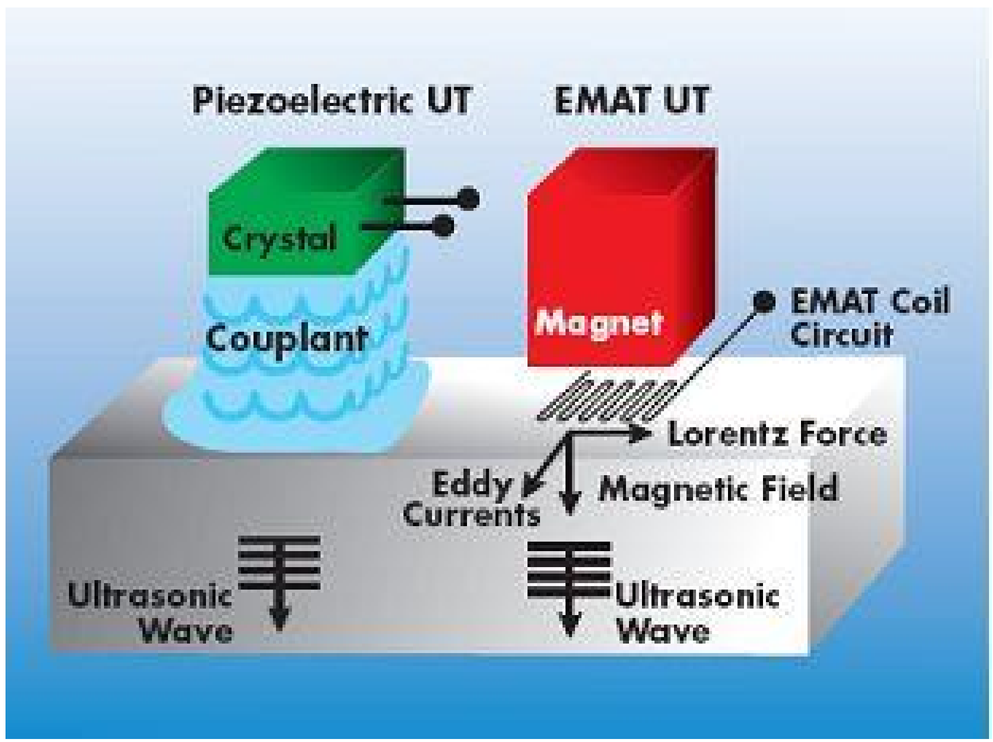
speaker



- Note: voice coil can also be used to generate fast motion

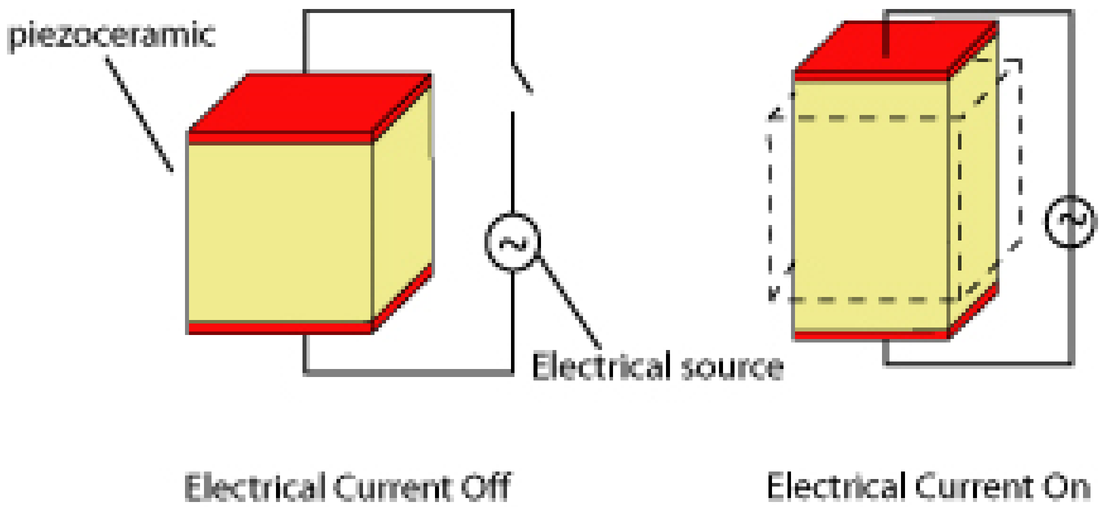
Acoustic Transducers

1. **Piezo transducers**
2. **Magnetostrictive transducer (or)**
   Electromagnetic acoustic transducer (EMAT)



Piezo transducers

- Detect motion (high and low frequency)
- Sound, pressure, fast motion
- Cheap, reliable but has a very limited range of motion



Piezoelectric transducer

- The definition of a Piezoelectric transducer is an electrical transducer which can convert any form of physical quantity into an electrical signal, which can be used for measurement.
- An electrical transducer which uses properties of piezoelectric materials for conversion of physical quantities into electrical signals is known as a piezoelectric transducer.

- Piezoelectric materials exhibit the property of piezoelectricity, according to which on the application of any type of mechanical stress or strain leads to the generation of an electric voltage proportional to the applied stress.
- This produced electric voltage can be measured using voltage measuring instruments to calculate the value of stress or strain applied to the material.

Types of piezoelectric materials

Natural materials:

Quartz, Rochelle salt, Topaz, Tourmaline-group minerals, and some organic substances as silk, wood, enamel, bone, hair and rubber.

Artificial materials:

Polyvinylidene difluoride (PVDF), Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Potassium niobate, Lithium niobate, Lithium tantalate, and other lead-free piezoelectric ceramics.

- Not all piezoelectric materials can be used in piezoelectric transducers.
- There are certain requirements to be met by the piezoelectric materials to be used as transducers.
- The materials should have frequency stability, high output values, insensitive to the extreme temperature and humidity conditions and which can be available in various shapes or should be flexible to be manufactured into various shapes without disturbing their properties.

- Quartz crystal coated with silver is used as a sensor to generate a voltage when stress is applied on it. A charge amplifier is used to measure the produced charge without dissipation. To draw very low current the resistance R1 is very high. The capacitance of the lead wire that connects the transducer and piezoelectric sensor also affects the calibration. So the charge amplifier is usually placed very near to the sensor.
- So in a piezoelectric transducer when mechanical stress is applied a proportional electric voltage is generated which is amplified using charge amplifier and used for calibration of applied stress.
- **Piezoelectric Ultrasonic Transducer**
- The ultrasonic piezoelectric transducer works on the principle of the converse piezoelectric effect. In this effect when electricity is applied to a piezoelectric material, it undergoes physical deformations proportional to applied charge.

Applications of Piezoelectric Transducer

- As piezoelectric materials cannot measure static values these are primarily used for measuring surface roughness, in accelerometers and as a vibration pickup.
- They are used in seismographs to measure vibrations in rockets.
- In strain gauges to measure force, stress, vibrations etc…
- Used by automotive industries to measure detonations in engines.
- These are used in ultrasonic imaging in medical applications.

Advantages

- These are active transducer i.e. they don’t require external power for working and are therefore self-generating.
- The high-frequency response of these transducers makes a good choice for various applications.

Limitations

- Temperature and environmental conditions can affect the behavior of the transducer.
- They can only measure changing pressure hence they are useless while measuring static parameters.

- **Electromagnetic acoustic transducer** (**EMAT**)
- It is a transducer for non-contact acoustic wave generation and reception in conducting materials.
- Its effect is based on electromagnetic mechanisms, which do not need direct coupling with the surface of the material.
- Due to this couplant-free feature, EMATs are particularly useful in harsh, *i.e.*, hot, cold, clean, or dry environments.
- EMATs are suitable to generate all kinds of waves in metallic and/or magnetostrictive materials.
- Depending on the design and orientation of coils and magnets, bulk wave, surface wave, plate waves, Lamb waves, and all sorts of other wave modes can be excited.

Basic components

- There are two basic components in an EMAT transducer. One is a magnet and the other is an electric coil.
- The magnet can be a permanent magnet or an electromagnet, which produces a static or a quasi-static magnetic field.
- In EMAT terminology, this field is called bias magnetic field. The electric coil is driven with an alternating current (AC) electric signal at ultrasonic frequency, typically in the range from 20 kHz to 10 MHz.
- Based on the application needs, the signal can be a continuous wave, a spike pulse, or a tone-burst signal.
- The electric coil with AC current also generates an AC magnetic field.
- When the test material is close to the EMAT, ultrasonic waves are generated in the test material through the interaction of the two magnetic fields.

Transduction mechanism

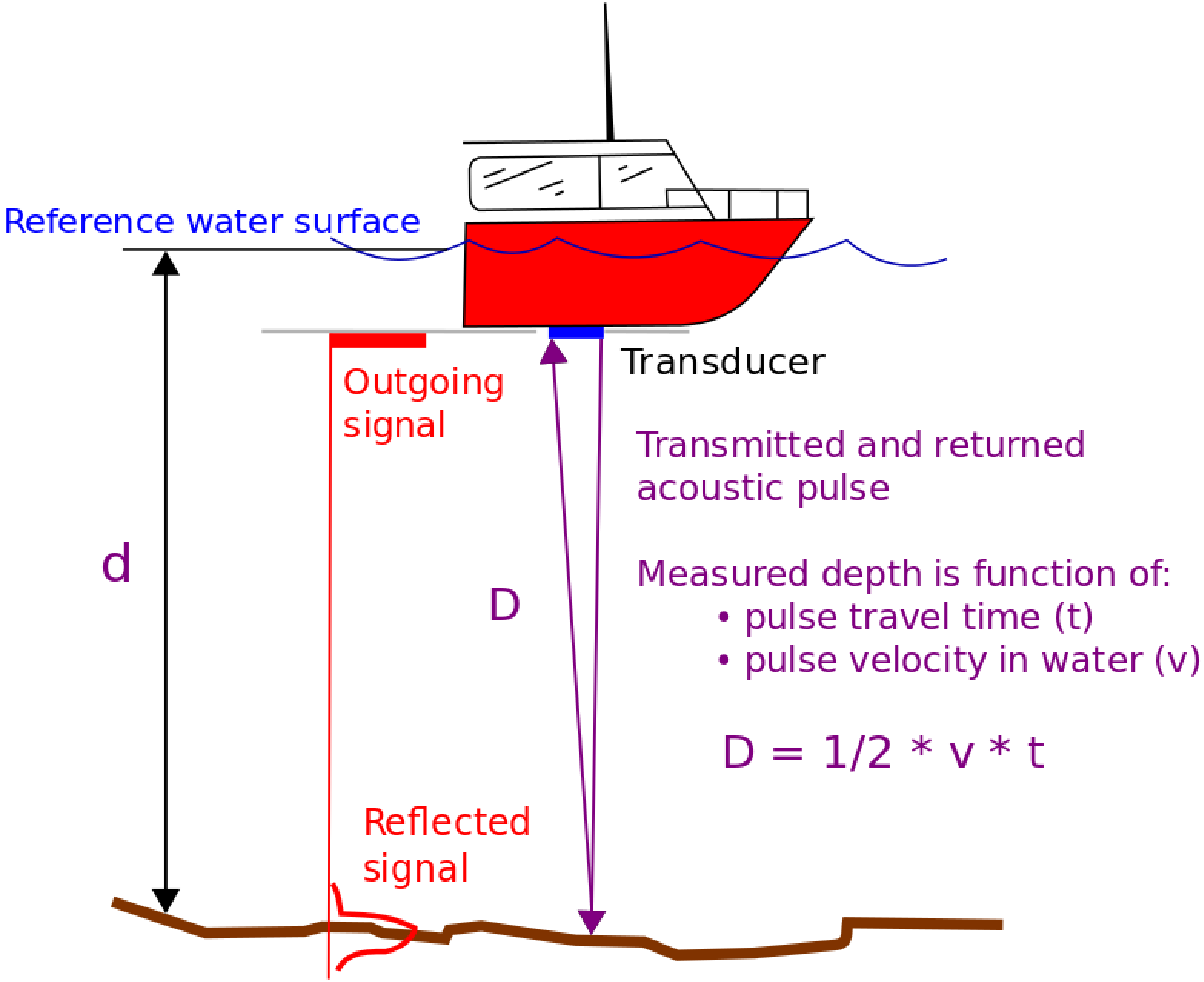
- There are two mechanisms to generate waves through magnetic field interaction.
- One is Lorentz force when the material is conductive.
- The other is magnetostriction when the material is ferromagnetic.

- A ferromagnetic material will have a dimensional change when an external magnetic field is applied. This effect is called magnetostriction. The AC current in the electric coil induces an AC magnetic field and thus produces magnetostriction at ultrasonic frequency in the material. The disturbances caused by magnetostriction then propagate in the material as an ultrasound wave.
- In polycrystalline material, the magnetostriction response is very complicated. It is affected by the direction of the bias field, the direction of the field from the AC electric coil, the strength of the bias field, and the amplitude of the AC current.
- The magnetostriction effect has been used to generate both SH-type and Lamb type waves in steel products. Recently, due to the stronger magnetostriction effect in nickel than steel, magnetostriction sensors using nickel patches have been developed for the nondestructive testing of steel products.

- **Advantages**
- Compared to piezoelectric transducers, EMAT probes have the following advantages:
- No couplant is needed. Based on the transduction mechanism of EMAT, couplant is not required. This makes EMAT ideal for inspections at temperatures below the freezing point and above the evaporation point of liquid couplants
- EMAT is a non-contact method. Although proximity is preferred, a physical contact between the transducer and the specimen under test is not required.
- Dry Inspection. Since no couplant is needed, the EMAT inspection can be performed in a dry environment.
- Less sensitive to surface condition. With contact-based piezoelectric transducers, the test surface has to be machined smoothly to ensure coupling. Using EMAT, the requirements to surface smoothness are less stringent; the only requirement is to remove loose scale and the like.
- Easier to generate SH-type waves. Using piezoelectric transducers, SH wave is difficult to couple to the test part. EMAT provide a convenient means of generating SH bulk wave and SH guided waves.
- **Challenges and disadvantages**
- EMAT transducers typically produce raw signal of lower power than piezoelectric transducers. As a result, more sophisticated signal processing techniques are needed to isolate signal from noise.
- Plastic and ceramic material is not suitable for EMAT.
- **Applications**
- Thickness measurement for various applications
- Flaw detection in steel products
- Plate lamination defect inspection
- Bonded structure lamination detection
- Laser weld inspection for automotive components
- Weld inspection for coil join, tubes and pipes
- Railroad rail and wheel inspection
- Austenitic weld inspection for the power industry
- EMATs have been used in research for ultrasonic communication
- Used in underwater and underground environments as well as sealed environments

Echo Sound Transducers

- Echo sounding is a type of sonar used to determine the depth of water by transmitting sound waves into water.
- The time interval between emission and return of a pulse is recorded, which is used to determine the depth of water along with the speed of sound in water at the time.
- This information is then typically used for navigation purposes or in order to obtain depths for charting purposes.
- Echo sounding can also refer to hydroacoustic "echo sounders" defined as active sound in water (sonar) used to study fish schools.
- Hydroacoustic assessments have traditionally employed mobile surveys from boats to evaluate fish biomass and spatial distributions. Conversely, fixed-location techniques use stationary transducers to monitor passing fish.


Reference water surface
Transducer
Outgoing signal
Transmitted and returned acoustic pulse
Measured depth is function of:
• pulse travel time (t)
• pulse velocity in water (v)
D = 1/2 * v * t
d
D
Reflected signal

- The echo sounder transmits the sound pulses downward into the water by a transducer.
- The echo reflected from the bed is also received by the echo sounder.
- The time interval between the emission of the sound pulse and its return as an echo is used to estimate the depth of the water.
- Aid to navigation, commonly used for fishing.
- Variations in elevation often represent places where fish congregate.
- Schools of fish will also register.
- A fish finder is an echo sounding device used by both recreational and commercial fishers.

- **Single beam echo sounders** (SBES), also known as **depth sounders** or fathometers determine water **depth** by measuring the travel time of a short sonar pulse, or “ping”.
- The sonar ping is emitted from a transducer positioned just below the water surface, and the SBES listens for the return **echo** from the bottom.

- **Double beam echosounder**
- The majority of hydrographic echosounders are dual frequency, meaning that a low frequency pulse (around 24 kHz) can be transmitted at the same time as a high frequency pulse (around 200 kHz). As the two frequencies are discrete, the two return signals do not typically interfere with each other.
- There are many advantages of dual frequency echosounding, including the ability to identify a vegetation layer or a layer of soft mud on top of a layer of rock.
- A screen grab of the difference between single and dual frequency echograms
- Most hydrographic operations use a 200 kHz transducer, which is suitable for inshore work up to 100 metres in depth.
- Deeper water requires a lower frequency transducer as the acoustic signal of lower frequencies is less susceptible to attenuation in the water column. Commonly used frequencies for deep water sounding are 33 kHz and 24 kHz.
- This is especially important when sounding in deep water, as the resulting footprint of the acoustic pulse can be very large once it reaches a distant sea floor.
- In addition to the single beam echo sounder, there are echo sounders that are capable of receiving many return "pings". These systems are detailed further in the section called multibeam echo sounder.

- **Sub-bottom Profiling**
- A depth sounder, also known as a Sub-bottom profiler, SBP, or a sediment profiler is a device that penetrates the seabed.
- Structurally, the SBPs are similar to Singlebeam Echosounders, but they are working at lower frequencies and gathering vertical cross-sections of the inner sediment seabed.
- The function of a sediment profiler is to record echoes from the interfaces between sedimentary layers. These layers correspond to breaks in acoustic impedance, generating reflection of the acoustic signal.
- The frequency range of sediment profilers is a few kHz which respond to acoustic wavelengths typically between 0.2 and 1m. The most commonly used nominal frequency is 3.5kHz. The choice of the main working frequency is very important, as it constrains greatly the penetration range of the sounder.

- **How does a Sub-bottom Profiler work?**
- The usual bandwidths of 1-3 kHz correspond to resolutions between 0.75m and 0.25m.
- After a ping is transmitted, the next pings are transmitted without waiting for the first ping echo to return.
- Important is to pay attention only that the transmissions do not interfere with reception windows for the echoes from the seabed.
- Ambiguities are solved either by using the true water depth after the first non-ambiguous detections or the data from another sounder.

- **Sub-bottom Profiler with chirp**
- CHIRP stands for “Compressed High-Intensity Radar Pulse.” Chirp sonars show more detailed information about the sea ground or environment because it produces a more accurate and detailed return of the echoes of the target.
- CHIRP technology modifies the pulse that is sent by the Transducer.
- Instead of transmitting distinct pulses beneath the Boat, CHIRP technology modifies the pulse so that a range of frequencies are transmitted by the transducer; say 28 to 60 kHz, or 130 to 210 kHz, or 42 to 65 kHz.

- **Sub-bottom Profiler data processing**
- First, the data has to be imported into Sub-bottom Profiler Processing Software in a readable format such as the SEG-Y format. Then some processing tests, filters and stacking velocity analysis are done.
- Next steps include:
- Muting of leaked timing and first arrivals.
- Band pass filtering
- Amplitude the balance of the whole trace.
- Multiple suppression to eliminate related multiple surfaces.
- Common midpoint sorting
- Normal Moveout Correction (NMO) with calculated velocity function to stretch the time axis and make all seismograms look like zero offset seismograms.
- Trimming non-surface consistent statics around water bottom
- Set the right automatic gain control
- Common midpoint stacking
- Minimum entropy deconvolution
- Finite difference time migration using stacking velocity function

- **Applications of Sub-bottom Profilers**
- Sediment profilers facilitate investigation of the characteristics of buried sediment layers such as cables, pipes, boulders, layers or natural resource pockets like oil and gas, minerals or water.

Biosensor is a device for the detection of an analyte that combines a biological component with a physicochemical detector component.

It consists of 3 parts.

1. Biological material (eg. tissue, microorganisms, organelles, cell receptors, enzymes, antibodies, nucleic acids, etc), a biologically derived material or biomimic. The sensitive elements can be created by biological engineering.

2. Transducer or the detector element (works in a physicochemical way; optical, piezoelectric, electrochemical, etc.).

   It transforms the signal resulting from the interaction of the analyte with the biological element into another signal (i.e., transducers) that can be more easily measured and quantified.

3. Associated electronics or signal processors that are primarily responsible for the display of the results in a user-friendly way.

- A common example of a biosensor is the **blood glucose biosensor**.
- It uses the enzyme glucose oxidase to break blood glucose.
- It first oxidizes glucose and uses two electrons to reduce the FAD (flavin adenine dinucleotide) to FADH2.
- This in turn is oxidized by the electrode (accepting two electrons from the electrode) in a number of steps.
- The resulting current is a measure of the concentration of glucose.

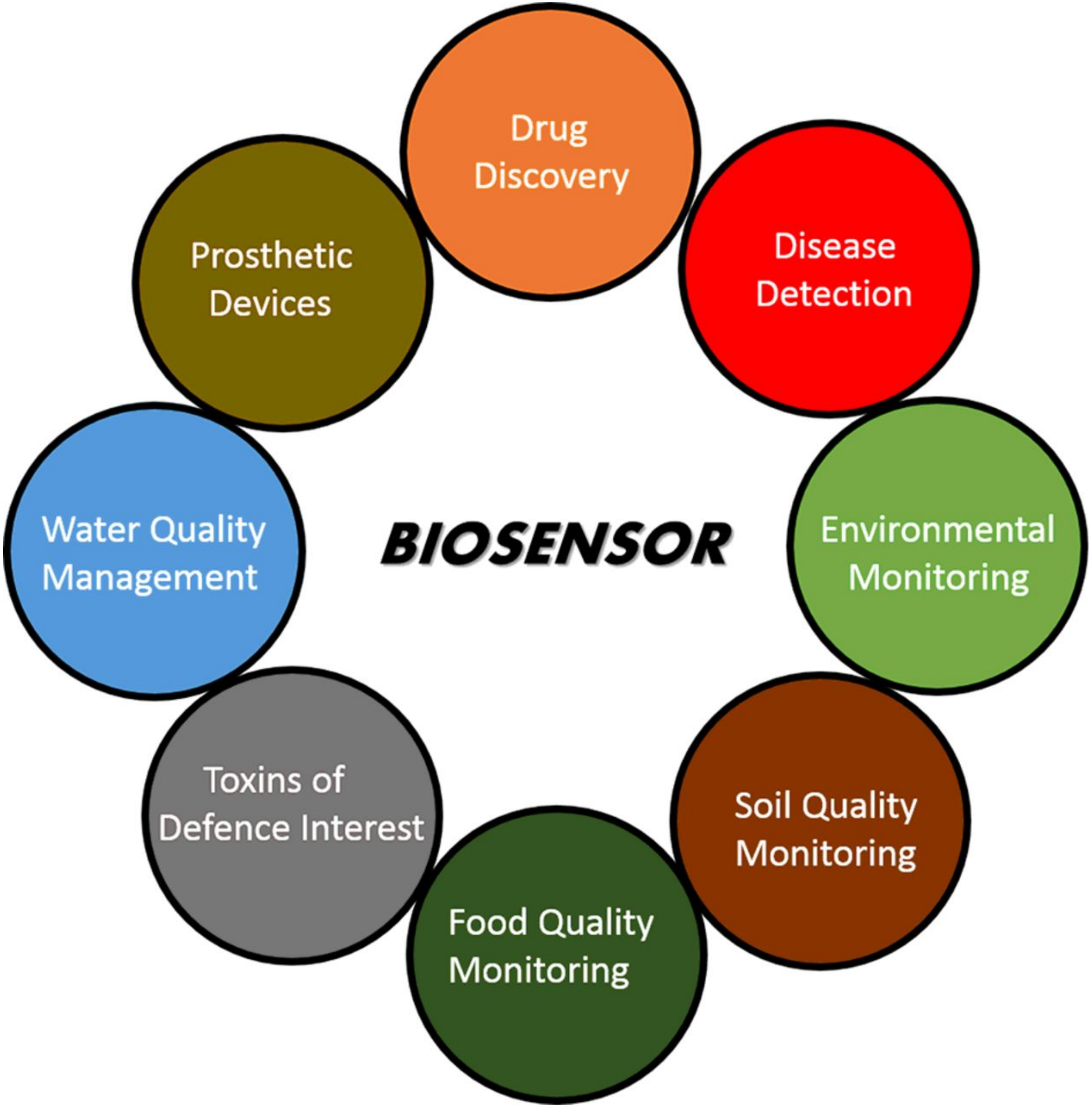
- In this case, the electrode is the transducer and the enzyme is the biologically active component.
- Many of today's biosensor applications are similar, in that they use organisms which respond to toxic substances at a much lower level.
- Such devices can be used in environmental monitoring, trace gas detection and in water treatment facilities.

Applications

- Glucose monitoring in diabetes patients
- Environmental applications

  e.g. detection of pesticides and river water contaminants
- Detection of pathogens
- Determining levels of toxic substances before and after bioremediation
- Detection and determining of organophosphate

- Analytical measurement of folic acid, biotin, vitamin B12 and pantothenic acid as an alternative to microbiological assay
- Determination of drug residues in food, such as antibiotics and growth promoters, particularly meat and honey.
- Drug discovery and evaluation of biological activity of new compounds.
- Detection of toxic metabolites such as mycotoxins.


Drug Discovery
Disease Detection
Environmental Monitoring
Soil Quality Monitoring
Food Quality Monitoring
Toxins of Defence Interest
Water Quality Management
Prosthetic Devices
BIOSENSOR

Biosensors in fisheries

- Problems of poor water quality affect most developed countries in the world, the contaminants stemming largely from industrial waste and sewage.
- The effects of these pollutants have already been noted, particularly in fish, which often show reproductive dysfunction with males displaying feminization.
- The biochemical responses of organisms to organic and metal compounds in the water can be measured and used as a biomarker for the level of pollution.

- Most commonly, Cytochrome P4501A is used as it is responsive to a number of organic chemicals including aromatic hydrocarbons and dioxins.
- The induction of this gene by these contaminants measured by changes in protein expression or mRNA levels.
- Alternatively, metallothioneins are utilized, which are induced specifically by metals.

EnviGuard$^{(R)}$

- EnviGuard is a trade name of a biosensor developed by Dr. Ian Johnston, University of Hertfordshire, UK.
- It is used for environmental monitoring and disease prevention in aquaculture.
- EnviGuard's integrated modular approach utilises 3 independent bio-sensing technologies in a single, durable device. Providing an easier, faster and cheaper way to measure harmful substances in-situ in real-time.
- By combining innovations in nanotechnology and molecular science EnviGuard is developing the future state-of-the art in terms of accuracy, reliability and simplicity in operation.

- Three independent biosensors:

1. A quantitative nucleic acid based detection sensor for relevant toxic algae in waters.

2. An anti-body based optical nano-biosensing unit for the detection of chemicals & toxins.

3. An microfluidic aptamer-based fluorescence detection system to specifically detect pathogens

Sea-on-a-CHIP

- It is an immunosensor system with electrochemical transduction. The features are miniaturized, autonomous and remote operation system.

- Based on nanotechnology, microelectronics and microfluidics the chips are developed at a very low cost.

- The goal of this Sea-on-a- chip project is to develop a warning system for the health of oceans or sea, located in several marine areas.
- This system is characterized by a device, assembled on buoys, that will give information on the status of the water in real time through the use of a wireless connection and remotely controlled processes.
- The expected output could be used to attain information on a single analyte (tributyltin,diuron) or on a group of analytes (penta BDPEs, sulphonamides and algal toxins with their algal species).
- This tool can be elaborate the partial or total data collected in a station.
- The combination of a real time data collection concerning the general status of the water (routine measurements) with the toxicity prototypes could lead a warning system that could elucidate some phenomena not observed earlier and thus could lead to a better understanding of phenomena and improved sea water management.

- The device has an important for application in particular areas, where pollution due to industrial activities and natural events are present, and the cost of water treatment and control becomes significant.
- In this context, the biosensor technology, applied in seawater monitoring, could provide attractive solution with a substantial reduction of labour-intensive field sampling and laboratory analysis regimes.