Bubble Detection Sensors for Non-conducting Liquids

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Goals for Bubble Sensing Devices:

1. Detect small bubbles in a small fluid channel without immersion of sensor parts in the channel
2. Differentiate between a gas filled channel and a fluid filled channel
3. Be sensitive to rather small gas fractions passing down the small fluid channel

Desirable Features:

1. Small and flat
2. Inexpensive
3. Reliable

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Zen – No Sensor Sensor:

EIS

Magnetostatic Methods:

Magnetostatic Bubble Sensing – Impedance Method – 1 Coil
Magnetostatic Bubble Sensing – Transformer Method – 2 Coils
Magnetostatic Bubble Sensing – Gradiometer Method – 3 Coils

Galvanic Contact Methods:

Noble Metal Electrodic Methods

Permittivity (Capacitive) Methods:

Absolute Capacitance
Differential Capacitance

Mass flow Methods:

Mechanical Resonance of Fluid Loaded Beams

Ultrasonic Methods:

Pitch – Catch
Mechanical Impedance

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Nature of the Bubbles

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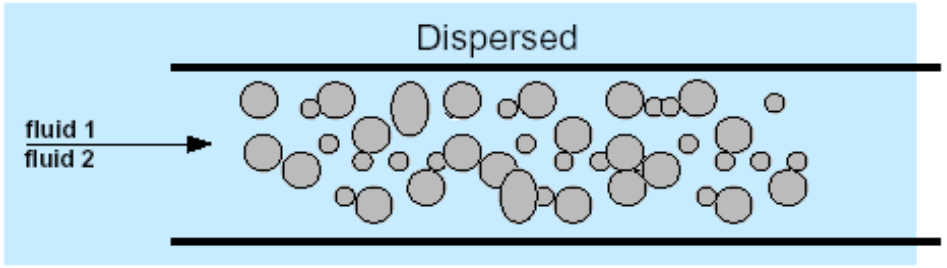
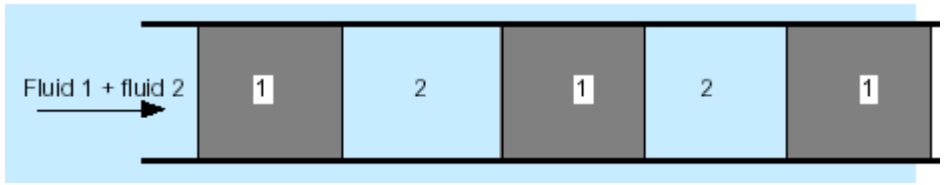
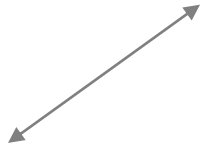
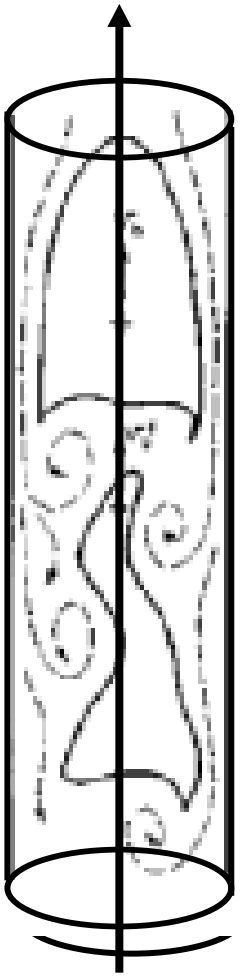
Nature of the Bubbles









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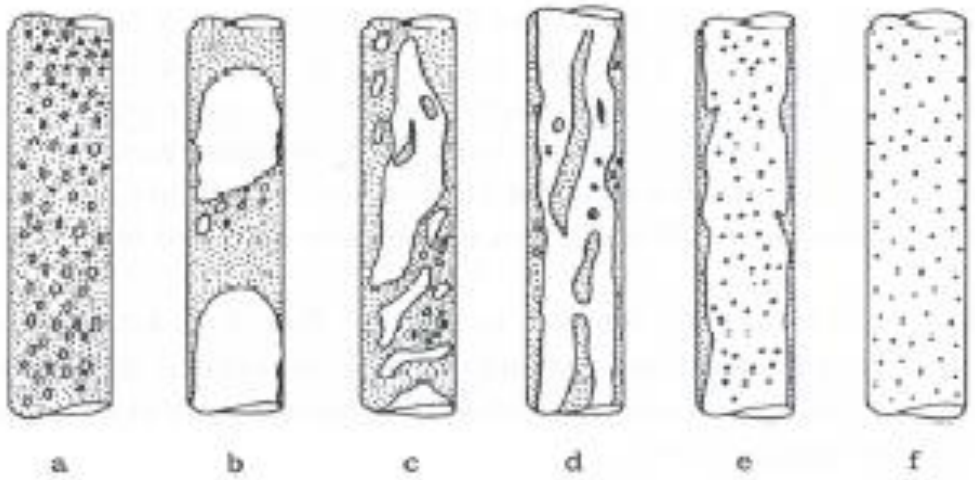
Nature of the Bubbles



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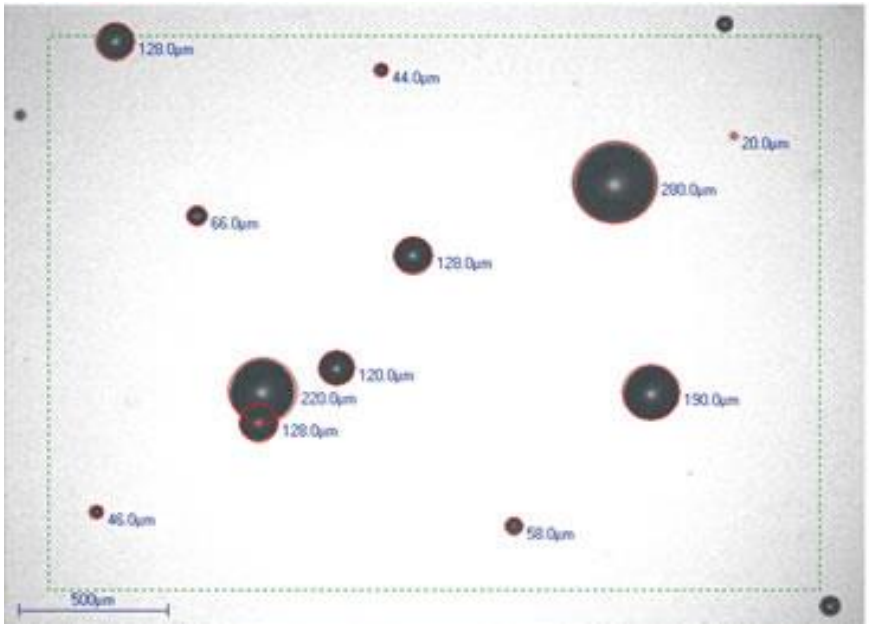
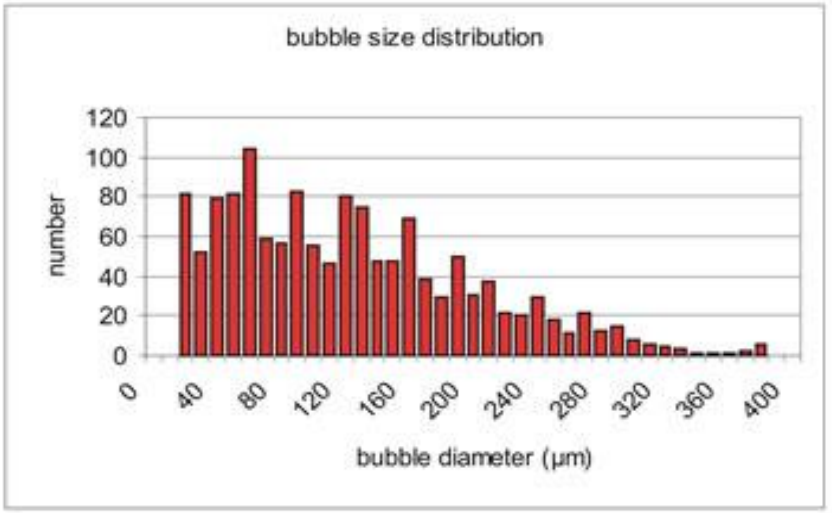
Nature of the Bubbles





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Nature of the Bubbles

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Electrical Impedance Bubble Sensing

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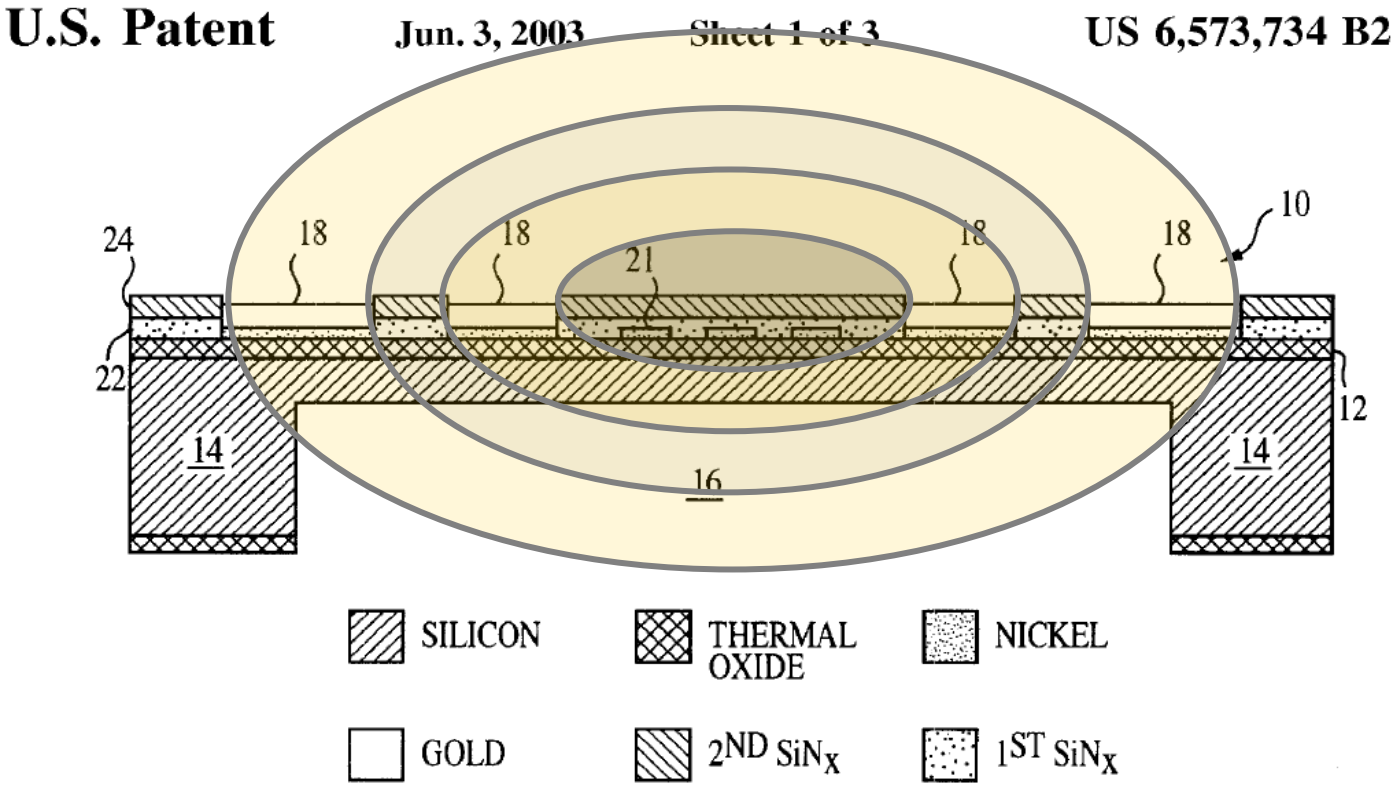
Electrodic Bubble Sensing Methods - MEMS



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Zen – No Sensor Sensor - EIS

Measure the liquid electrical impedance using electrode already in place for other reasons.

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Capacitive Bubble Sensing Methods

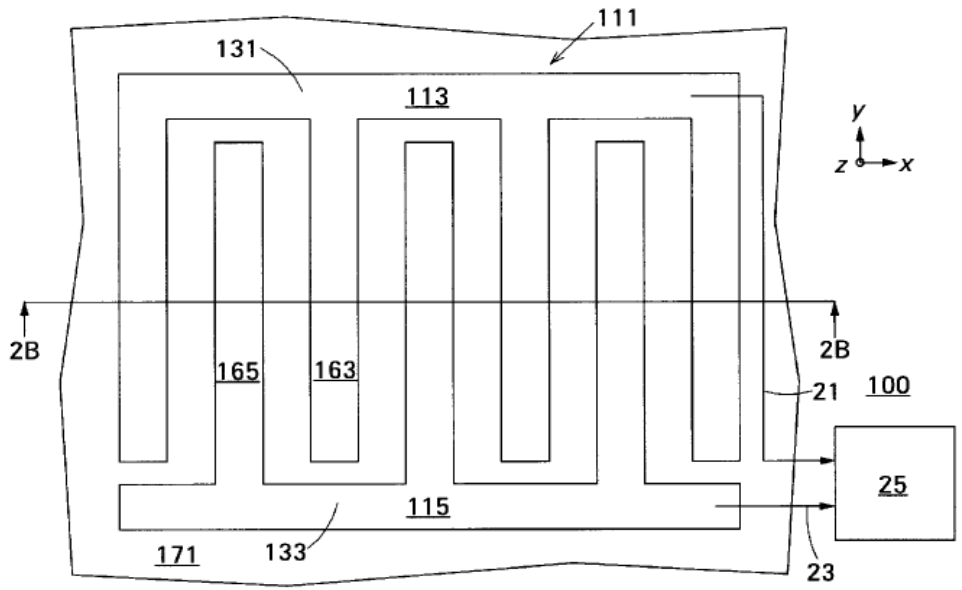

FIG.2A

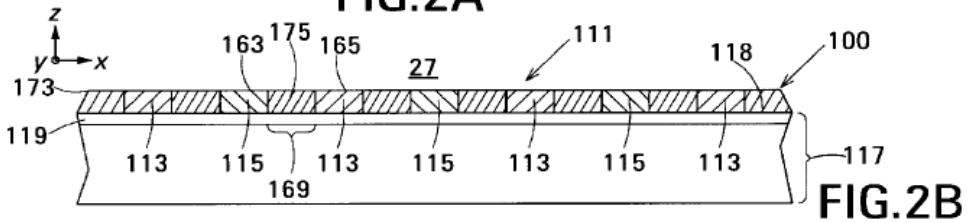

FIG.2B

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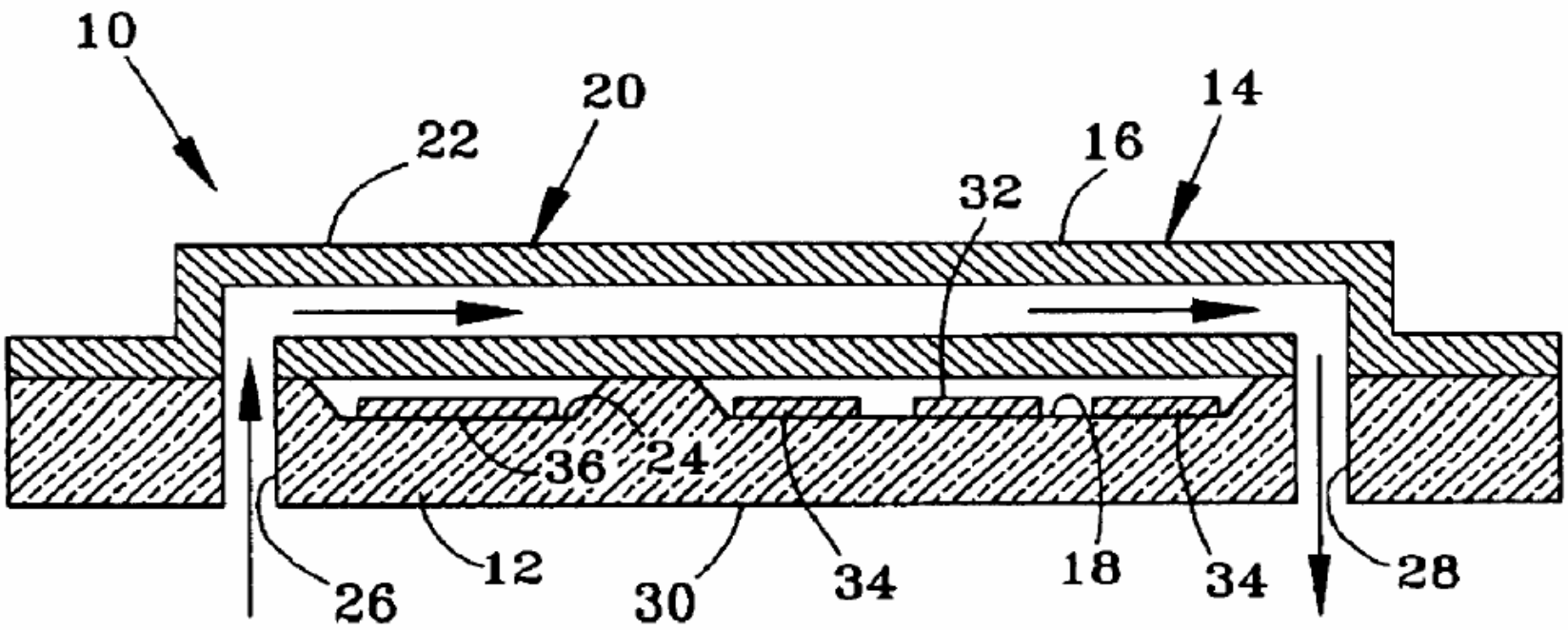
Mass Resonance Bubble Sensing - MEMS



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Optical Bubble Sensing Methods

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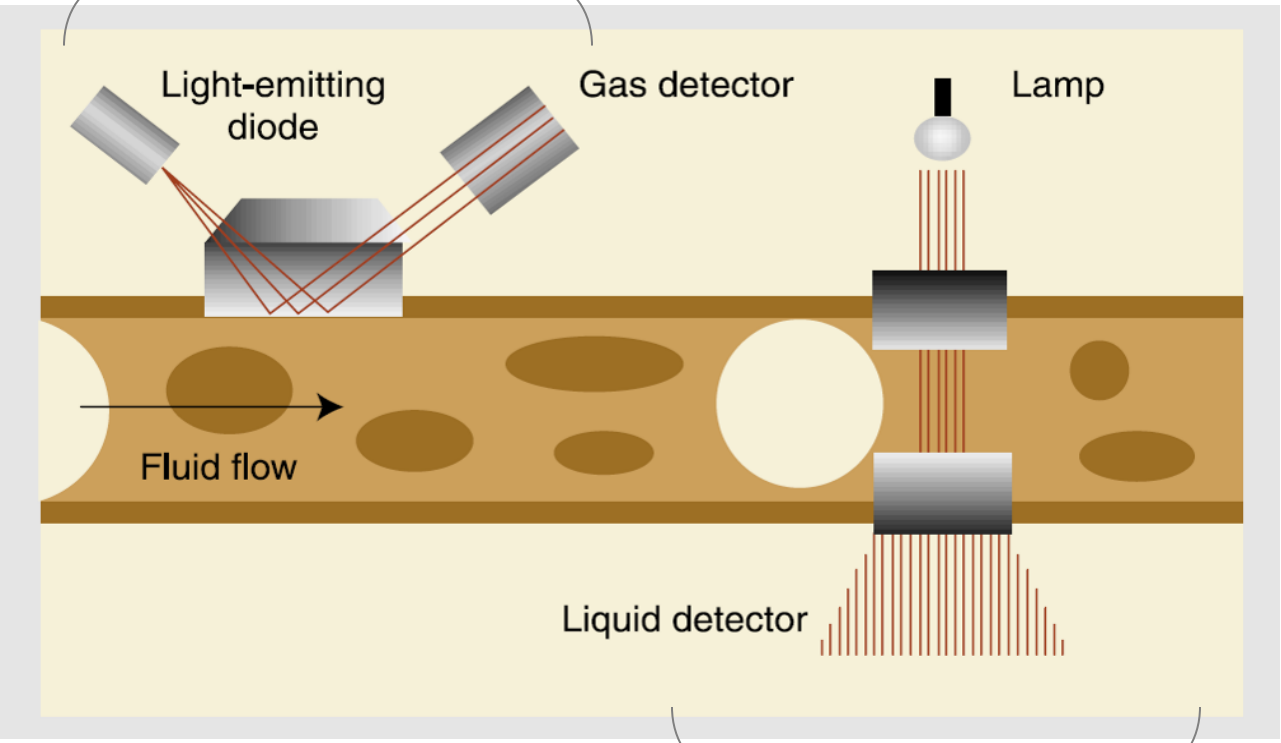
Optical Bubble Sensing Schemes

Pitch – Bounce - Catch



Pitch - Catch

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Optical Bubble Sensing – Pitch Catch Method

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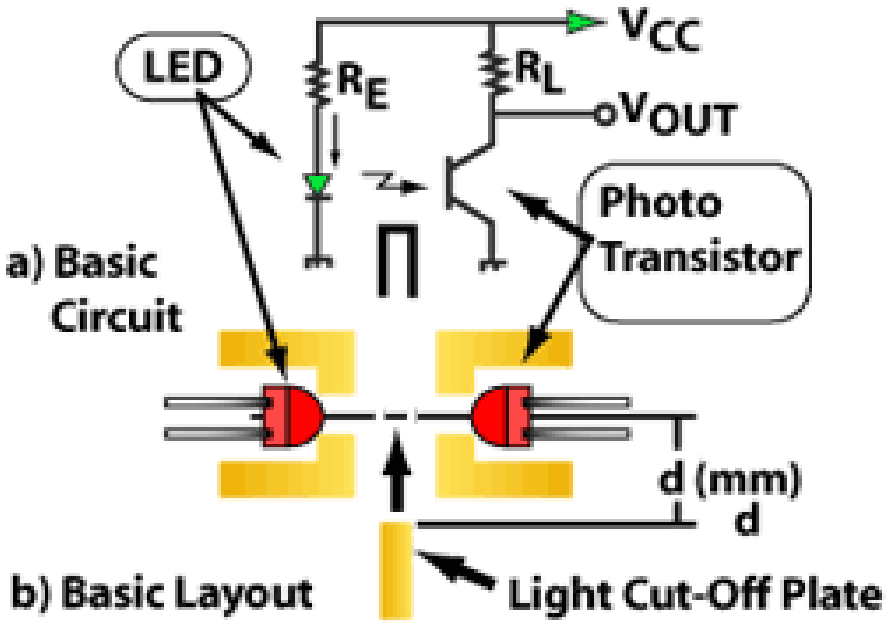
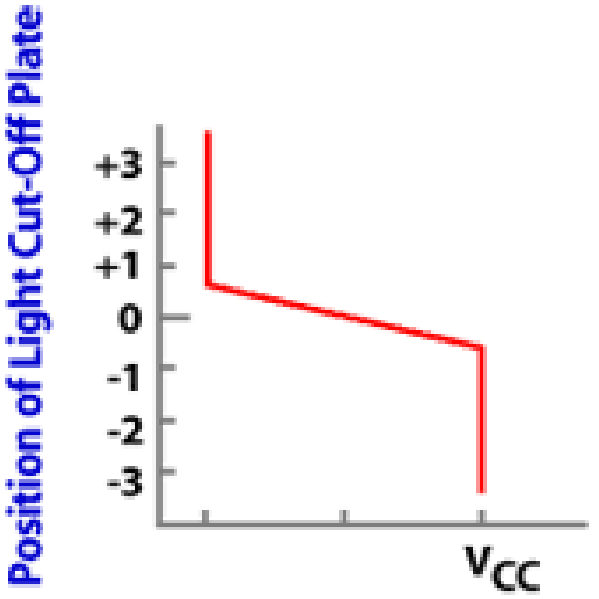
Optical Bubble Sensing – TIR Method





c) detecting Position Charactersistic

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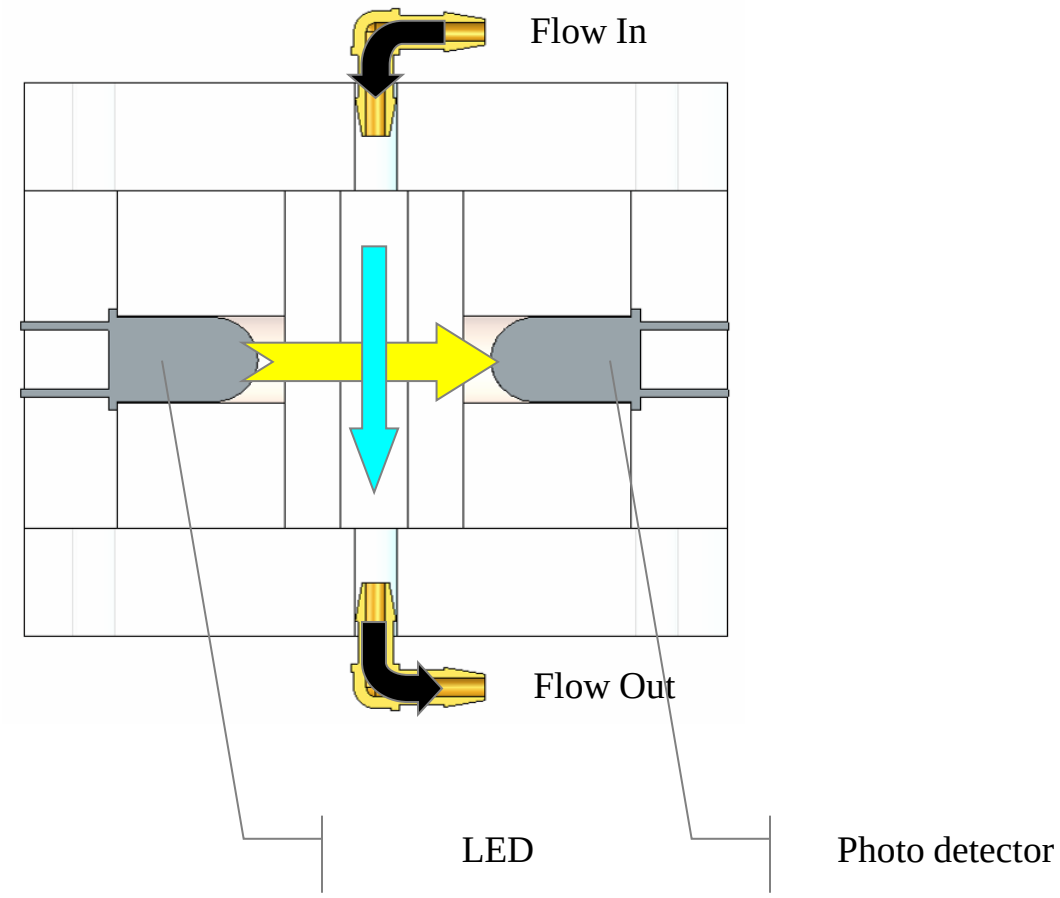
Optical Bubble Sensing – Pitch Catch Method



This bubble detection method cannot discriminate between “all gas” and “all electrolyte”

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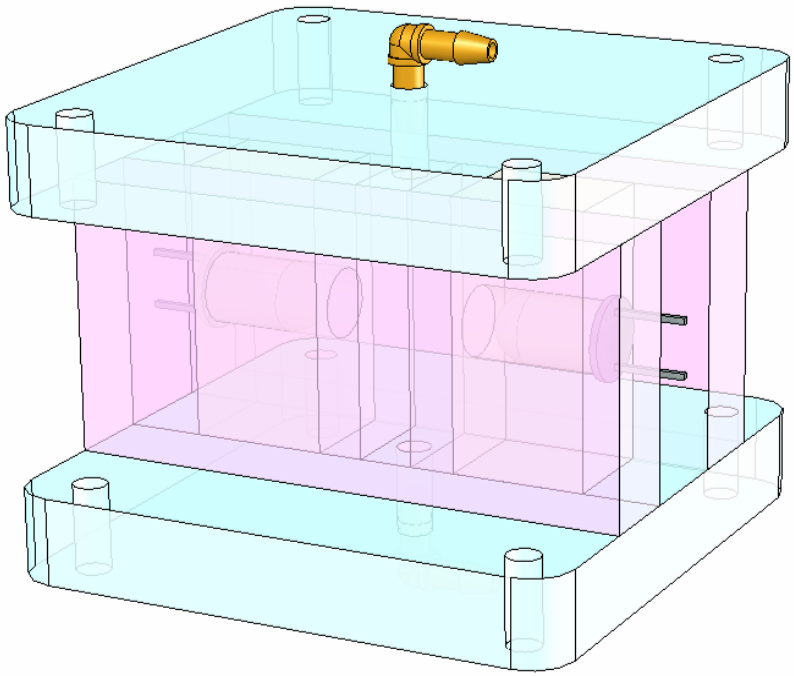
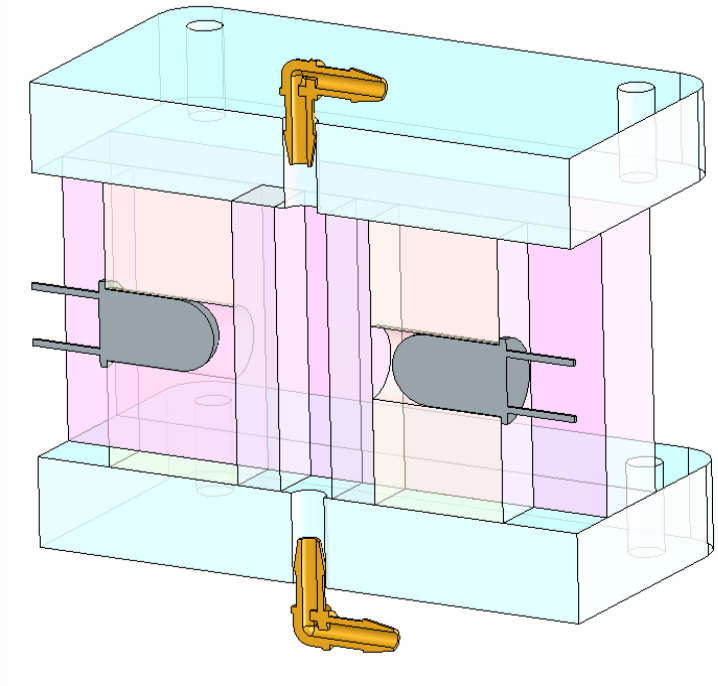
Optical Bubble Sensing – Pitch Catch Method





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Optical Bubble Sensing – Total Internal Reflectance (TIR) Method

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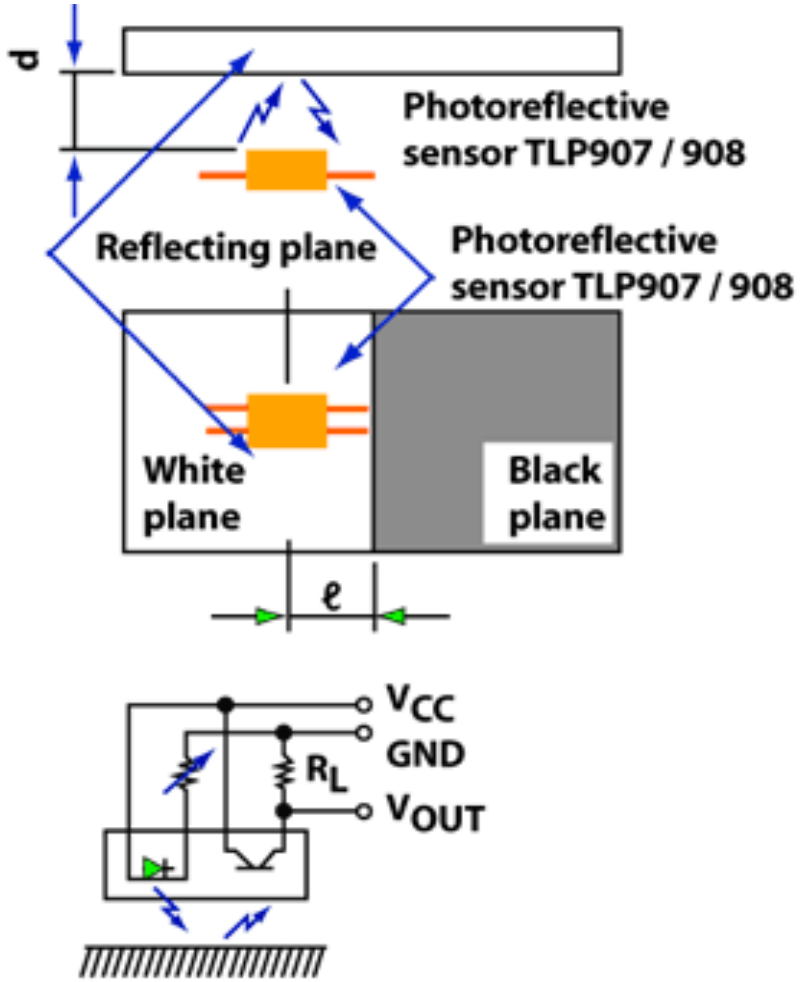
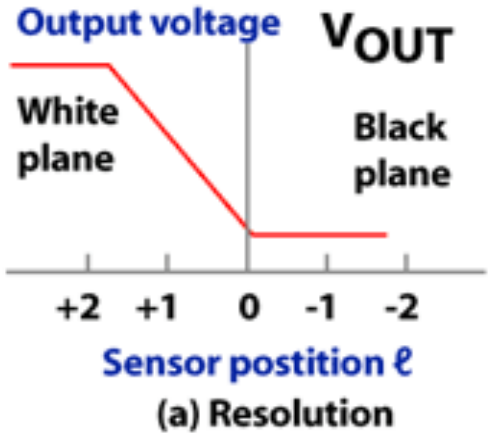
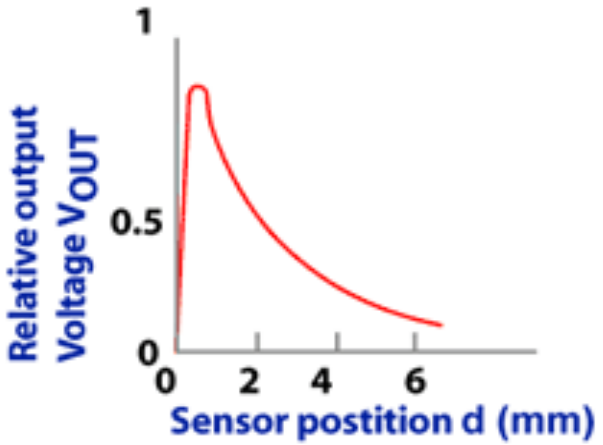
Optical Bubble Sensing – Pitch Bounce Catch Method





(a) Resolution



(b) Proximity

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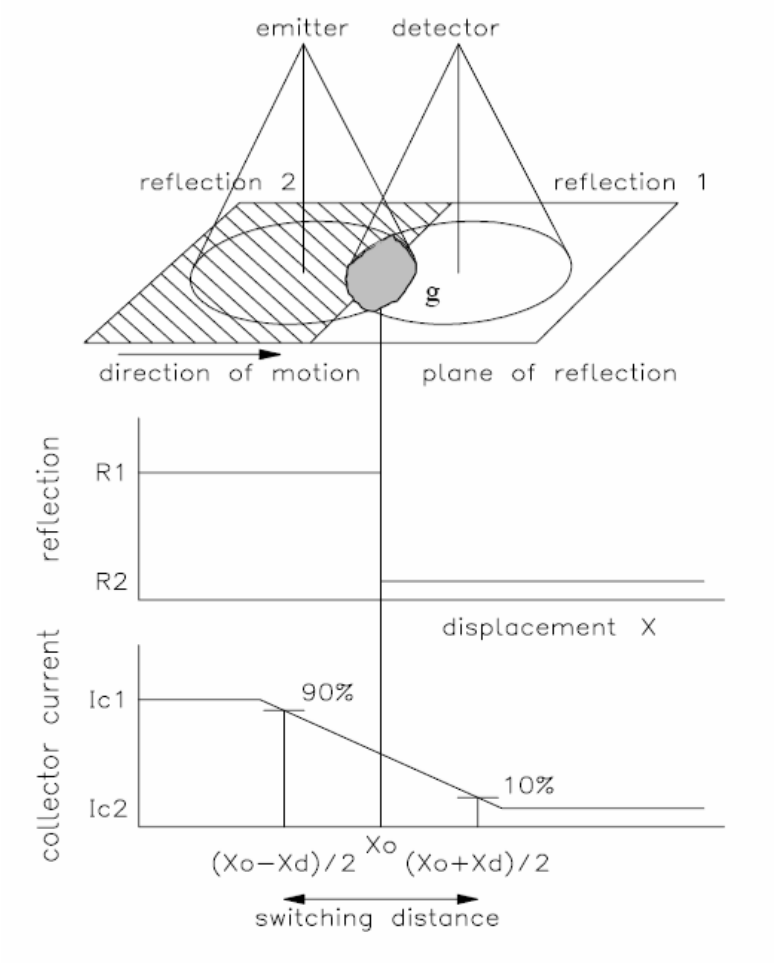
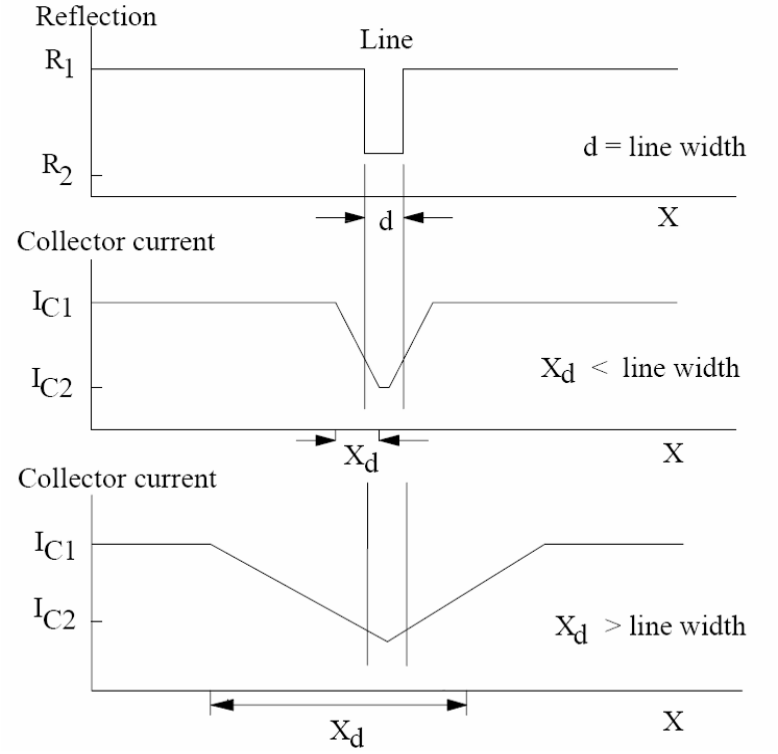
Optical Bubble Sensing – TIR Method





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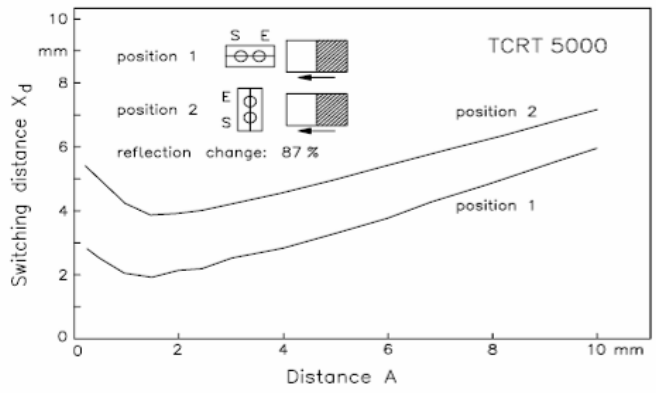
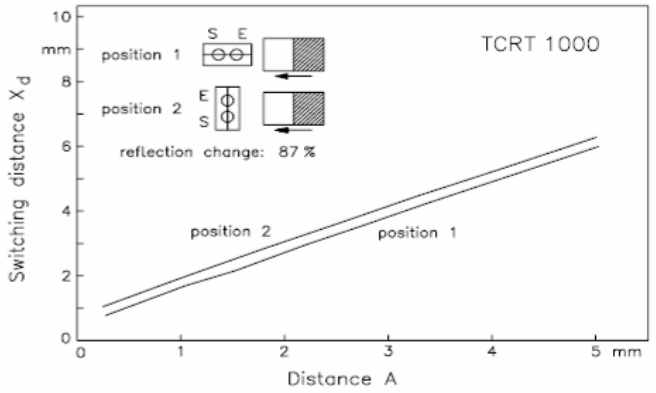
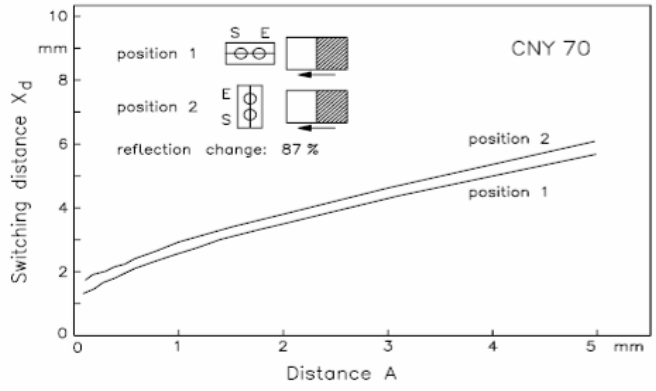
Effect of Target Distance and Orientation



a) TCRT5000



c) TCRT1000



b) CNY70

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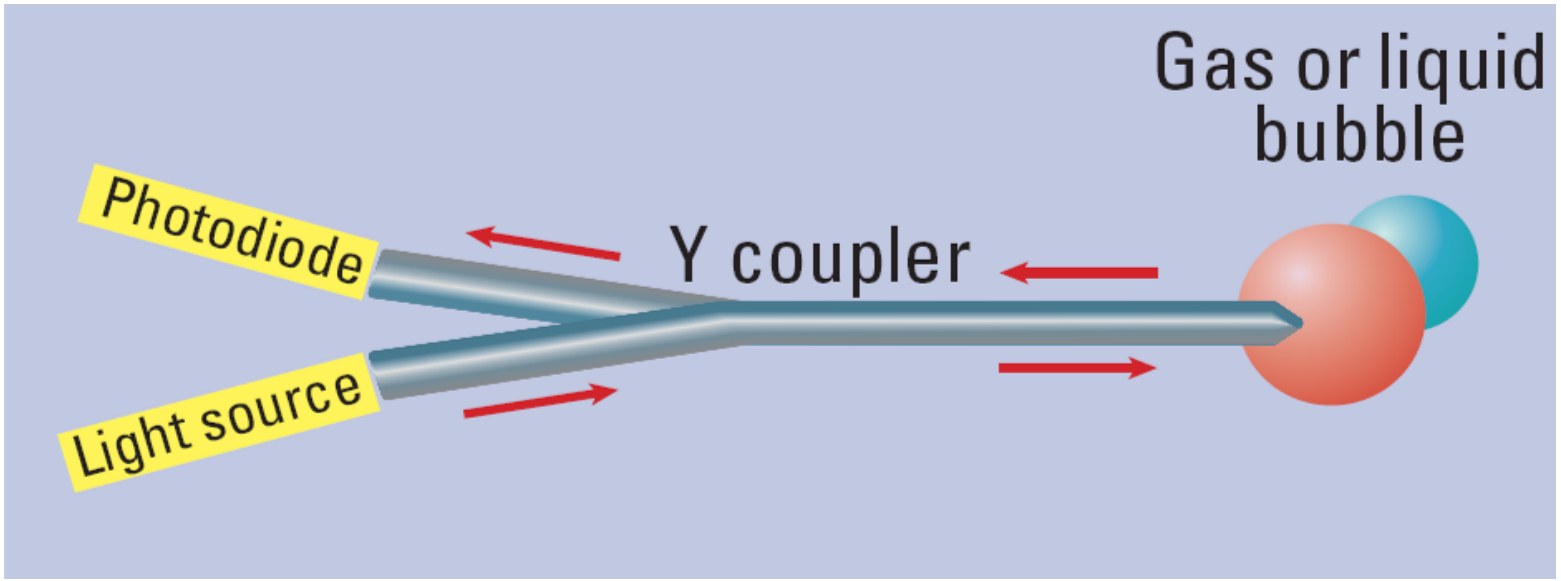
Optical Bubble Sensing – Pitch Bounce Catch Method



Fiber optic path extension

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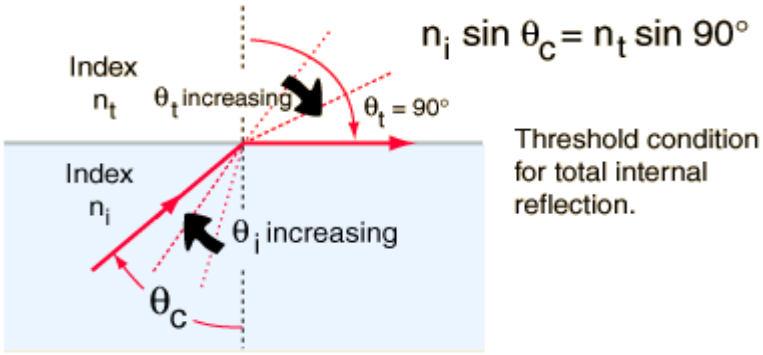
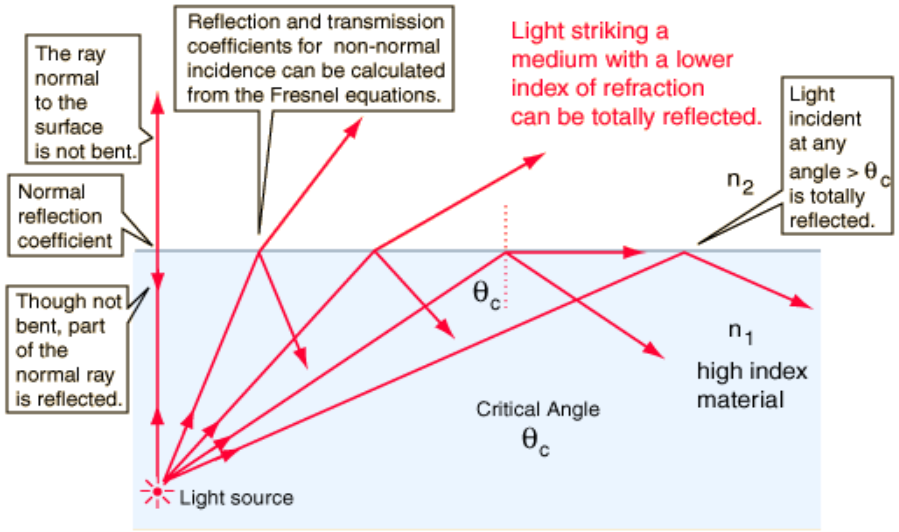
Optical Sensing – Total Int. Reflection Method





Critical angle

In geometric optics, at a refractive boundary, the critical angle is the angle of incidence above which total internal reflection occurs.

The angle of incidence is measured with respect to the normal at the refractive boundary. It is given by:

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$$

where θc is the critical angle, n2 is the refractive index of the less dense medium, and n1 is the refractive index of the denser medium. This equation is a simple application of Snell's law where the angle of refraction = 90°.

Note: Total internal reflection only occurs when the incident ray is in the denser medium.

If the incident ray is precisely at the critical angle, the refracted ray is tangent to the boundary at the point of incidence.

For visible light traveling from glass into air (or vacuum), the critical angle is approximately 41°.

For water into air (or vacuum), the critical angle is approximately 48.6°.

For polycarbonate (n=1.59) into air (or vacuum), the critical angle is approximately 39°.

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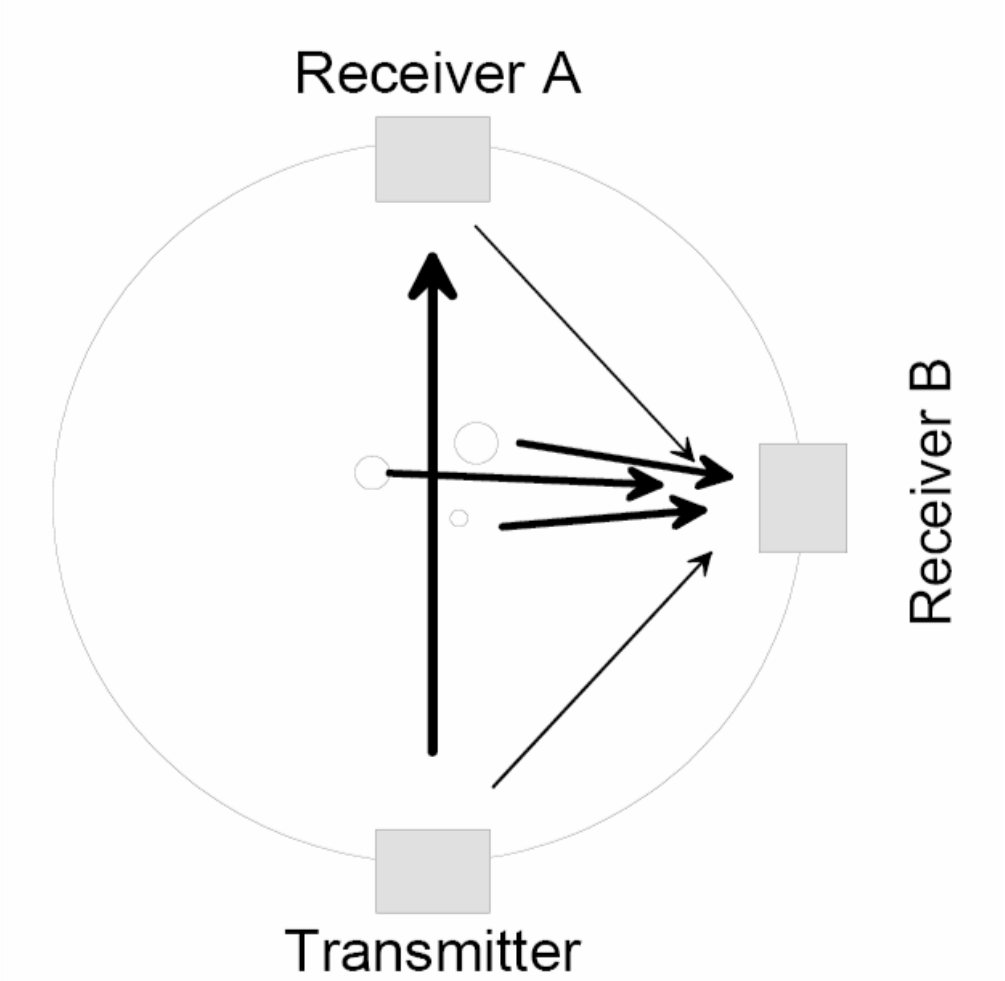
Optical Bubble Sensing – Other Geometries



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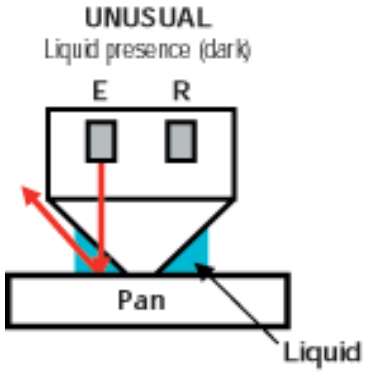
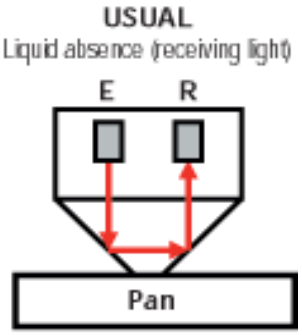
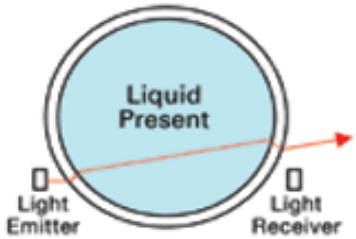
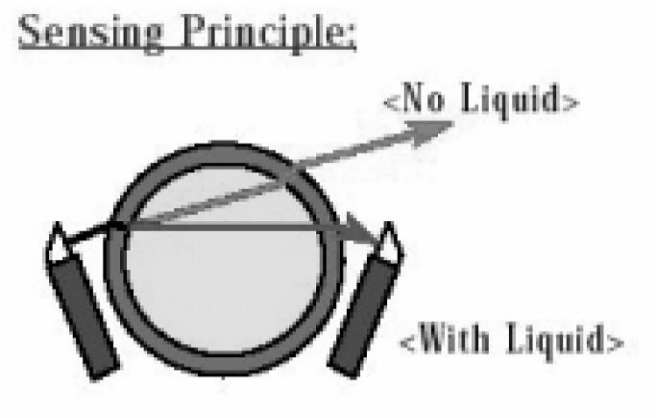
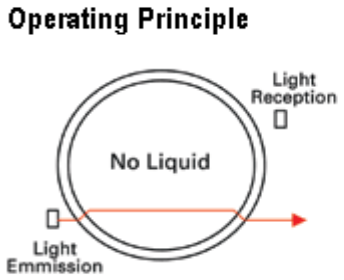
Optical Bubble Sensing – Other Geometries

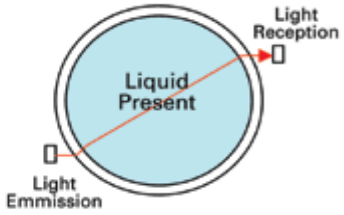












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Optical Bubble Sensing – Other Geometries

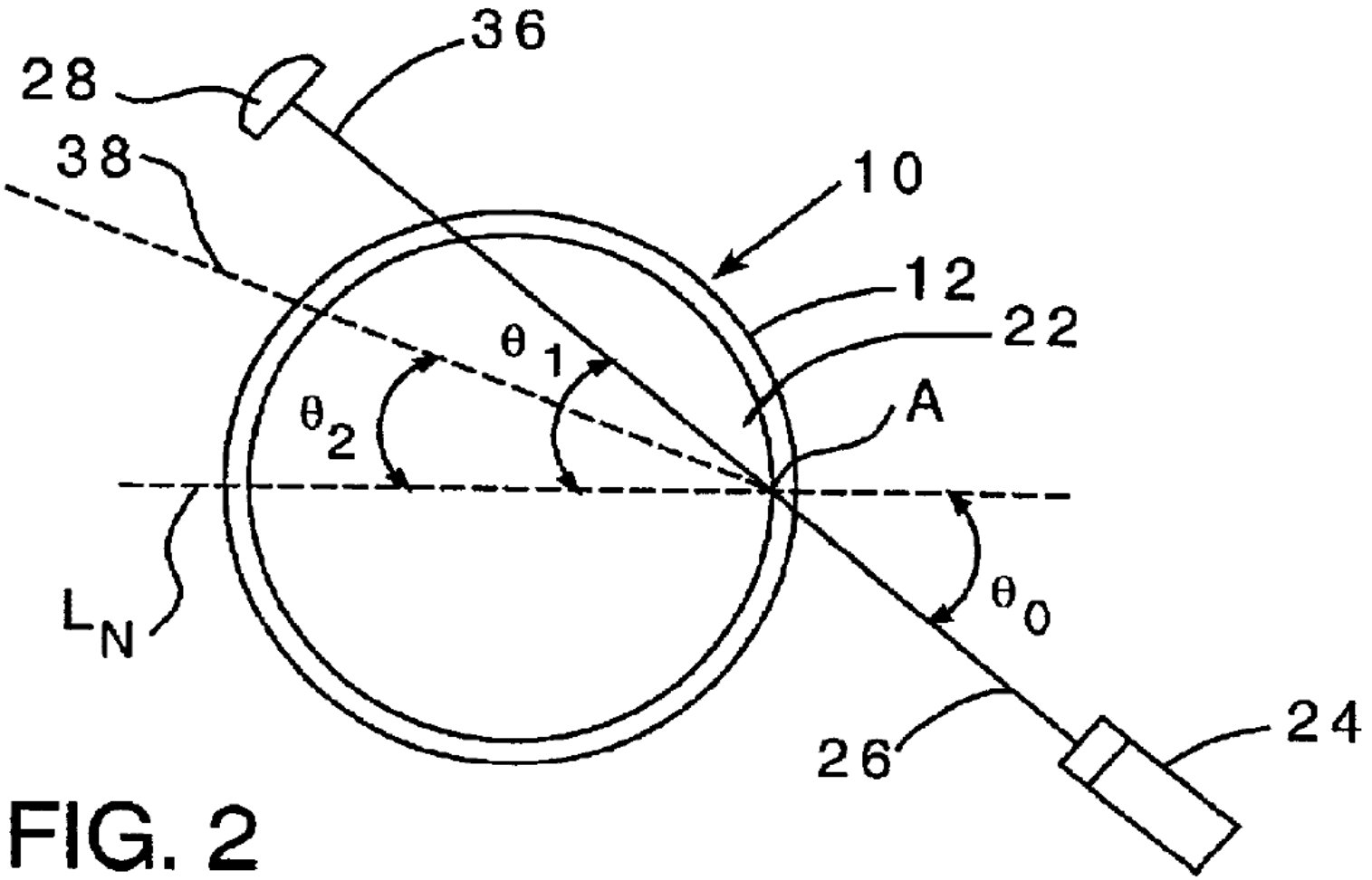

FIG. 2

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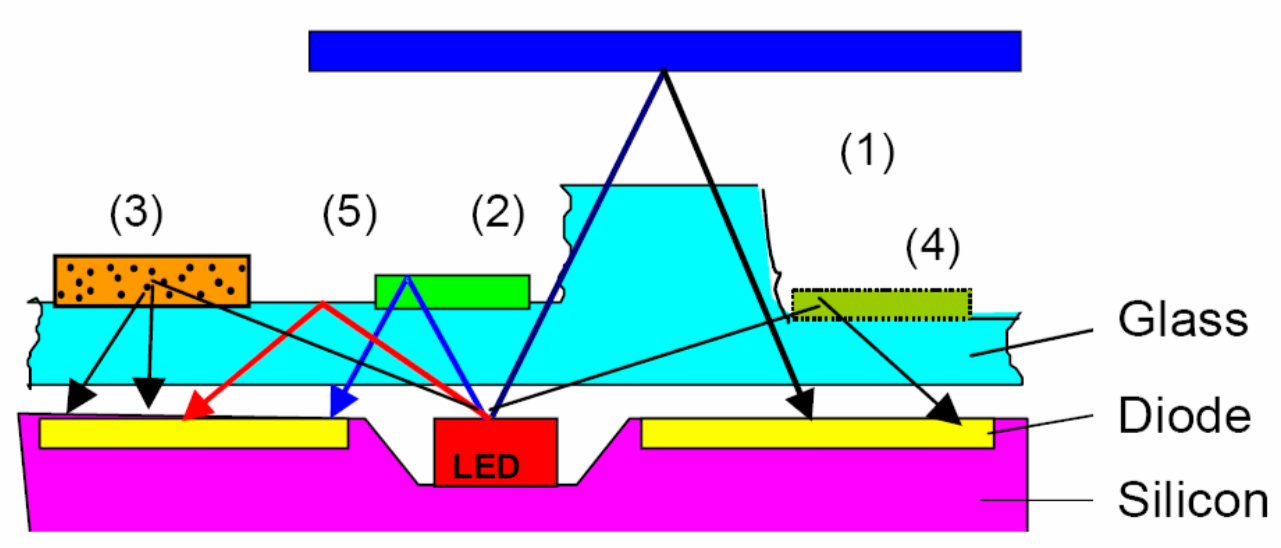
Optical Bubble Sensing – Other Geometries



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Electronics – Optical Sensing

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Optical Bubble Sensor Electronics - Basic

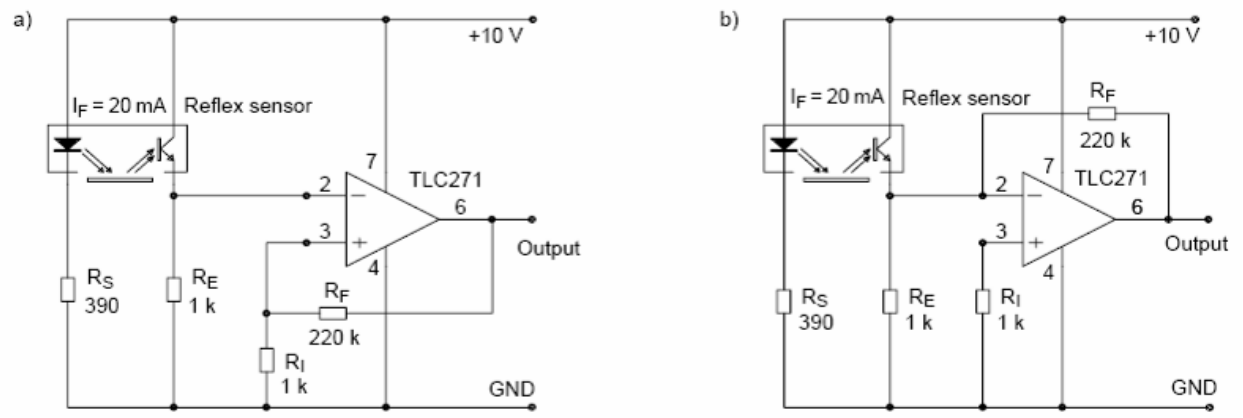

Figure 12. Circuits with operational amplifier

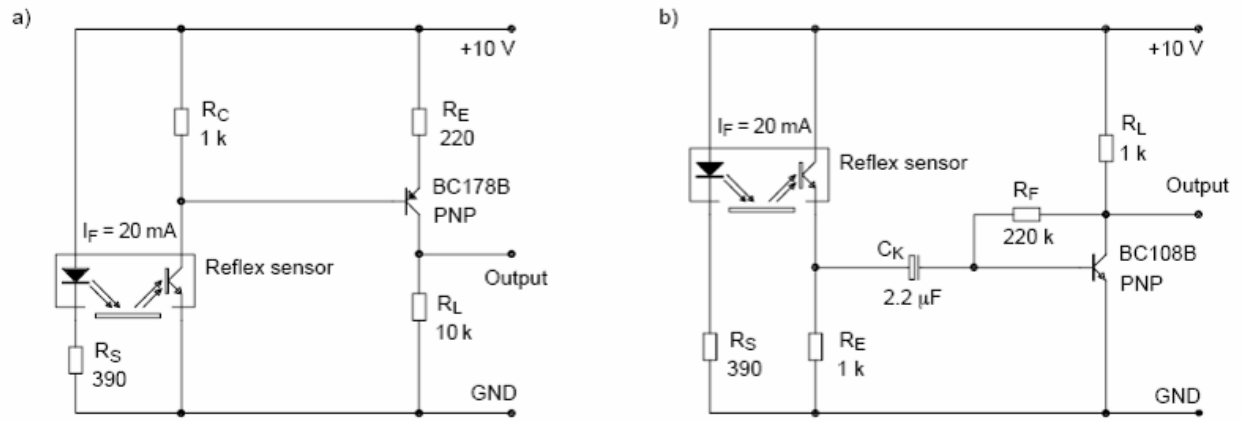

Figure 13. Circuits with transistor amplifier

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Optical Bubble Sensor Electronics - Practical

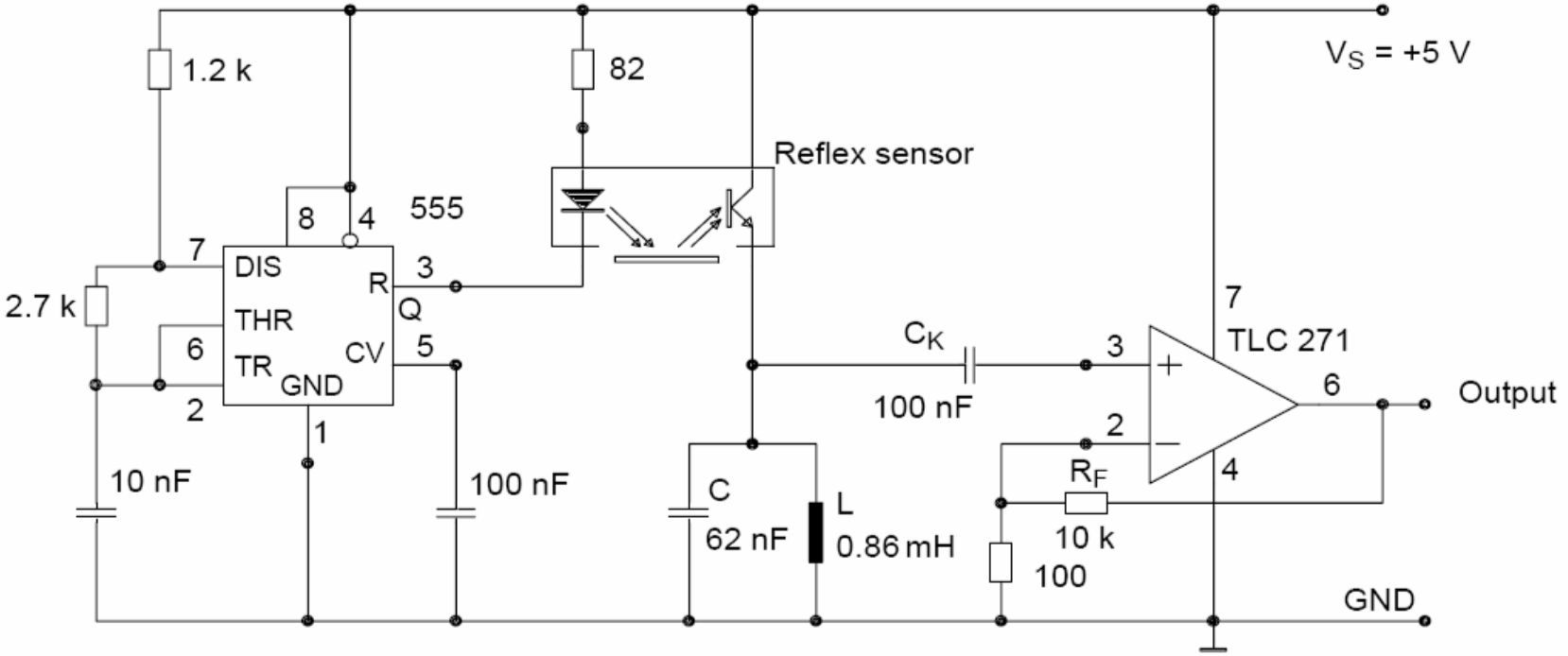

Figure 14. AC operation with oscillating circuit to suppress ambient light

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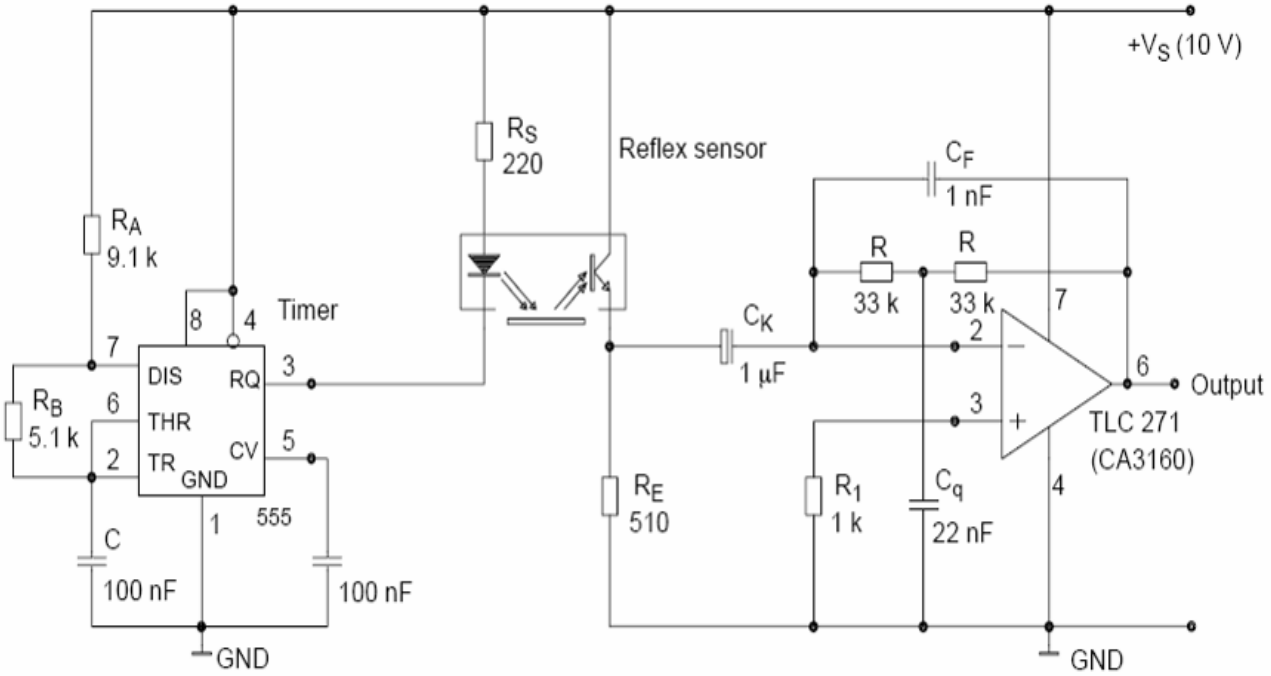
Optical Bubble Sensor Electronics - Practical



Timer dimensions: t_p (pulse width) = 0.8 RC = 400 µs
T (period) = 0.8 (R_A + R_B) × C = 1 ms

Active filter : $C = \sqrt{C_f \times C_q}$ $Q = \sqrt{\frac{C_q}{C_f}}$

$f_o = 1/(6.28 \times C \times R)$ $V_{uo} = \frac{2R}{R_E} \times Q^2$

Figure 15. AC operation with active filter made up of an operational amplifier, circuit and dimensions

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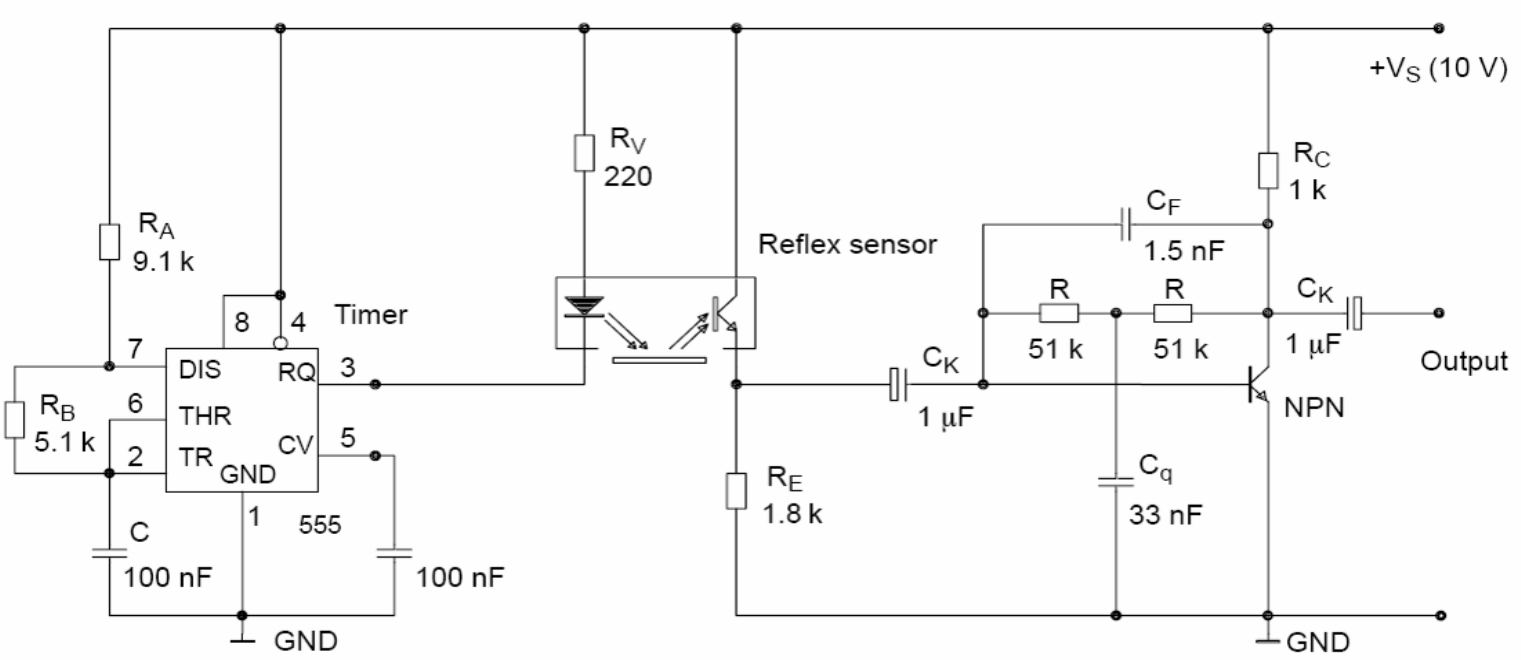
Optical Bubble Sensor Electronics - Practical



Timer dimensions: t_p (pulse width) = 0.8 RC = 400 ms
T (period) = 0.8 (R_A + R_B) × C = 1 ms

Active filter : $C = \sqrt{C_f \times \times C_q}$ $Q = \sqrt{\frac{C_q}{C_f}}$

$f_o = 1/(6.28 \times C \times R)$ $V_{uo} = \frac{2\,R}{R_E} \times Q^2$

Figure 16. AC operation with transistor amplifier as active filter

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Optical Bubble Edge Detector

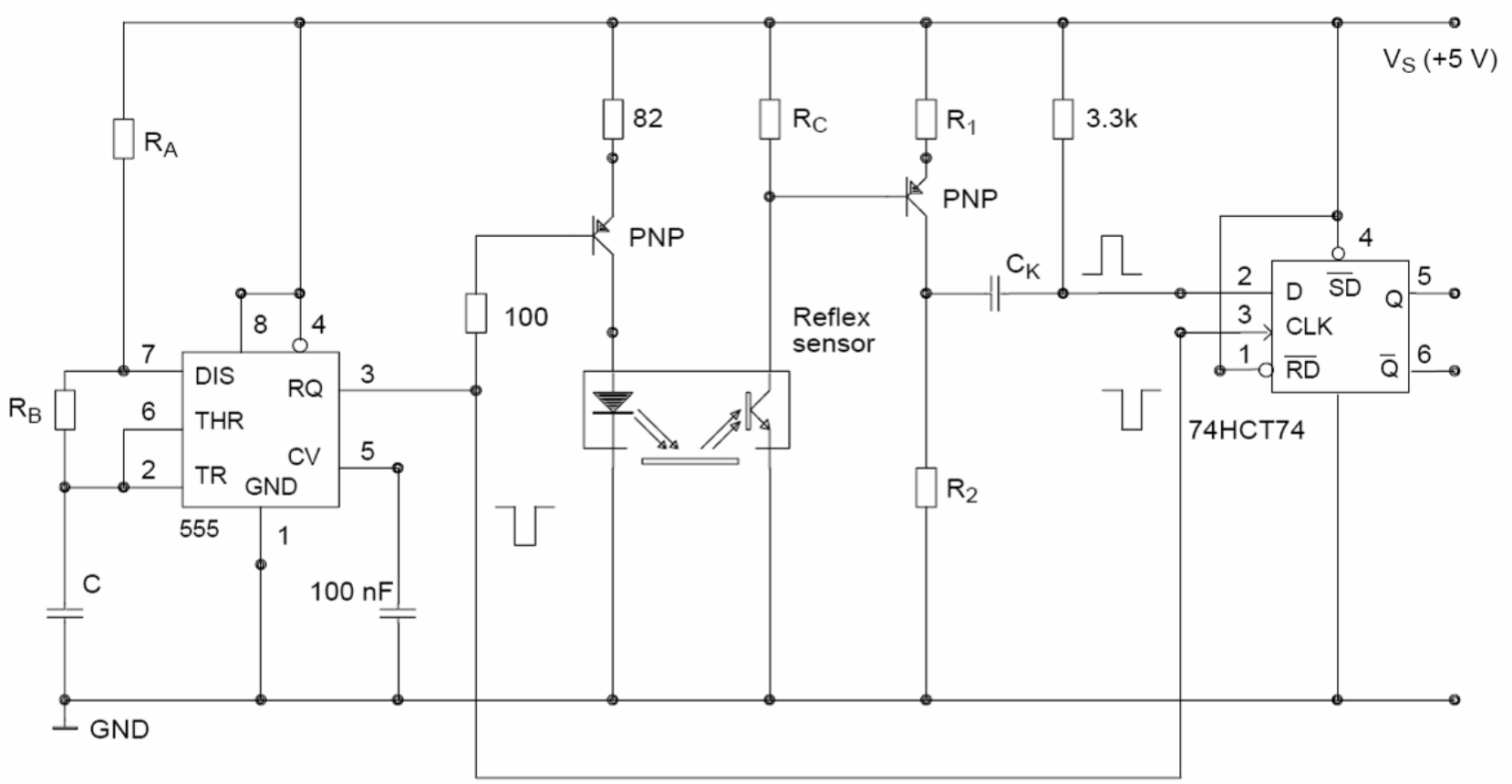

Figure 18. Pulse circuit with buffer storage

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Other Bubble Sensing Schemes

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Capacitive Bubble Sensing Methods

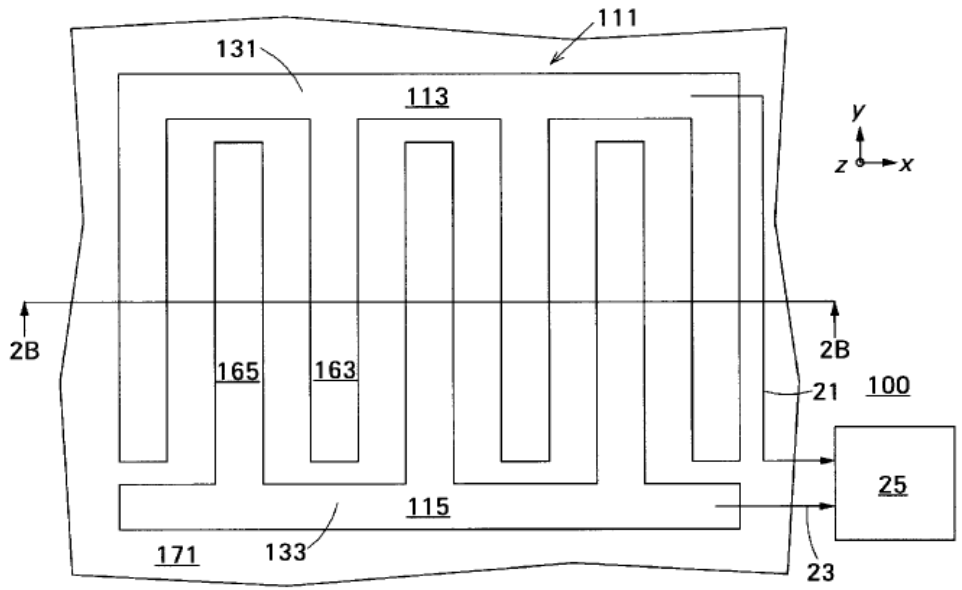

FIG.2A

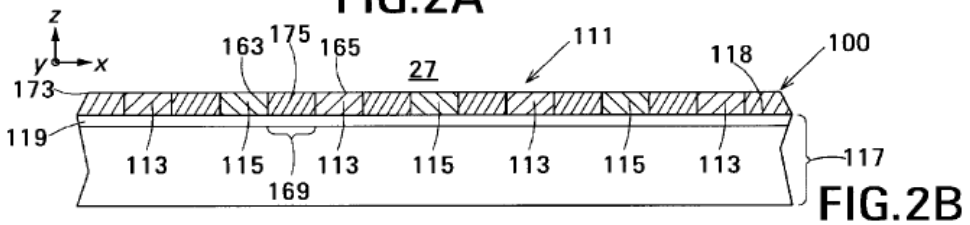

FIG.2B

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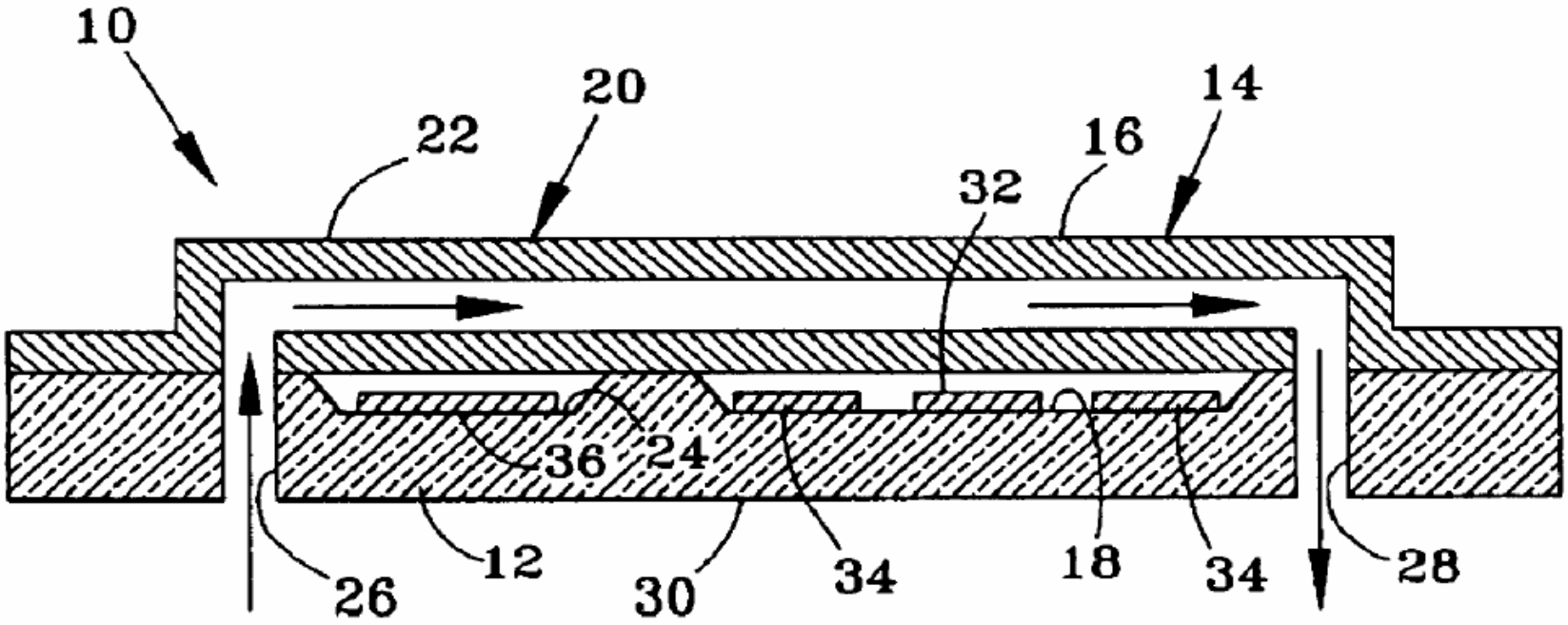
Mass Resonance Bubble Sensing - MEMS



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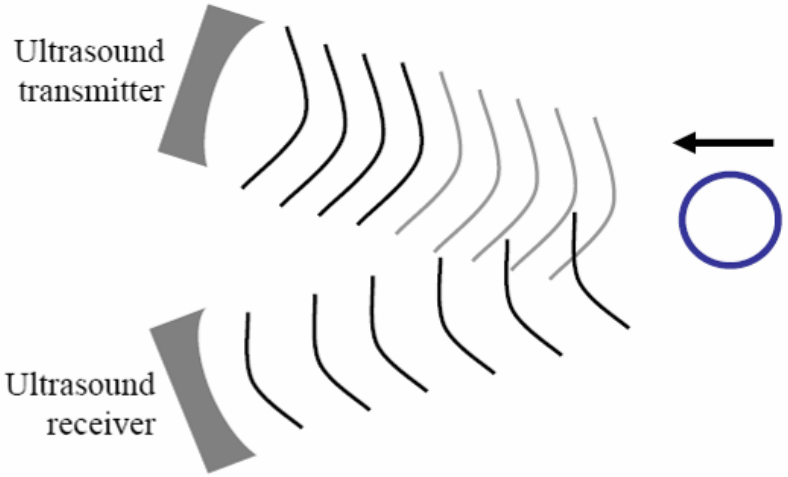
Doppler Ultrasonic Bubble Sensing

Gas bubbles that form in the blood are observed in the pulmonary artery using Doppler ultrasound. The pulmonary artery is chosen to estimate all the bubbles present in the body. The output of the Doppler device is an audio signal, in which the moving bubbles can be heard as pops or clicks, against a regular swishing sound produced by reflections from blood cells moving in response to the heart beat.

The bubbles are highly reflective to ultrasound. Bubbles that are moving will cause a shift in the frequency of the reflected ultrasound according to the Doppler effect:

$$f_D = f_0\left(\frac{2v}{c-v}\right)$$

This frequency shift can be extracted, this forms the audio output from a Doppler ultrasound device.



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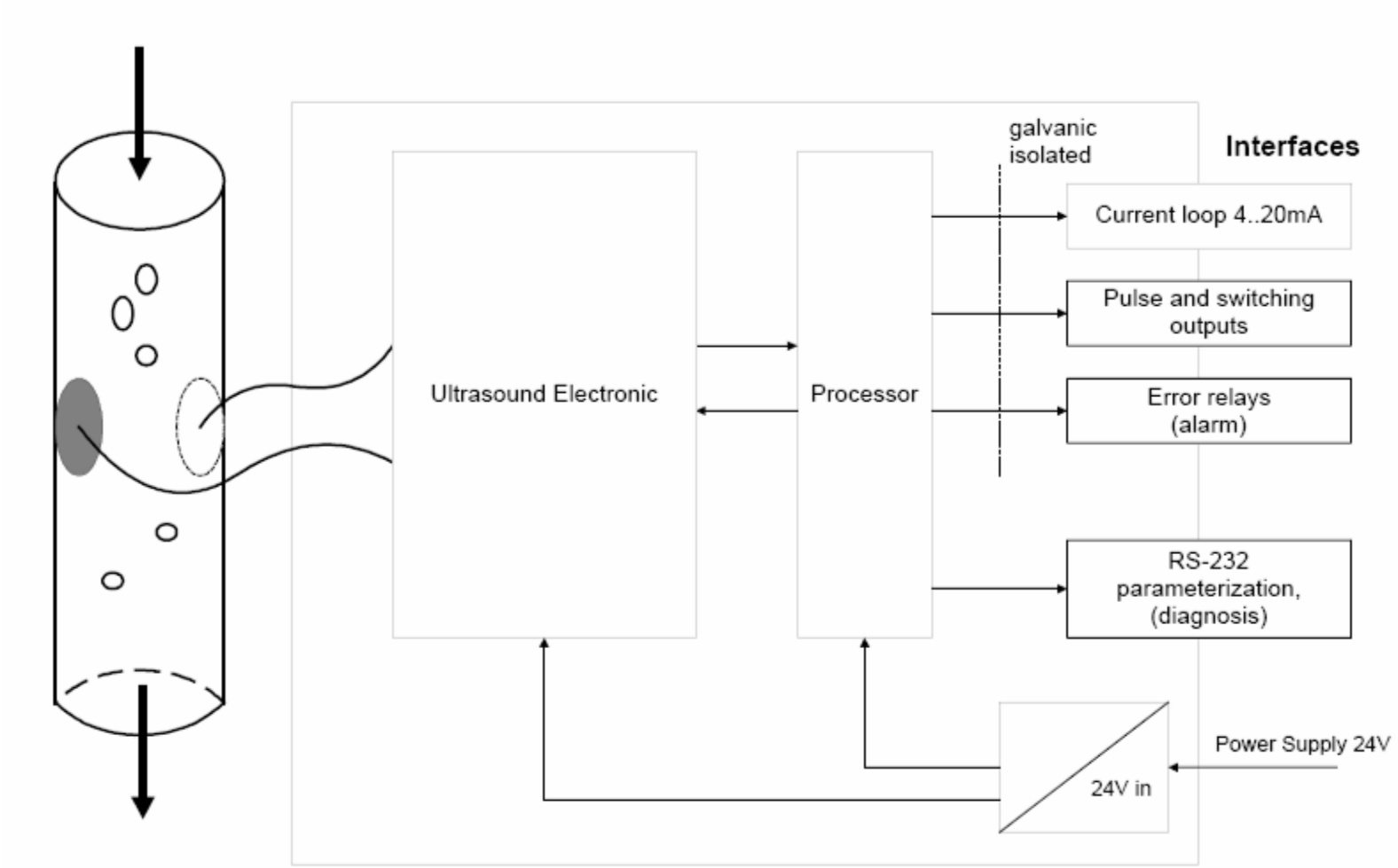
Ultrasonic Bubble Sensing – System Diagram



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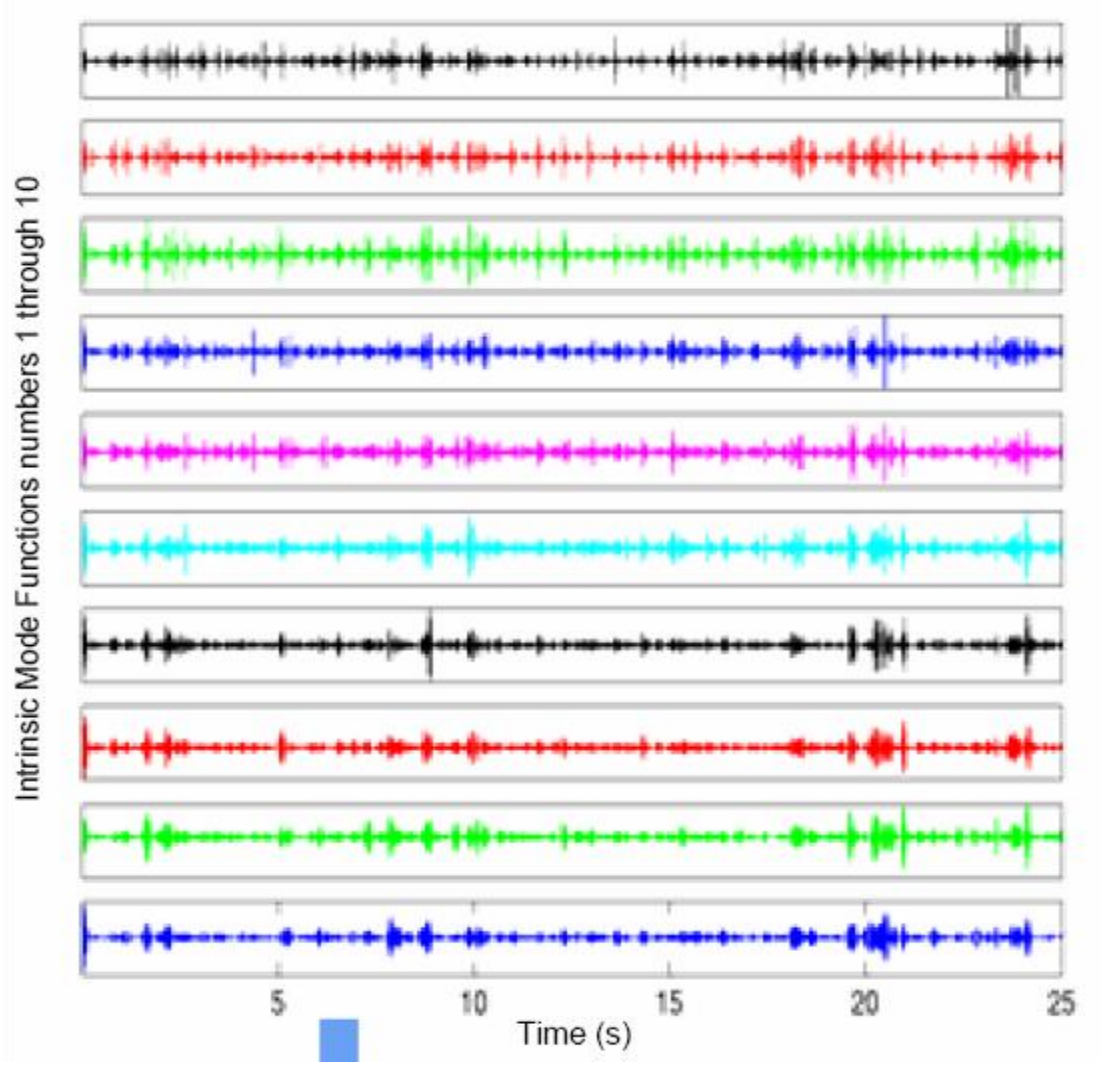
Doppler Bubble Sensing – Signal Patterns



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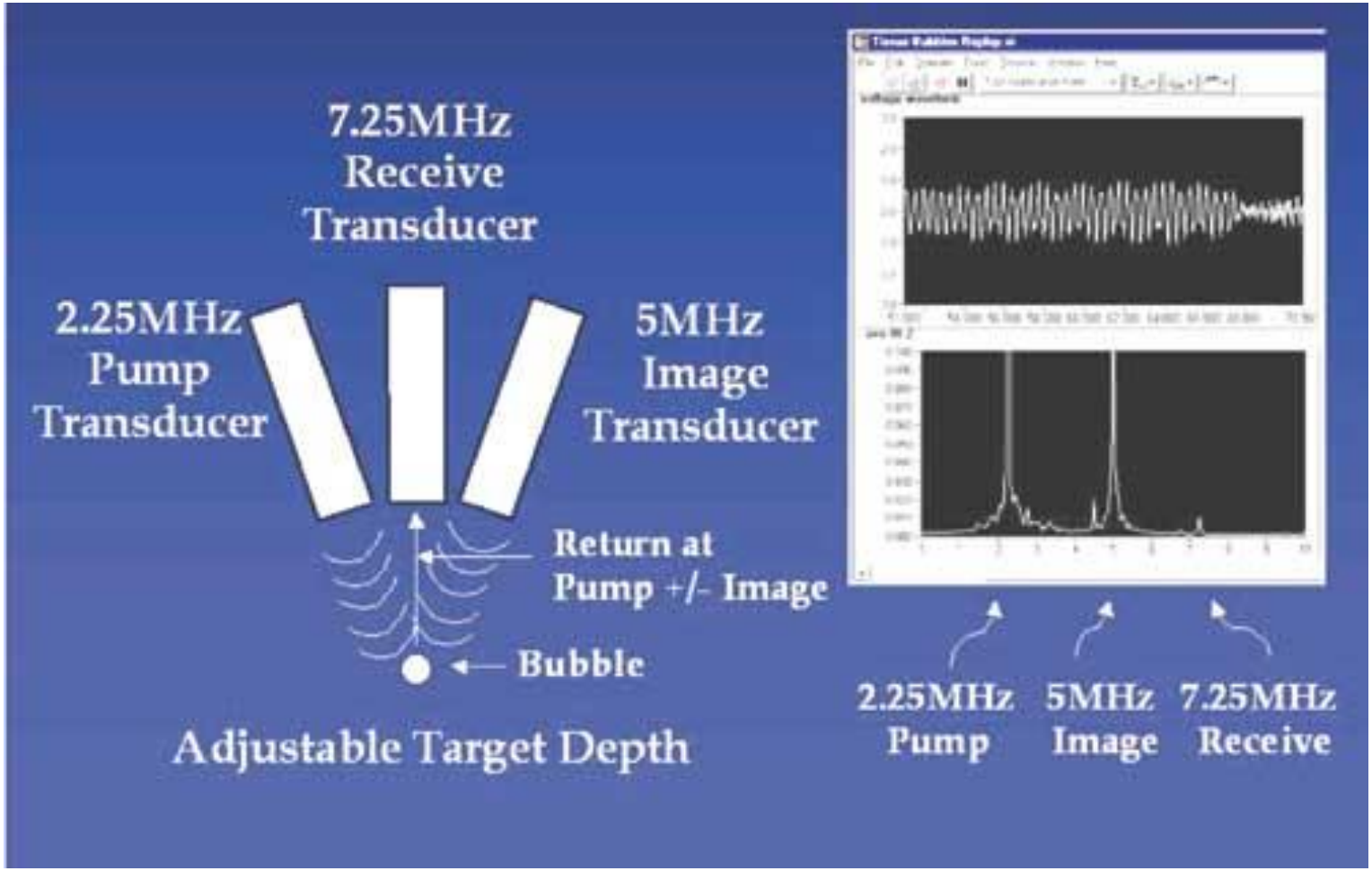
Typical Ultrasonic Bubble Sensing Setup



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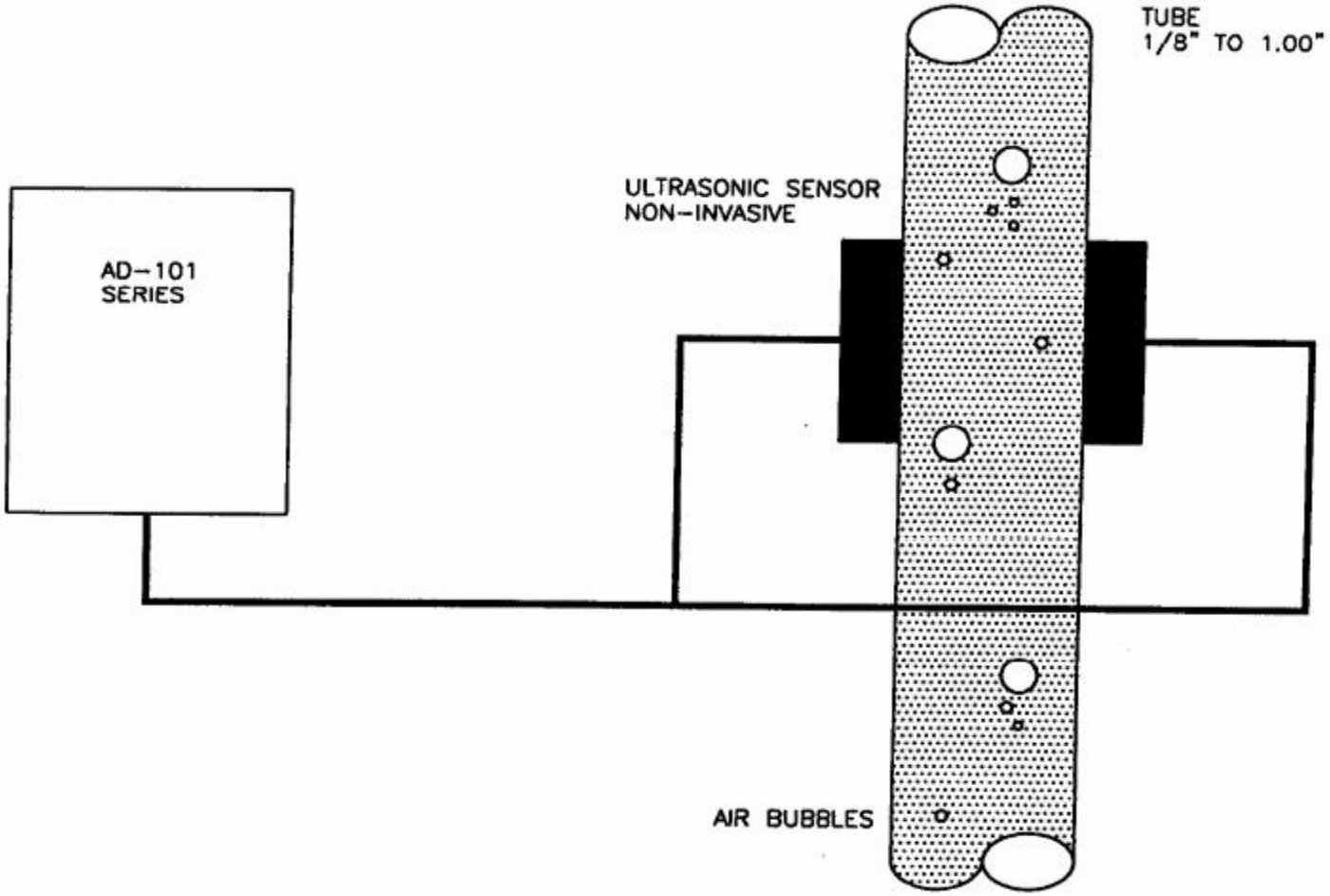
Bubble Sensing in Small Tubing - Cosense



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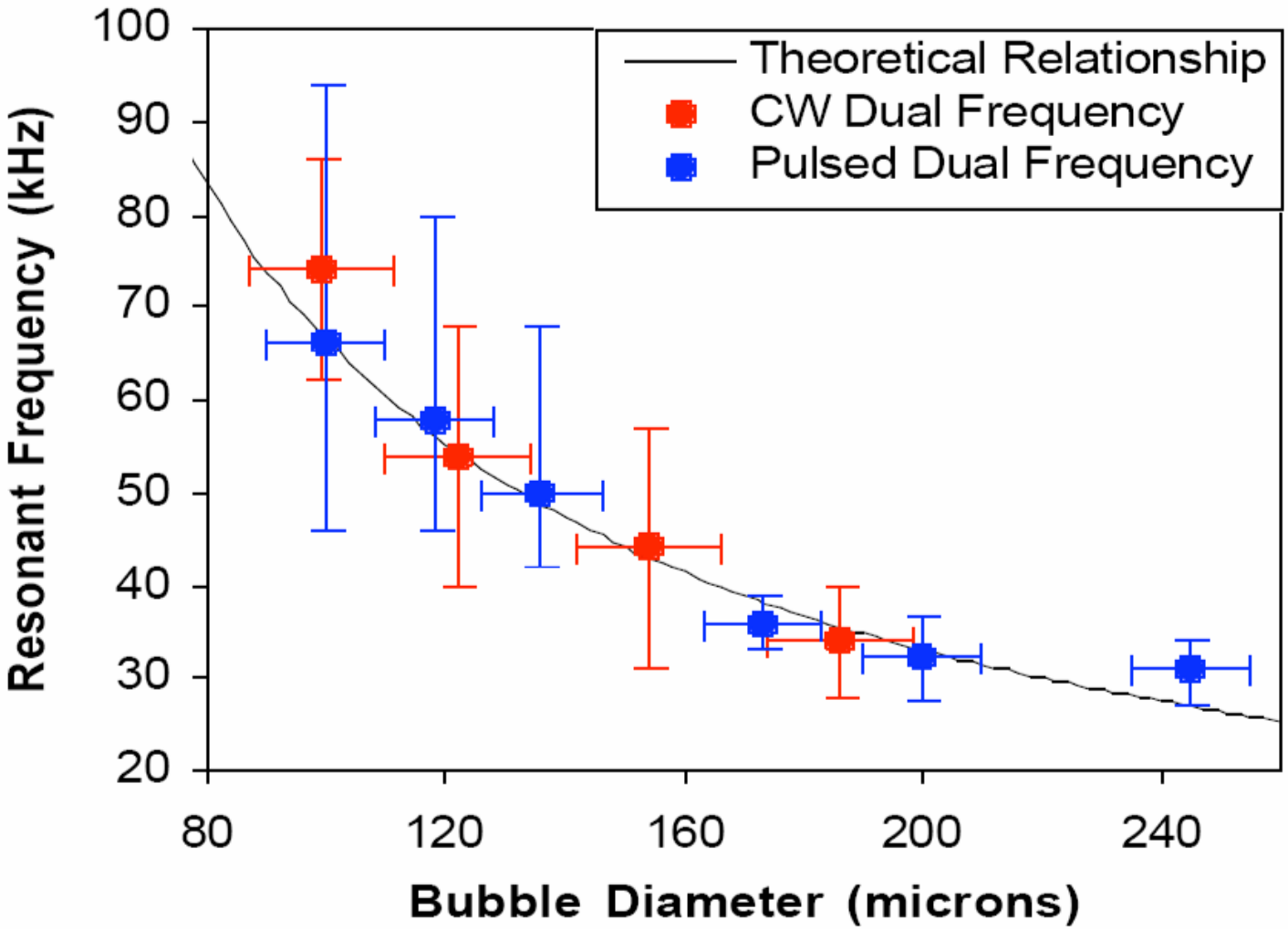
Ultrasonic Bubble Sensing - Resonance



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Commercial – Off – the – Shelf (COTS) Product Offerings

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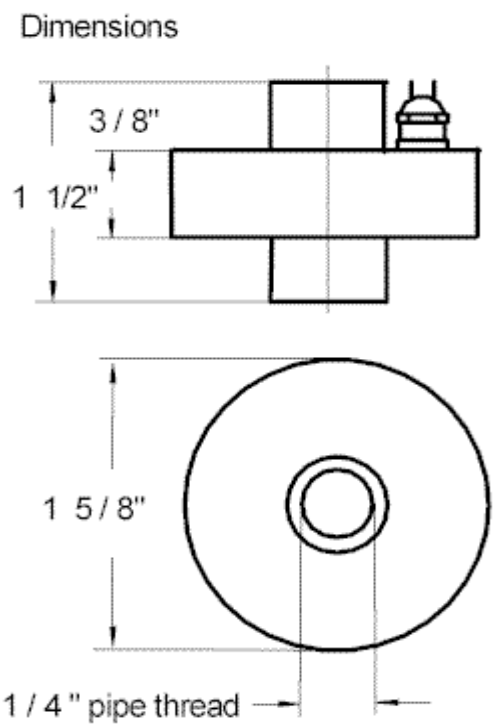
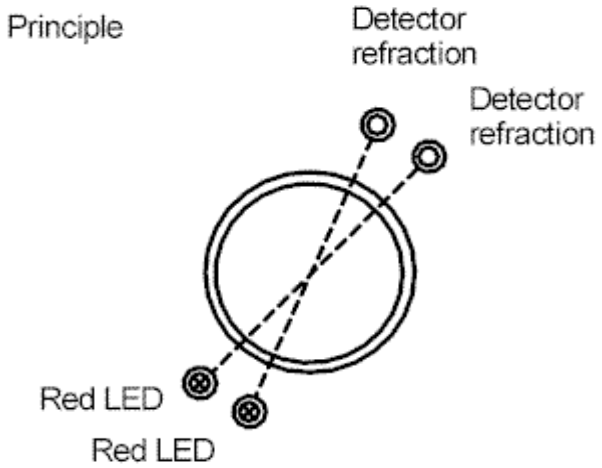
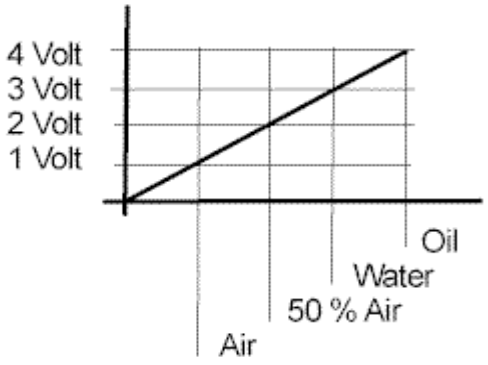
Optical Sensing – Commercial Device - Hohner







10 ft cable with 3 wires red = + 5 Volts
black = GND
white = output
Customer input resistor 1 Kohm to GND

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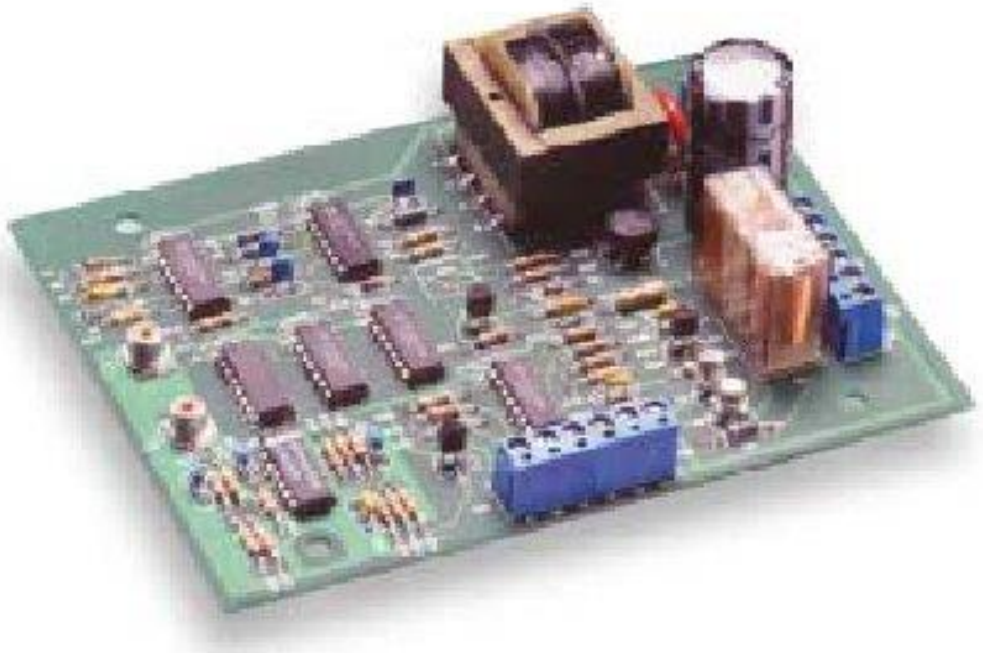
Ultrasonic Bubble Sensing - Introtek



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Ultrasonic Bubble Sensing - Zevex

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Optical Bubble Sensing – Erlich Industrial Dev.

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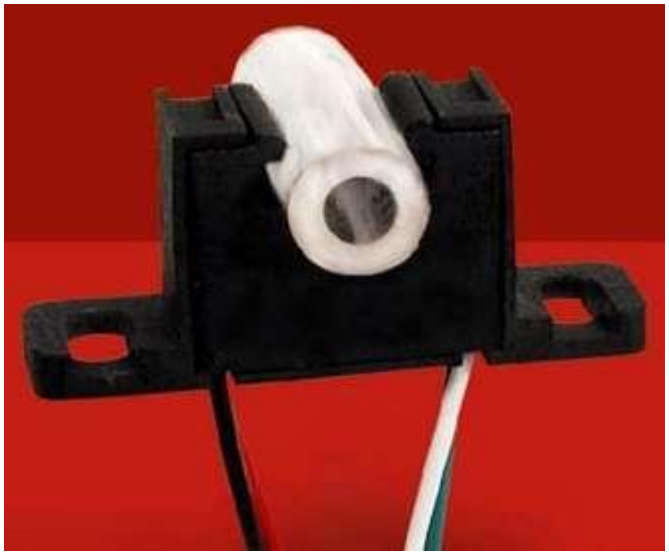
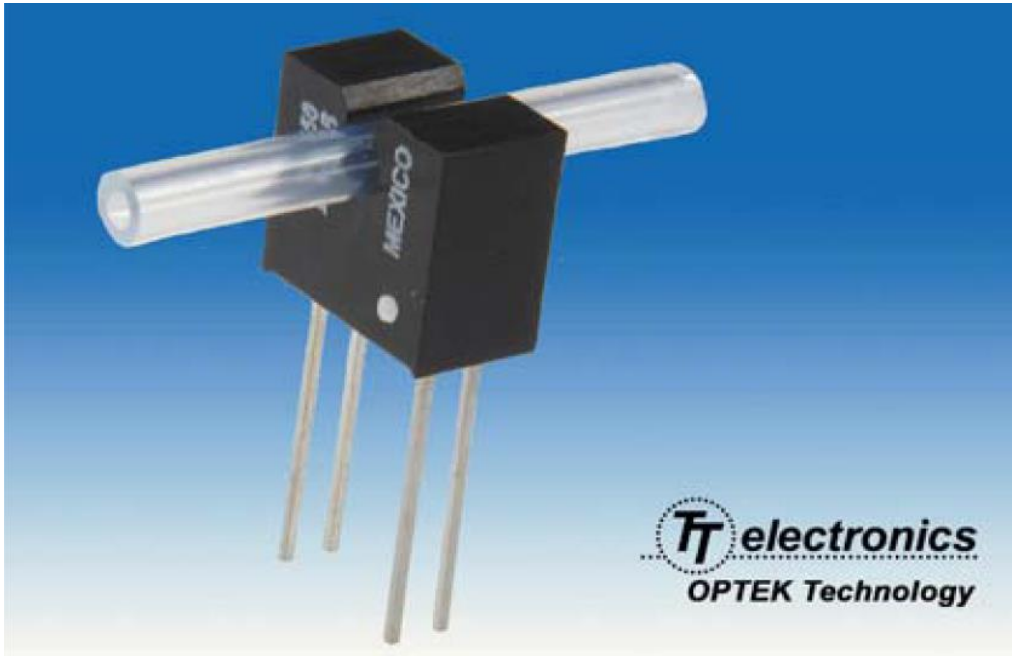
Optical Bubble Sensing – Optek





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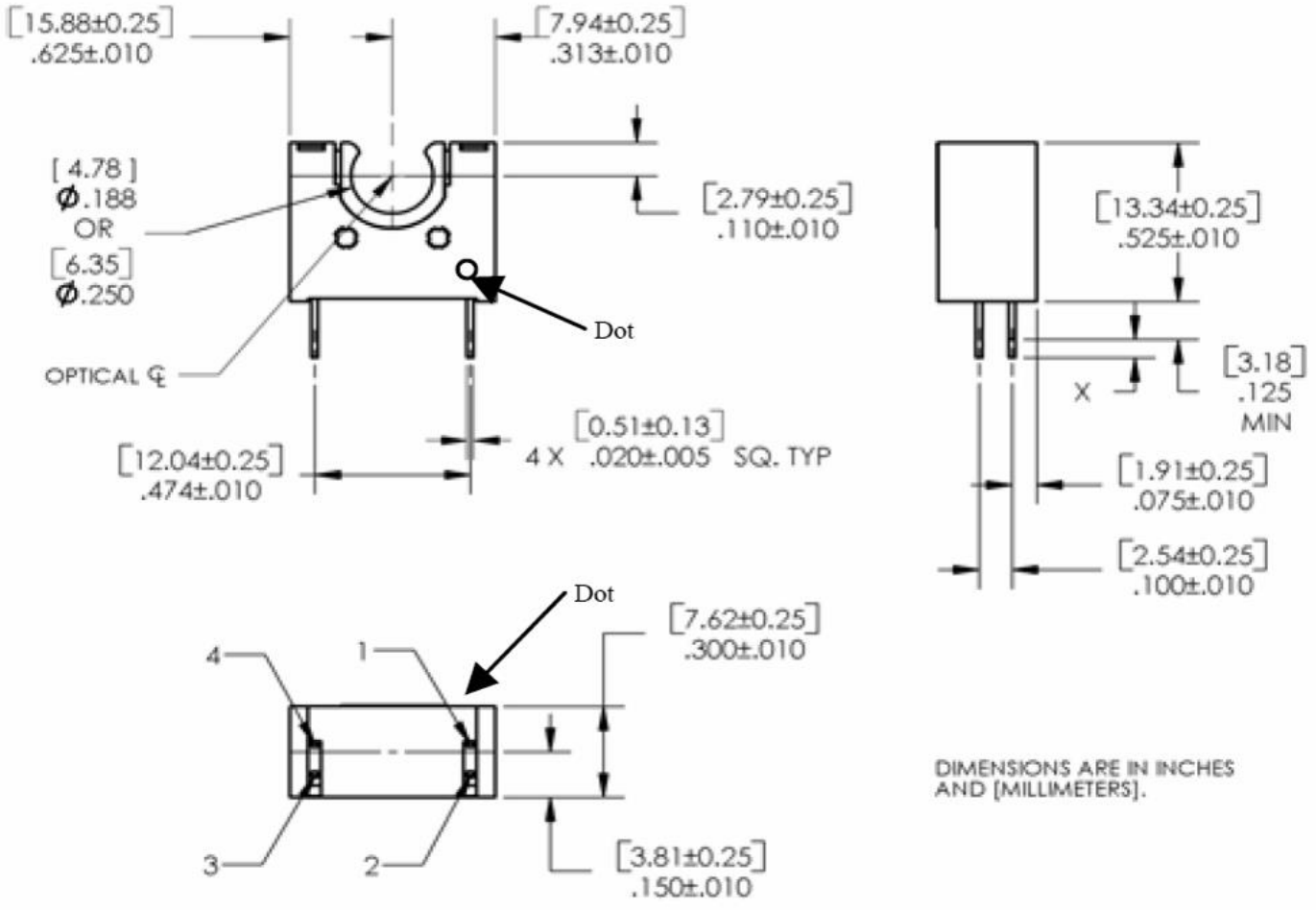
Optical Bubble Sensing – Optek



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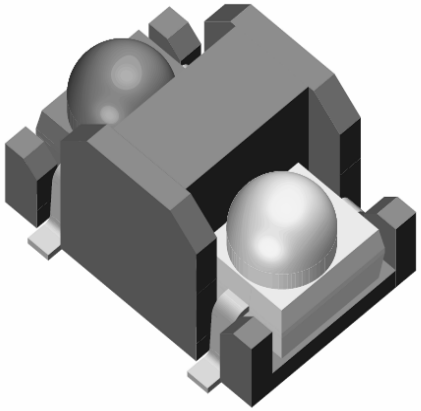
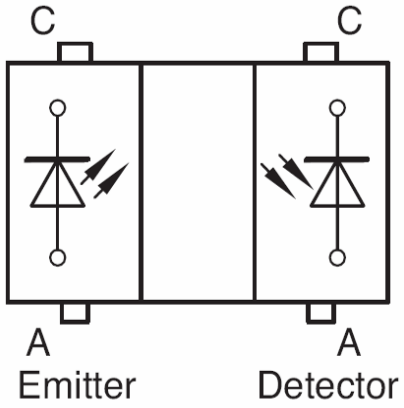
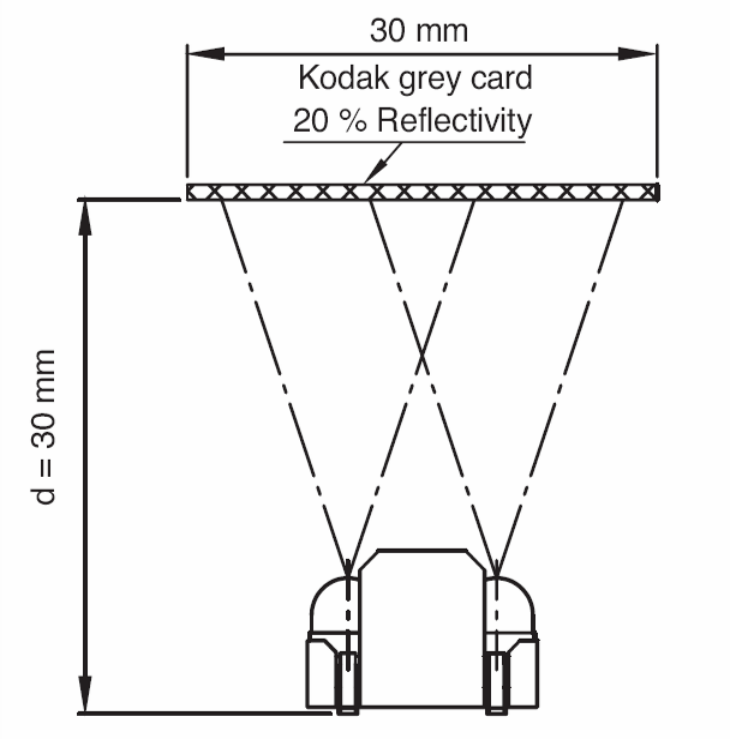
Optical Bubble Sensing – TIR Method





Description

TCND5000 is a reflective sensor SMD in plastic package including IR emitter and PIN Photodiode. Optical axes of emitter and detector are parallel aligned for reflective operation. Sensor includes IR filter and cross talk barrier.



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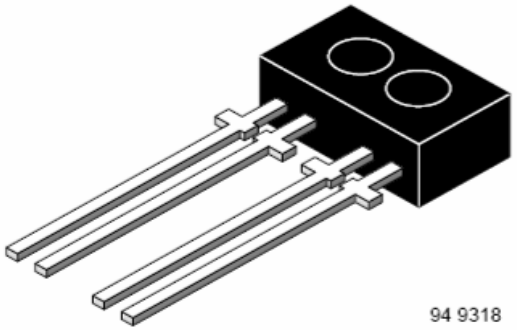
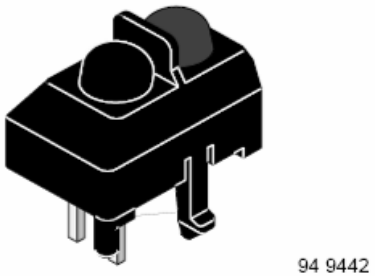
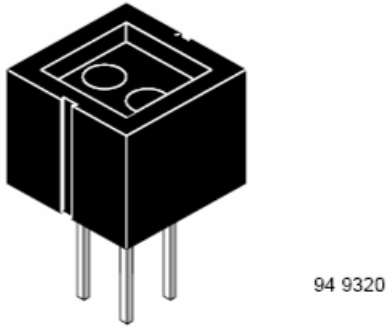
Optical Bubble Sensing – TIR Method



TCRT1000



TCRT5000



CNY70

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Optical Bubble Sensing – TIR Method

Marktech Optoelectronics

Photo Reflector

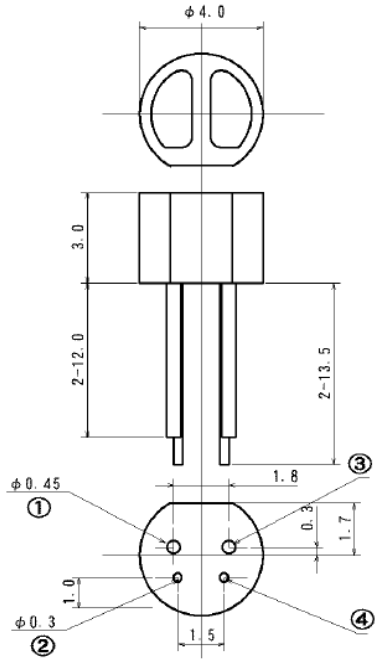
MTRS5750

Features

High Reliability
Compact

Applications

Card Reader
Bar Code Reader
Edge Sensing
Money/Bill Reader



① LED Cathode ③ PD Cathode
② LED Anode ④ PD Anode

Maximum Ratings (Ta=25°C)

Characteristic	Symbol	Max.	Test Condition	Unit
Forward Current	I_F	30	–	mA
Pulsed Forward Current	I_{FP}	50.00	tw=10μ S, T=10mS	A
Reverse Voltage	V_R	4	–	V
Power Dissipation	P_D	75.00	–	mW
Operating Temperature	T_{opr}	−20 ~ +80	–	°C
Storage Temperature	T_{stg}	−30 ~+100	–	°C
Soldering Temperature	T_{sol}	260	for 5 sec. max	°C

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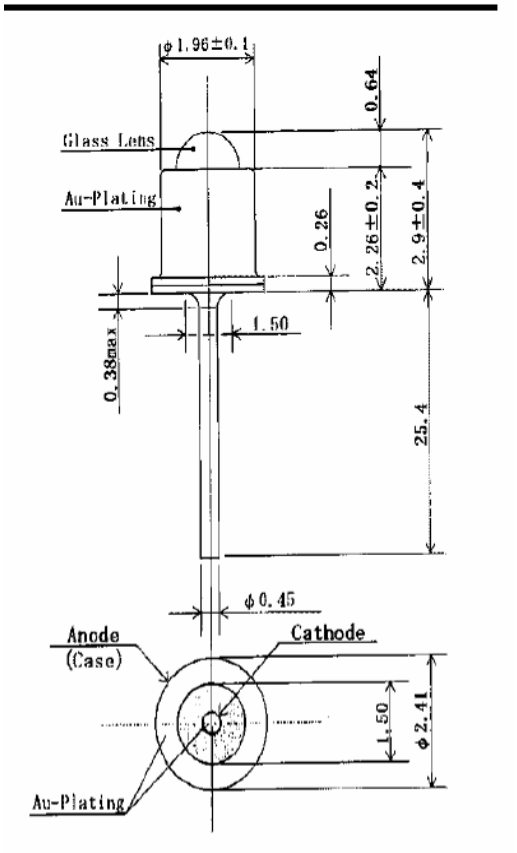
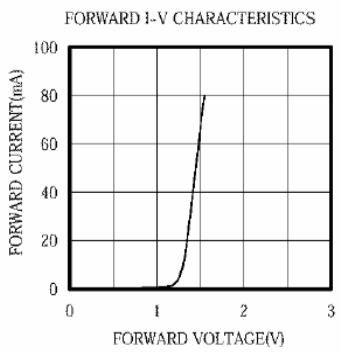
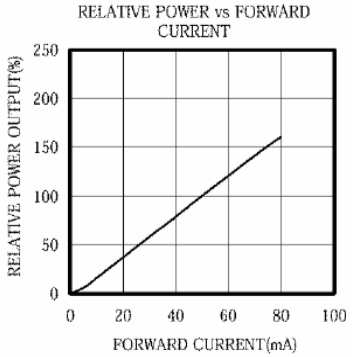
Optical Bubble Sensing – TIR Method

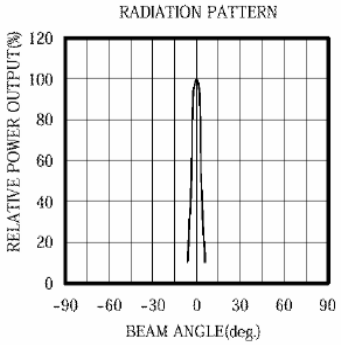
Point Source LED



MTPS9087PT Graphs







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Optical Bubble Sensing – TIR Method

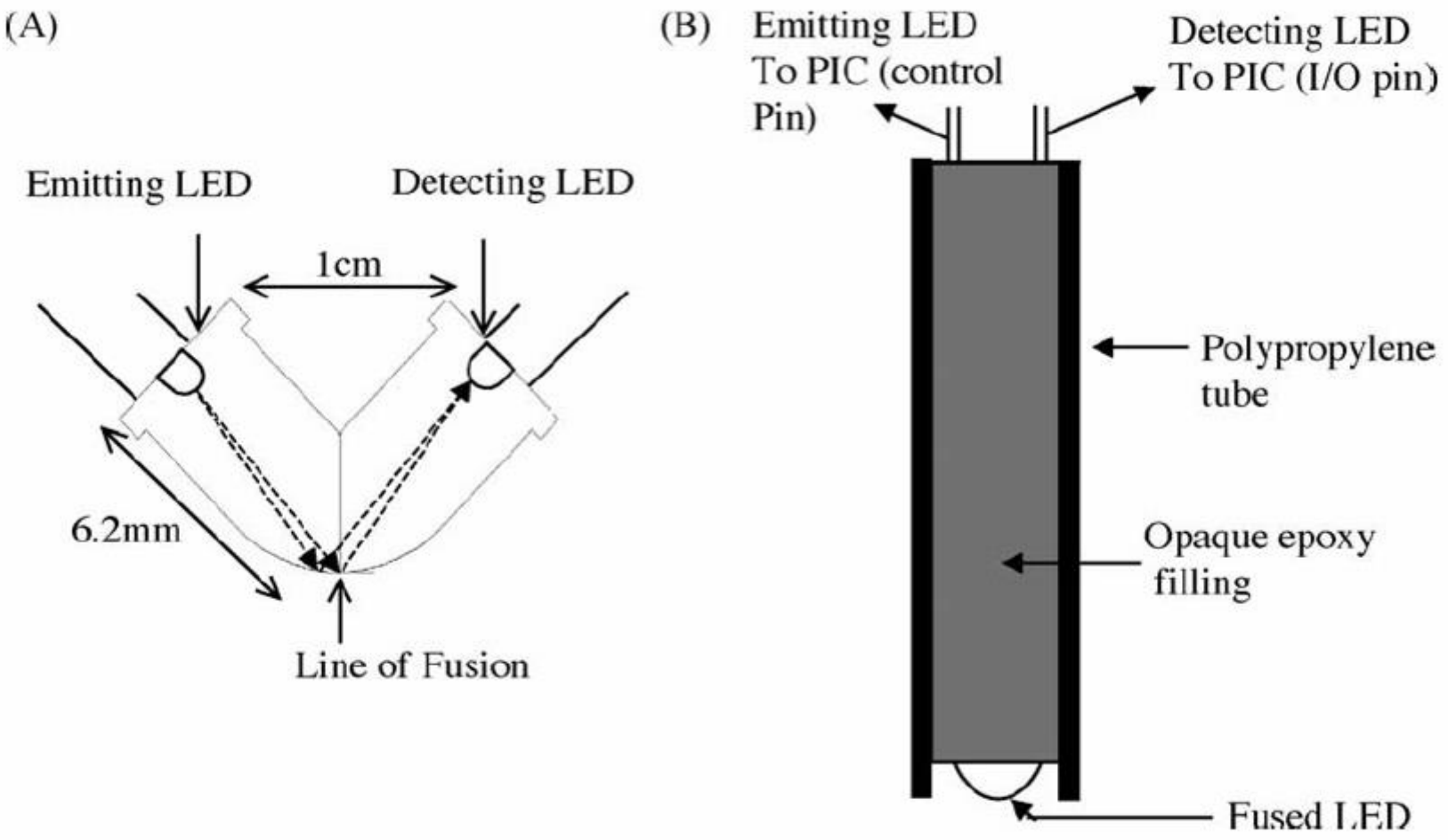

Fig. 1. Schematic of (A) a fused-LEDs and (B) cross-section of the optical probe.

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Summary and Conclusions

A wide variety of bubble detection schemes suitable for use with non-conductive liquids have been introduced

Many of these are practical for miniature application

Microprocessor based electronic readouts for these sensing schemes are not complex or expensive

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