POLITECNICO
MILANO 1863

Introduction

SENSOR SYSTEMS

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FOR APPOINTMENTS: write an e-mail about 1 week in advance
and we will agree a day

24 hours theoretical classes Vill

sensors and frontend circuits

Wednesday	8:30 – 10:00	On-line

26 hours hands-on classes (design laboratory)

using **STM32 microcontroller**

Monday	14:30 – 16:00	3.1.8 or on-line	Squad A
Thursday	13:30 – 15:00	26.14 or on-line	Squad B

Recording for all the classes (both theory and labs) will be available

1. **Sensors and front-end circuits**

- Basics on sensors: definitions, classifications and characteristics.

- Working principle and front-end circuits of the most employed sensors:
  o light and imaging (photodiode, CCD and CMOS sensor);
  o temperature (RTD, thermistors, thermocouple, thermal diode, IR thermometer);
  o magnetic field (Hall sensors, magneto-resistances);
  o strain and forces (strain gauges, piezoelectric sensor);
  o displacement, distance and proximity (capacitive, inductive, acoustic, optical, magnetic, touch sensors);
  o acceleration and orientation (MEMS);
  o audio (dynamic and condenser microphones).

2. Microcontrollers for embedded sensors systems

- Introduction on ARM-Cortex M cores, STM32F4 microcontroller by STMicroelectronics peripherals and Nucleo development board.

- Basics on the main microcontrollers peripherals (GPIO, PWM, ADC, SPI, I2C, USART, etc.) and simple projects (pushbutton, blinking LED, sending strings to remote terminal, using communication interfaces, etc.).

- Sensors expansion board: hardware description and details of the sensors included in the board.

- Hands on activities to interface sensors (temperature, light, sound, rotation, accelerations) with the microcontroller using its peripherals and providing an output (sending data to pc or displaying on an LCD or generating a sound through a speaker). Low power mode will be introduced for power saving smart sensors.

- The main developed projects will include:
    - readout of a temperature smart sensor with I2C interface;
    - measure light intensity through a Light Dependent Resistor;
    - detect sounds with a microphone;
    - readout of a rotary encoder;
    - acquisition of the x, y, z accelerations with a tri-axial accelerometer.
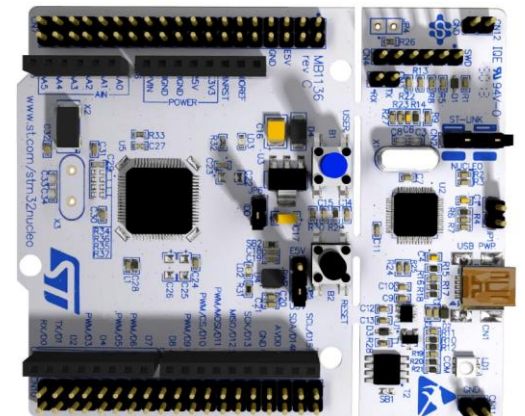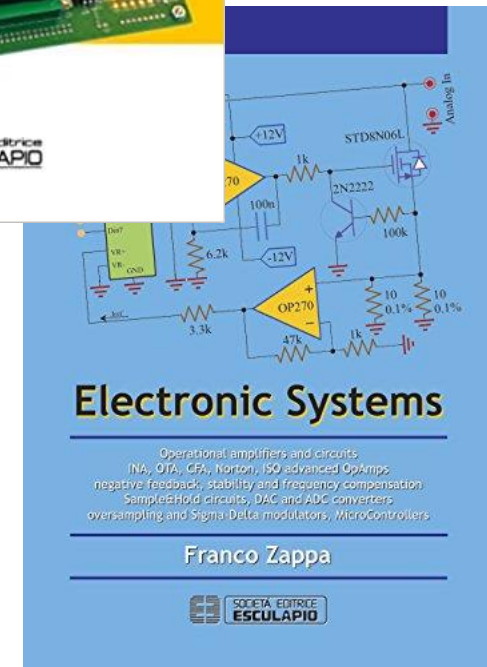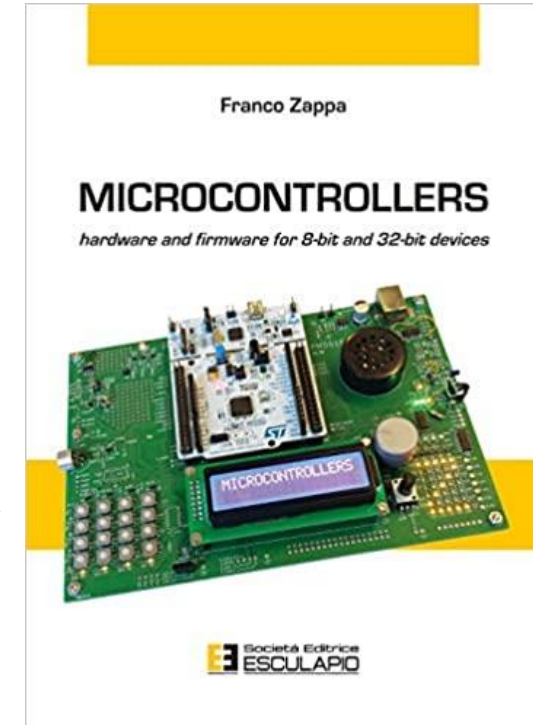
Oral Test:

- Theory
- Microcontroller project *modify program*

When?

- Official exam dates
- One day per months that will be announced on WeBeep month by month

Remember to register for the first official exam after you have passed the oral test.

WeBeep: 00 – Examples of questions

- ## Microcontrollers
  Franco Zappa – Esculapio

- ## Electronic Systems
  Franco Zappa – Esculapio

- ## Handbook of Modern Sensors - Physics, Designs, and Applications
  Jacob Fraden - Springer

- ## Electronics Sensors for the Evil Genius - 54 electrifying projects
  Tom Petruzzellis - TAB Electronics

- ## Make: Getting Started with Sensors - Measure the Word
  with Electronics, Arduino, and Raspberry Pi
  Kimmo Karvinen & Tero Karvinen - makezine.com

- ## Measurement, Instrumentation, and Sensors Handbook
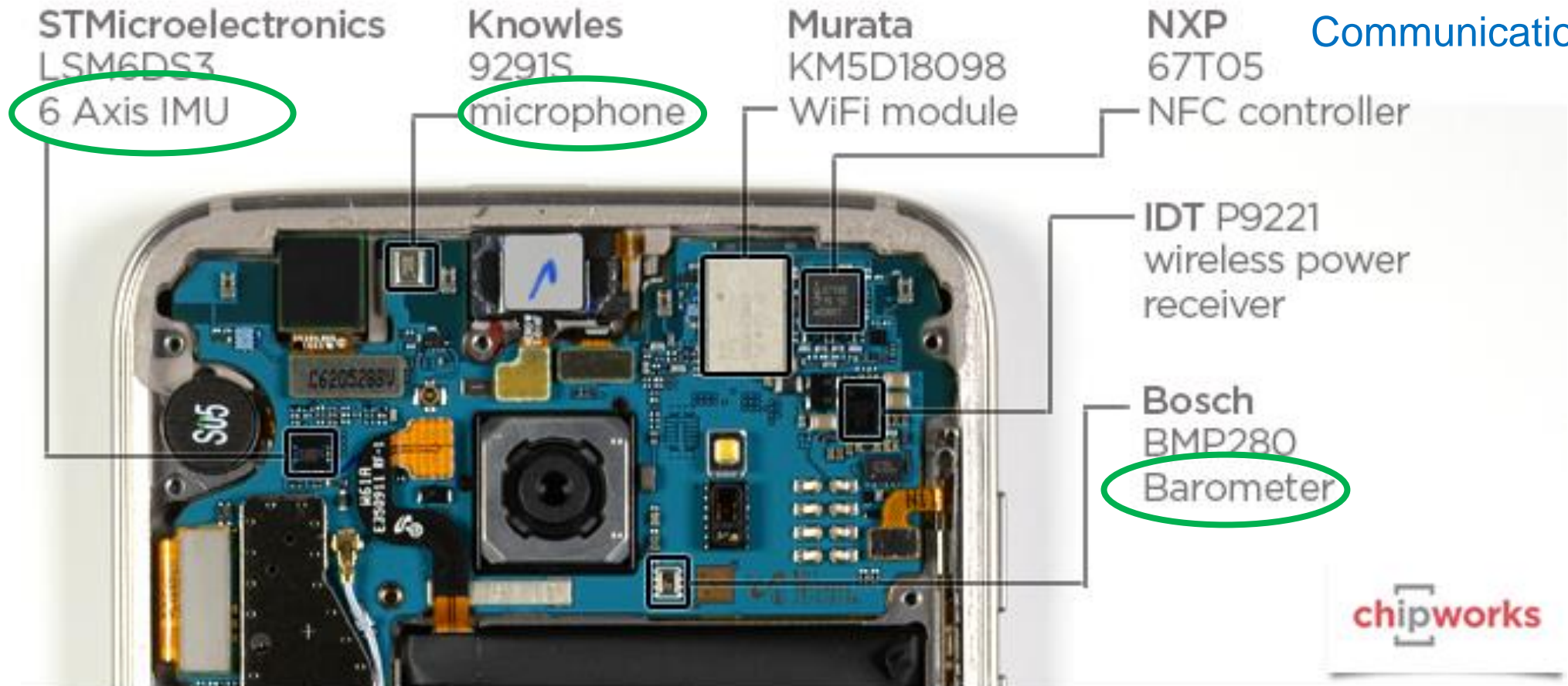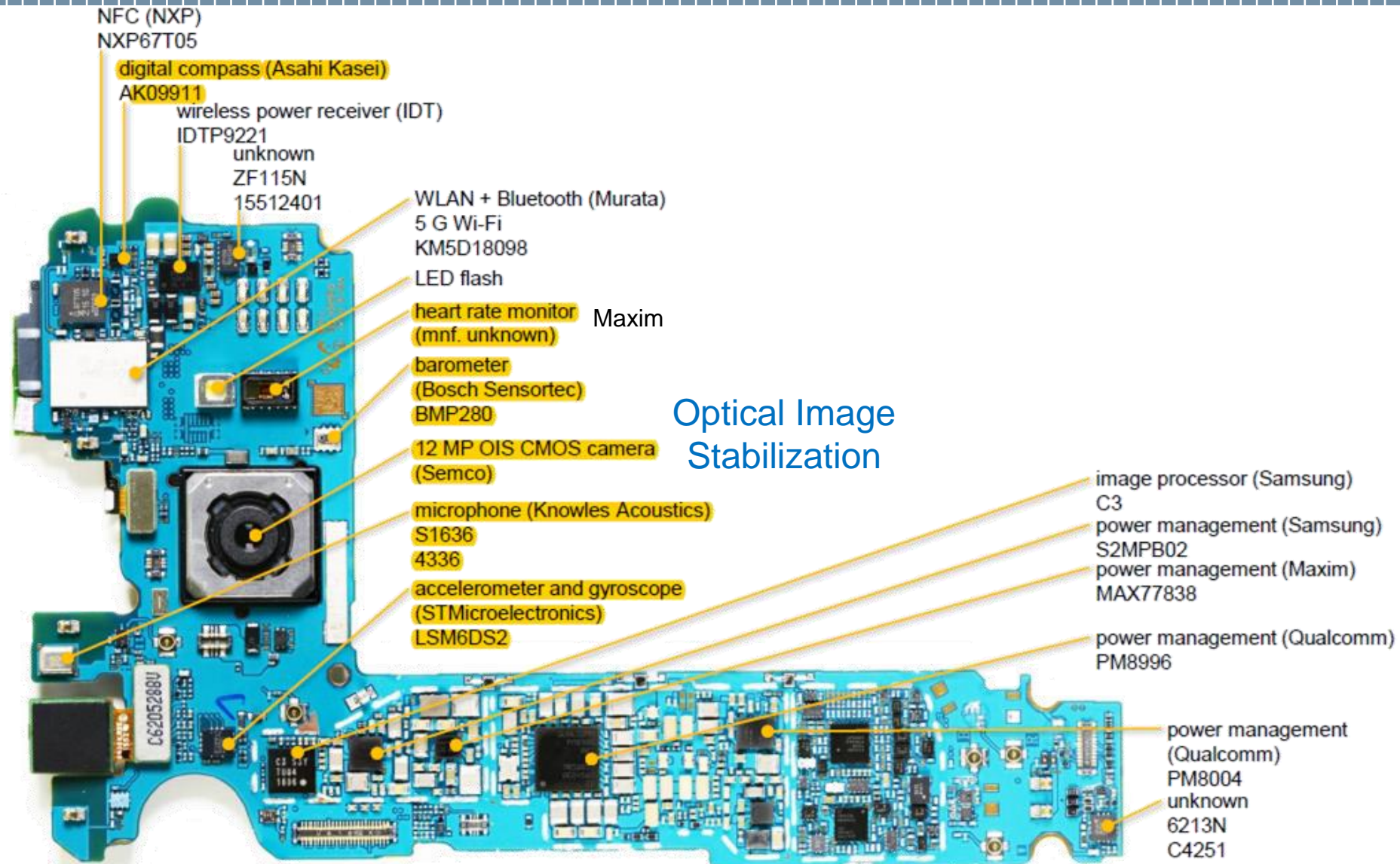 John G. Webster, Halit Eren - CRC press

https://www.techinsights.com/

WeBeep: 01 - Galaxy s7 edge

Inertial Measurement Unit

Near Field Communication

STMicroelectronics
LSM6DS3
6 Axis IMU

Knowles
9291S
microphone

Murata
KM5D18098
WiFi module

NXP
67T05
NFC controller

IDT P9221
wireless power
receiver

Bosch
BMP280
Barometer

chipworks

NFC (NXP)
NXP67T05

digital compass (Asahi Kasei)
AK09911

wireless power receiver (IDT)
IDTP9221

unknown
ZF115N
15512401

WLAN + Bluetooth (Murata)
5 G Wi-Fi
KM5D18098

LED flash

heart rate monitor
(mnf. unknown)   Maxim

barometer
(Bosch Sensortec)
BMP280

Optical Image
Stabilization

12 MP OIS CMOS camera
(Semco)

microphone (Knowles Acoustics)
S1636
4336

accelerometer and gyroscope
(STMicroelectronics)
LSM6DS2

image processor (Samsung)
C3

power management (Samsung)
S2MPB02

power management (Maxim)
MAX77838

power management (Qualcomm)
PM8996

power management
(Qualcomm)
PM8004
unknown
6213N
C4251

chipworks

Sensor	Manufacturer	Code
CMOS image sensor 12Mpx (rear camera)	Sony	IMX260
CMOS image sensor 5Mpx (front camera)	Samsung	S5K4E6
Microphone	Knowles	SPH0641LM4H-1
Pulse Oximeter	Maxim	MAX30100
Proximity sensor	AMS	TMD490X
Barometer (pressure sensor)	Bosch	BMP280
Gyroscope	STMicroelectronics	L2G2IS
6 axis IMU (Inertial Measurement Unit)	STMicroelectronics	LSM6DS3
Electronic compass	AKM	AK09911
Touch Screen Controller	Samsung	S6SA552X

Resolution **12 Mpixel**

Pitch **1.44 µm**

Sony back-illuminated (Exmor R) CMOS image sensor
implemented with a non-stacked hybrid-bonding (CIS + ISP) solution:
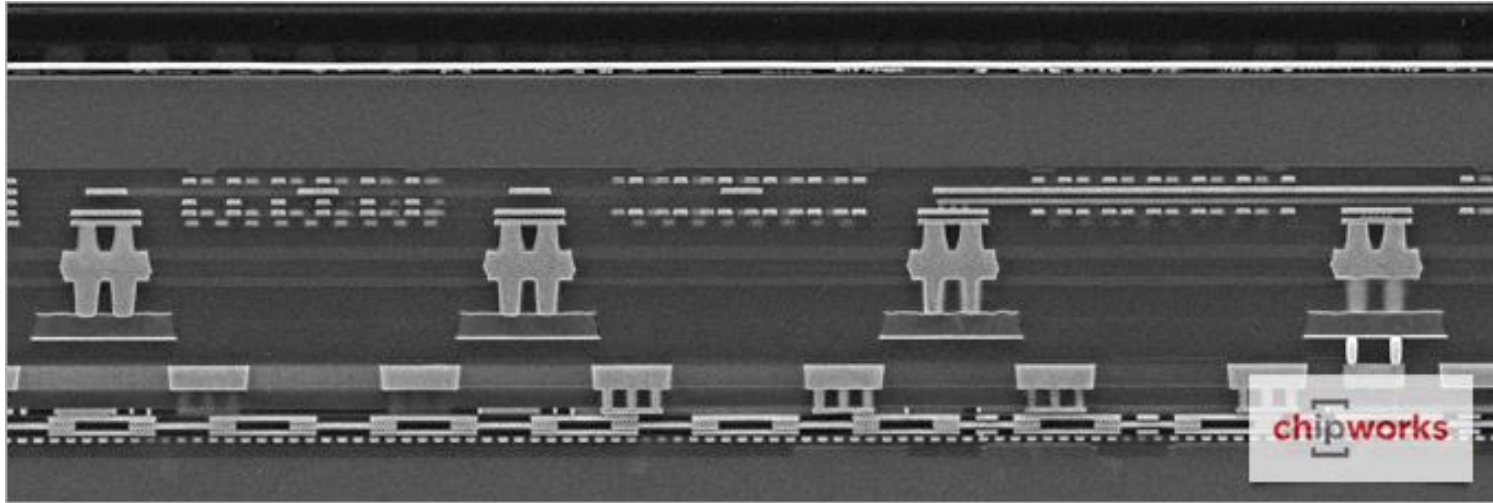CIS = 5 metal CMOS Image Sensor
ISP = 7 metal Image Signal Processor

Dual pixel phase detection **autofocus** (PDAF)
(100% of the active pixel array committed to both sensing and AF system)
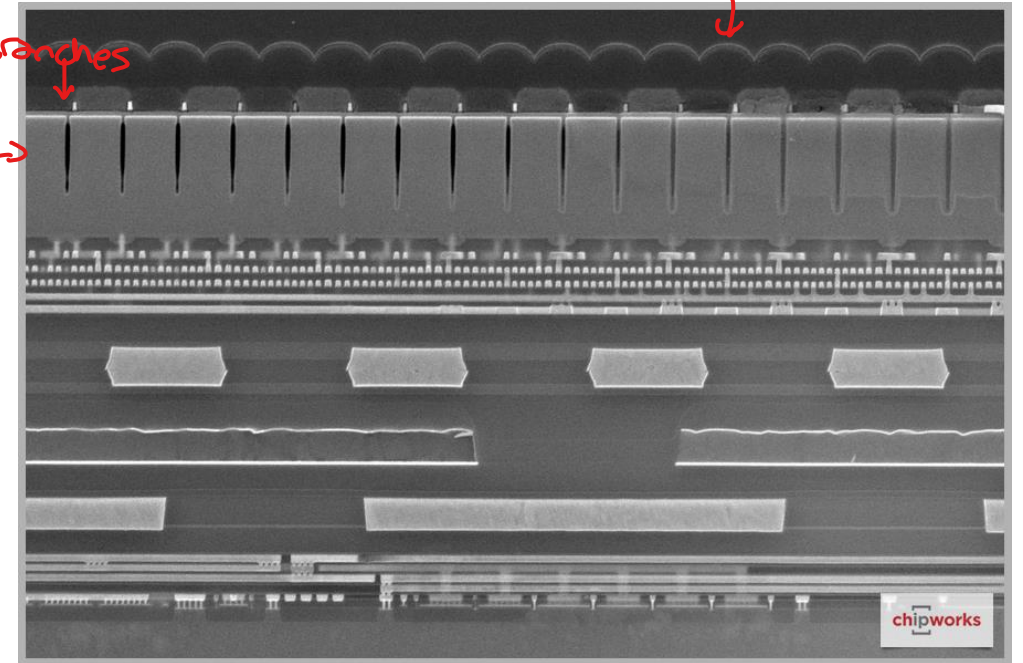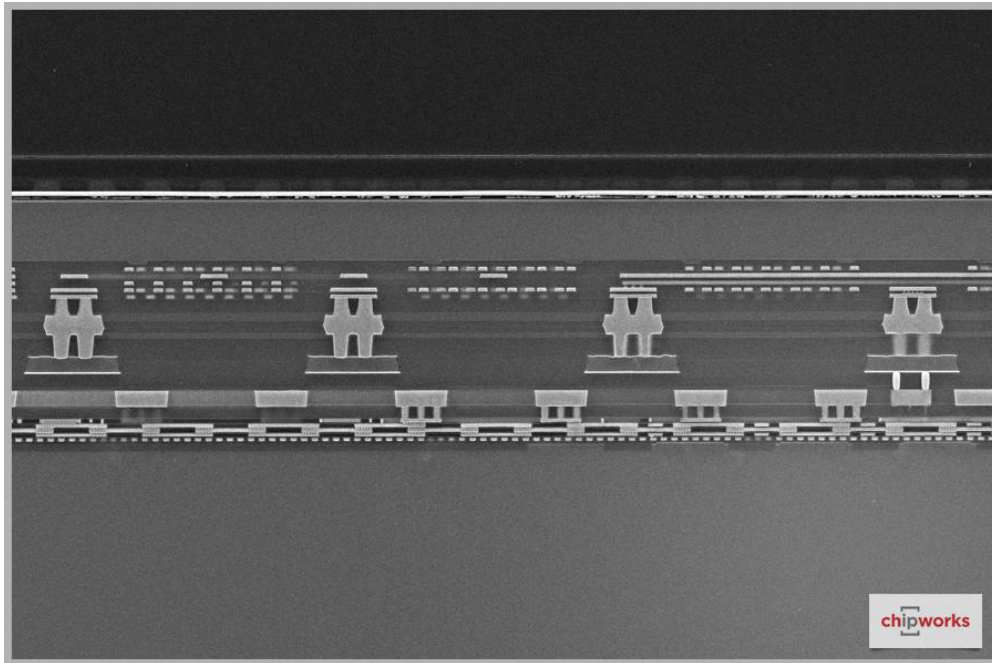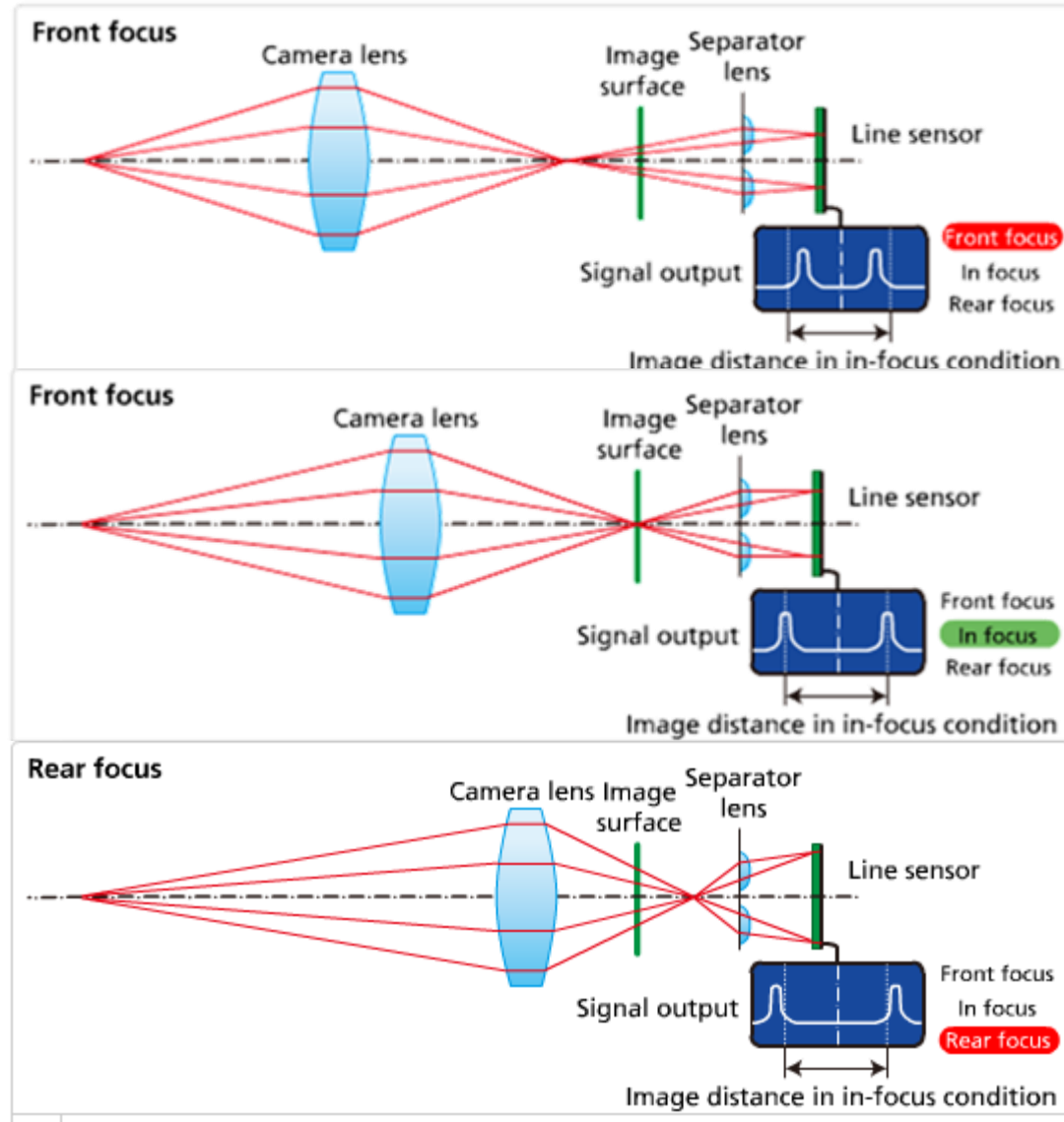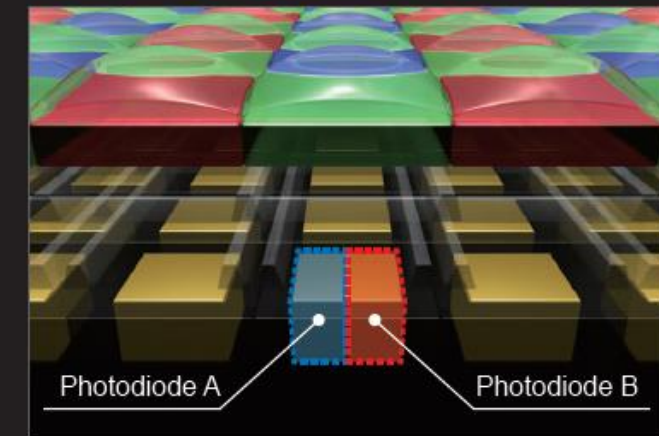
front end surface

microlenses to focus light

trenches

vertical cuts: separate 2 pixels

2 px ensible togreen, 1 blue, 1 red

Front focus

Camera lens

Image surface — Separator lens

Line sensor

Signal output

Front focus
In focus
Rear focus

Image distance in in-focus condition

Front focus

Camera lens

Image surface — Separator lens

Line sensor

Signal output

Front focus
In focus
Rear focus

Image distance in in-focus condition

Rear focus

Camera lens Image surface — Separator lens

Line sensor

Signal output

Front focus
In focus
Rear focus

Image distance in in-focus condition

CMOS sensor configuration

Photodiode A   Photodiode B

Composed of pixels that each have two separate photodiodes

discover if front or rear focus in base of pixel compared to others
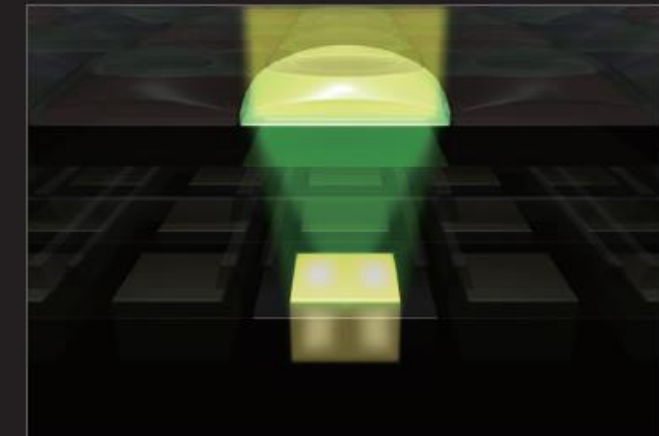
- Each signal is detected during AF, and it is used as a phase-difference detection AF sensor
- During imaging they are combined as one pixel for output of the image signal

Digital Zero-Height SiSonic™ Microphone With Multiple Performance Modes

Knowles

"intelligent": not only analog but ~DC (handwritten annotation)
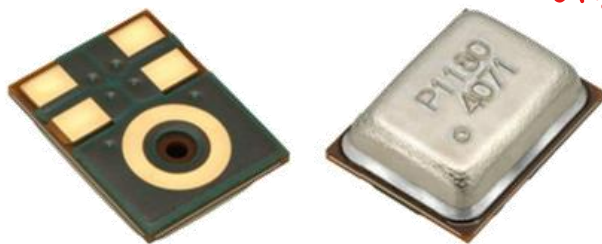
Pulse Density Modulation

The SPH0641LM4H-1 is a miniature, high-performance, low power, **bottom port** silicon digital microphone with a **single bit PDM output**. Using Knowles' proven high performance SiSonic™ MEMS technology, the SPH0641LM4H-1 consists of an **acoustic sensor**, a **low noise input buffer**, and a **sigma-delta modulator**. These devices are suitable for applications such as cellphones, **smart phones**, laptop computers, sensors, digital still cameras, portable music recorders, and other portable electronic devices where excellent wideband audio performance and RF immunity are required. In addition, the SPH0641LM4H-1 offers multiple performance modes

Features:

- High SNR of 64dB
- Low Current Consumption of 230uA in Low-Power Mode
- Flat Frequency Response
- RF Shielded
- Zero-Height Mic™
- Supports Dual Multiplexed Channels
- Standard SMD Reflow
- Omnidirectional
- Multiple performance modes (Sleep, Low-Power, Standard Performance)
- Sensitivity Matching
- Small Size

Alpha Character A:
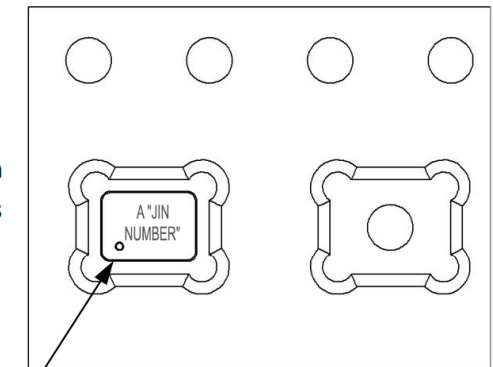   "S": Knowles SiSonic™ Production
   "E": Knowles Engineering Samples
   "P": Knowles Prototype Samples
"JIN NUMBER":
   Unique Job Identification Number
   for product traceability

Pin 1

Pin #	Pin Name	Type	Description
1	DATA	Digital O	PDM Output
2	SELECT	Digital I	Lo/Hi (L/R) Select This pin is internally pulled low but should not be left floating.
3	GROUND	Power	Ground
4	CLOCK	Digital I	Clock Input
5	V_{DD}	Power	Power Supply

Photodiode + 2 LED

MAX30100

maxim integrated™

Pulse Oximeter and Heart-Rate Sensor IC for Wearable Health

General Description

The MAX30100 is an integrated pulse oximetry and heart-rate monitor sensor solution. It combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse oximetry and heart-rate signals.
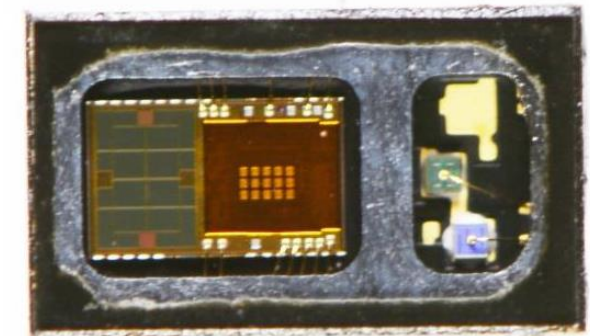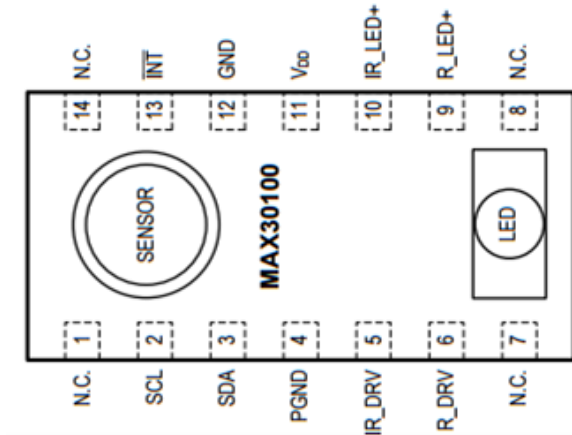
The MAX30100 operates from 1.8V and 3.3V power supplies and can be powered down through software with negligible standby current, permitting the power supply to remain connected at all times.

Applications
- Wearable Devices
- Fitness Assistant Devices
- Medical Monitoring Devices
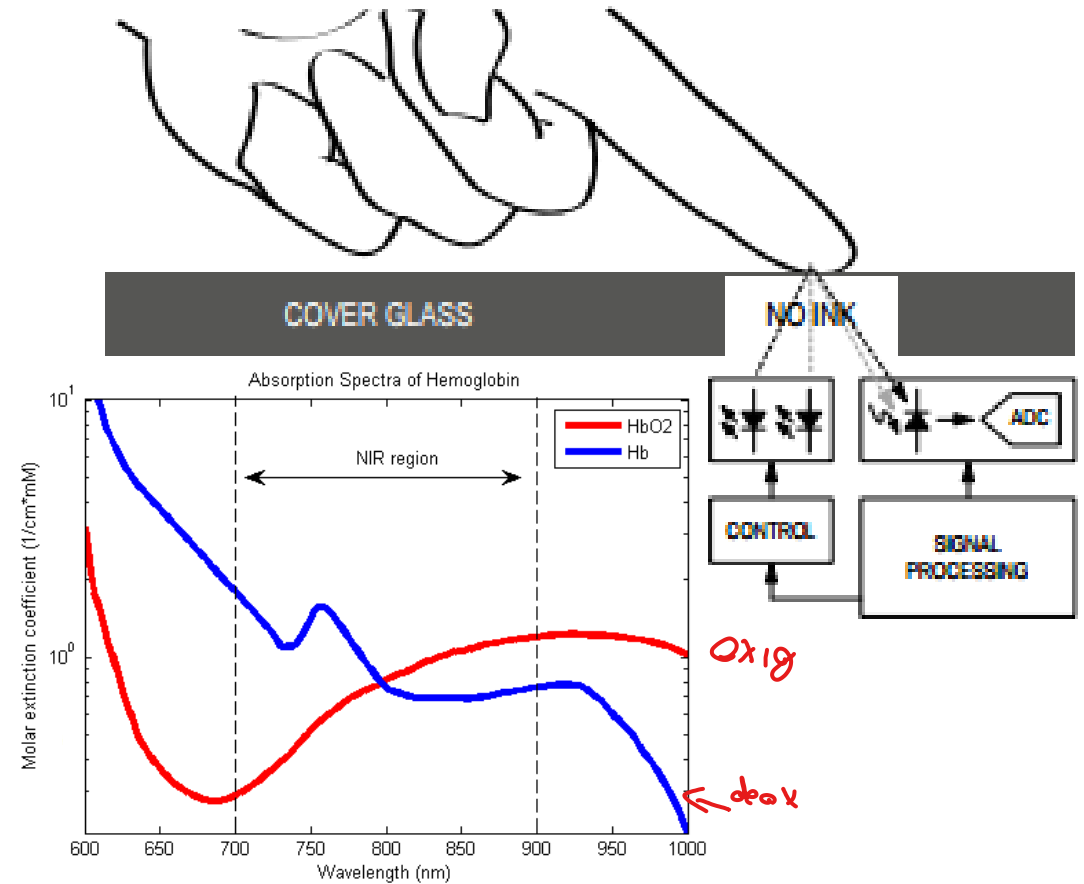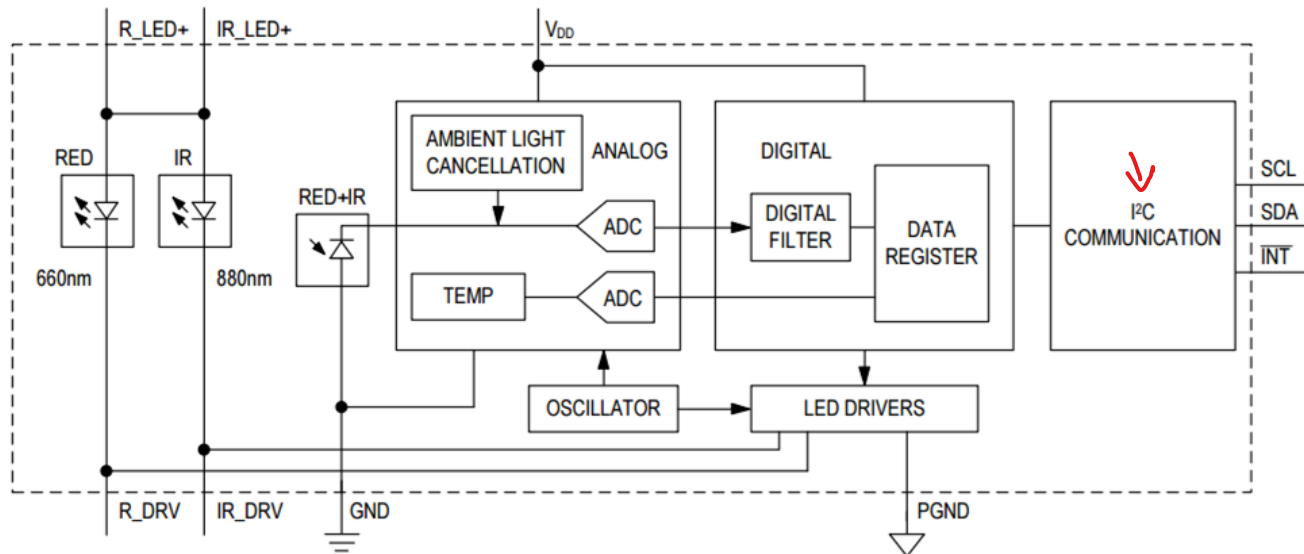
Benefits and Features
- Complete Pulse Oximeter and Heart-Rate Sensor Solution Simplifies Design
  - Integrated LEDs, Photo Sensor, and High-Performance Analog Front -End
  - Tiny 5.6mm x 2.8mm x 1.2mm 14-Pin Optically Enhanced System-in-Package
- Ultra-Low-Power Operation Increases Battery Life for Wearable Devices
  - Programmable Sample Rate and LED Current for Power Savings
  - Ultra-Low Shutdown Current (0.7µA, typ)
- Advanced Functionality Improves Measurement Performance
  - High SNR Provides Robust Motion Artifact Resilience
  - Integrated Ambient Light Cancellation
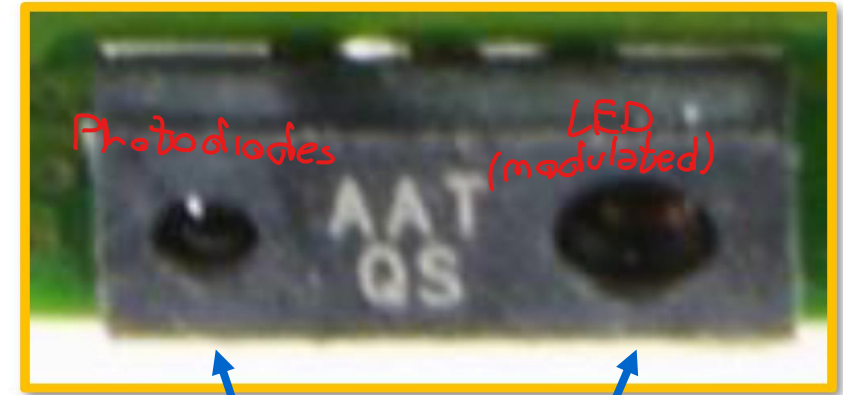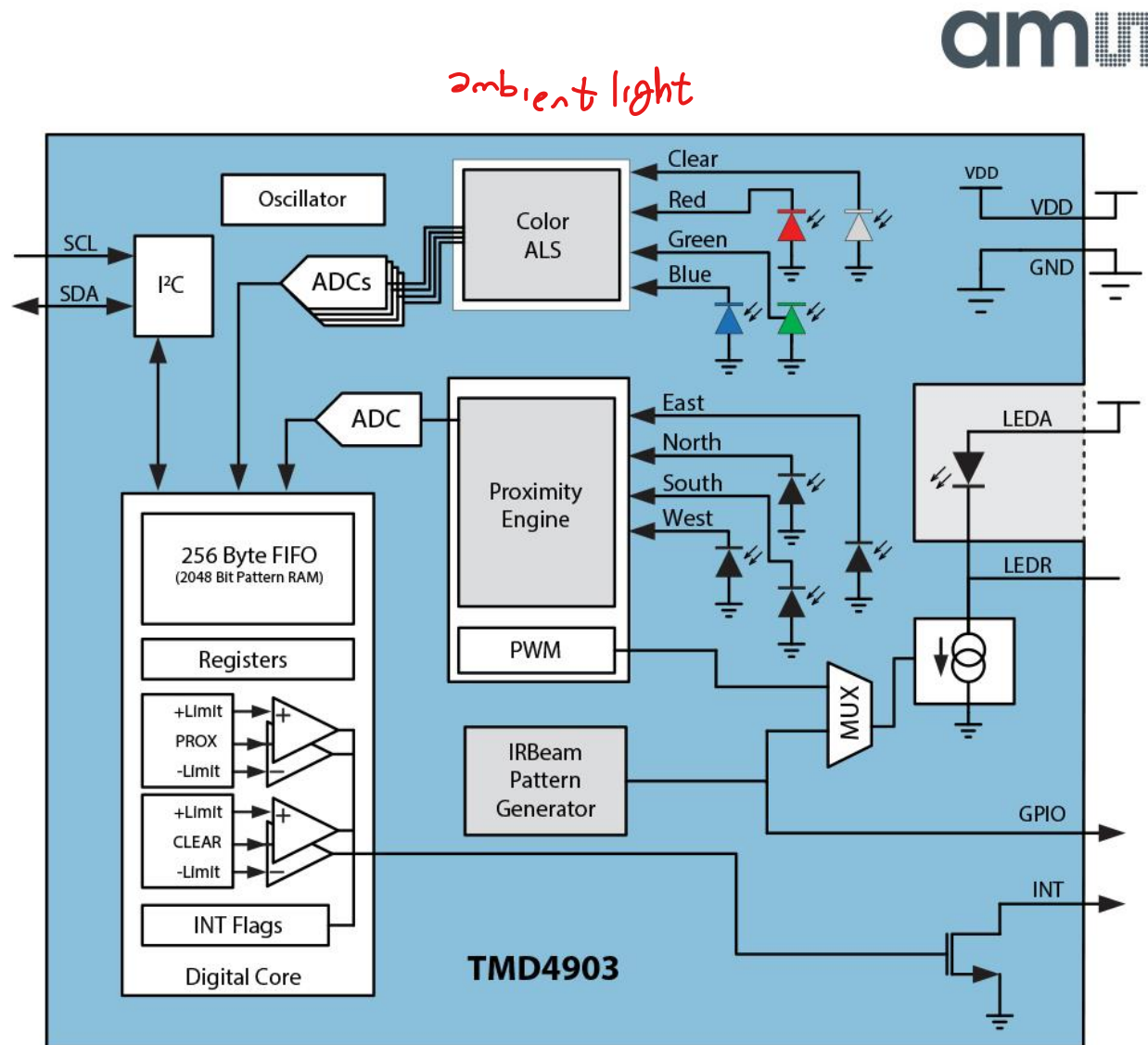 - High Sample Rate Capability
  - Fast Data Output Capability

2 LEDs (RED and IR)

1 photodiode

Oxigenated and deox
different spectrum

Absorption Spectra of Hemoglobin

Oxig

deox

ambient light

light/proximity sensor (AMS)
TMD490X

Photodiodes

LED (modulated)

Optical windows for LED and photodiodes

BMP280
Digital, barometric pressure sensor

Bosch Sensortec

BOSCH
Invented for life

General description

BMP280 is an absolute barometric pressure sensor especially designed for mobile applications. The sensor module is housed in an extremely compact package. Its small dimensions and its low power consumption allow for the implementation in battery driven devices such as mobile phones, GPS modules or watches.

As its predecessor BMP180, the BMP280 is based on Bosch's proven piezo-resistive pressure sensor technology featuring high accuracy and linearity as well as long term stability and high EMC robustness.

Numerous device operation options offer highest flexibility to optimize the device regarding power consumption, resolution and filter performance. A tested set of default settings for example use case is provided to the developer in order to make design-in as easy as possible.

Key parameters

- Pressure range
  300 ... 1100 hPa
  (equiv. to +9000...-500 m above/below sea level)

- Package
  8-pin LGA metal-lid
  Footprint : 2.0 × 2.5 mm², height: 0.95 mm

- Relative accuracy
  (950 ... 1050hPa @25°C)
  ±0.12 hPa, equiv. to ±1 m

- Absolute accuracy
  (950 ...1050 hPa, 0 ...+40 °C)
  typ. ±1 hPa

- Temperature coefficient offset   1.5 Pa/K, equiv. to 12.6 cm/K
  (25 ... 40°C @900hPa)

- Digital interfaces
  I²C (up to 3.4 MHz)
  SPI (3 and 4 wire, up to 10 MHz)

- Current consumption
  2.7µA @ 1 Hz sampling rate

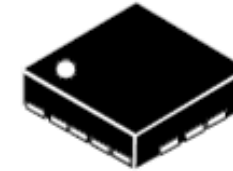- Temperature range
  -40 ... +85 °C

0.95mm   2mm   2.5mm
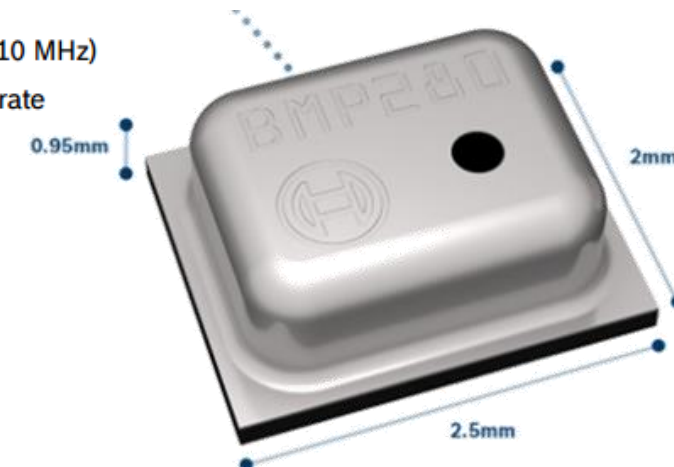
L2G2IS

MEMS motion sensor:
ultra-compact two-axis gyroscope for optical image stabilization

LGA-16 (2.3x2.3x0.7 mm)

Description

The L2G2IS is a two-axis MEMS gyroscope for optical image stabilization applications.

It includes a sensing element and an IC interface capable of providing the measured angular rate to the application through an SPI digital interface.

The unique sensing element is manufactured using a dedicated micromachining process developed by STMicroelectronics to produce inertial sensors and actuators on silicon wafers.

The IC interface is manufactured using a CMOS process that allows a high level of integration to design a dedicated circuit which is trimmed to better match the characteristics of the sensing element.

The L2G2IS is available in a plastic land grid array (LGA) package and can operate over a temperature range of -40 °C to +85 °C.

degree per second

Features

- ±100 dps / ±200 dps full-scale range
- Wide supply voltage range: 1.71 V to 3.6 V
- Low-voltage compatible IOs
- 3- and 4-wire SPI digital interface
- Embedded temperature sensor
- Embedded self-test
- Integrated low- and high-pass filters with user-selectable bandwidth
- Power-down and sleep modes for smart power saving
- ECOPACK®, RoHS and "Green" compliant

Applications

- Optical image stabilization

12 MP OIS CMOS camera (rear)

Optical Image Stabilization

OIS driver (Renesas)
RAY00

gyroscope (STMicroelectronics)
L2G2IS

serial flash memory (Winbond)
W25Q32FW

LSM6DS3

iNEMO inertial module:
always-on 3D accelerometer and 3D gyroscope

Description

The LSM6DS3 is a system-in-package featuring a 3D digital accelerometer and a 3D digital gyroscope performing at 1.25 mA (up to 1.6 kHz ODR) in high-performance mode and enabling always-on low-power features for an optimal motion experience for the consumer.

The LSM6DS3 supports main OS requirements, offering real, virtual and batch sensors with 8 kbyte for dynamic data batching.

ST's family of MEMS sensor modules leverages the robust and mature manufacturing processes already used for the production of micromachined accelerometers and gyroscopes.

The various sensing elements are manufactured using specialized micromachining processes, while the IC interfaces are developed using CMOS technology that allows the design of a dedicated circuit which is trimmed to better match the characteristics of the sensing element.

The LSM6DS3 has a full-scale acceleration range of ±2/±4/±8/±16 g and an angular rate range of ±125/±245/±500/±1000/±2000 dps.

High robustness to mechanical shock makes the LSM6DS3 the preferred choice of system designers for the creation and manufacturing of reliable products.

The LSM6DS3 is available in a plastic land grid array (LGA) package.

LGA-14L
(2.5 x 3 x 0.83 mm) typ.
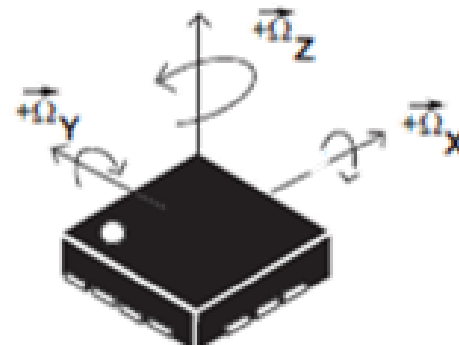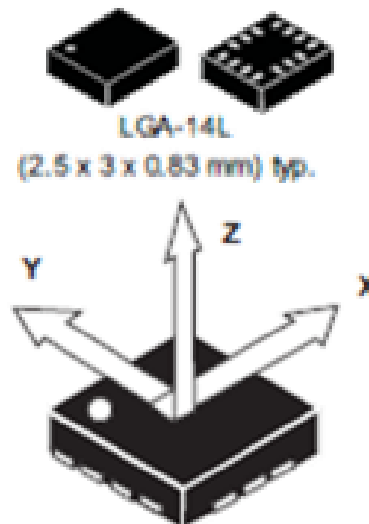
Features

- Power consumption: 0.9 mA in combo normal mode and 1.25 mA in combo high-performance mode up to 1.6 kHz.
- "Always-on" experience with low power consumption for both accelerometer and gyroscope
- Smart FIFO up to 8 kbyte based on features set
- Compliant with Android K and L
- Hard, soft ironing for external magnetic sensor corrections
- ±2/±4/±8/±16 g full scale
- ±125/±245/±500/±1000/±2000 dps full scale
- Analog supply voltage: 1.71 V to 3.6 V
- Independent IOs supply (1.62 V)
- Compact footprint, 2.5 mm x 3 mm x 0.83 mm
- SPI/I^2C serial interface with main processor data synchronization feature
- Embedded temperature sensor
- ECOPACK®, RoHS and "Green" compliant

Applications

- Pedometer, step detector and step counter
- Significant motion and tilt functions
- Indoor navigation
- Tap and double-tap detection
- IoT and connected devices
- Intelligent power saving for handheld devices
- Vibration monitoring and compensation
- Free-fall detection
- 6D orientation detection
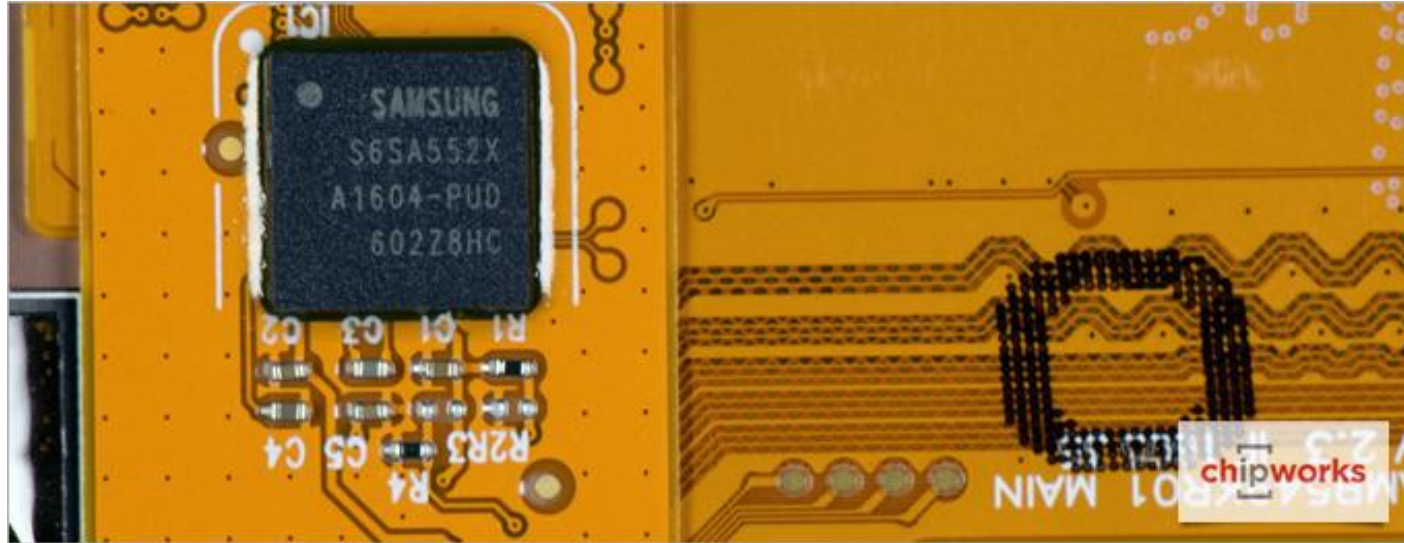
3 axial hall sesor (magnetic)

AsahiKASEI

[AK09911]

4. Circuit Configration
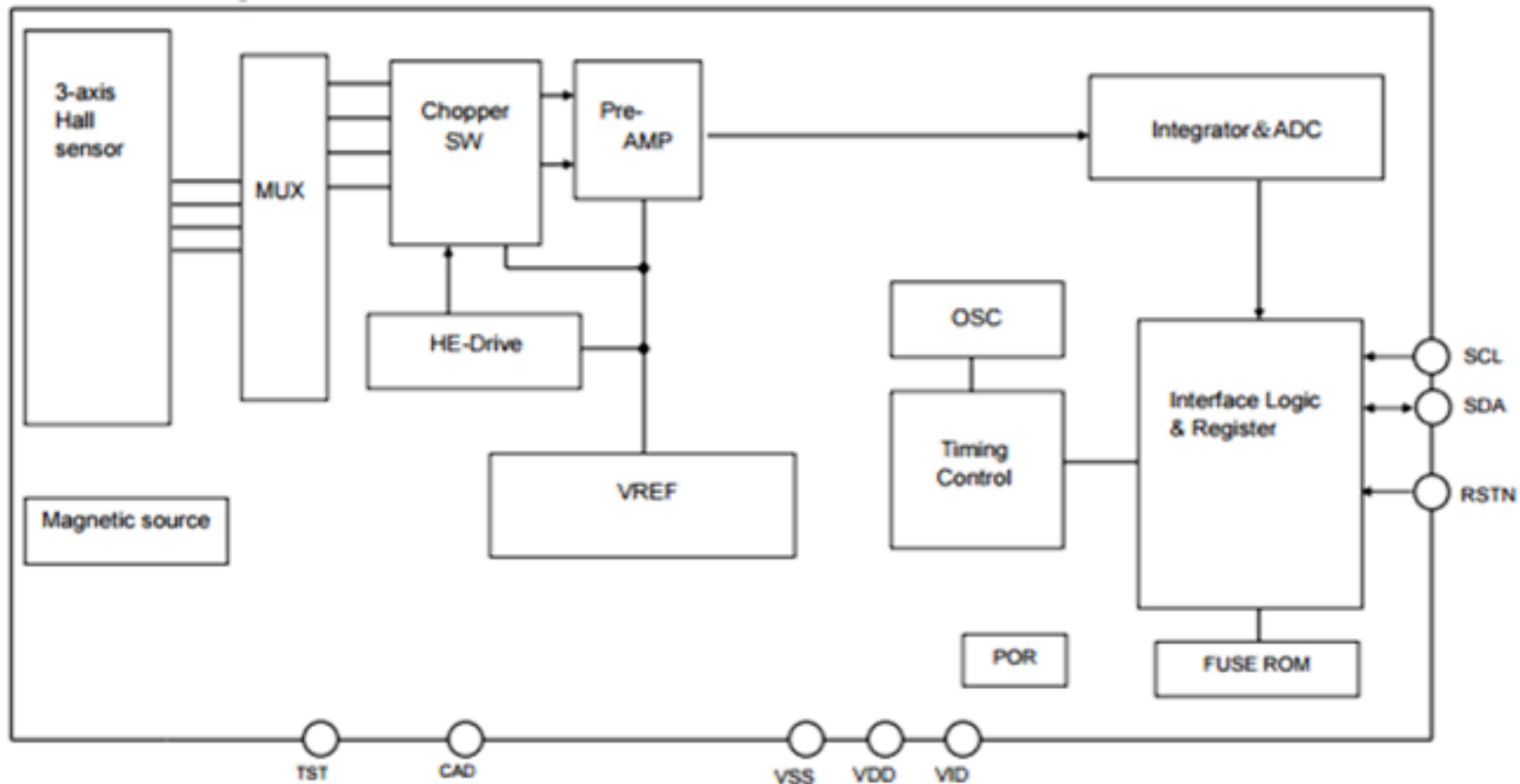
resitive
capacitive → in smartphones

Samsung S6SA552X – Capacitive touch screen

SPECIFICATIONS
TOUCH CONTROLLER > S6SA551

Scan/Report rate	160Hz/120Hz
Channel	52
Package	FBGA (Fine Pitch Ball Grid Array)
VDD max	1.65V