Sensor Analog IP Developments for IOT application

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2023-11-08

About Me

- Principal Analog Engineer, Renesas Electronics Dresden Germany, 2023 -
  - Technical Lead, Fraunhofer IIS/EAS, 2018 - 2011
  - Principal Engineer/PL, SK Hynix Korea, 2013-2017
  - Scientist II, Institute of Microelectronics A*STAR, Singapore, 2011-2013
  - Senior Engineer, System LSI, Samsung Electronics, Korea 2007 - 2011
  - Member of Research Staff, SAIT, Samsung Electronics, Korea, 2004-2011

- Dr.-Ing., Electrical Engineering, Technische Universität München, Germany 2005
  - Doktorand, Corporate Research, Infineon Tech. AG, Munich, Germany 2001 – 2004
  - Diplomand, Automotive & Idustrial, Infineon Tech. AG, Munich, Germany 2000

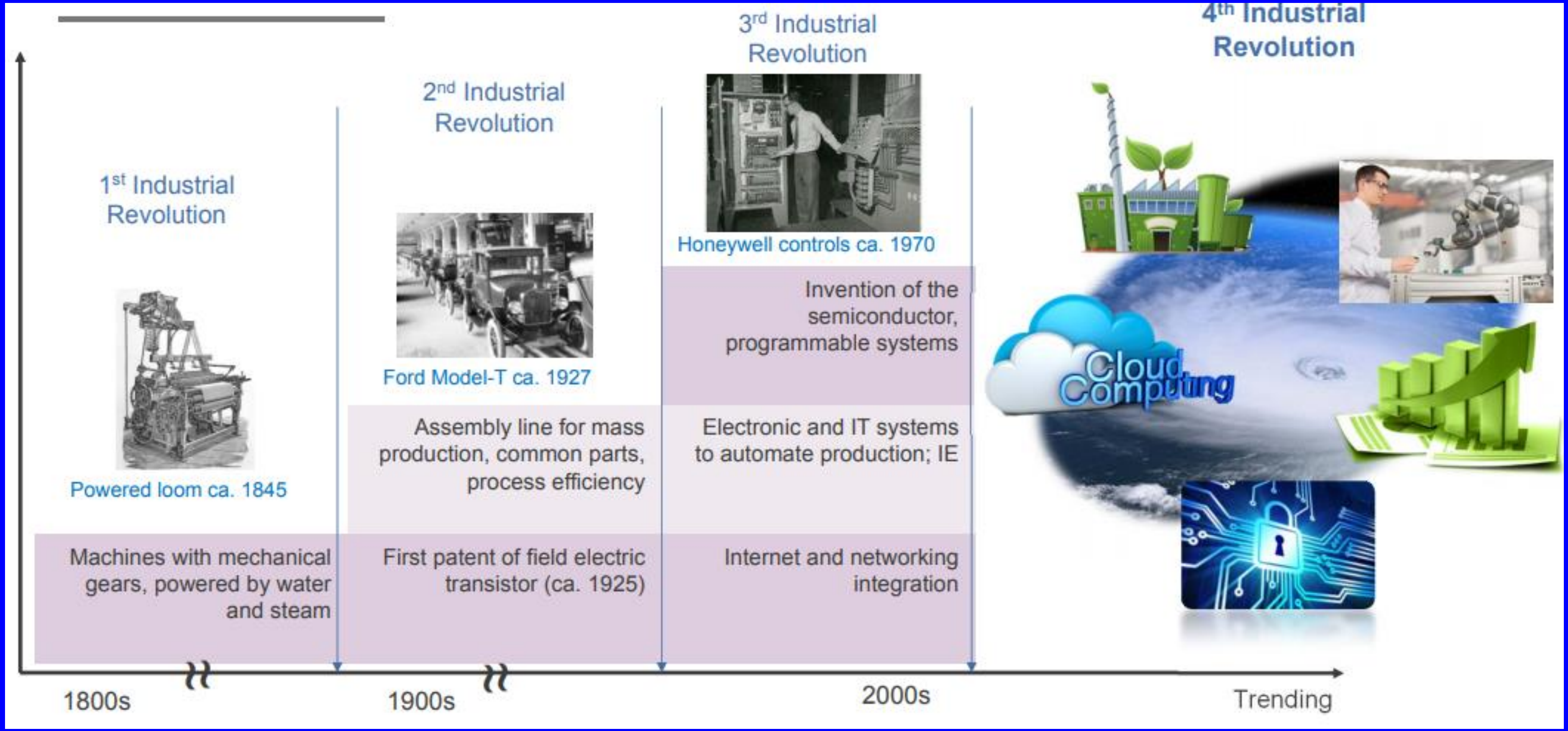
Today's talk

1. IOT ?
   1.1 Components in IOT systems
   1.2 IOT Player
   1.3 IOT Market
2. Sensor Analog IP Developments for IOT
   2.1 Sensor Analog IP Developments in PD-SOI
   2.2 Sensor Analog IP Developments in FD-SOI

1. Internet of Things ?

Internet Of Things ??

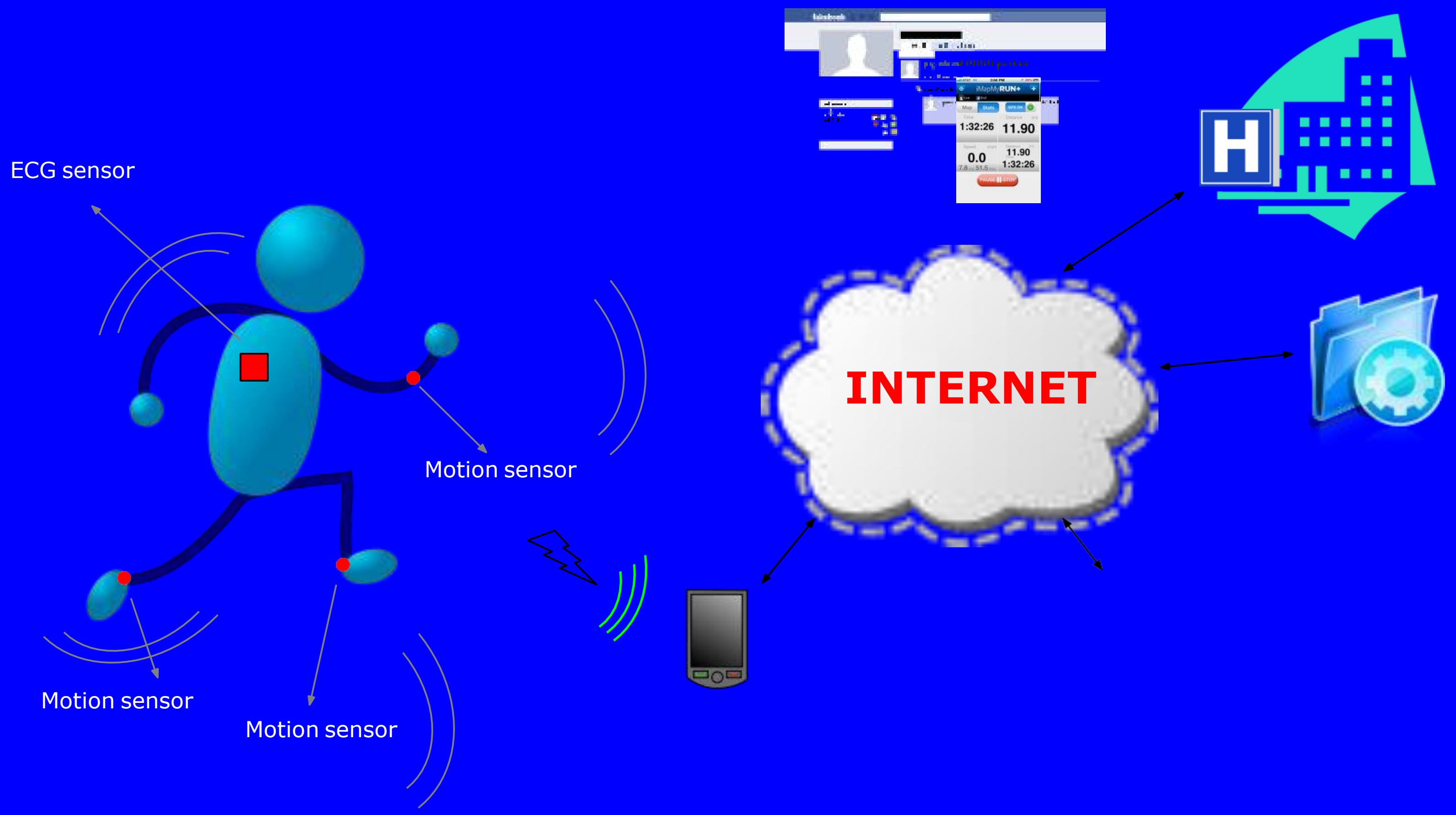
- Industry 4.0



Source: industry4_1_Renesas

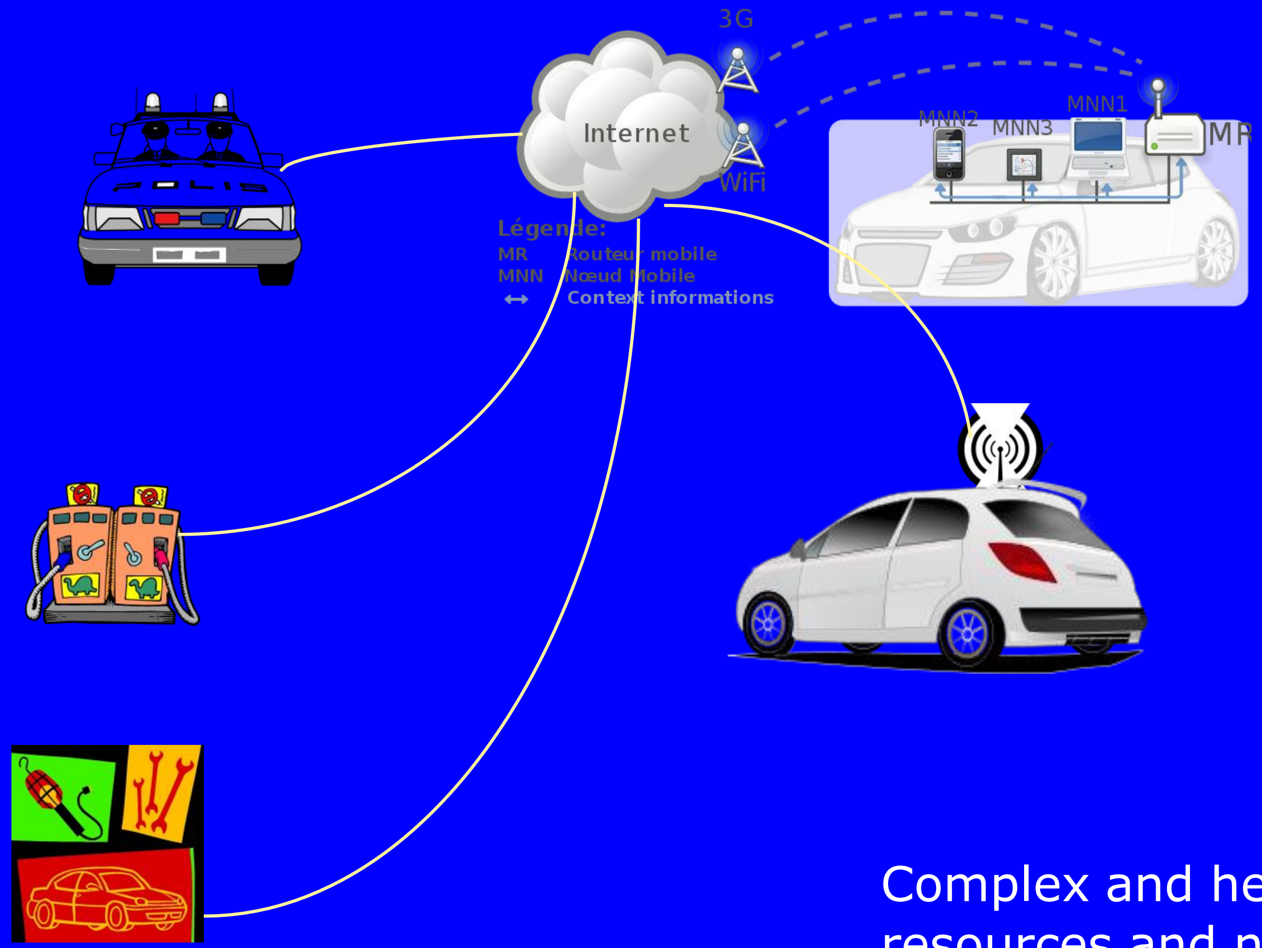
Internet Of Things ??

- **PEOPLE** connecting to **THINGS**



Internet Of Things ??

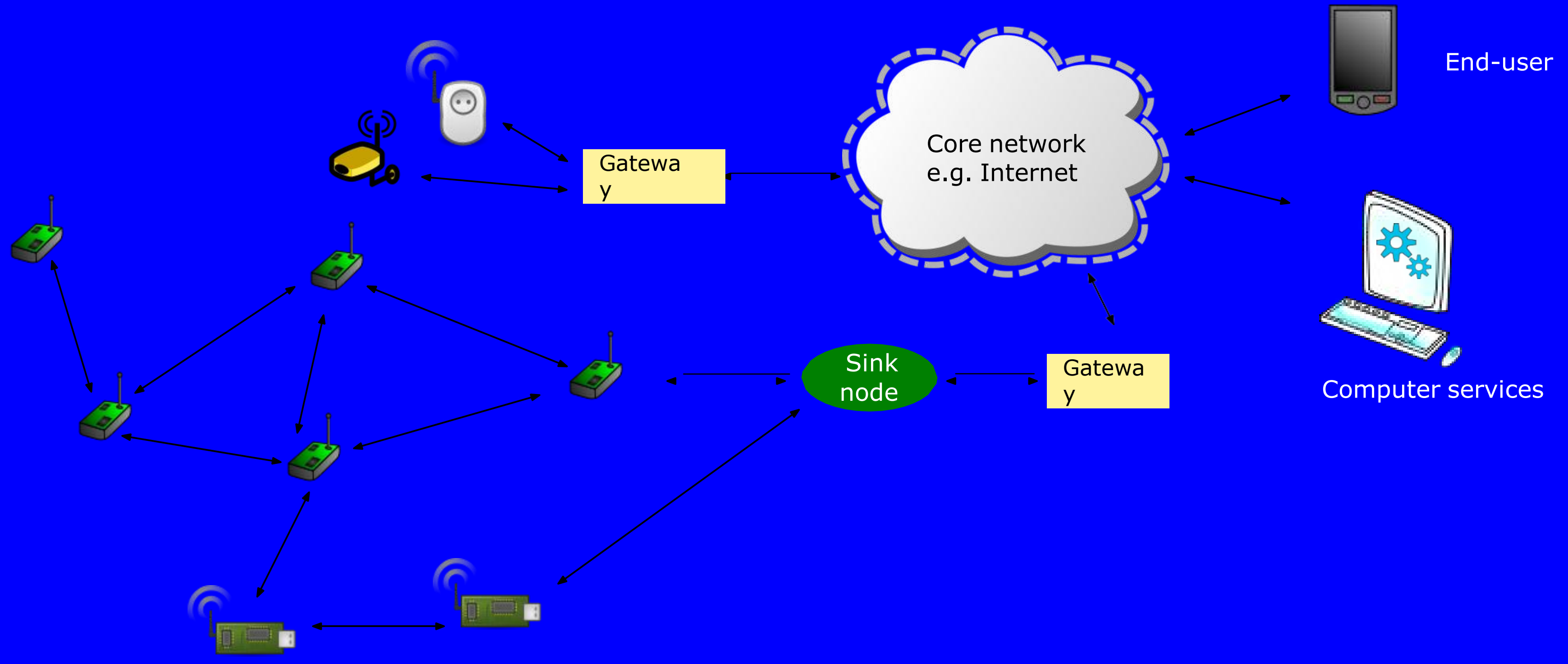
- **THINGS** connecting to **THINGS**



Complex and heterogeneous
resources and networks

Internet Of Things ??

- **Wireless Sensor Network**



The networks typically run Low Power Devices
Consist of one or more sensors, could be different type of sensors (or actuators)

Internet Of Things ??

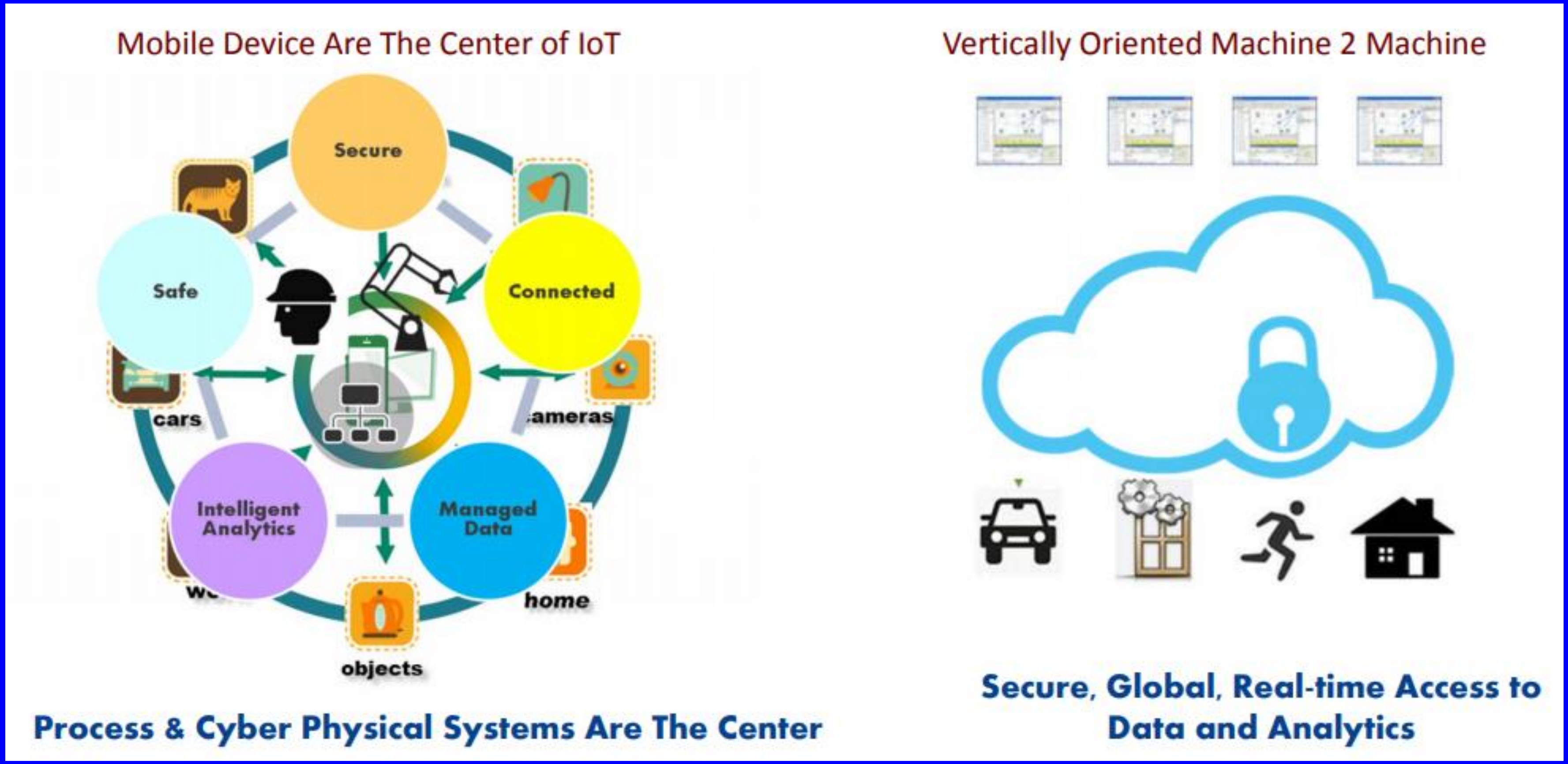
- **More Things are connected**

Home/daily-life devices Business and Public infrastructure Health-care

...

Internet Of Things ??

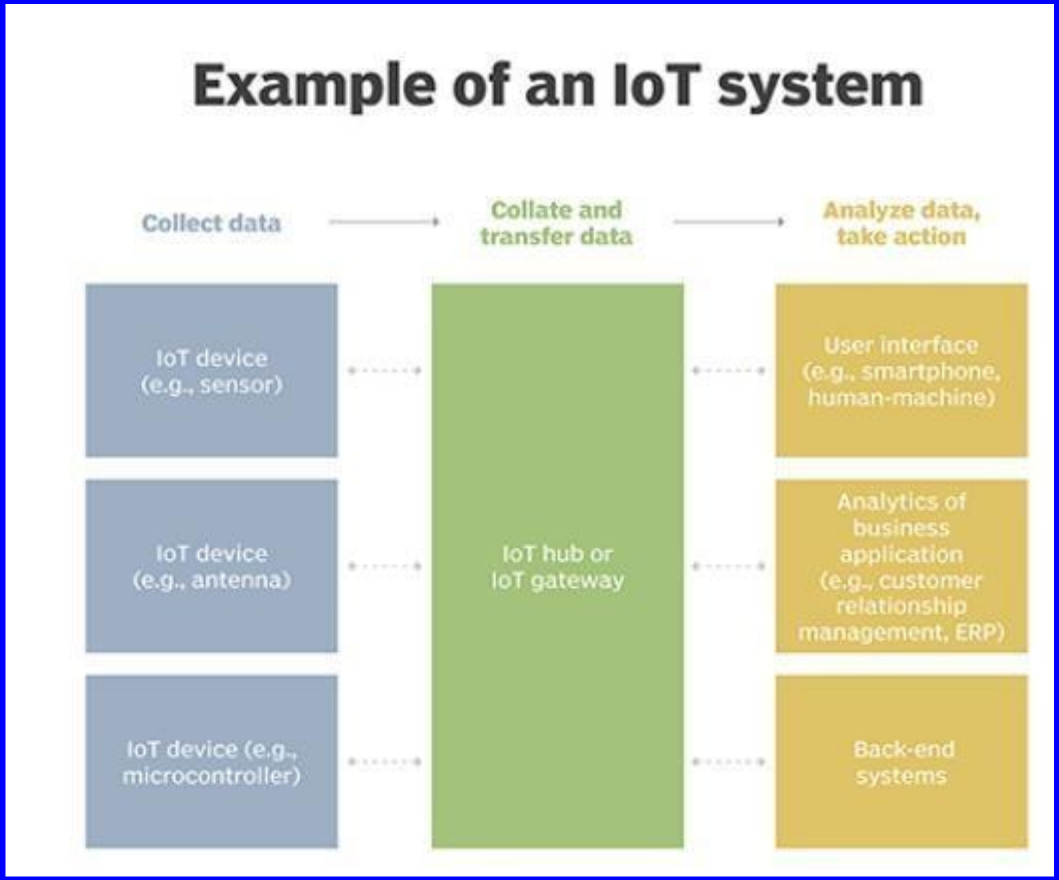
- IoT keeps changing The Typical Definition

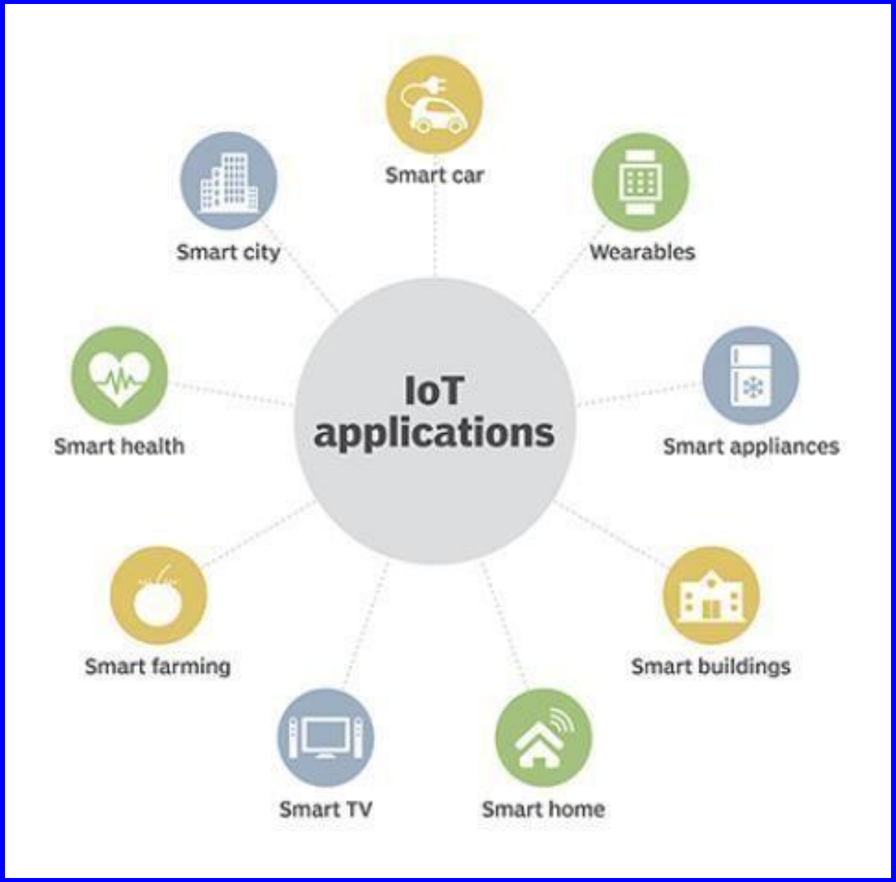


Source: industry4_1_Renesas

Internet Of Things ??

- Examples of IOT systems





NOW WE CAN SAY Internet Of Things

- The Internet of Things (IoT) is the network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.

- IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.

“SENSORs/ACTUATORs” in IOT systems

- Sensors:
  - They are mainly input components
  - They sense and collect surrounding information
- Basically three types:
  - Passive, omnidirectional (e.g. mic)
  - Passive, narrow-beam sensor (e.g. PIR)
  - Active sensors (e.g. sonar, radar, etc.)

- Actuators:
  - They are mainly output components
  - They alter the surrounding
- Some examples:
  - Adding lighting, heat, sound, etc.
  - Controlling motors to move objects
  - Displaying messages
  - and others…

“THINGs” in IOT systems

- We can turn almost every object into a “thing”.
- A “thing” still looks much like an embedded system currently.
- A “thing” generally consists of four main parts:
  - Sensors & actuators
  - Microcontroller
  - Communication unit
  - Power supply

- A “thing” has the following properties:
  - It’s usually powered by battery. This implies limited source of energy.
  - It’s generally small in size and low in cost. This limits their computing capability.
  - It doesn’t usually perform complicated tasks.
- Power consumption is the main design issue.

“COMMUNICATIONs” in IOT systems

- A “thing” always feature communications for “team working”
- The Role of Communications
  - Providing a data link between two nodes
- Communication type:
  - Wireline (e.g. copper wires, optical fibers)
  - Wireless (e.g. RF, IR). RF-based communication is the most popular choice (and also our focus)
- Popular RF-based communication solutions:
  - IEEE 802.15.4 □ used in XM1000
  - IEEE 802.11 (or Wifi)
  - Bluetooth
  - Near Field Communication (NFC), e.g. RFID
- Main concern: Security, Reliability & Performance

“NETWORKs” in IOT systems

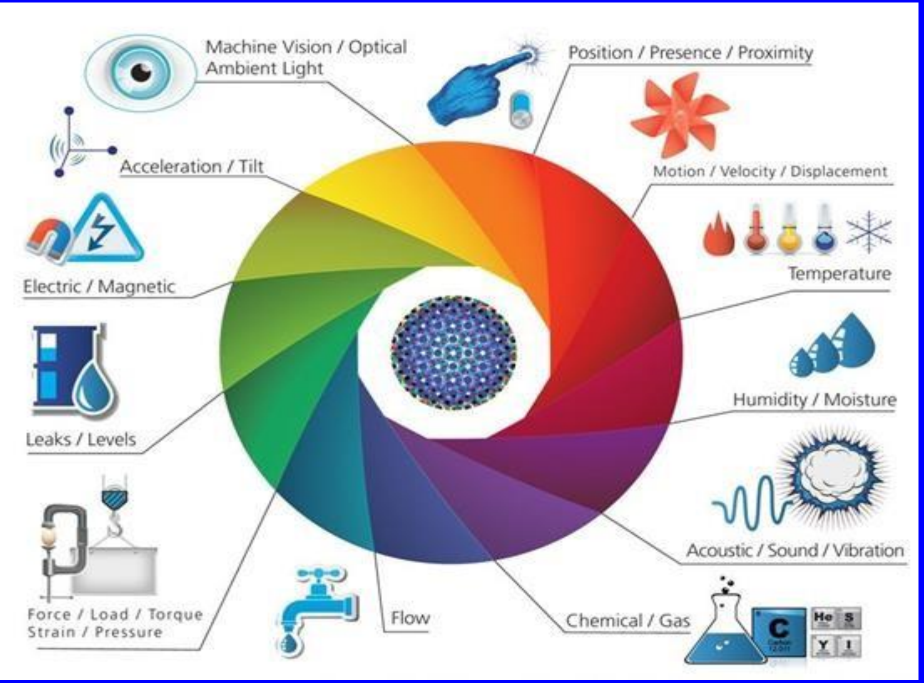
- The Roles of Networks
  - Managing nodes (discovery, join, leave, etc).
  - Relaying data packets from the source to the destination node in the network.
- Networks are a distributed system. All nodes need to perform networking related tasks.
- RF-based Network in IoT is usually a Wireless Multi-hop Network. Some examples:
  - Wireless Sensor Networks (WSNs)
  - Mobile Wireless Ad hoc Networks (MANETs)
  - Wireless Mesh Networks (WMNs)
  - Vehicular Ad Hoc Networks (VANETs)
  - and others...
- Main concern: Security, Reliability & Performance

“THE INTERNET” in IOT systems

- The Internet uses TCP/IP.
  - This implies that things must also support TCP/IP.

- Gateway (or sink)
  - For a practical deployment, a gateway is often needed in a network.
  - It offers relaying packets between the network and the Internet.

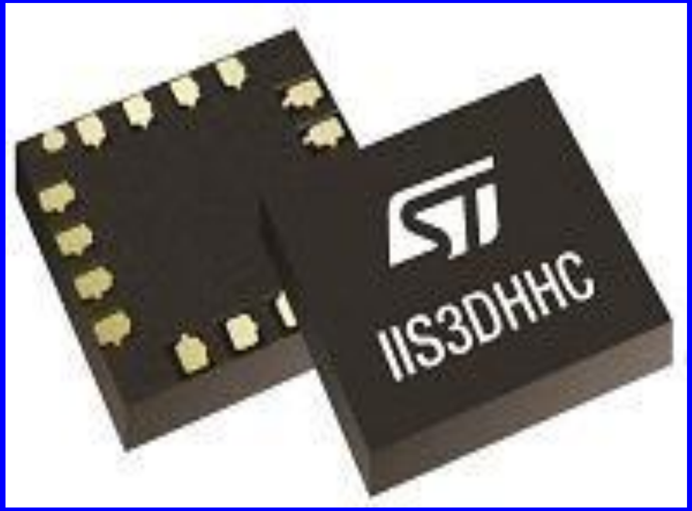
Examples of “SENSORs/ACTUATORs” in IOT systems



- By combining a set of sensors and a communication network, IoT devices share information with one another and are improving their effectiveness and functionality.”

IOT Players

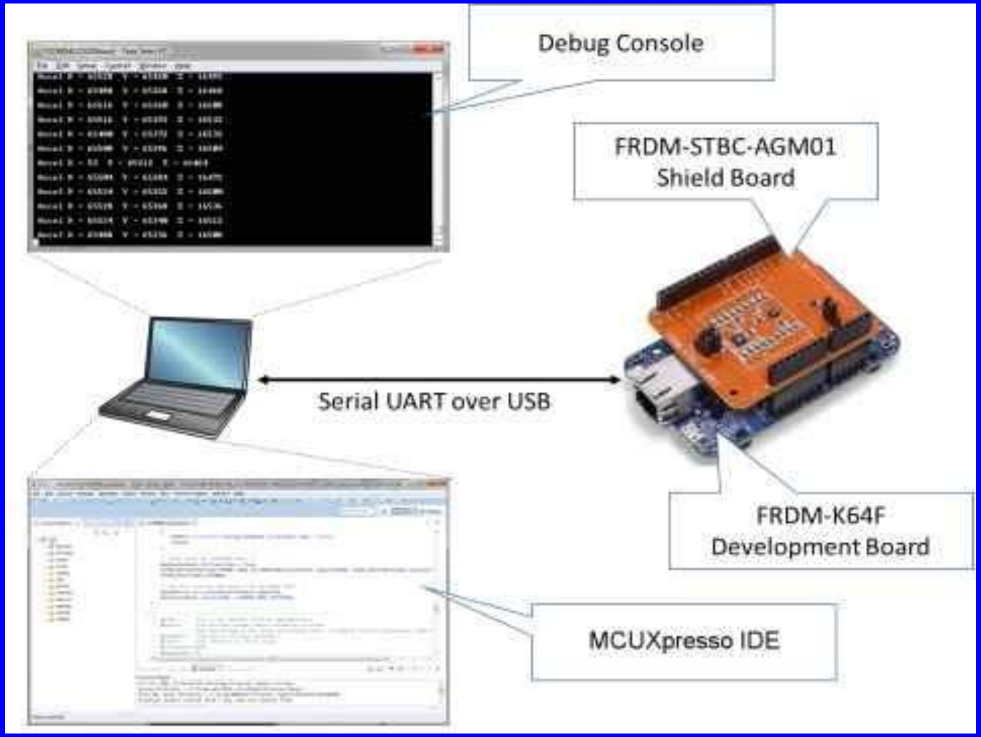
- ST Microelectronics (France)
  - Strong in MEMS sensor products
  - Produces MEMS sensor based Gyro, 3 axis accelerator sensor
  - Now expands those products with AI



Motion sensor (2.5x3x0.83 mm2) from STM

IOT Players

- NXP (The Netherlands)
  - Strong in Sensor Products
  - Motion Sensor, Magnetic Sensor, Touch Sensor, Temperature Sensor etc
  - Announces ISSDK (IOT Sesning Software Development Kit)



ISSDK from NXP

IOT Players

- INFINEON (Germany)
  - Strong in Automotive Products
  - Very active in Lidar Sensor (ADAS)
  - Announces XENSIV for multi sensor applications

Lidar Sensor from Infineon

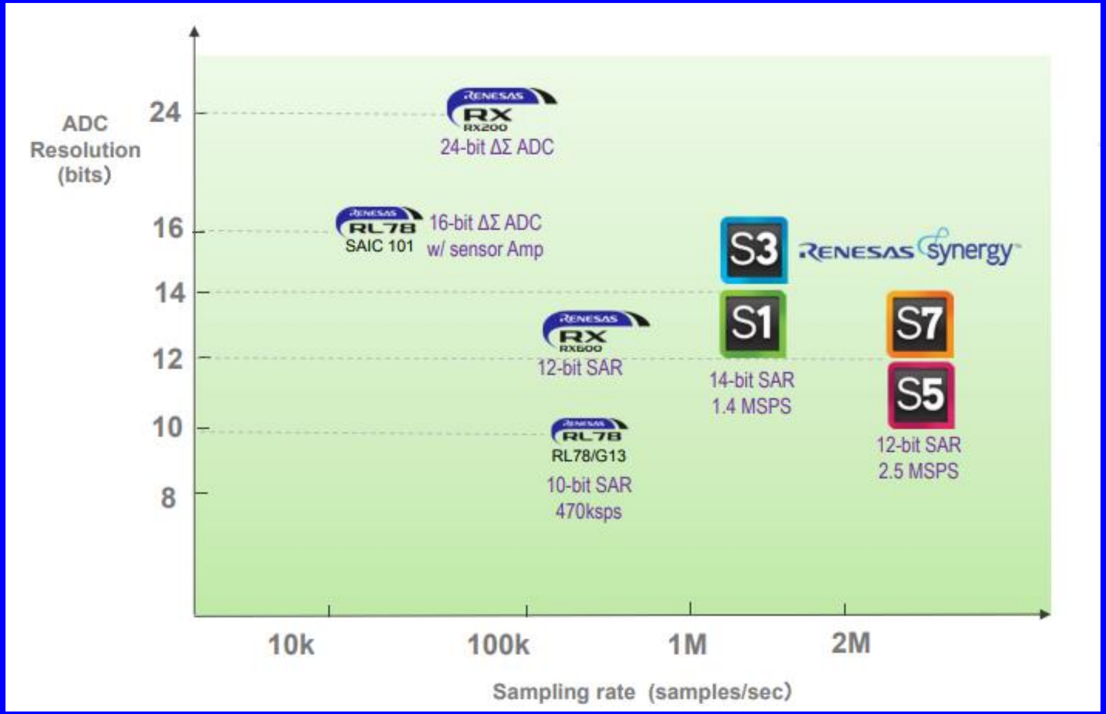
IOT Players

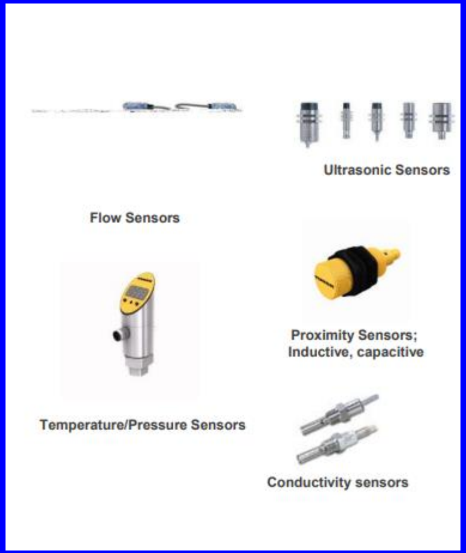
- BOSCH (Germany)
  - Strong in MEMS Process/Products
  - Bosch Sensortec (Dresden) provides mobile sensor products
  - Bosch (Reutlingen) provides Automotive/Industrial sensor products

MEMS Sensor from Bosch

IOT Players

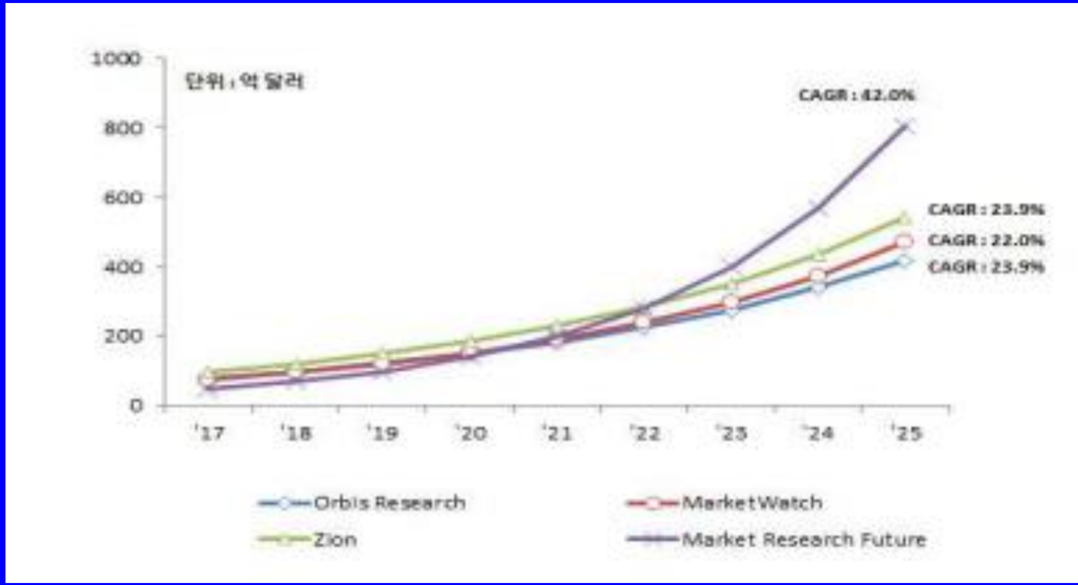
- RENESAS ELECTRONICS (Japan)
  - Strong in MCU, Automotive
  - Expands products for Industrial IOT application





Industrial IOT Sensor from Renesas

IOT Market

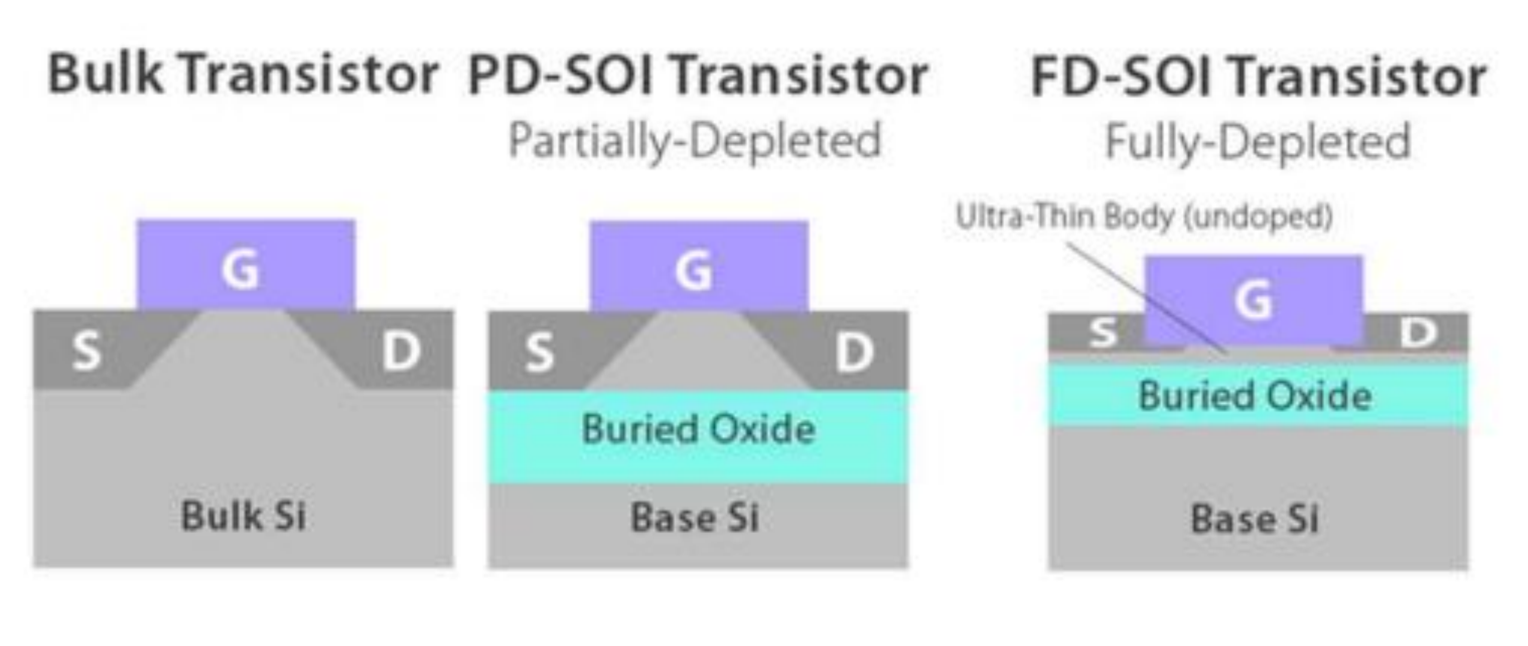


IOT Sensor Market Volume Size
From Gartner

IOT Sensor Market Share by Region
From Marketand (2018)

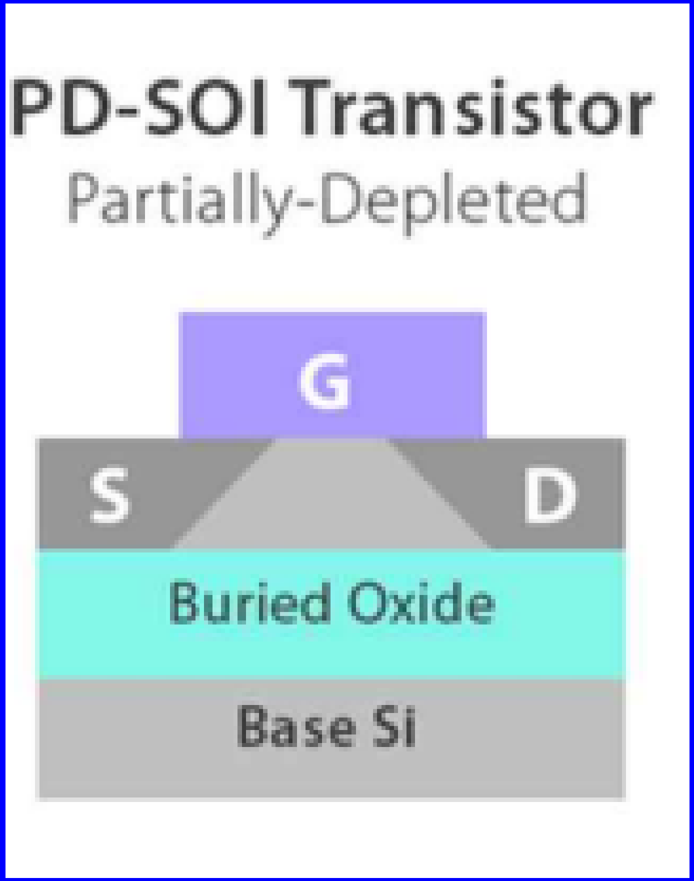
2. Sensor Analog IP Developments for IOT

SOI process



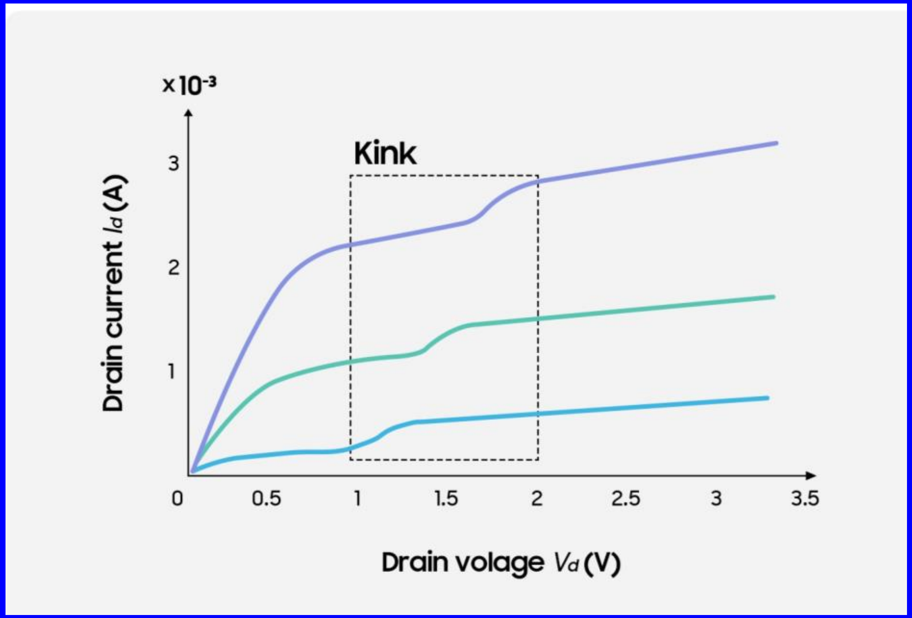
- **What are PD-SOI and FD-SOI?**
  - Partially Depleted SOI (PD-SOI) and Fully Depleted SOI (FD-SOI), based on the thickness of the Buried Oxide Layer (BOX) and the thickness of the monocrystalline silicon for the channels.

PD-SOI process



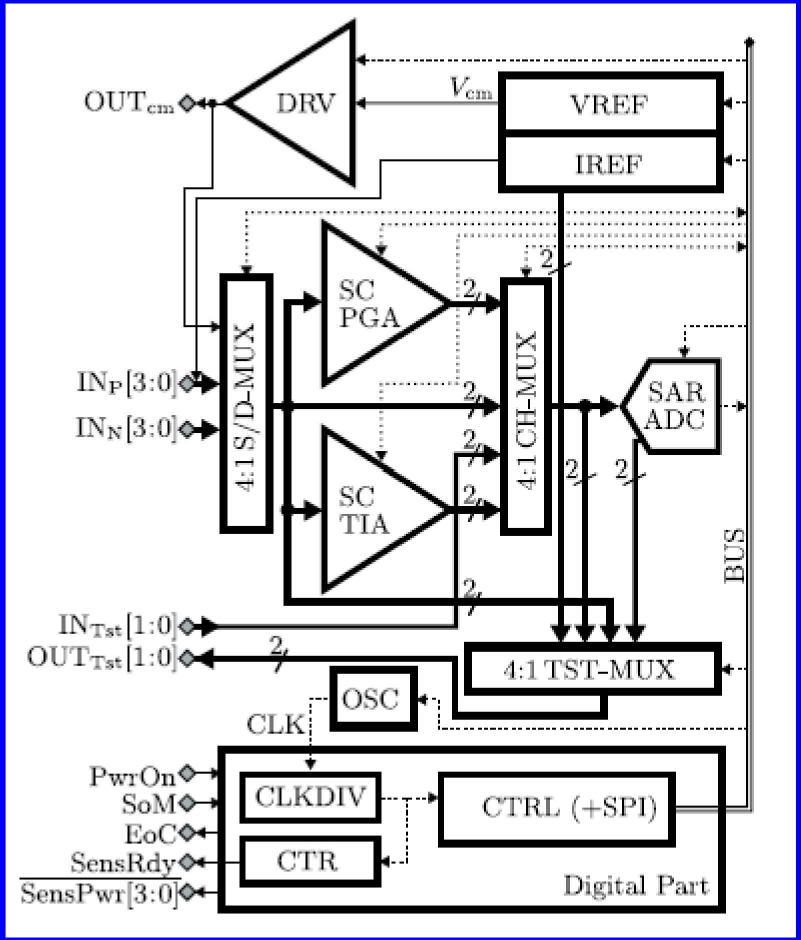
- **PD-SOI process pros** PD-SOI is applied to analog products such as power devices, with the thickness of the monocrystalline silicon for the channel ranging from 50nm-100nm, and the thickness of the BOX ranging from 100-200nm.
  - PD-SOI has the advantage of blocking leakage current through the junction when compared to bulk transistors, and it also reduces the capacitance generated between the source, drain and body.

PD-SOI process



- **PD-SOI cons**
  - No/not enough body contacts causes a floating body effect.
  - Floating boday effect cause threshold voltage (Vth) variation of the device, resulting in an increased off current when the device is turned off, with a kink effect occurring when the drain current suddenly increases from the point where the Vth is lowered.
  -

Multi-Channel Sensor Analog-Frontend for IOT



Ultra-low power analog sensor frontend (AFE) for IOT are developed in a PD-SOI 180 nm process

- The flexible channel-wise configuration enables processing of various signal types and therefore offers a versatile solution for sensors from the Internet-of-Things (IoT) market segment.
- Four input channels are separately configurable to process voltage, current and potentiometric signals of external or internal sources.
- Resolution (6 bit to 13 bit), sample rate (1 to 7.5 kS/s), voltage gain (−6 to 12 dB), transimpedance (1.5 MΩ to 12 MΩ) are programmble
- Fabricated samples in PD-SOI180 nm technology show an ultra-low power consumption of **8.8μW**.
- Specifically, the SARADC achieves 10.6 effective bits while consuming 1.8μW, resulting in a Figure-of-Merit of 116.0 fJ/conv.-step

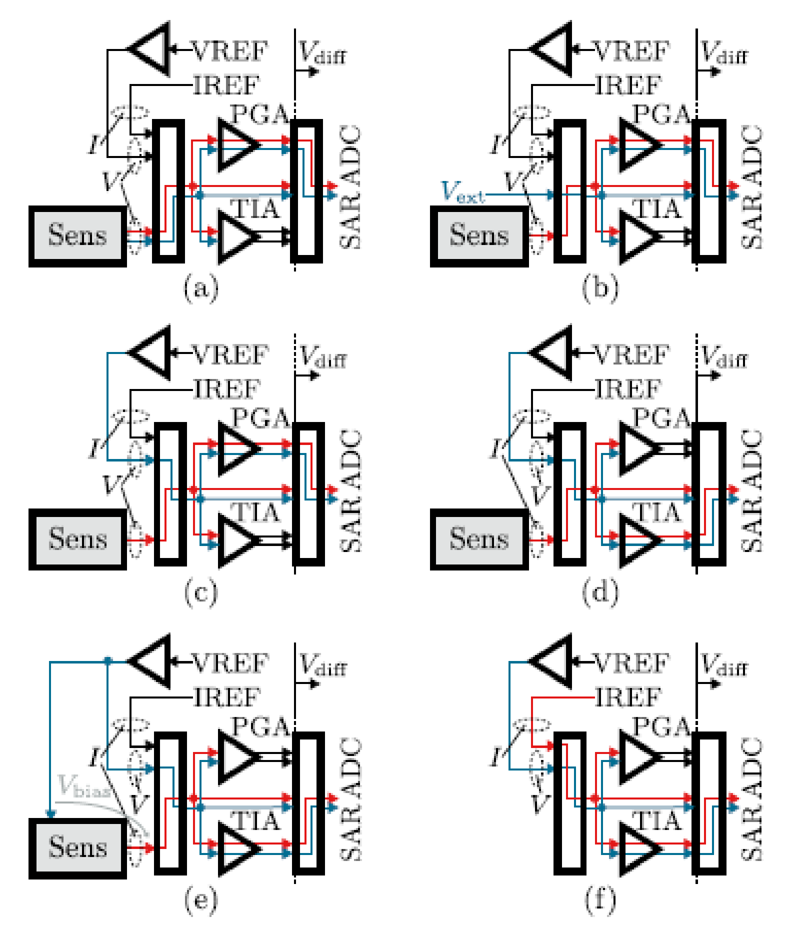
Multi-Channel Analog-Frontend for IOT

- **Design Targets are derived based on industry requirements through the survey.**

1	**Temperature**	MAXIM	MAX6607[1]	-20 °C to +85 °C	Voltage: 0.2 V to 1.4 V	below 1 Hz	8 µA to 15 µA
2	**Ambient Light**	Renesas	ISL1902[1]	0.3 lux to 10 klux	Voltage: 0.02 V to Supply	below 5 kHz	0.65 µA to 15 µA
3	**CO Gas**	Spec Sensors	3SP_CO[1]	0 ppm to 1000 ppm	Potentiometric Current: 0 A to 26 µA	below 1 Hz	10 µW to 50 µW
4	**Accoustic**	PUI Audio	PMM3738	more than 100 Hz	Voltage: 0 V to Supply	more than 100 Hz	5 µA to 85 µA
5	**Acceleration**	Analog Devices	ADXL316	±16 g to ±19 g	Voltage: 0.1 V to 75% Supply	below 1.6 kHz	250 µA to 400 µA
6	**Humidity**	Honeywell	HIH5030	0 %RH to 100 %RH	Voltage: 0.5 V to Supply	below 5 kHz	200 µA to 500 µA

- **Survey of commercially available, IoT-compatible sensors with current consumption below 300µA.**

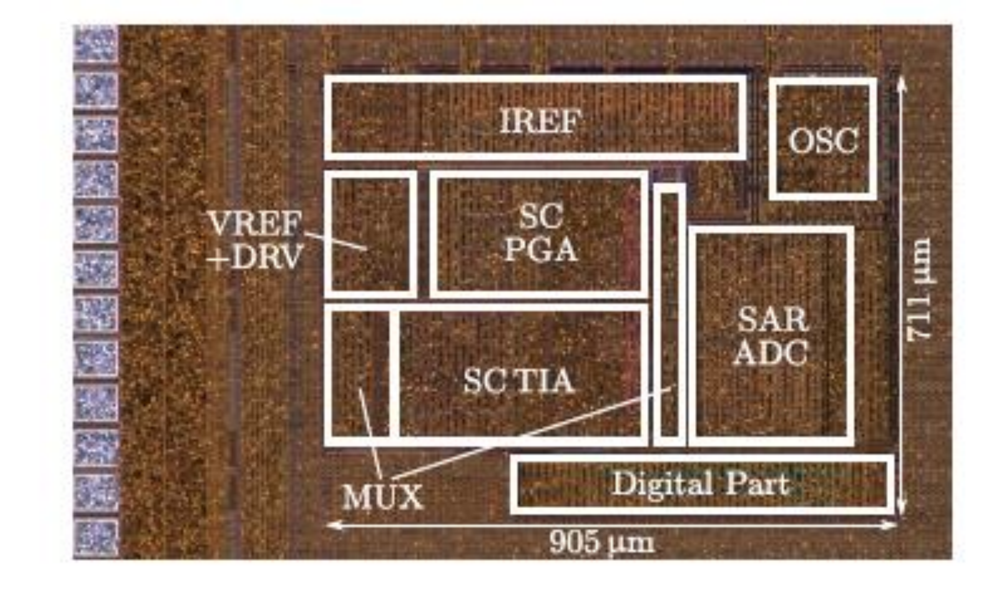
Multi-Channel Sensor Analog-Frontend for IOT

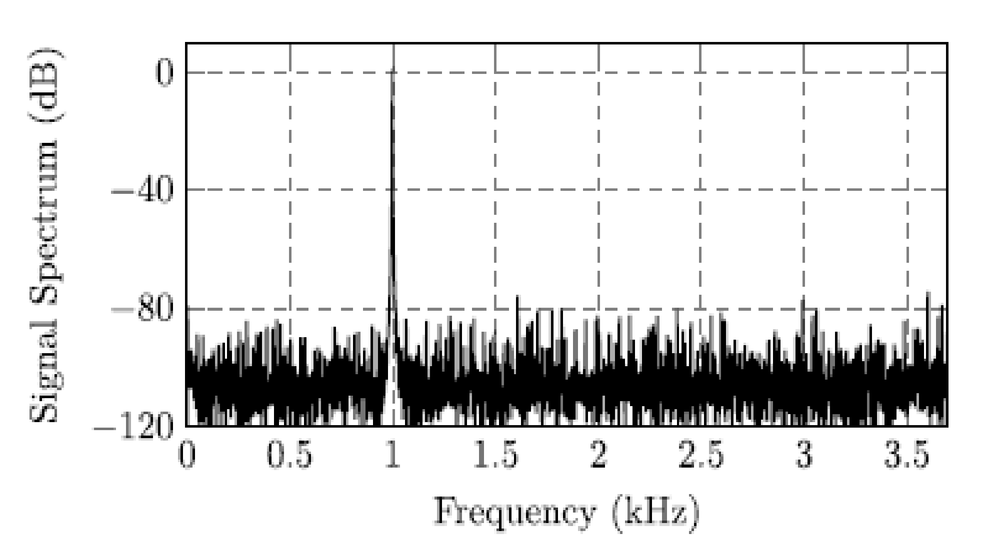


The Sensor supports 6 operation modes.

- (a) differential voltage
- (b) single-ended voltage with external reference
- (c) single-ended voltage with internal reference
- (d) single-ended current with internal reference
- (e) potentiometric current with internal reference
- (f) temperature monitoring

Multi-Channel Sensor Analog-Frontend for IOT





- The total active area : 0.64mm2
- Analog parts: SARADC (14.9%), PGA (23.8%), TIA (14.9%) and current reference (15.6%)
- Digital parts : 9%

- The output spectrum is obtained with FFT with 1 kHz input.
- The peak differential ENOB : 10.6 bit

Multi-Channel Sensor Analog-Frontend for IOT

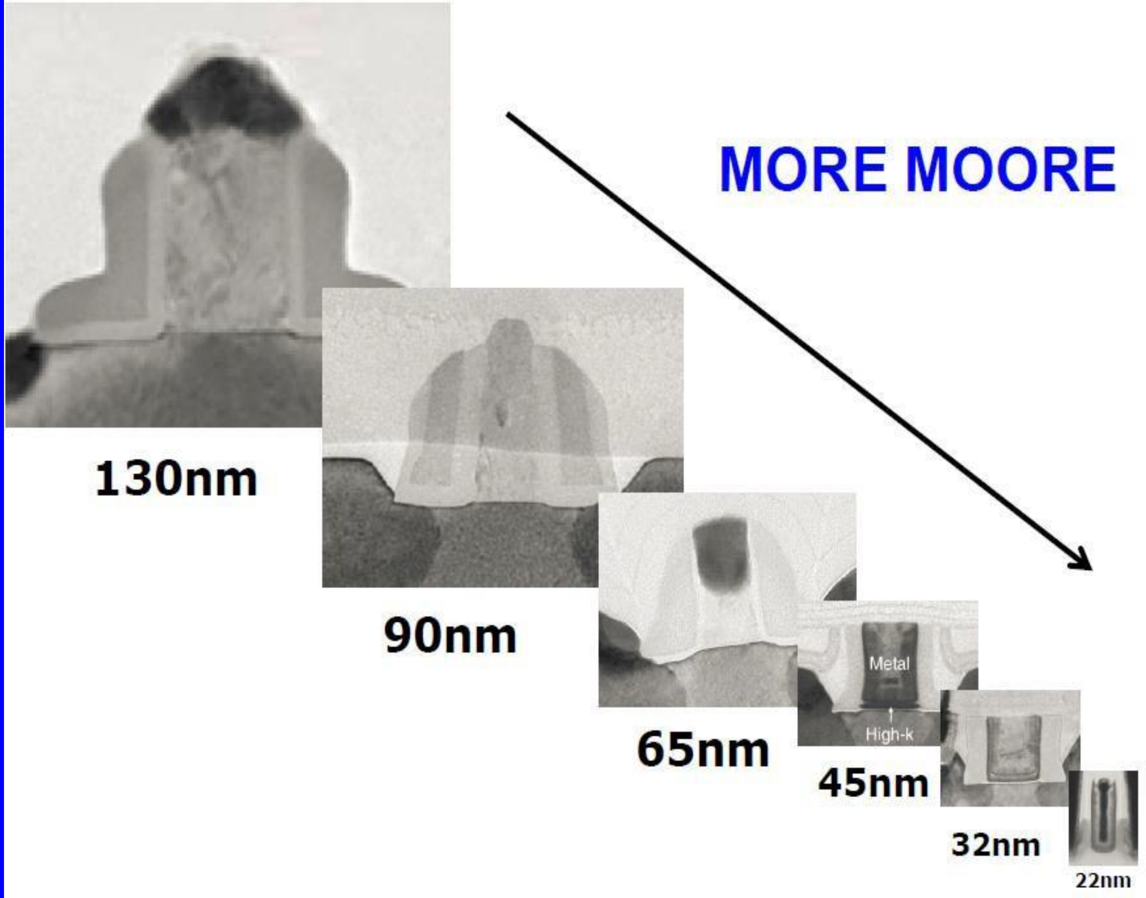
	This Work, 2021	[9], 2021	[10], 2020	[13], 2019	[6], 2019	[8], 2018	[17], 2017	[7], 2017
General								
Analog Supply (V)	1.8	1.8	2	0.6	1	0.6	1.2	0.3
Tech. (nm)	180	180	130	65	180	40	65	65
Application	IoT	IoT	Bio	IoT	Bio	Bio	Bio	Bio
Total Sample Rate (kS/s)	1 to 7.5	0.1	1	10 to 100	N/A	20 to 400	0.4	1.0
Total Band-width (kHz)	0.01 to 3.8	0.0001 to 0.05	0.04 to to 0.32	N/A	N/A	0.001 to 128	N/A	0.02 to 0.42
Area (mm^2)	0.64	1.81	0.6	0.08	0.23	1	0.13^2	0.22
Average Power (μW)	1.8^2 / 8.8	160.5^2 / 425 to 500	1.3^2 / 6.3	0.0003 to 0.6	2^2 / 5.4	0.24^2 / 3.8	0.1^2	0.0038
Support commerical IoT sensors? (e.g. Table I)	Yes	Yes[3]	No[4]	No[4]	No[4]	No[4]	No[4]	No[4]
ADC								
ADC Sample rate (kS/s)	1.25 to 10	N/A	1	10 to 100	N/A	20 to 400	0.4	1.0
Resolution (bit)	6 to 13	SAR: 8 to 12	8	10	N/A	13	10	8
ENOB (bit)	10.6	8.5 to 12.9	7.9	N/A	7	9.7	9.6	7
FoM_{ADC} (fJ/st.)	116.0	N/A	5.2e3	31 to 150	14.4	322.0	15.6	34.8
Preamplifier								
Prog. Gain?	Yes	No	Yes	No	Yes	Yes	N/A	No
Gain (dB)	-6 to 12	N/A	43 to 55	N/A	N/A	20 to 30	N/A	40
Preamp Power (μW)	3.9	28.6 to 107.8	1.6	N/A	N/A	N/A	N/A	0.0009

[2] stand-alone ADC excluding preamplifier

[3] electrochemical sensors and chemo-resistive sensors

[4] Table I bandwidth and/or voltage range not achieved

Moore's law



How leading semiconductor manufacturer keeps pace with Moore's law ?

- "Doubling of number of transistors per chip every 2 years" lowers cost per transistor → scaling 0.7 size every 2 years
- Performance improvement with scaling → advent of non-planar devices

Transistor size becoming smaller

ITRS Roadmap

Table 4-1. RF and analog/mixed-signal CMOS technology requirements according to the ITRS roadmap, 2005 edition (see http://www.itrs.net).

Year of production	2005	2007	2010	2013	2016	2020
DRAM ½ pitch[(a)] (nm) (Technology node)	80	65	45	32	22	14
Supply voltage[(b)] (V)	1.2	1.2	1.1	1.0	1.0	1.0
Gate length[(c)] (nm)	75	53	32	22	16	11
t_{EOT}[(d)] (nm)	2.2	2.0	1.5	1.3	1.1	0.9
$1/f$ noise[(e)] ($\mu V^2 \cdot \mu m^2/Hz$)	190	160	90	70	50	30
g_m/g_{ds} at $5 \cdot L_{min\ digital}$[(f)]	47	32	30	30	30	30
σV_T matching[(g)] (mV·μm)	6	6	5	5	4	3
Peak f_T[(h)] (GHz)	120	170	280	400	550	790
Peak f_{max}[(i)] (GHz)	200	270	420	590	790	1110
NF_{min}[(j)] (dB)	0.33	0.25	<0.2	<0.2	<0.2	<0.2

Source from ITRS2004

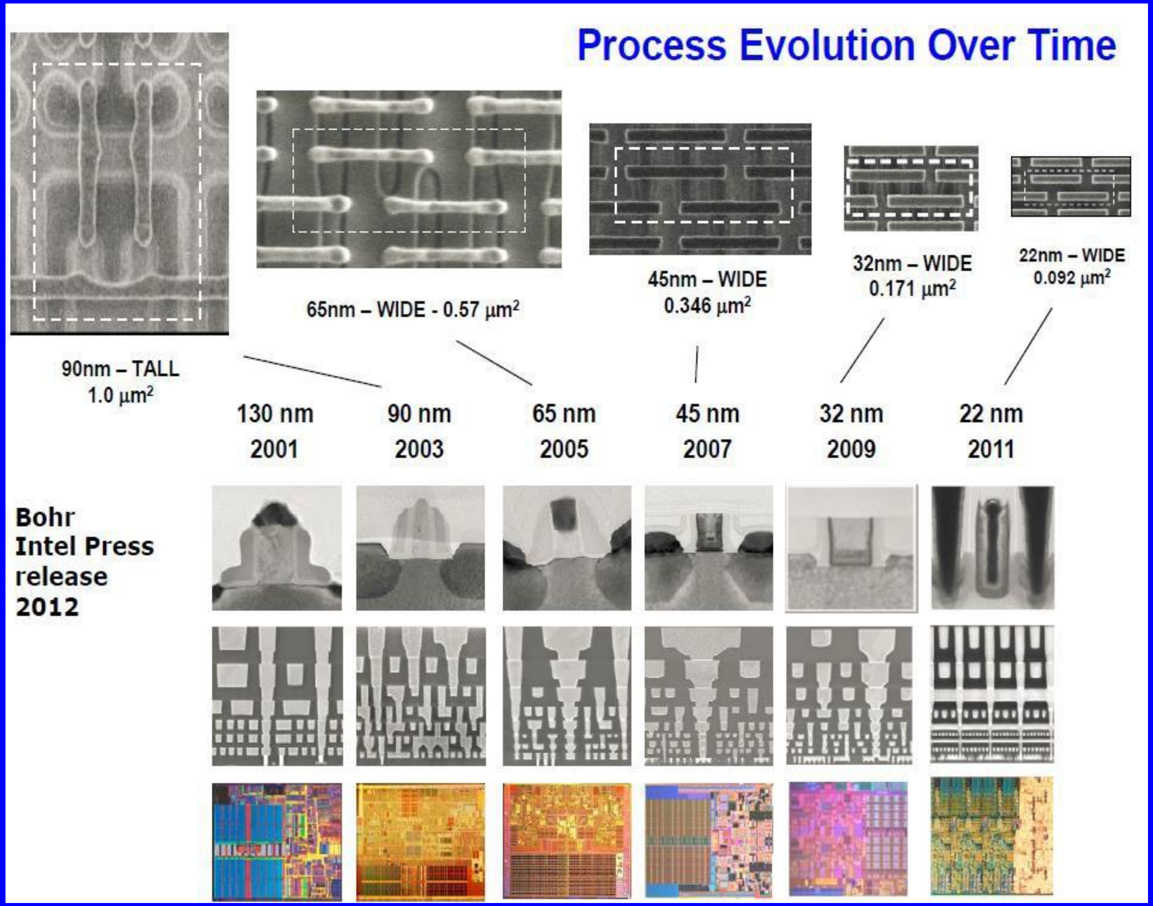
International Technology Roadmap for Semiconductors

- The International Technology Roadmap for Semiconductors (ITRS) is a set of documents produced by a group of semiconductor indust ry experts. These experts are representative of the sponsoring organizations which include the Semiconductor Industry Associations of Taiwan, South Korea, the United States, Europe, Japan, and China. As of 2017, ITRS is no longer being updated. Its successor is the I nternational Roadmap for Devices and Systems.
- International Roadmap for Devices and Systems (IRDS) assess present status and future evolution of the ecosystem in their specific fie ld of expertise and produce a 15-year roadmap.
- IRDS reports includes evolution, key challenges, major roadblocks, and possible solutions.

CMOS Technology Scaling/Evolution

The International Technology Road map for Semiconductors

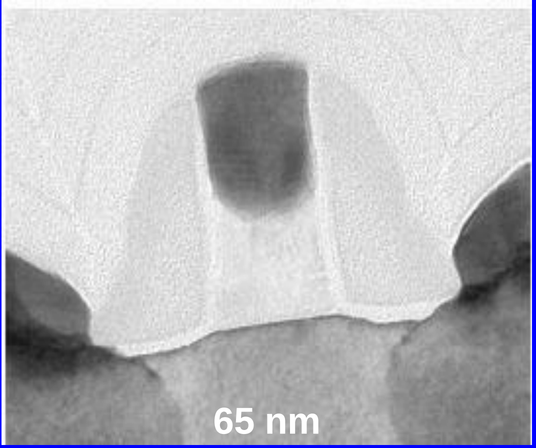
Table MM01 - More Moore Device Technology Roadmap								
YEAR OF PRODUCTION	**2015**	**2016**	**2018**	**2020**	**2022**	**2024**	**2026**	**2028**
Logic device technology naming	P70M52	P52M36	P42M24	P32M16	P24M12	P24M12V1	P24M12V2	P24M12V3
Logic industry "Node Range" Labeling (nm)	"16/14"	"11/10"	"8/7"	"6/5"	"4/3"	"3/2.5"	"2/1.5"	"1/0.75"
Node production years	3	3	3	3	3	3	3	>3
Device structure options	finFET FDSOI	finFET FDSOI	finFET LGAA	finFET LGAA VGAA	VGAA, M3D	VGAA, M3D	VGAA, M3D	VGAA, M3D
DEVICE ARCHITECTURE & MODULES								
Starting substrate	Si, SOI	Si, SOI	Si,SOI, SRB, QW	Si,SOI, SRB, QW	Si,SOI, SRB, QW	Si,SOI, SRB, QW	Si,SOI, SRB, QW	Si,SOI, SRB, QW
N-channel	Si	sSi	sSi, Ge	sSi, sGe, IIIV	sSi, sGe, IIIV	sSi, sGe, IIIV	sSi, sGe, IIIV	sSi, sGe, IIIV
P-channel	Si	Si,SiGe	Si,SiGe	Si,SiGe	Ge	Ge	Ge	Ge
Channel formation	Etch	Etch, EPI	Etch, EPI	Etch, EPI	Etch, EPI	Etch, EPI	Etch, EPI	Etch, EPI
Contact material	Silicide	Low-SBH	Low-SBH	Low-SBH	Low-SBH	Low-SBH	Low-SBH	Low-SBH
Contact integration	EPI	EPI	EPI WAC	EPI WAC	EPI WAC	EPI WAC	EPI WAC	EPI WAC
DEVICE PERFORMANCE BOOSTERS								
Main performance booster	SCE finHeight Vt	SCE finHeight Vt	Parasitics finHeight	Parasitics finHeight	Low Vdd 3D	Low Vdd 3D	Low Vdd 3D	Low Vdd 3D
Scaling focus	Perf	Power	Power	Power	Function	Function	Function	Function
Channel strain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
S/D strain	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transport scheme	DD	Quasi Ballistic	Quasi Ballistic	Ballistic	Ballistic TFET, JFET, NCMOS	Ballistic TFET, JFET, NCMOS	Ballistic TFET, JFET, NCMOS, Spin	Ballistic TFET, JFET, NCMOS, Spin

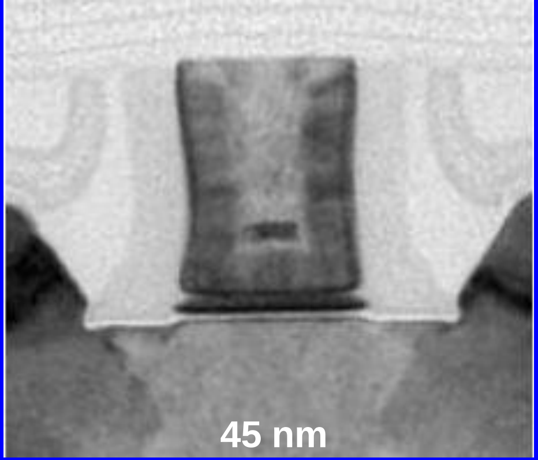


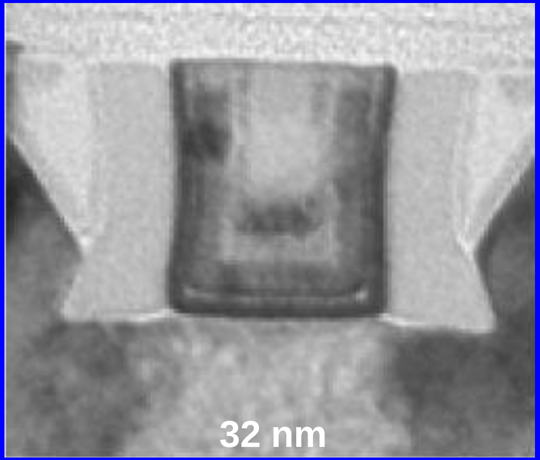
source from Intel Corporation

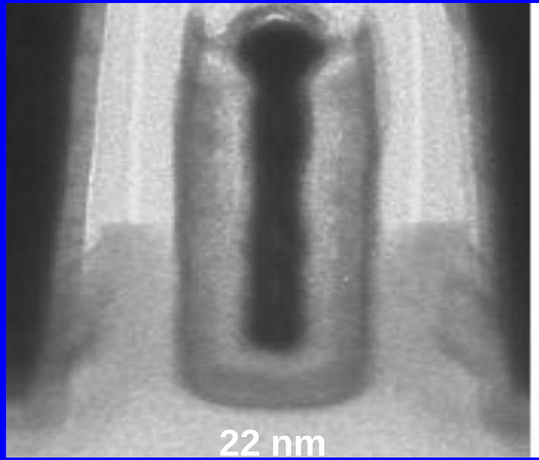
Scaling Focus

Source from Bai, Mistry, Natarajan, Auth IEDM/VLSI, 2004/7/8/12









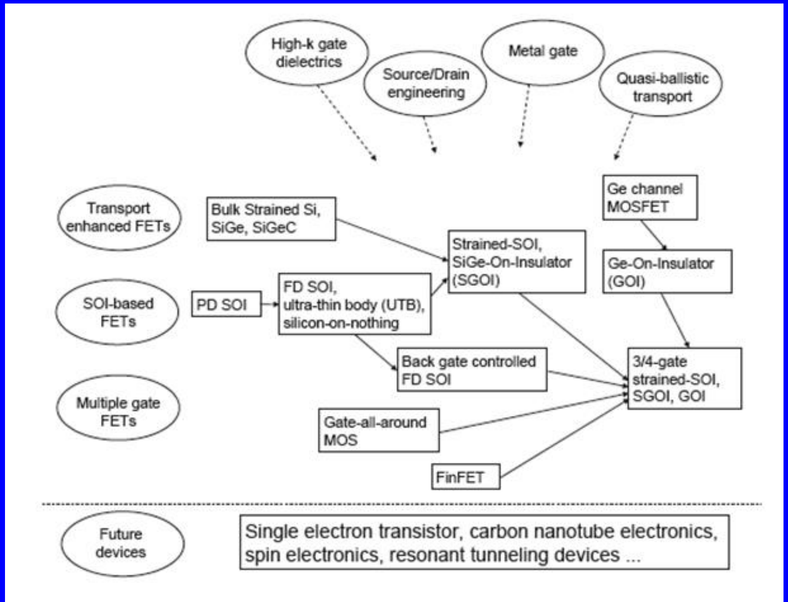
Scaling – Before

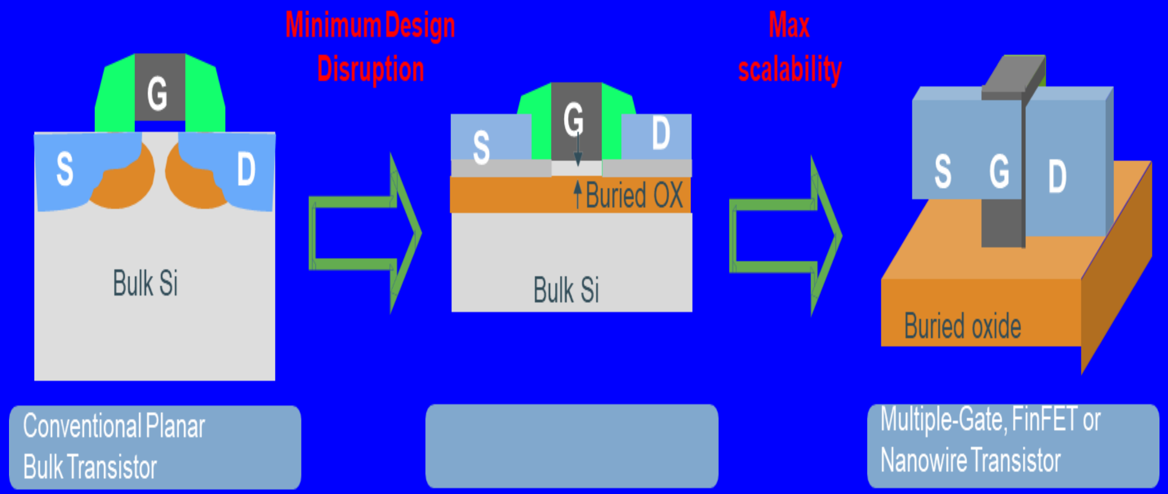
- Scaling drove down cost
- Scaling drove performance
- Performance constrained
- Active power dominates
- Independent design-process

Scaling - Now

- Scaling drives down cost
- Materials drive performance
- Power constrained
- Standby power dominates
- Collaborative design-process

Planar FDSOI or Multi-Gate Transistor





Mutiple Deivce Architecture

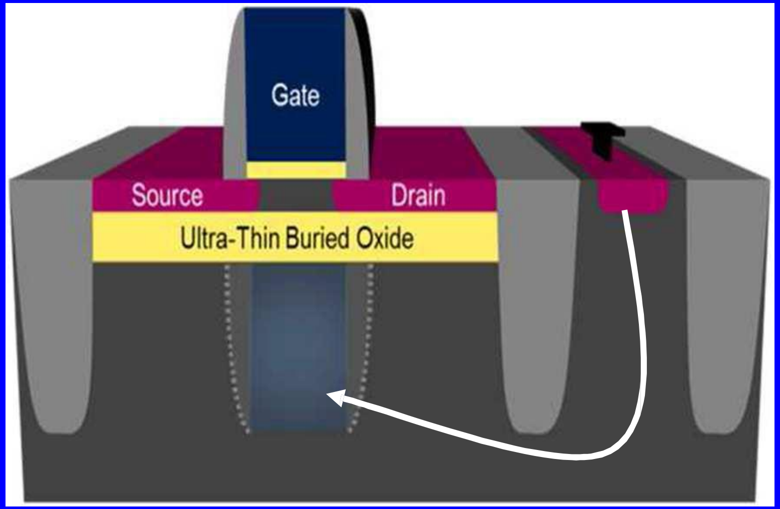
- A multitude of different approaches to enhance the performance of CMOS devices (in order for them to meet the ITRS requirements)

FD-SOI

- Thin channel (Fully Depleted) with multi gates for better gate or short channel (SCE) control
- Better gate control → better transistors scaling

FD-SOI Transistor Advantages

Source: GF 22FDX™ Platform



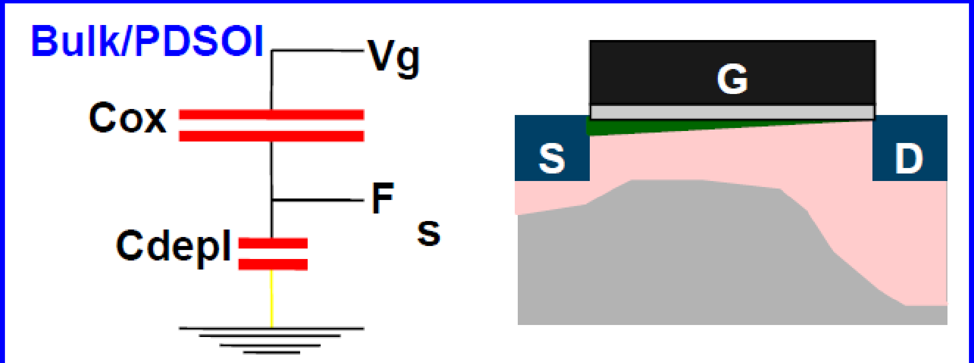
Knobs to control Performance/Power:

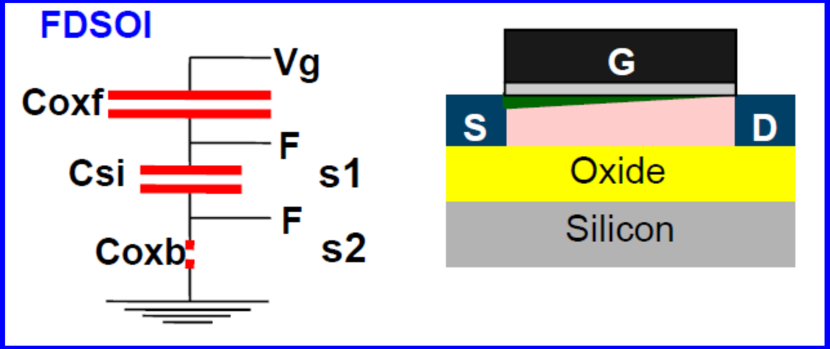
- **Gate bias**
- **Back Bias**

UTBB FDSOI Transistor Advantages	
Total dielectric isolation	• Lower S/D capacitances • Lower S/D leakage • Latch-up immunity
Ultra thin Body	• Excellent SCE (SS, DIBL) • No History Effect • Lower SER
No channel doping	• Improved V_T variability • Improved mismatch (SRAM & analog) • Better analog gain • Reduced process cost
Ultra thin BOX option	• Enables Extended body biasing
Channel mobility boost	• Scalable down to 10nm
Conventional planar processing	• Lower manufacturing risk • Equivalent bulk design

FDSOI Device Physics

Source: GF 22FDX™ Platform





FDSOI shows better performance compared to Bulk Transistor

- Body factor: n = …1.05… in FDSOI; …1.5… in Bulk

Linear current: $I_D = \mu C_{ox} \frac{W}{L}\left((V_G - V_{TH}) V_D - \frac{1}{2} n V_D^2 \right)$

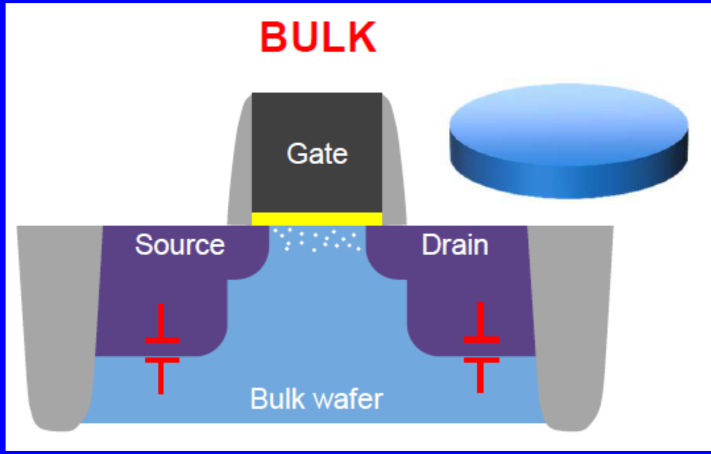
Saturation current: $I_{Dsat} = \frac{1}{2n} \mu C_{ox} \frac{W}{L}\left((V_G - V_{TH})^2 \right)$

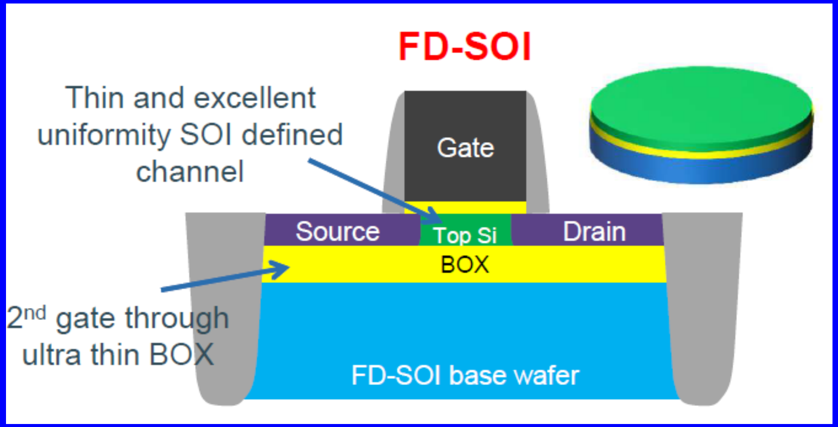
Sub-threshold slope: $S = n \frac{kT}{q} \ln(10)$

Gain (strong inversion): $\frac{g_m}{I_D} V_A = \sqrt{\frac{2 \mu C_{ox} W L}{n I_D}} V_A$

FD-SOI Transistor Level Benefits

Source: GF 22FDX^{TM} Platform



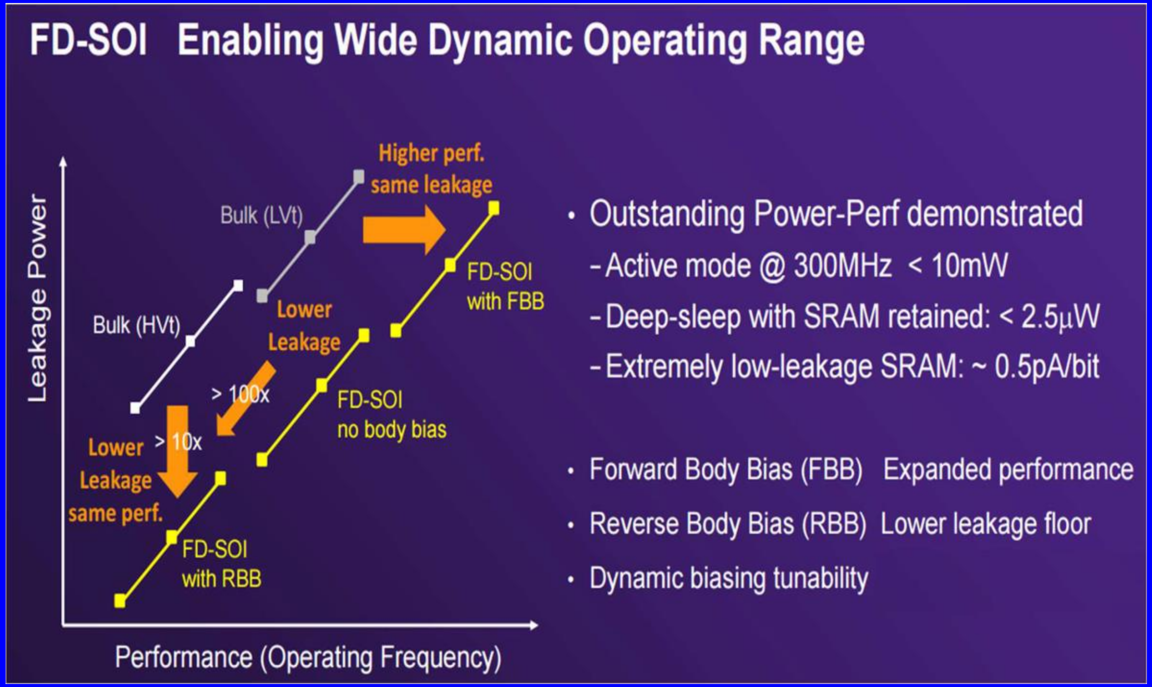


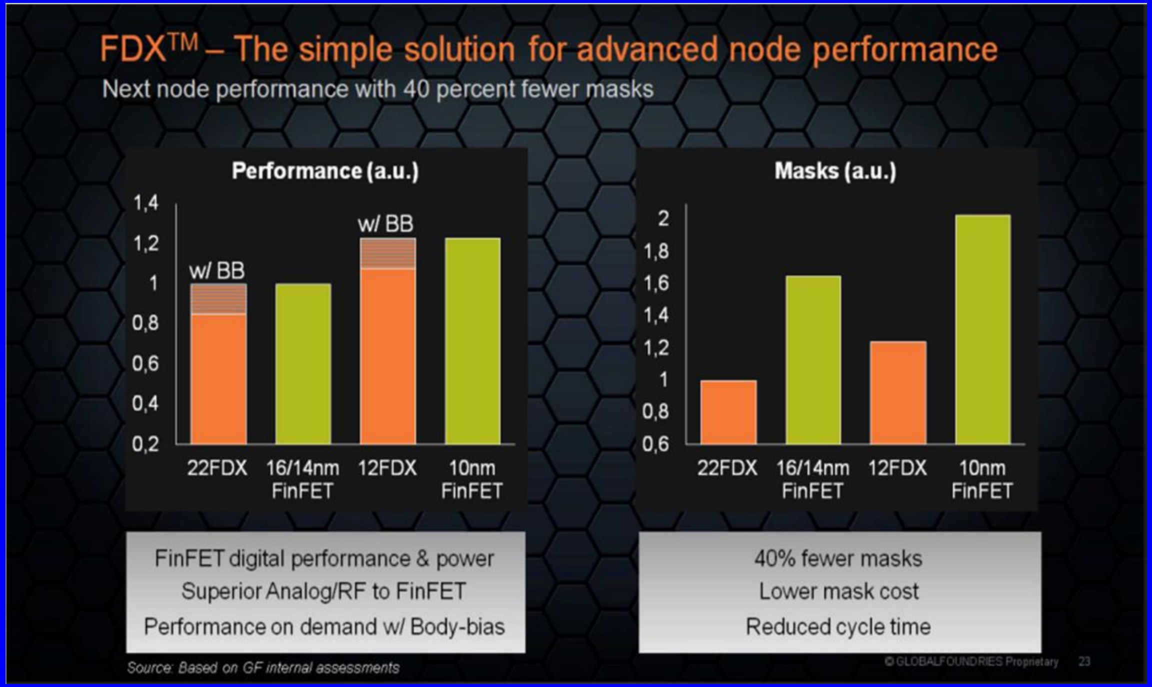
- **Vth and SCE defined by complex and heavily channel and halo doping techniques**
- **Large Vt mismatch due to random dopant fluctuation => limit Vdd scaling**
- **Strong sensitivity to short channel effect**
- **Large junction capacitance (Cj), GIDL and Didode leakage**
- **Limited well bias capability**

- **Vertical transistor layout determined by FD-SOI engineered substrate and undoped channel**
- **Significant improved Vt mismatch due to minimize random dopant fluctuation => enable Vd scaling down to 0.4V or lower**
- **Excellent SCE**
- **Minimum Cj, GIDL & diode leakages Extensive back bias capability**

FD-SOI Performance

Source: GF 22FDX™ Platform



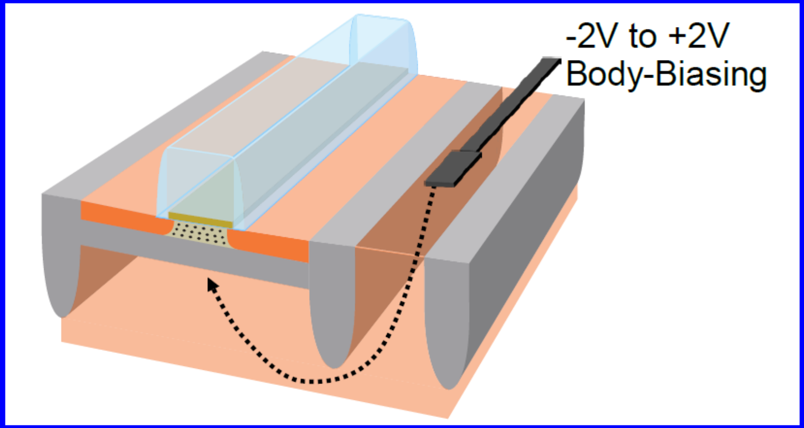


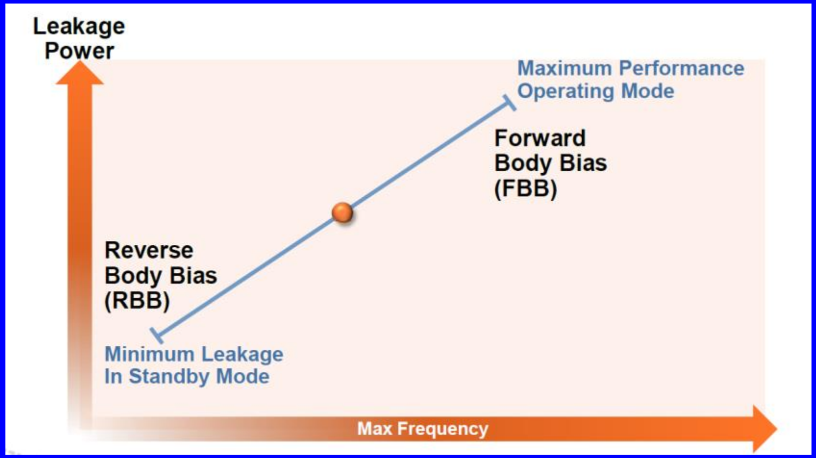
Body-Bias enabling wider dynamic operating range

FD-SOI: FinFET performance at lower manufacturing cost

FD-SOI enables "effective Body-Bias"

Source: GF 22FDX™ Platform





Body-Bias provides greatest power efficiency and design flexibility

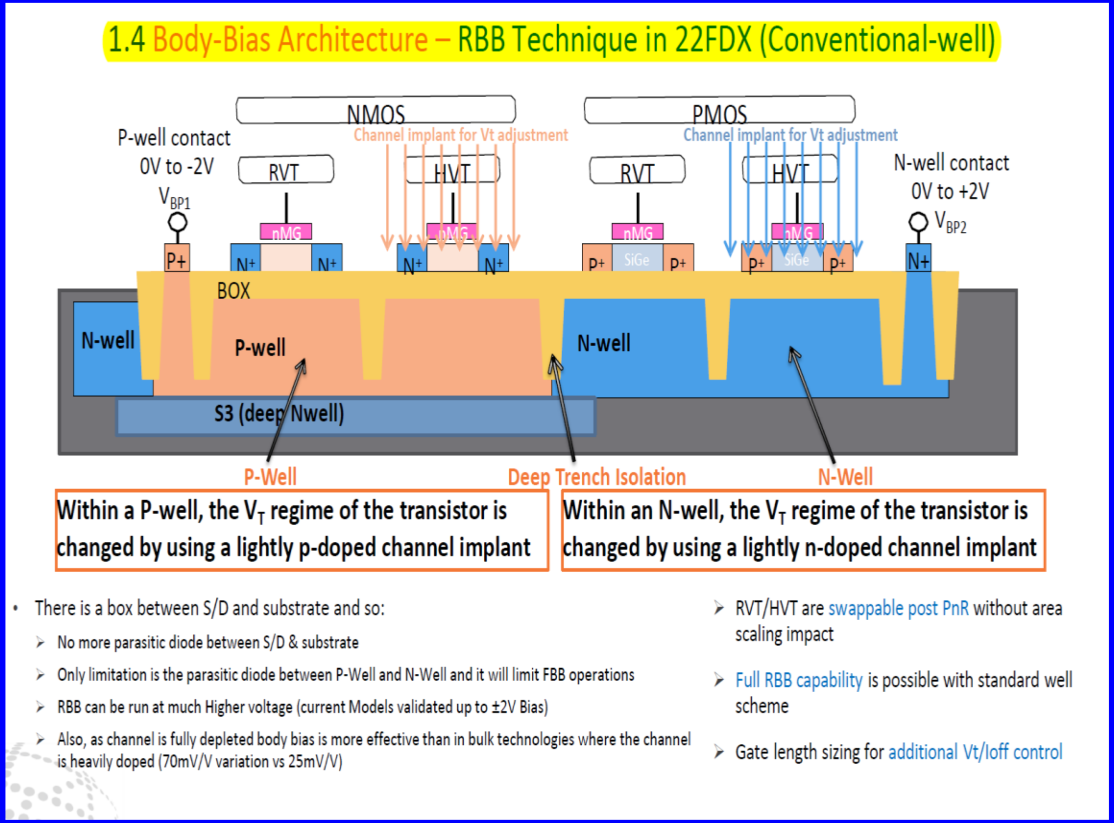
- Forward Body Bias (FBB) enables low voltage operation down to 0.4V
- Reverse Body Bias (RBB) enables low leakage down to 1pA/micron
- Dynamic body biasing enables active tradeoff of performance vs. power

Maximum Flexibility with Transistor Body Biasing

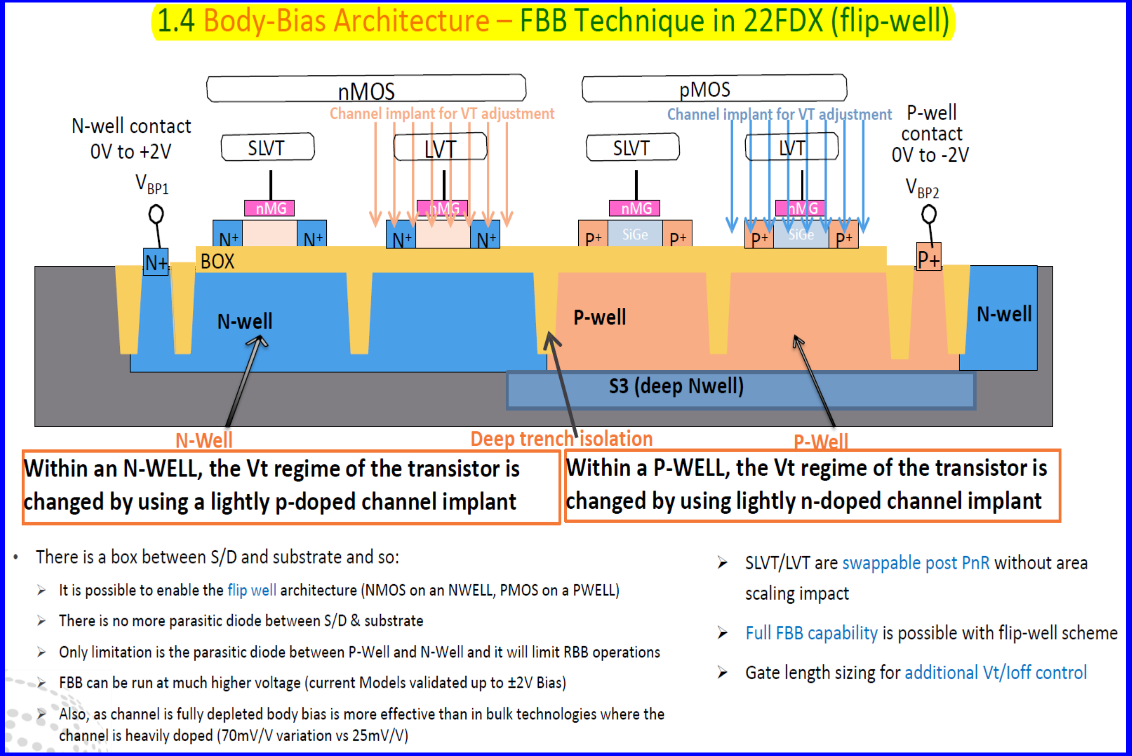
Body Biasing Architecture

Source: GF 22FDX^{TM} Platform

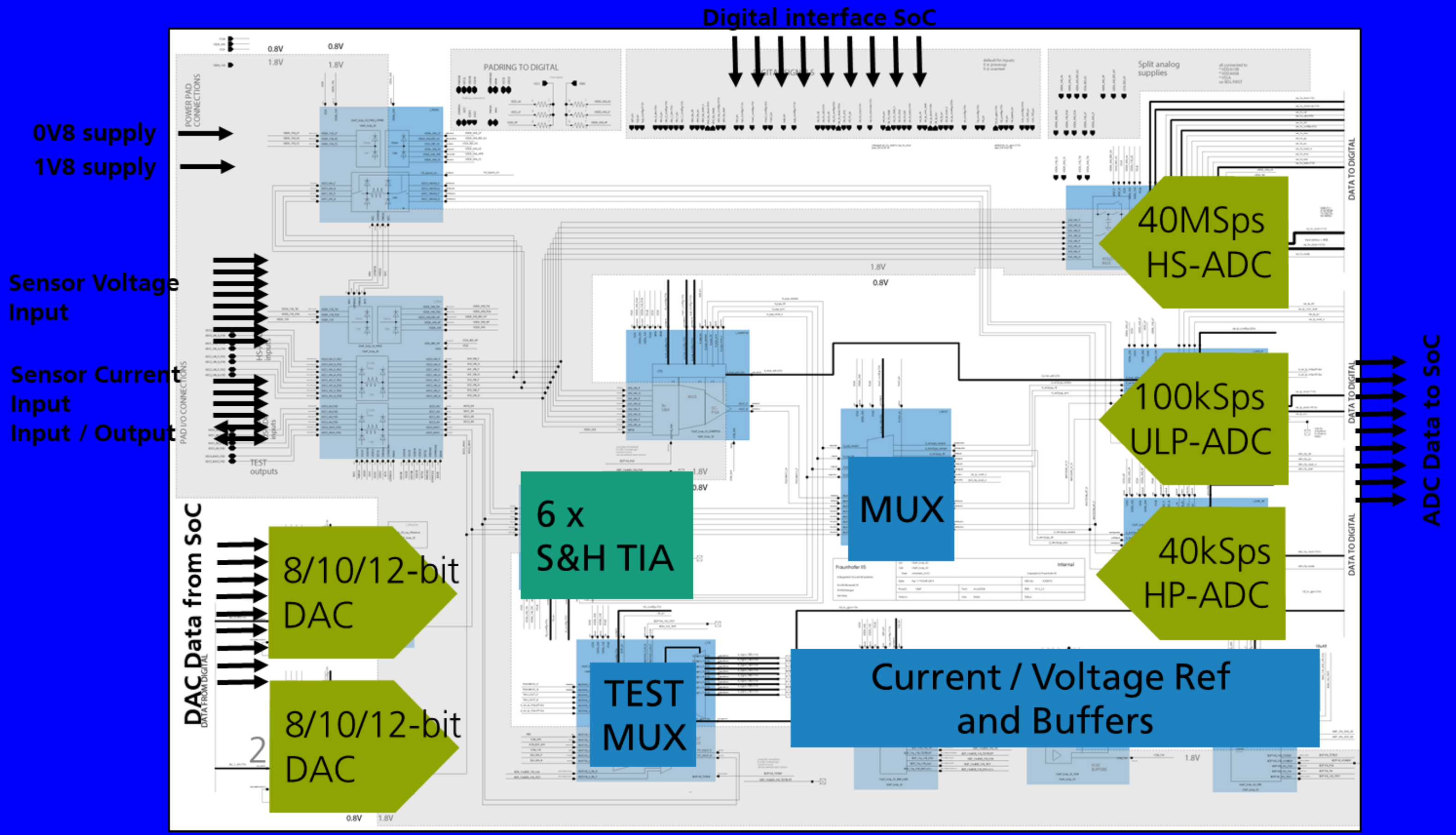
Revers Body Biasing (RBB)



Forward Body Biasing (FBB)



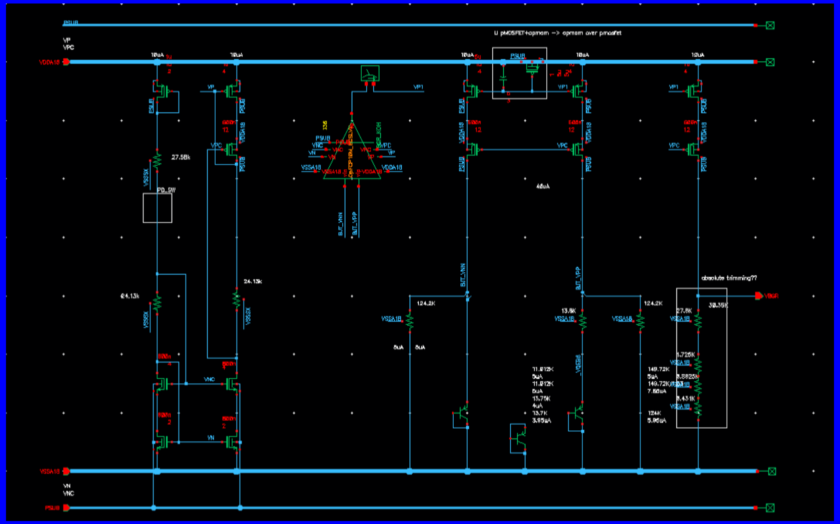
Sensor Analog Frontends for IOT (22 nm FD-SOI)

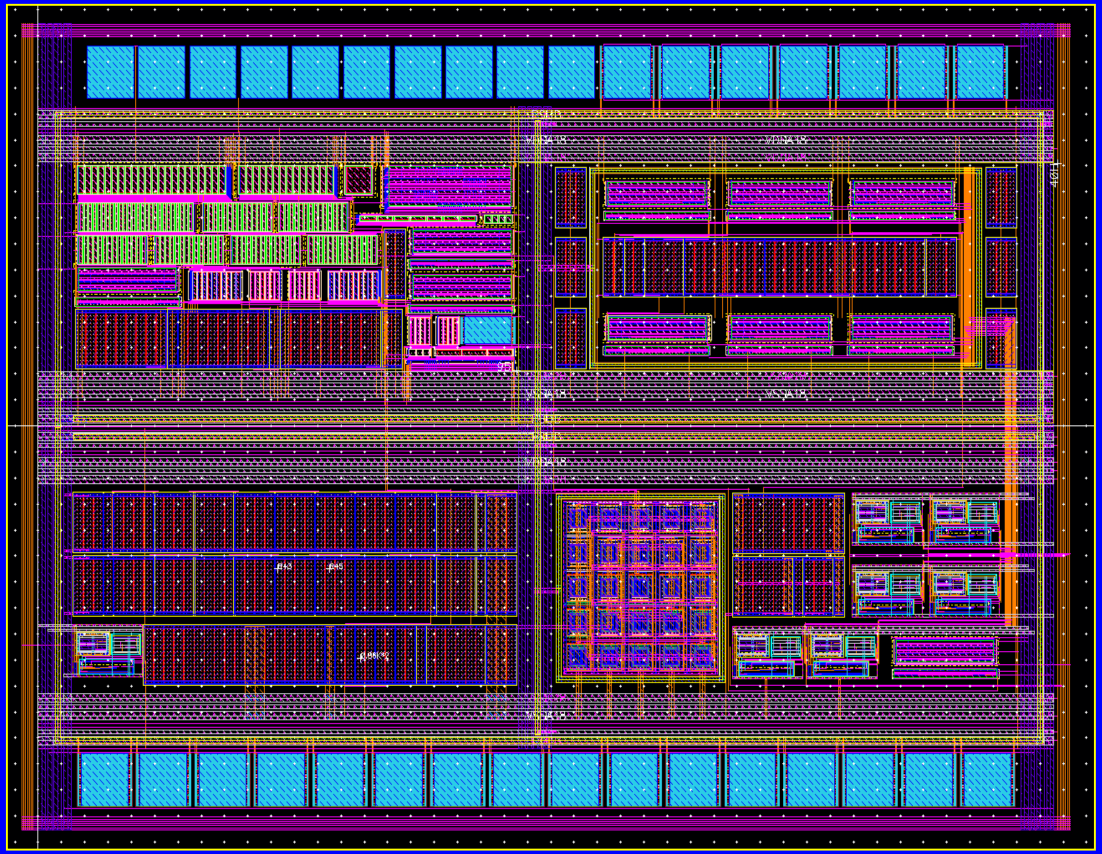


Universal Sensing system for IOT application

- The sensor technology integrated into the standard model already covers the acquisition of the majority of possible measurement parameters.
- This includes **bi- and triaxial acceleration**, **humidity, temperature, air pressure, gas, location and vibration**.
- GLOBALFOUNDRIES 22FDX® technology is chosen for low cost and high performance of the system.
- **22FDX is built according to the silicon-on-insulator principle (fully depleted SOI),** the highly integrated chip design permits the manufacture of particularly energy-efficient and cost-effective chips.

Bandgap Reference in 22 nm FD-SOI

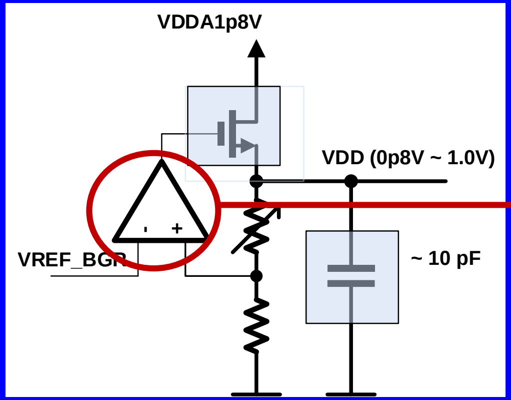


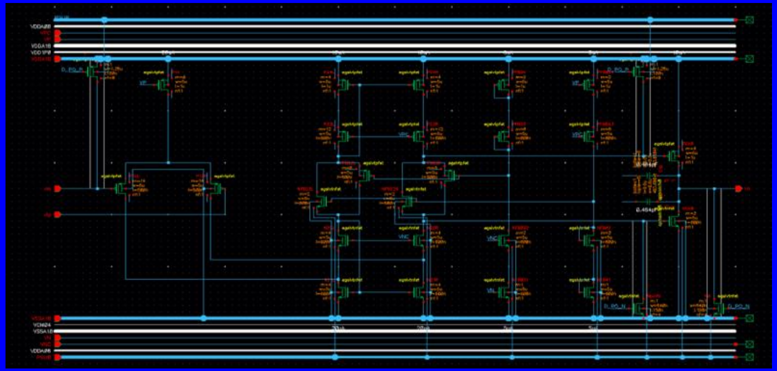


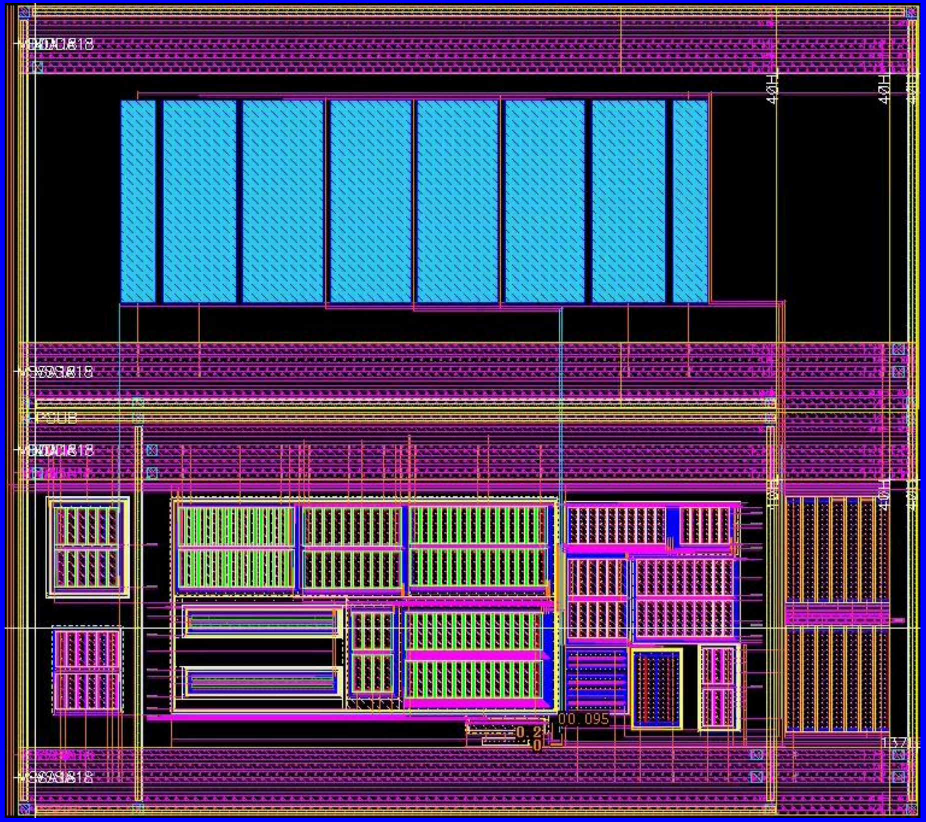
BGR is presented here

- **A sub 1.0 V current mode BGR ("Banba" BGR) is presented here for the low output voltage requirement**
- **VDD = 1.8V, VOUT = 0.4 V**
- **Layout occupies an active area of 215x155 um^2**

"Capless" nMOS Regulator in 22 nm FD-SOI



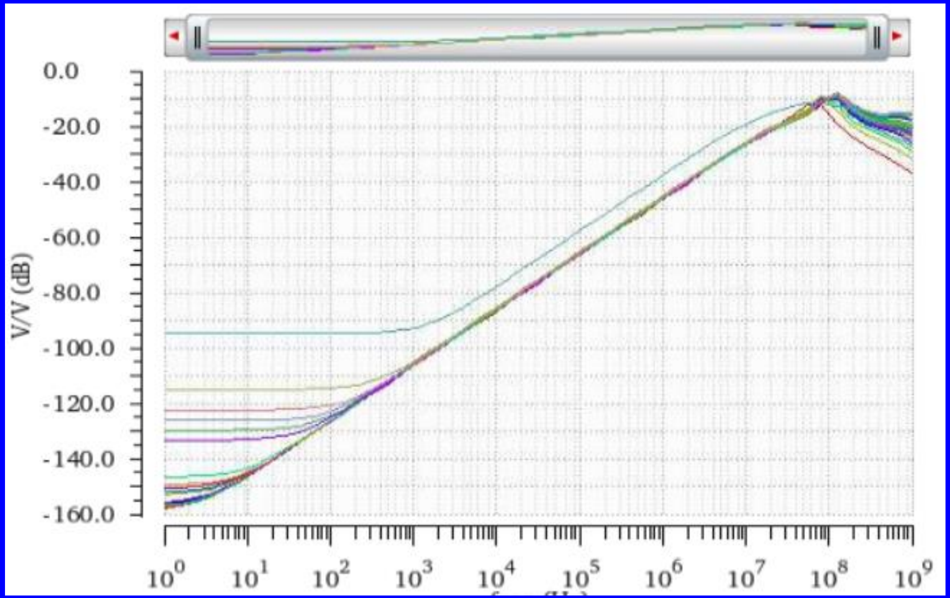




A capless nMOS Regulator is presented

- Class AB amplifier is adopted for better response of the Error Amp
- VIN = 1.8V, VOUT = 0.8 V
- No external compensation cap is needed.
- 10 pF is formed on silicon thanks to nMOS regulator pole location.
- Layout occupies an active area of 140x120 um^2

“Capless” nMOS Regulator in 22 nm FD-SOI



ITEM	MEASURE	ILOAD_Max
LDR	Vout(@ILOAD)=0.8V=VREF	3.1mA
LNR	LNR(@ILOAD) = 0.1%	1.3mA
PSR	PSR(@ILOAD) = 60dB@200kHz	2.5mA
STB	LOOPGAIN(@ILOAD) = 120dB, wi th PM=70'	1.8mA

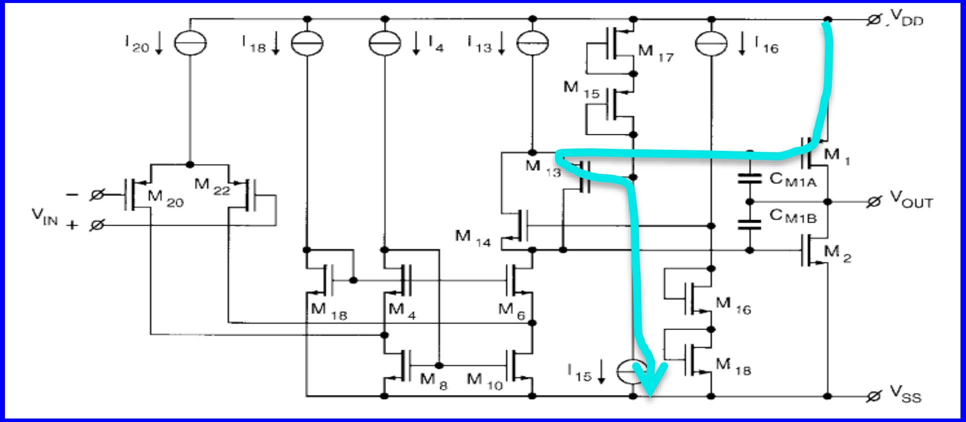
Design Result – Power Supply Rejection

- **ILOAD= 0uA to 3muA**
- **Upto ILOAD=2.5mA ~60dB attenuation (1/1000) is maintained @200kHz**

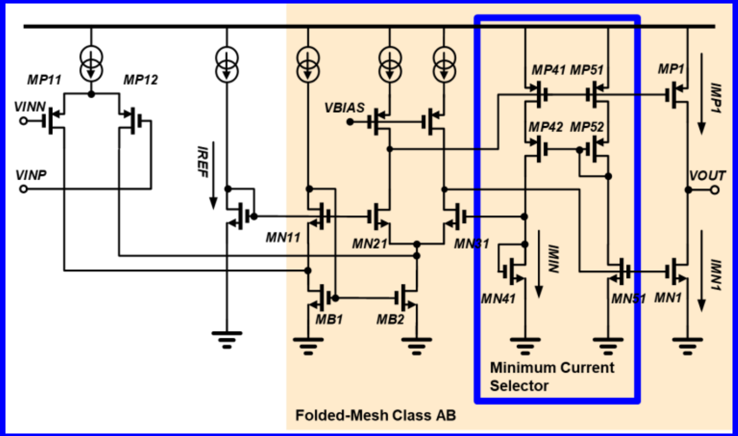
Trusted electronics

- **nMOS Linear regulator supports ILOAD=1.3mA**
- **Required range ILOAD ~ 200uA or at best 300uA**

Switched Capacitor PGA in 22 nm FD-SOI



R. Hogervorst et al, IEEE JSSC, Vol. 29, no. 12, 1994, pp. 1505–1513



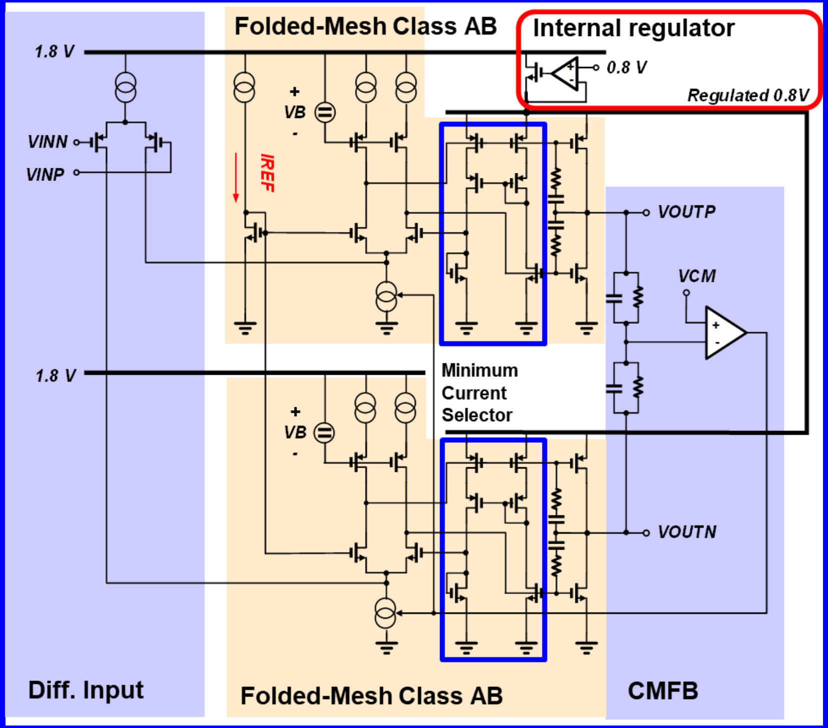
"Classic" Class AB Controller is not able to operate at 0.8 V VDD

- Minimum power supply voltage is given as **|VSGM1|+|VSGM13|+VDSATI15**
- VDD should be at least over 1.05 V for the correct operation
- **Class AB operation is guaranteed above 1.2 V VDD**

We propose a two-stage folded-mesh with min. current selector for 0.8 V VDD operation

- Minimum power supply voltage is given as **|VSGMP1|+VDSATMN21+VDSATMB2**
- VDD can be lowered to 0.65 V for the correct operation
- **Class AB operation is guaranteed at 0.8 V VDD in 22 nm FD-SOI process**

Switched Capacitor PGA in 22 nm FD-SOI

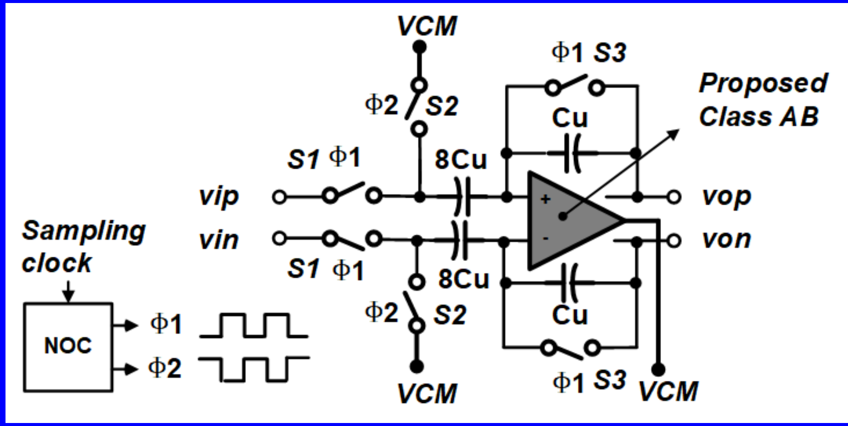


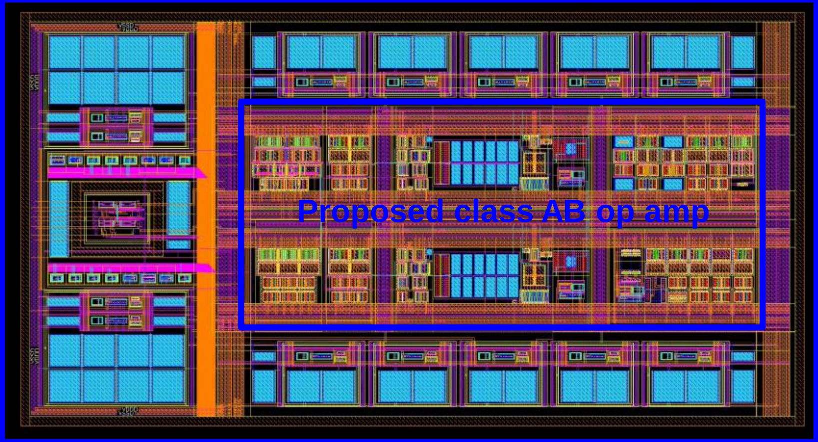
	Unit	TYP	MIN	MAX
Tech		22 nm FDSOI		
Supply	V	1.8	1.71	1.89
Area	mm^2	0.0384 (0.32x0.12)		
Current Consumption	uA	387.7	386.4	390.6
Open-Loop DC Gain	dB	147.1	144.4	148.6
Open-Loop Unity Gain Bandwidth	MHz	58.9	17.6	40.8
Open-Loop Phase Margin	Degree	68.2	53.0	75.0
CMFB DC GAIN	dB	151.0	148.1	152.7
CMFB Unity Gain Bandwidth	MHz	54.3	18.5	44.9
CMFB Phase Margin	Degree	40.0	35.0	50.3
NMOSREG DC GAIN	dB	140.3	115.6	150.4
NMOSREG Unity Gain Bandwidth	MHz	35.4	25.7	61.6
NMOSREG Phase Margin	Degree	64.0	46.4	61.9
Slew Rate Low to High	V/usec	15.8	14.2	17.4
Slew Rate High to Low	V/usec	14.2	12.8	15.6

Now we extend this concept to a fully diff. op-amp

- The proposed class AB op amp implements successfully push-pull output current driving capability with 1.8 V input to 0.8 V output level-shifting, thanks to the internal regulator.

Switched Capacitor PGA in 22 nm FD-SOI

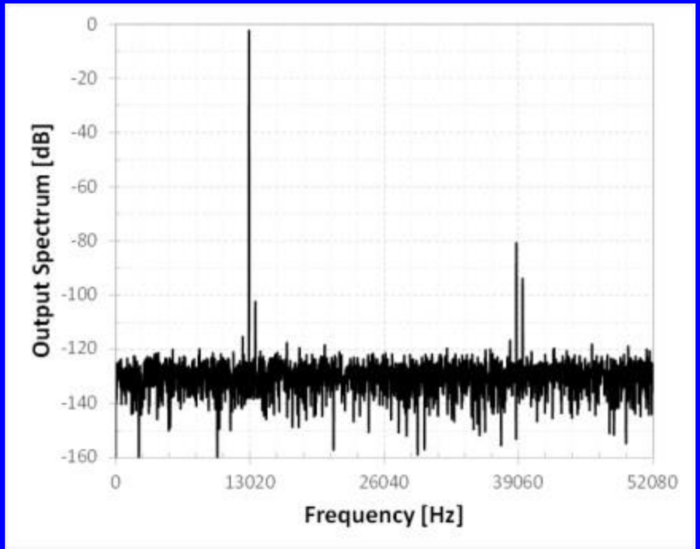


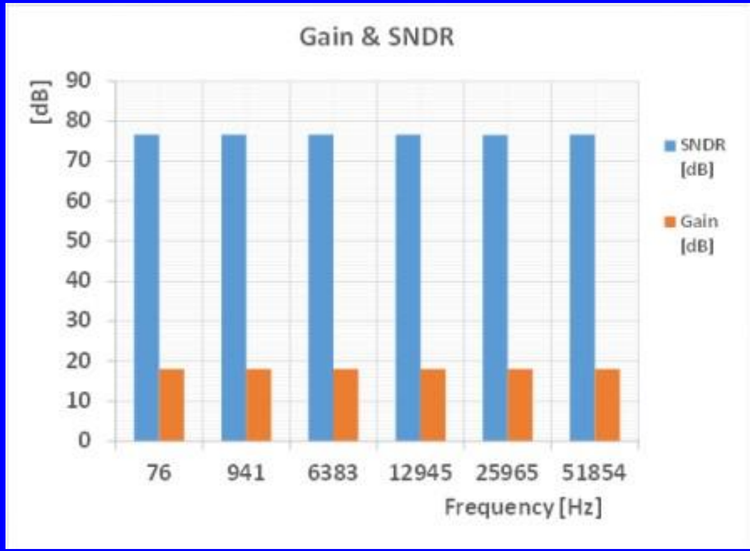


As a concept-demonstration, a switched capacitor amplifier with the proposed class AB is presented

- Non-overlapping clocks Φ1 and Φ2 are generated internally with an external 104.2 kHz sampling clock
- 0.5 pF is chosen for the unit capacitor Cu
- All implements are made in a 22 FD-SOI CMOS technology
- The switched capacitor amplifier occupies active area of 0.0946 mm^2
- Area of proposed operational amplifier is 0.0384 mm^2.

Switched Capacitor PGA in 22 nm FD-SOI





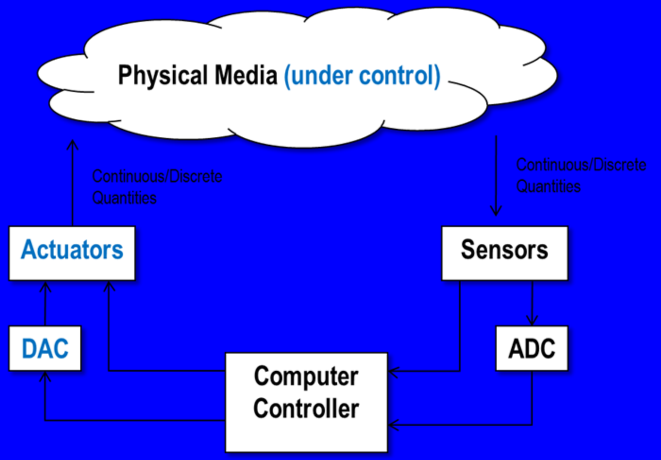
Measurement Results

- 12.4 bit accuracy with 95 mVpeak sinusoidal input with 12.945 kHz is sampled at a sampling frequency of 104.2 kHz
- 76.5 dB for SNDR and 77.3 dBc for SFDR are obtained
- 18 dB Gain are obtained from 76 Hz to 51.854 kHz in the same conditions

A 1.8 V-to-0.8 V input/output signal swing limited fully differential folded-mesh class AB operational amplifier is developed

- Low power supply folded mesh Class AB is presented.
- An internal regulator where “external” 1.8 V is regulated to 0.8V
- Output swing ranges are limited to 0.8 V
- No additional 1.8V-to-0.8V signal level shifter is needed.

Current Steering DAC in 22 nm FD-SOI



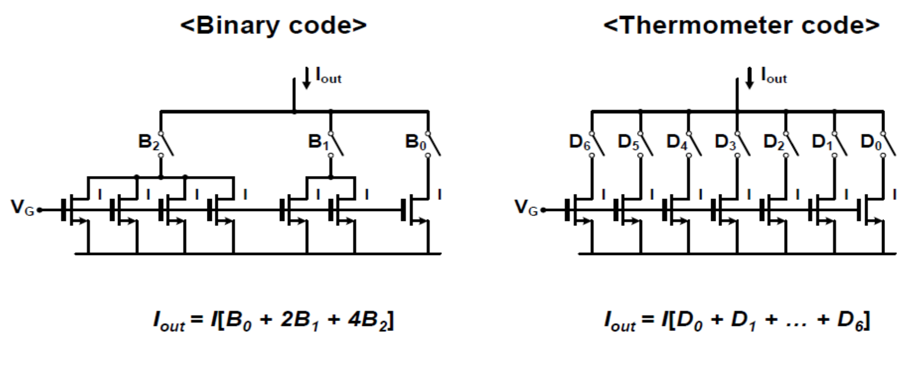
DACs are used for a correction/calibration purpose

- Example : Closed-loop operation of Sensor-Actuator Systems in automotive, industrial and mobile device, where DAC is to drive an actuator
- Voltage offset, gain or current bias in an actuator require some timely adjustments or corrections for performance enhancement of a sensor read out circuit

When a resistive actuator (load) needs to be driven in sensor-actuator systems, the DAC is required to have good output current driving capability

- Mostly, sensor-actuator system does not require a high speed, high accurate and high linearity of the DAC of the system [6]
- CS-DAC is the most suitable architecture for this case, since it naturally provides current as an output variable
- Some sensor-actuator systems pose a challenge
- Maximum output current needs to be correspondingly varied with a configurable resolution
- Motivation
- CS-DAC is required to have a resoultion programmability for maximum ouput current driving capability

Current Steering DAC in 22 nm FD-SOI



	Binary-Weighted	Unary Weighted
Decoder	No need, simple	Need, complex
Glitch	Huge (transition 011…1 to 1…000)	Less
DNL	Bad	Good

Binary-Weighted Architecture and Unary-Weighted Architecture are popularly used for implementation of CS-DAC

- Both has PROS and CON

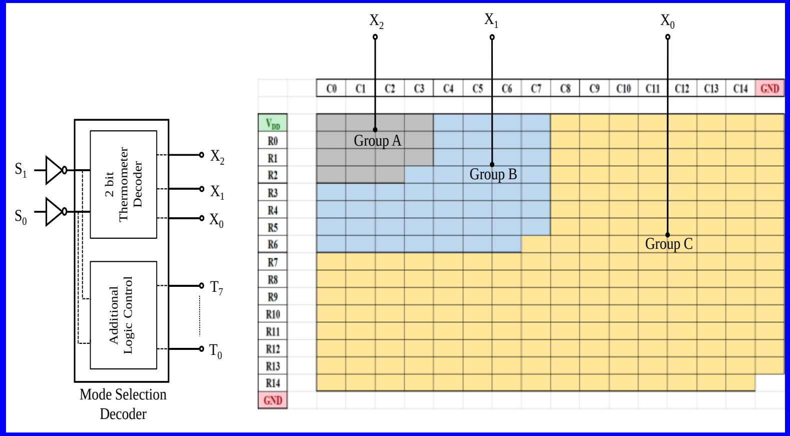
Application to CS-DAC Architecture

- MSBs (Most Significant Bits) conversion → UW architecture
- LSBs (Least Significant Bits) conversion → BW architecture

Now question arises how to make a good segmentations !

Current Steering DAC in 22 nm FD-SOI

Resolution	Unary Weighted	Binary-Weighted	Segmentation Level [%]
8	4	4	50.0
10	6	4	60.0
12	8	4	66.7



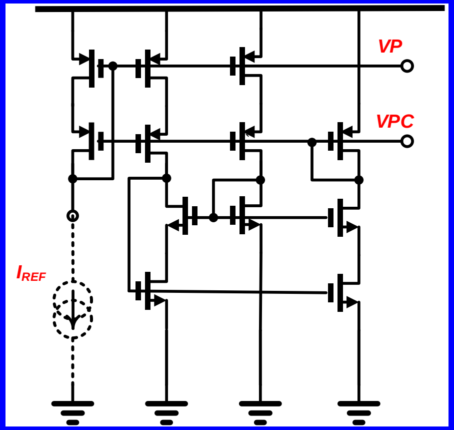
We propose "optimized segmentation" level of the "resolution programmable" CS-DAC based on "Area Optimization Method"

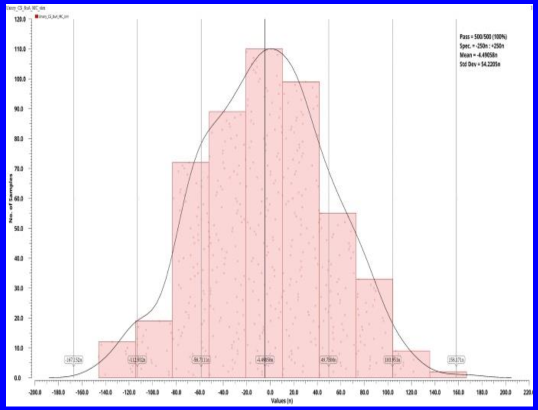
- CS-DAC is designed to have **DNL of 0.5 LSB** and **INL of 1 LSB** at three different resolution modes

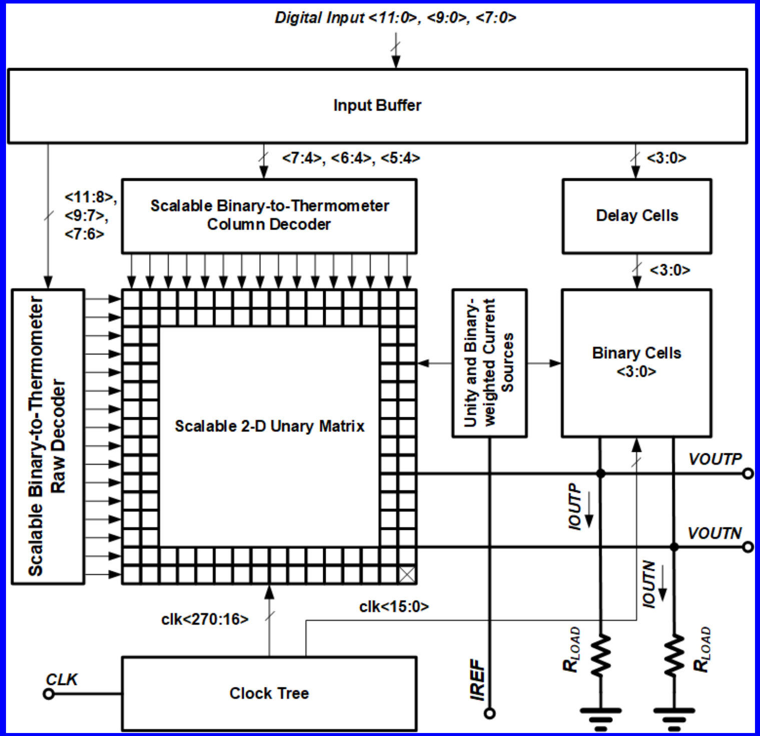
We propose "Grouping-Selection" of the necessary unary cells in the 2-D unary matrix

- **Resolution programmability** is achieved by proposed **„Grouping-selection"** using a **"resolution mode selector"**

Current Steering DAC in 22 nm FD-SOI





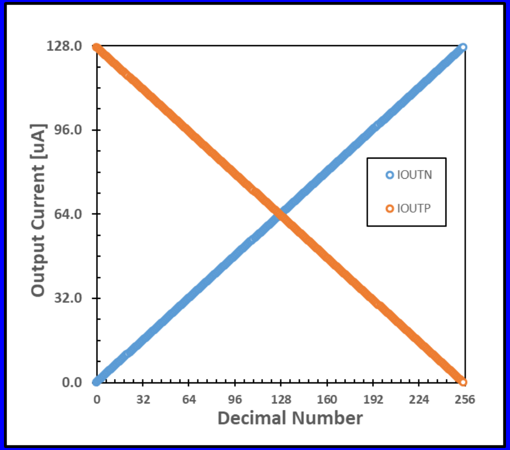


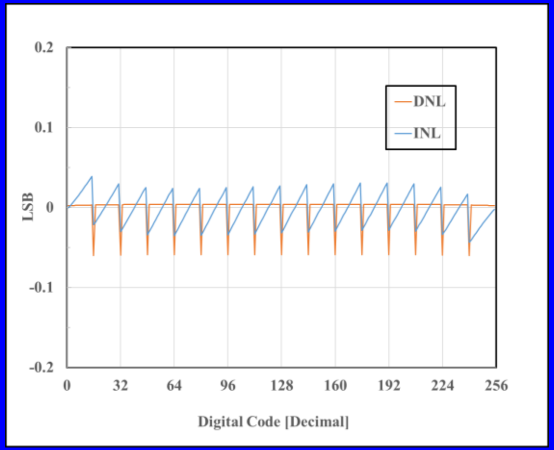
In segmented CS-DACs, INL ∝ Unary Current Source Variations

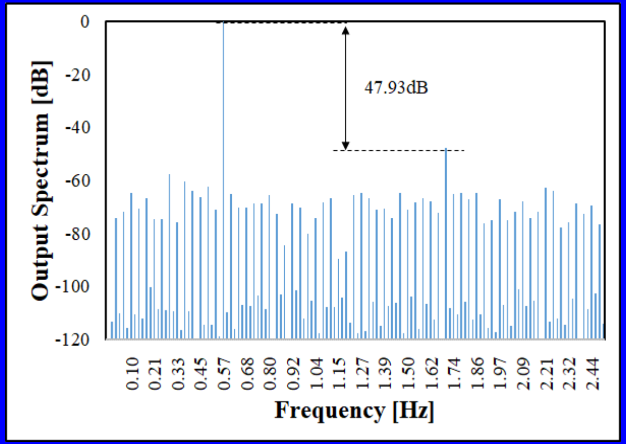
- Mismatch-aware design method was used
- The method was verified for current source using Monte-Carlo Simulation (with a specification range of ± 0.5 LSB)

Now we present the completed resolution programmable CS-DAC

Current Steering DAC in 22 nm FD-SOI







Full Current Driving Capability (resolution programmability)

- 250 Ω RLOAD is terminated here

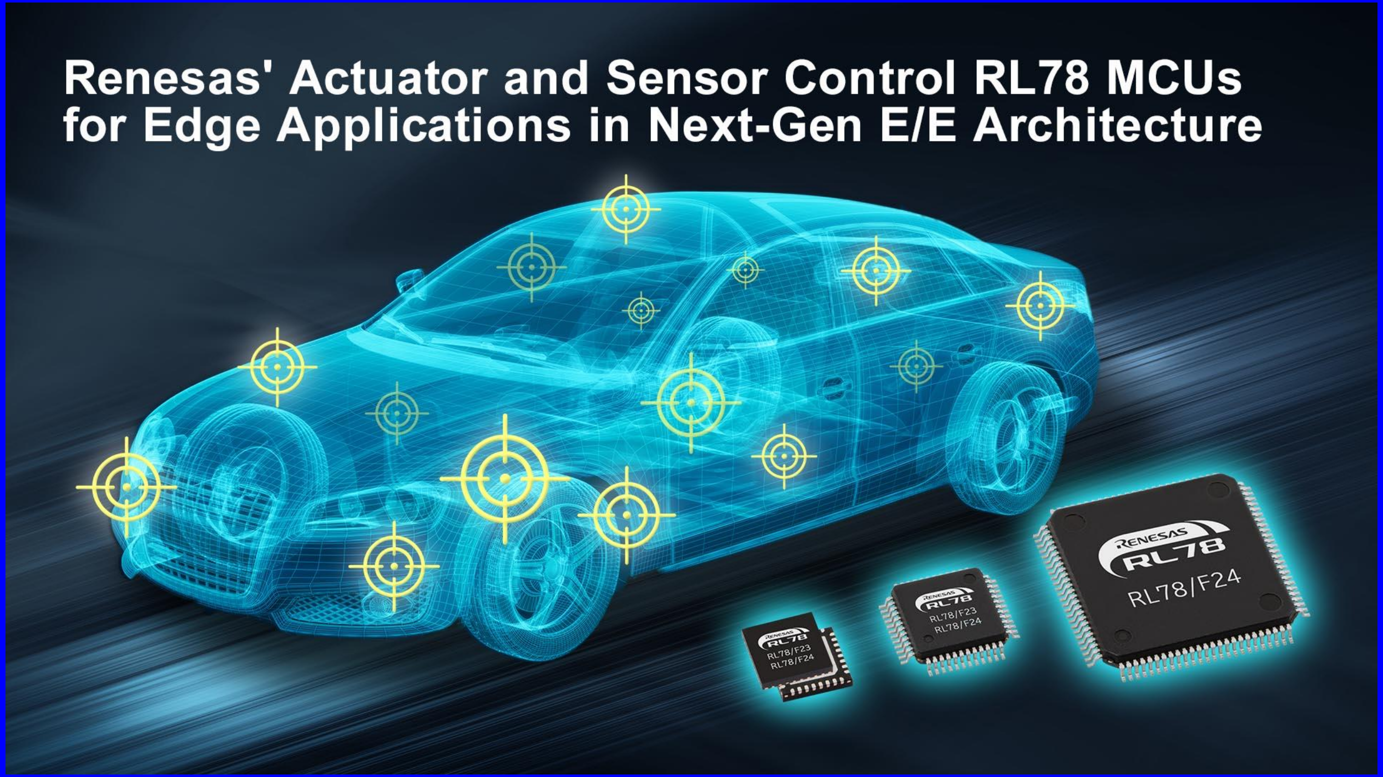
8 bit-mode CS-DAC – Static and Dynamic Performances

- Static Performance : DNL of 0.06 LSB and INL of 0.04 LSB are obtained
- Dynamic Performance : 47.93 dBc is obtained for SFDR

Resolution [bit]	8	10	12
Segmentation [U:B]	4:4	6:4	8:4
Supply [V]		0.8	
Rate [MS/s]		5	
DNL [LSB]	0.06	0.04	0.08
INL [LSB]	0.04	0.06	0.53
SFDR [dBc]	47.9	73.9	52.4
Power [mW]	0.214	0.513	2.407

Renesas Electronics

- Automotive IC



- Low supply current to reduce power consumption (critical for hybrid vehicles)
- Excellent electromagnetic compatibility and ESD protection
- Stable performance at wide operational temperature range (-40 °C to +150 °C)
- Meet Functional Safety Requirement (ISO 26262)

Renesas Electronics

- **Focus Segment**

Automotive

Highly reliable vehicle control,
safe & secure autonomous driving and eco-friendly electric vehicles

Industrial

Lean, flexible and smart industry

Infrastructure

Robust infrastructure, enabling
safety and efficiency

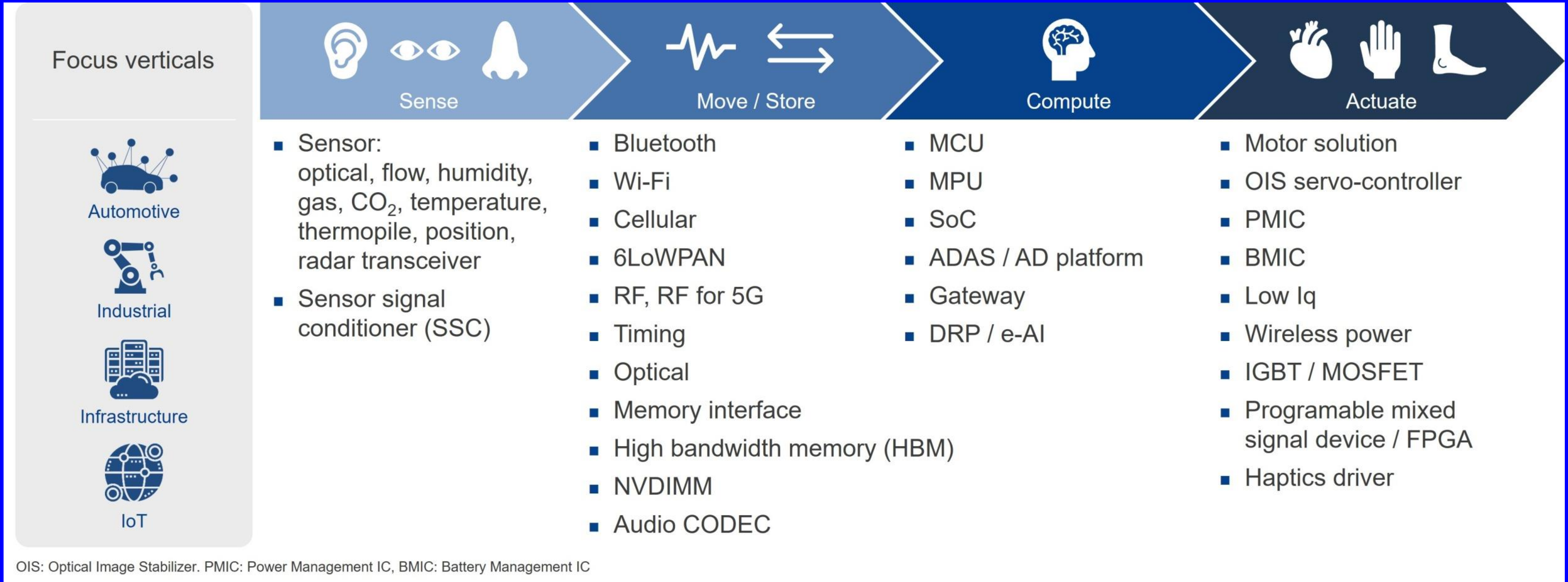
IoT

Comfortable, safe and healthy lifestyles through IoT

- Renesas Electronics Corporation is to develop a safer, healthier, greener, and smarter world by providing intelligence to our four focus growth segments: Automotive, Industrial, Infrastructure, **and** IoT that are all vital to our daily lives, m eaning our products and solutions are embedded everywhere.

Renesas Electronics

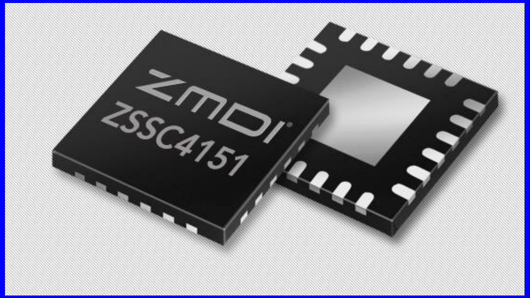
- **Product Portfolio**

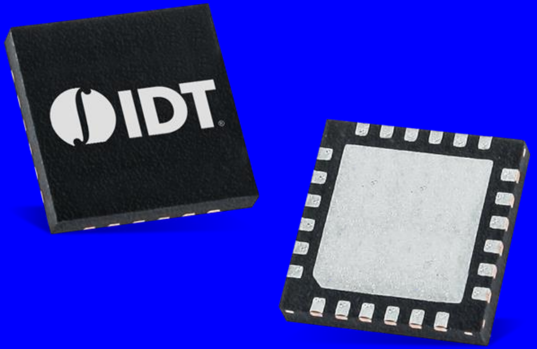


- **Renesas Electronics Corporation** designs and manufactures **microcontrollers, microprocessors, analog, power, and SoC products** for a broad range of **Automotive, Industrial, Infrastructure, and IoT applications**.

Renesas Electronics

- **Renesas Electronics Germany GmbH**

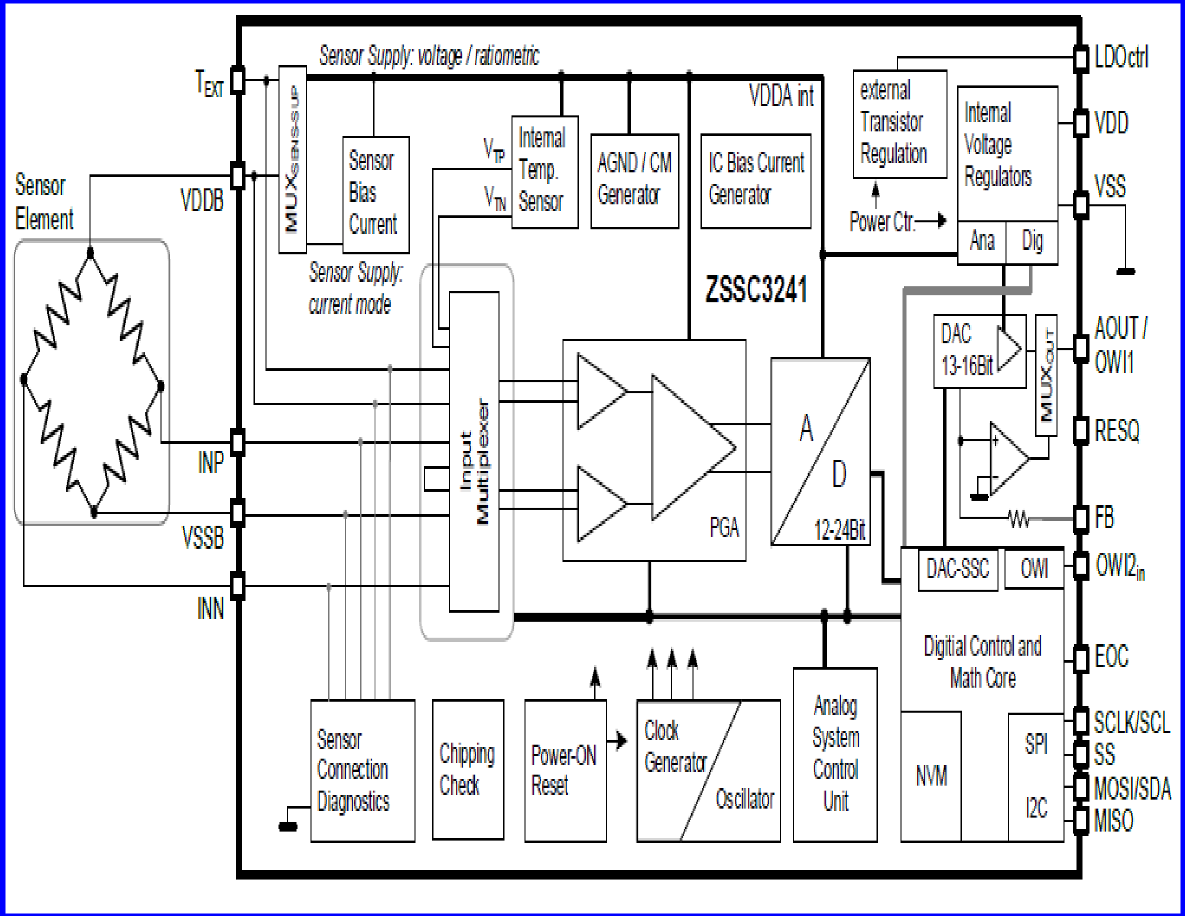


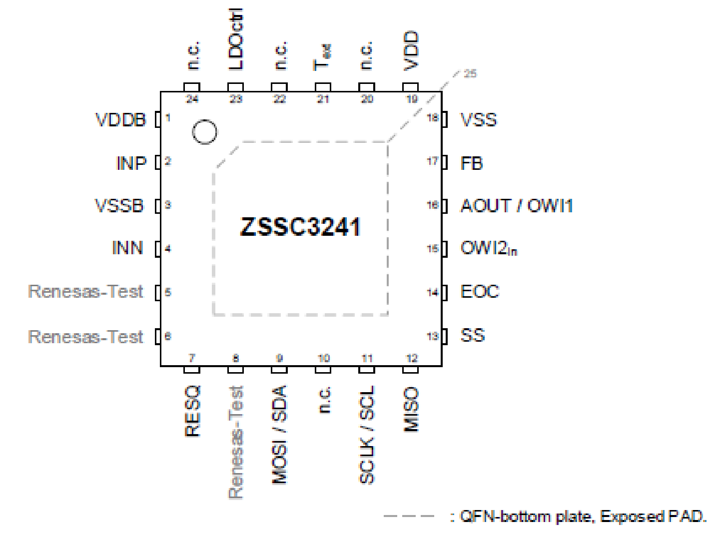


- Renesas Electronics Germany GmbH is a leading provider of innovative, high-precision, robust and cost-effective analog and mixed-signal ICs for automotive, industrial automation and consumer applications.
- **Renesas Electronics Germany GmbH** (Formerly ZMDi AG) has been based in Dresden for over 50 years and is present worldwide. Since April 2019, the company has been part of Renesas Electronics Corporation with around 22,000 employees worldwide.

CMOS Sensor Analog IP's Products

- ZSSC3241

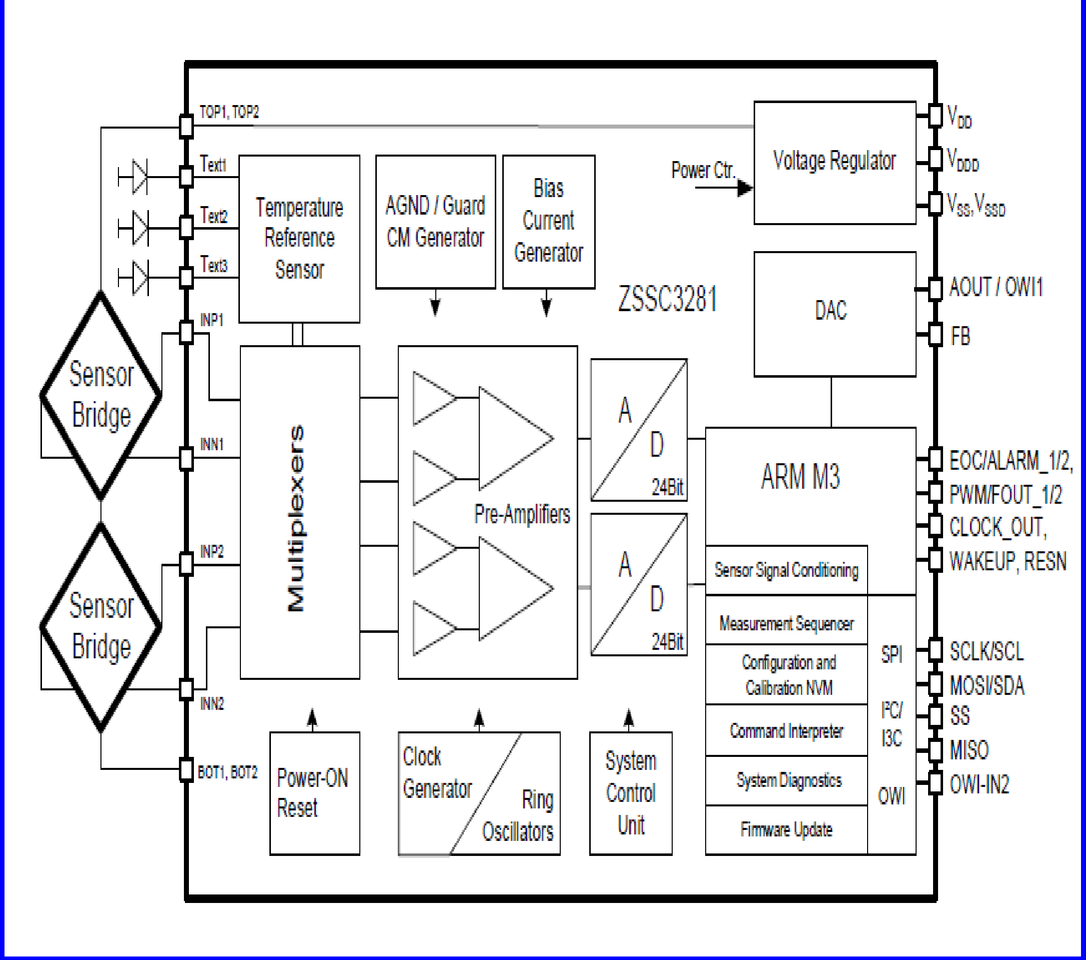


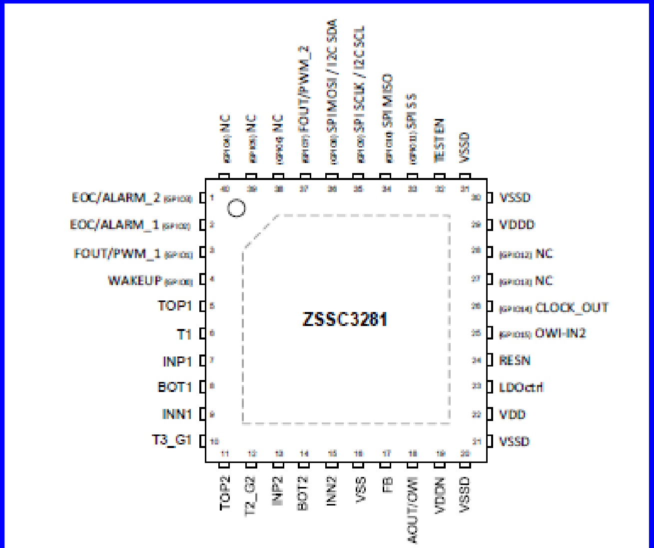


- *Physical Supply voltage, VDD: 2.7 V to 5.5 V*
- *Operating temperature: -40 °C to 150 °C*
- Supported sensor elements: 0.5 kΩ to 60 kΩ
- ZSSC3241 is available in a 24-QFN package, (4x4 mm^2)

CMOS Sensor Analog IP's Products

- **ZSSC3201**

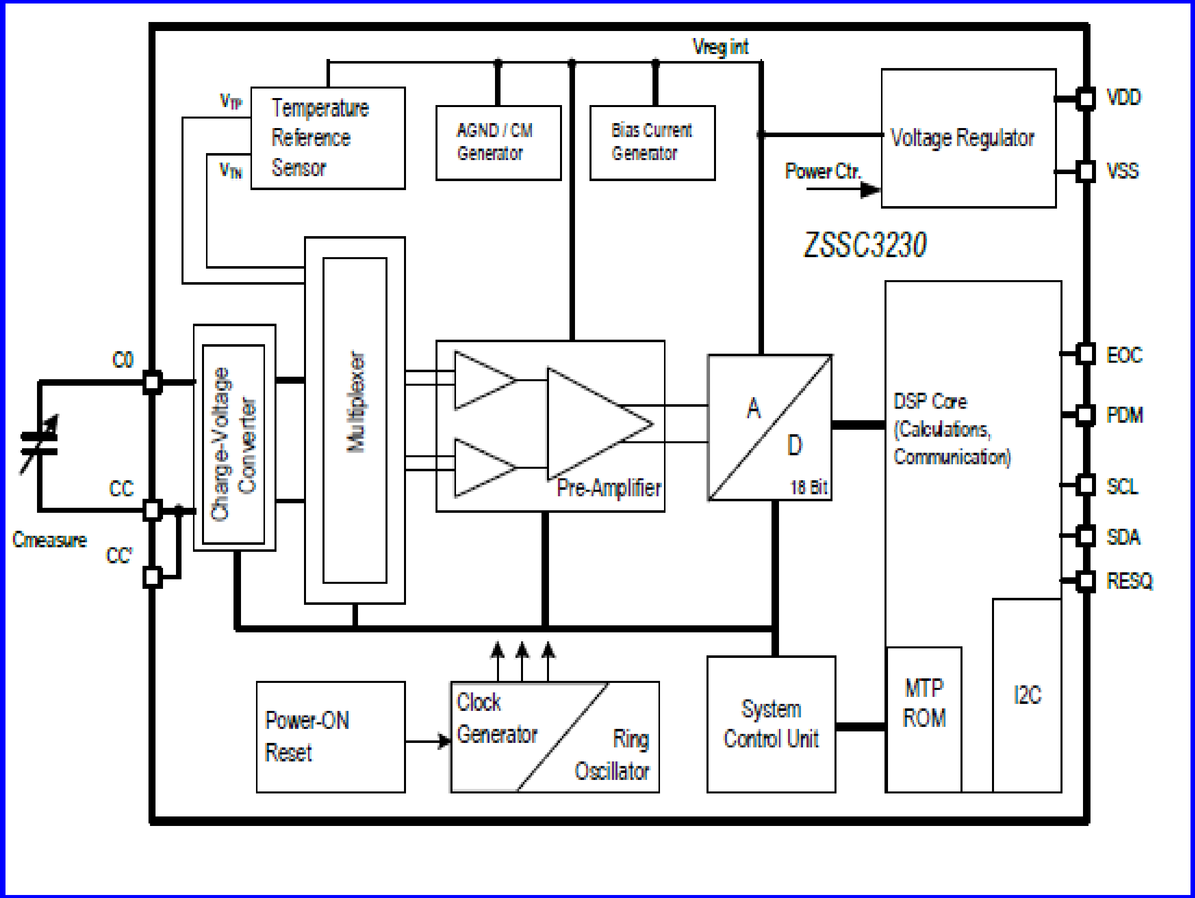


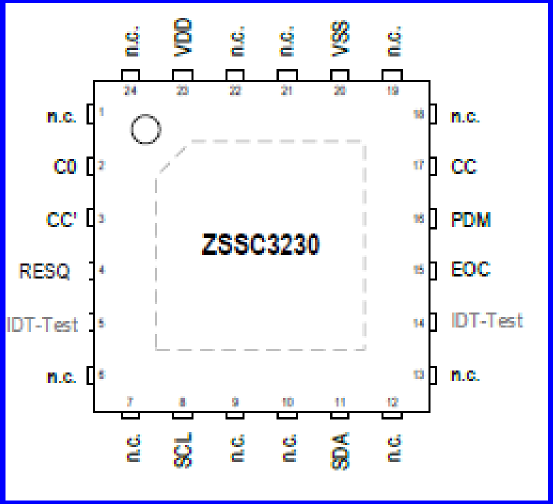


- Physical Supply voltage, VDD: 1.8 V to 5.5 V
- Operating temperature: -40 °C to 150 °C
- Supported sensor elements: 0.825 kΩ to 60 kΩ
- ZSSC3281 is available in 40-QFN (5x5 mm^2)

CMOS Sensor Analog IP's Products

- **ZSSC3201**





- Physical Supply voltage, VDD: 1.68 V to 3.6 V
- Operating temperature: -40 °C to 150 °C
- Supported sensor elements: 0 pF to 30 pF
- ZSSC3281 is available in 24-QFN package, (4x4 mm^2)

Many thanks for your attention !!

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