PANEL

Trends on Miniaturization

(energy, heat, optimisation, connections, accuracy, sensitivity, etc.)

Chair

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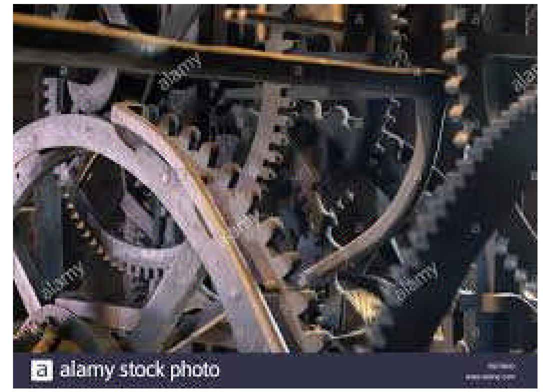
Needs for miniaturization

- Space saving
- Material saving
- Light devices/machineries
- More handily
- Less energy consuming
- Transportability easiness
- Less computation power
- Speeder devices
- Less costly
- Less storage (space - datacenters, memories chips – data, etc.)
- Nice looking



Journey for electronic circuitry

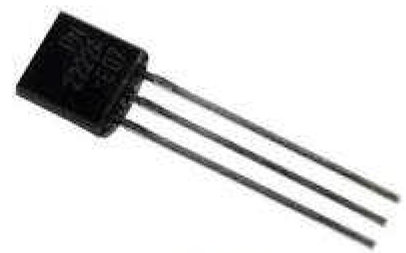
Domains

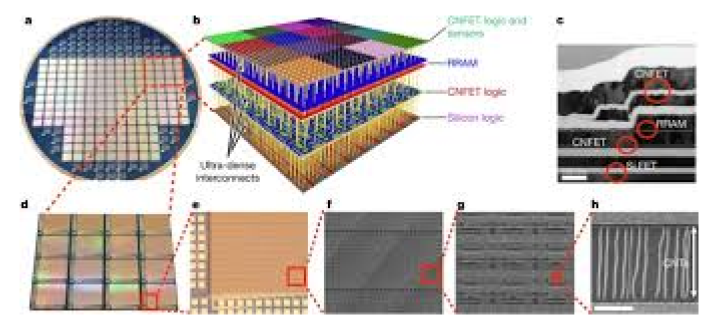
Human perception (arts): Micro-sculpture, mini-books, mini-picture, ...
Entertainment (games, devices): Screens: screens, medium, small, wearable, ...
Keyboards: medium, small, on-wrist, ...
Deployment (services): Micro-services, service composition, ...
Healthcare (surgeries): micro, nano (bio-robots), ...
Materials (devices) : Macro - mini - micro - nano - pico, ...
Volume (data): Huge data, large data, raw data, compressed/fusion data, temporary data,...

Changes/Innovation/Challenges

Size: Manufacturing tools, measurement tools, controlling procedures,...
Cooling/Heating: Special dedicated devices, techniques for heat dissipation, optimization, ...
Ergonomic: Hand-able, wear-able, harmless, light-weight, ..
Computation procedures: Local, Distributed, Intermittent, ...

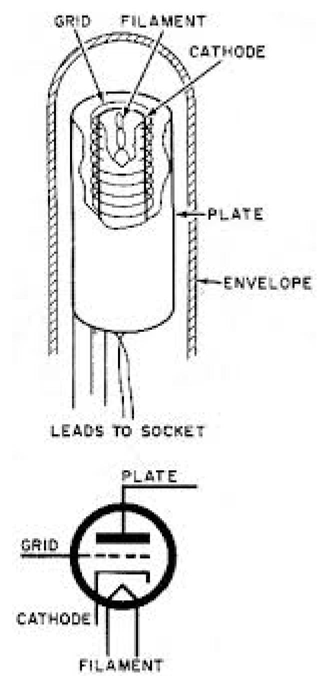
Case study



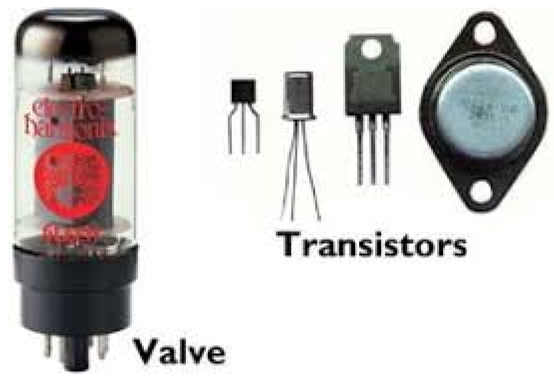


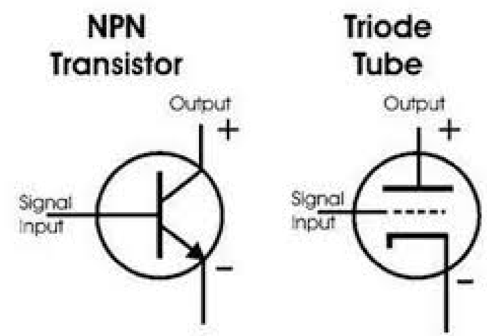
All the photos/pictures are public in open space

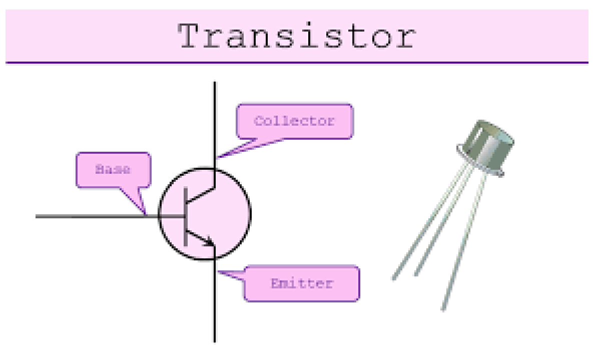
Vacuum tubes (the road to electrical devices)

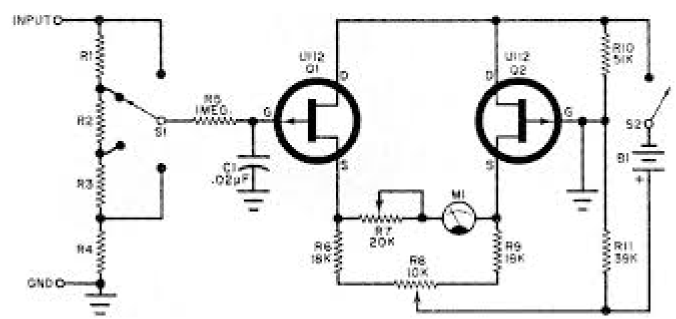


The road to transistors (4-decade period)

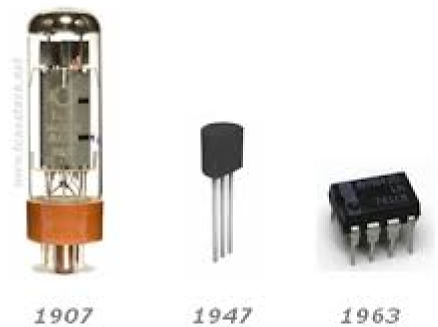


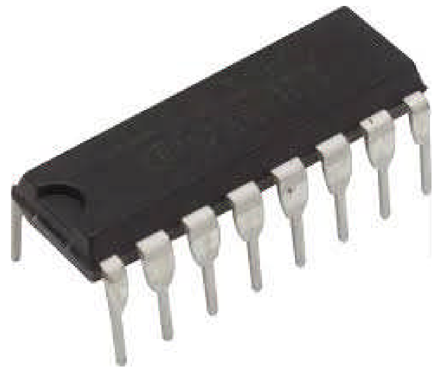


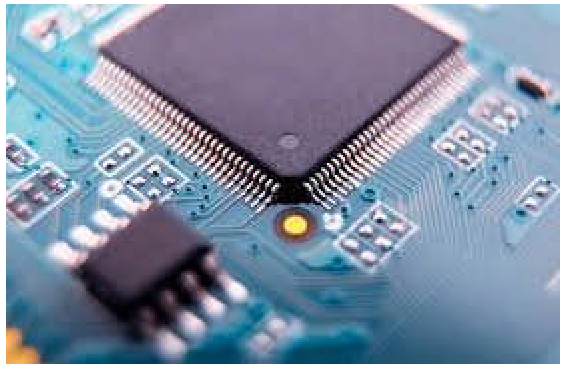


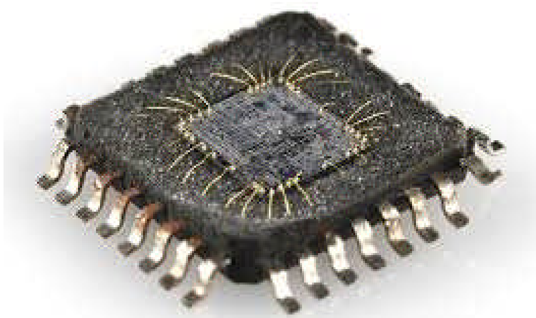


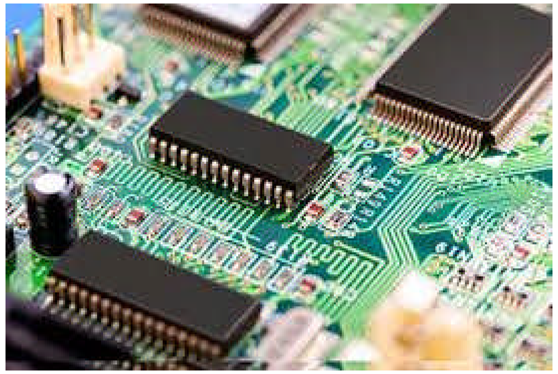
Chips (integrated circuits)

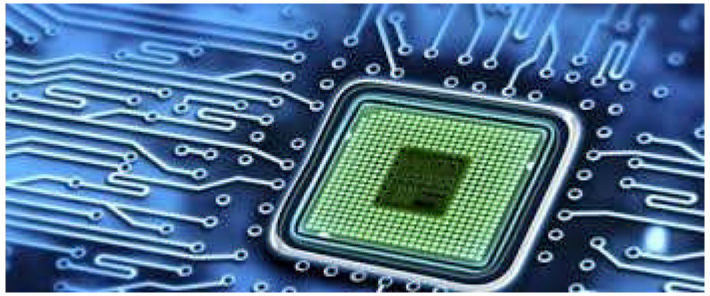


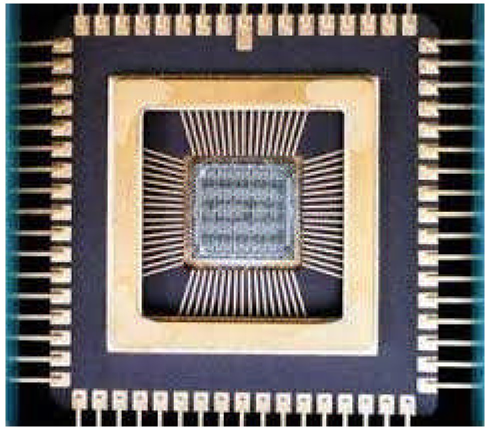


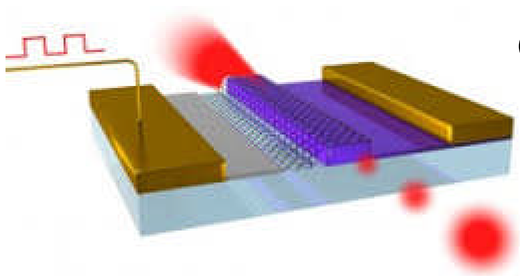






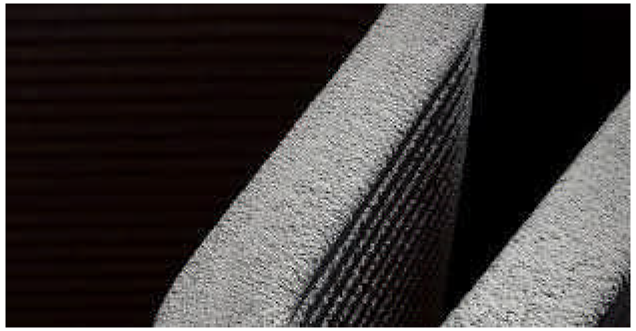




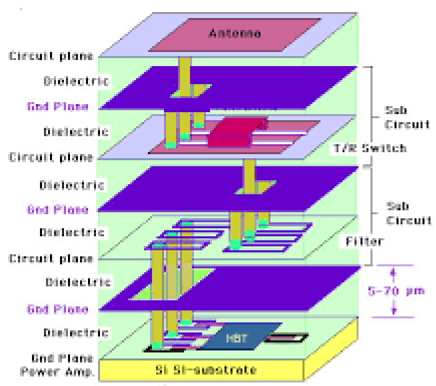


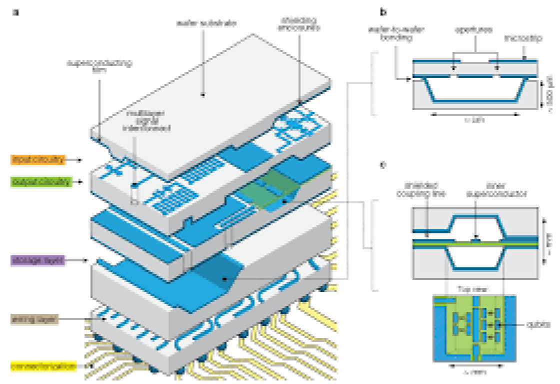
Graphene

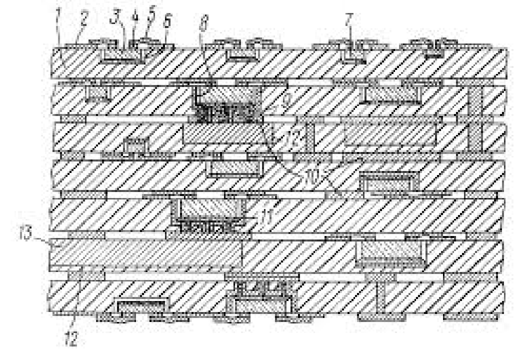
3D Printed



Multi-layers integrated circuits







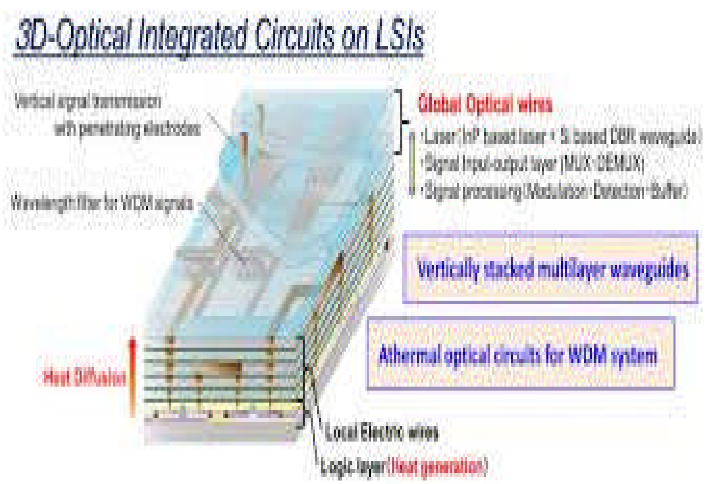
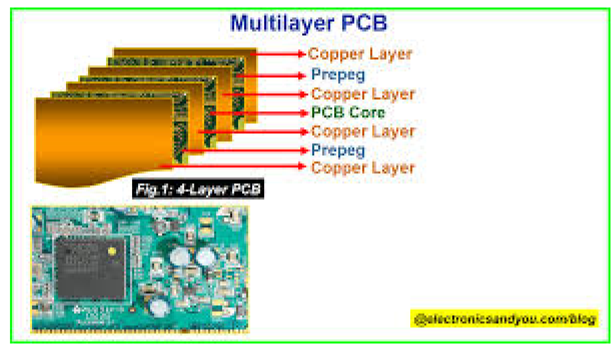
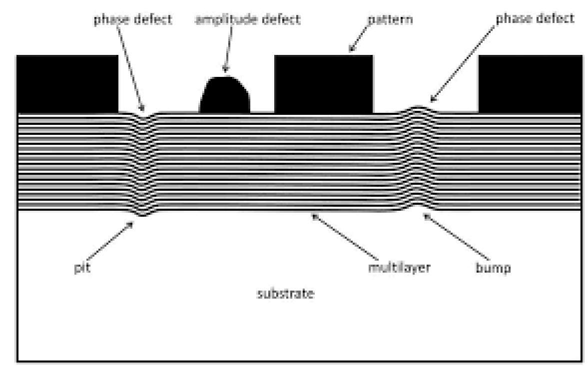


Fig. 1 3D-Optical Integrated Circuits on LSIs



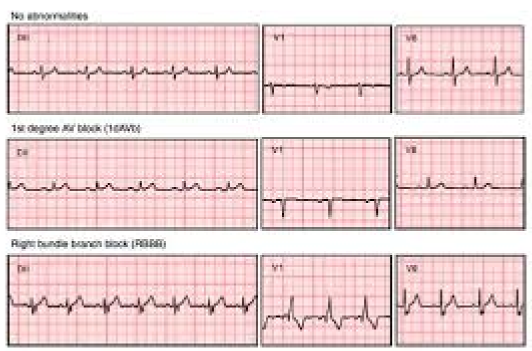
Multilayer PCB

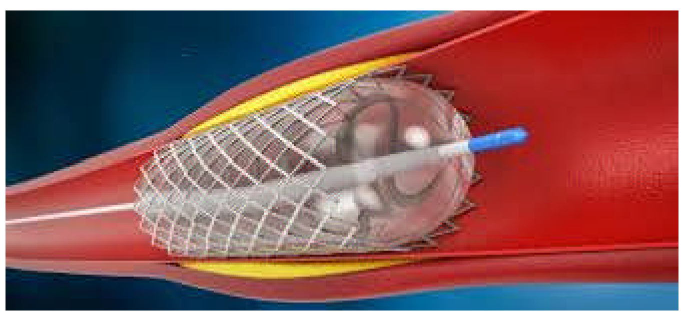


Ultraviolet lithography

Miniatured devices

(bio, blood, hearing, glycemia, heart, eye, brain. ….)





Continuing the journey

Still going:

Mini

Micro

Nano

Pico

Stories from the road by… Kyle, Sazzadur, Sorore

Panelists

- Kyle Sundqvist, San Diego State University, USA
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- Sorore Benabid, ESEO, France sorore.benabid@eseo.fr

- Sazzadur Chowdhury, University of Windsor, Canada
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Panelist Summary

Quantum-coherent devices using superconductors at millikelvin temperatures

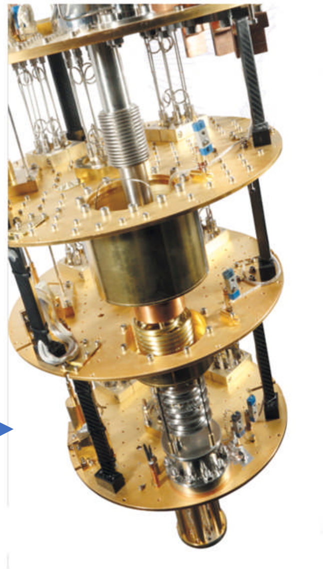
Kyle Sundqvist, Department of Physics, San Diego State University, San Diego, California, USA. ksundqvist@sdsu.edu

- Superconductive devices as qubits
- Readout using single-photon amplifiers at GHz frequencies
- Sources of entangled GHz photons

à How do we network quantum-coherent devices together? Use "SLH Formalism"

à Opportunities to explore new physics with entangled GHz photons, or with single-photon resolution, inside of a millikelvin cryostat.

Oxford Instruments' *Triton* 400uW dilution refrigerator, being installed at SDSU



Parametrically-driven superconductive devices

Kyle Sundqvist
San Diego State University
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NetWare 2020 Congress
Panel: *Trends on Miniaturization*

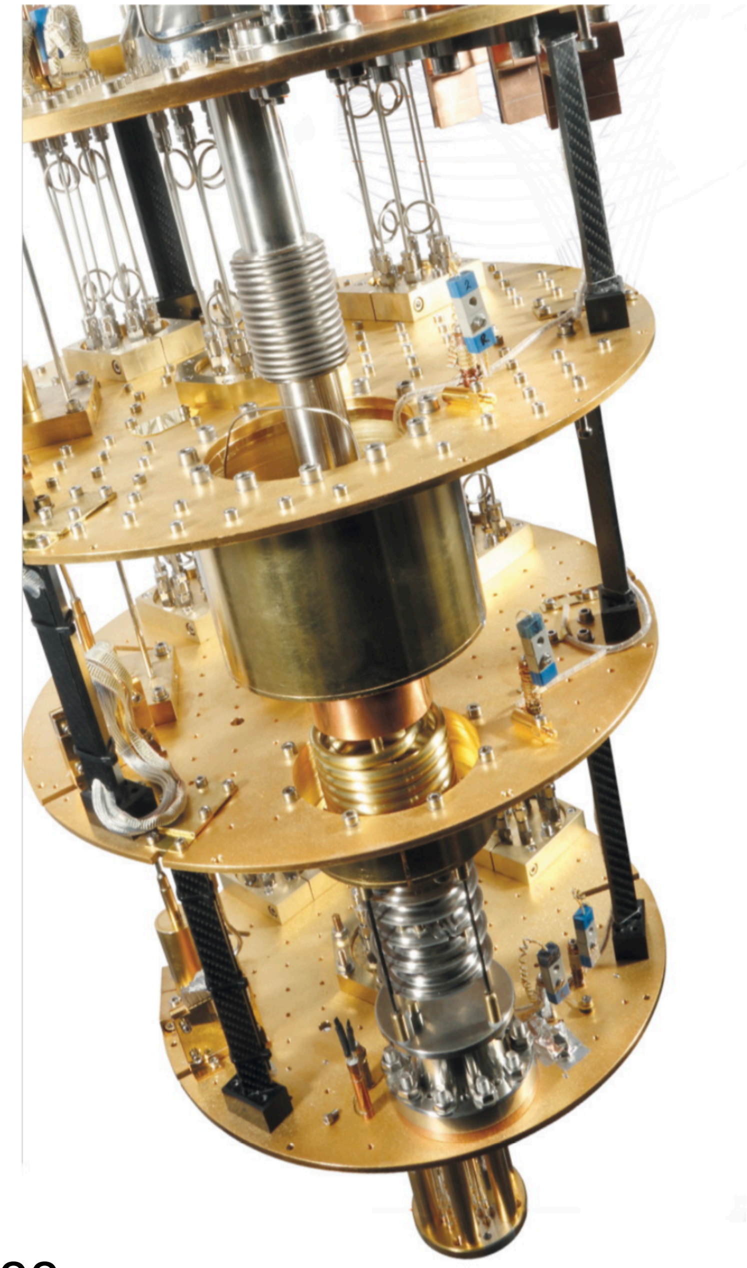
November 2020

We are setting up a low-temperature condensed matter lab.

With access to a **millikelvin** dilution refrigerator at SDSU, we are preparing a platform by which to amplify photons measuring nearly to the **quantum-noise limit.**

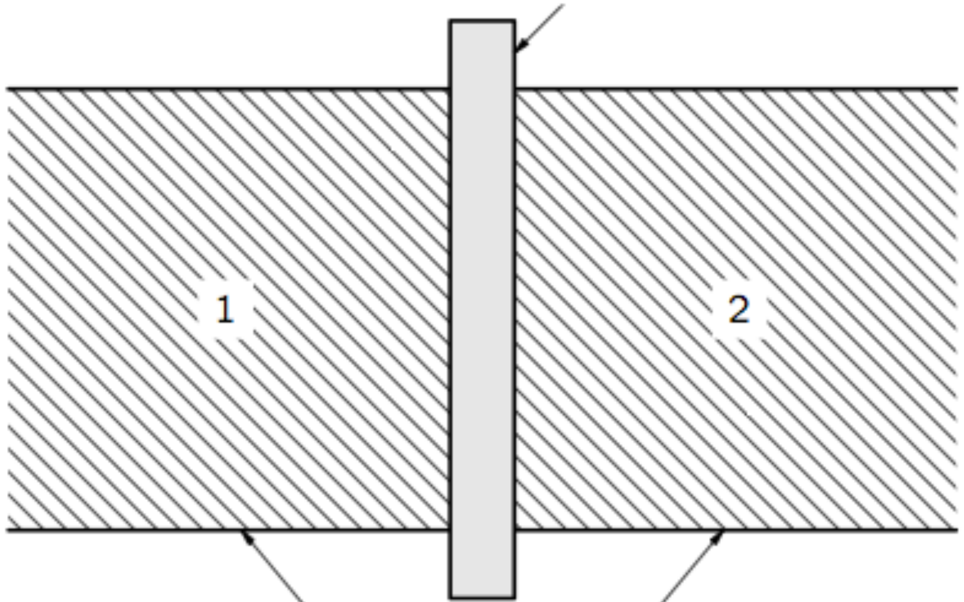
These amplifiers are designed with readout of superconducting qubits in mind, but have other potential applications.

Such **parametrically-driven** devices based on **superconducting electronics**, and operate by driving the natural non-linear inductance related to Josephson junctions.



Oxford Instruments' *Triton* 400
Dilution refrigerator

The Josephson junction: nature's only nonlinear inductor.



The only potentially active element in superconducting electronics is the **Josephson junction**.

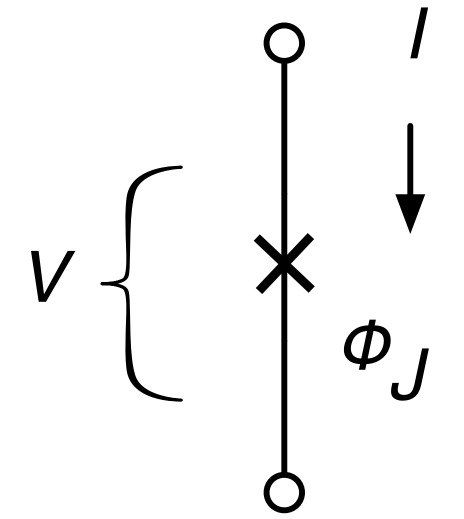
It is formed by two superconductors which are connected by a thin layer of insulating material.

The tendency between superconductors to phase-lock across the junction gives rise to the **Josephson relations**, which depend on the phase difference across the junction, $\phi_J = \phi_2 - \phi_1$.

Reviewing the Josephson relations.

DC Josephson Effect:

There is a relation between the current and macroscopic phase difference across the junction:



$$I = I_c \sin(\phi_J)$$

AC Josephson Effect:

The junction phase and voltage drop are related:

$$V = \left(\frac{\Phi_0}{2\pi}\right)\frac{d\phi_J}{dt}$$

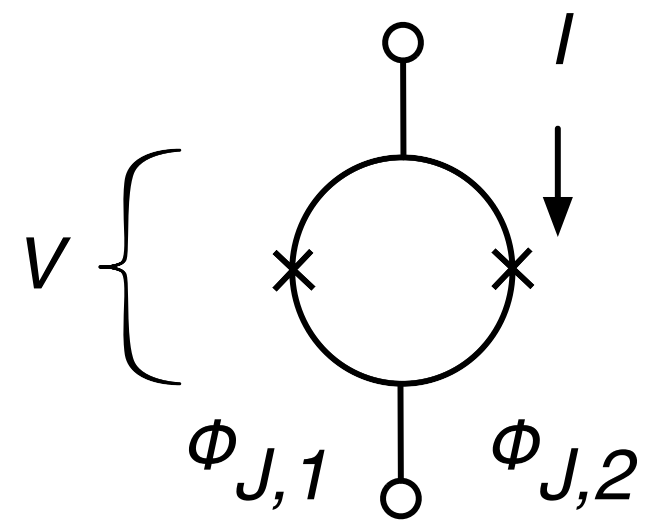
The DC SQUID looks like a tunable Josephson junction.

Current is the summation of parallel junctions:

$$I = \frac{I_c}{2}\sin\left(\phi_{\mathrm{J},1}\right) + \frac{I_c}{2}\sin\left(\phi_{\mathrm{J},2}\right)$$

Circular loop imposes phase boundary condition:

$$\phi_{\mathrm{J},1} + \phi_{\mathrm{J},2} + 2\pi \, \Phi_{\mathrm{ext}} / \Phi_0 = 2\pi n$$

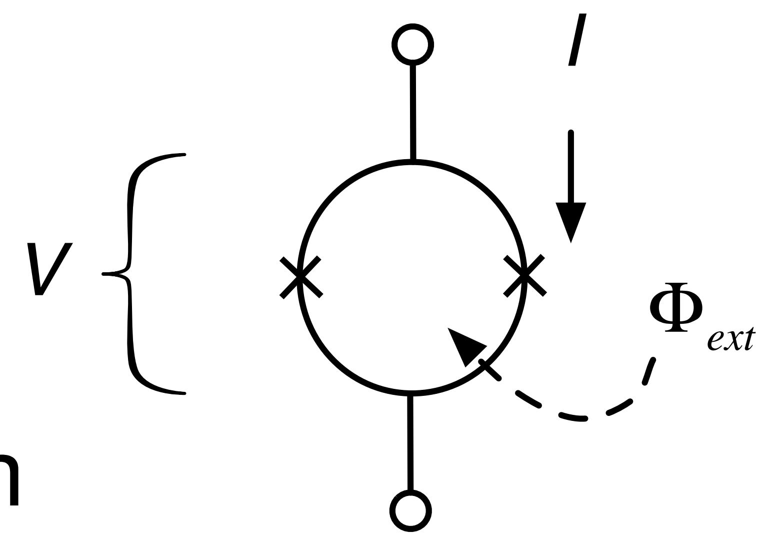


Simplifying, the DC SQUID looks like a Josephson junction, but with a critical current sensitive to the external flux:

$$\boxed{\begin{aligned} I &= \left[I_c \cos\left(\pi \Phi_{\mathrm{ext}} / \Phi_0\right)\right]\sin\left(\phi_J\right) \\ V &= \left(\frac{\Phi_0}{2\pi}\right)\frac{d\phi_J}{dt} \end{aligned}}$$

The flux-pumped SQUID acts like a flux+phase mixer.

$$I = \underbrace{I_c\cos\left(\pi\Phi_{\text{ext}}/\Phi_0\right)}_{\text{“flux” term}}\underbrace{\sin\left(\phi_J\right)}_{\text{“phase” term}}$$



apply a driven external flux:

$$\Phi_{\text{ext}} = \Phi_{\text{dc}} + \Phi_{\text{ac}}\cos\left(\omega_p t + \theta_p\right)$$

$$\sin\left(\phi_J\right) \approx \phi_J$$

$$\phi_J = \phi_s \sin\left(\omega_s t + \theta_s\right)$$

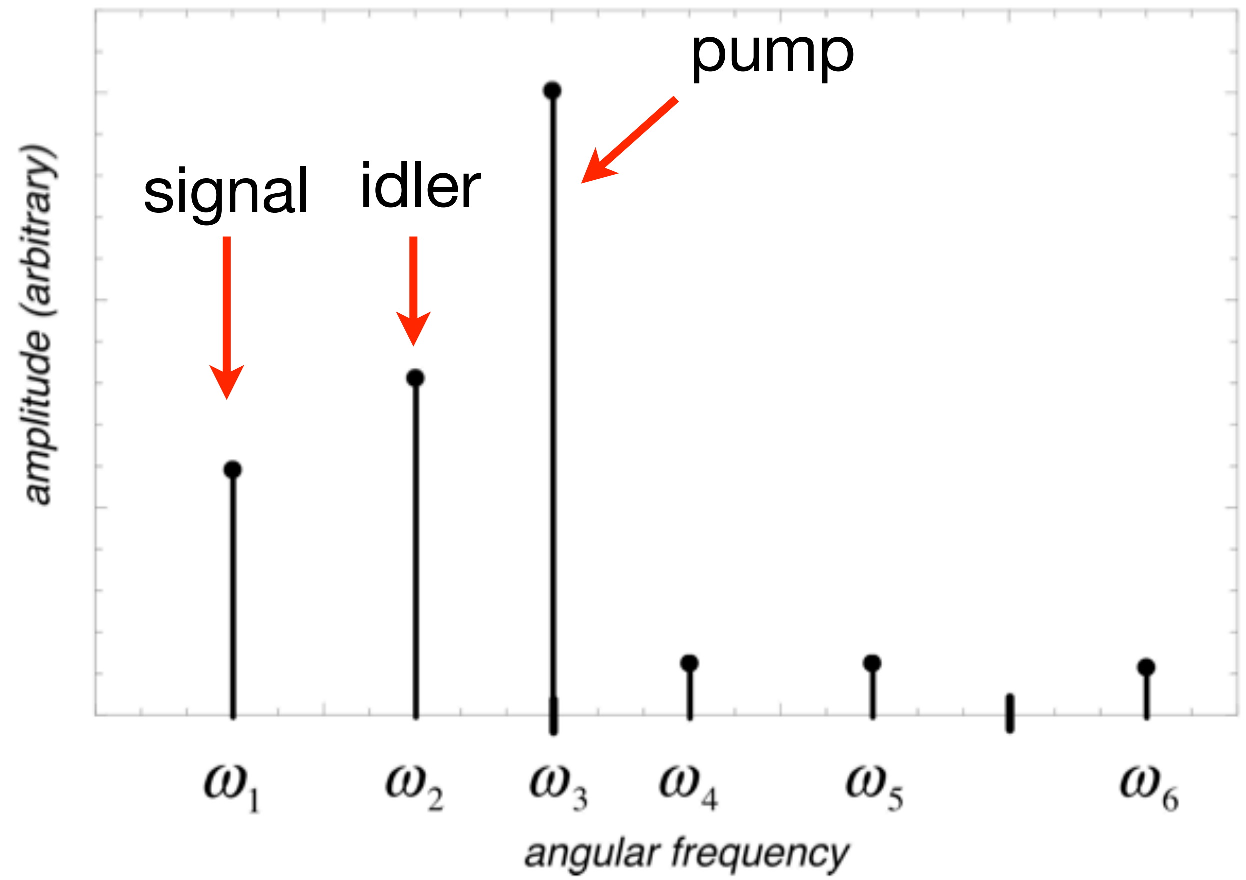
Series expand, as the ac flux is assumed small.

$$I = \overbrace{\left[I_c\cos\left(\pi\Phi_{\text{dc}}/\Phi_0\right) - I_c\frac{\pi\sin\left(\pi\Phi_{\text{dc}}/\Phi_0\right)}{\Phi_0}\Phi_{\text{ac}}\cos\left(\omega_p t + \theta_p\right)\right]}^{\text{“flux” term}}\overbrace{\left[\phi_s\sin\left(\omega_s t + \theta_s\right)\right]}^{\text{“phase” term}}$$

By frequency mixing, "idler" tones form.

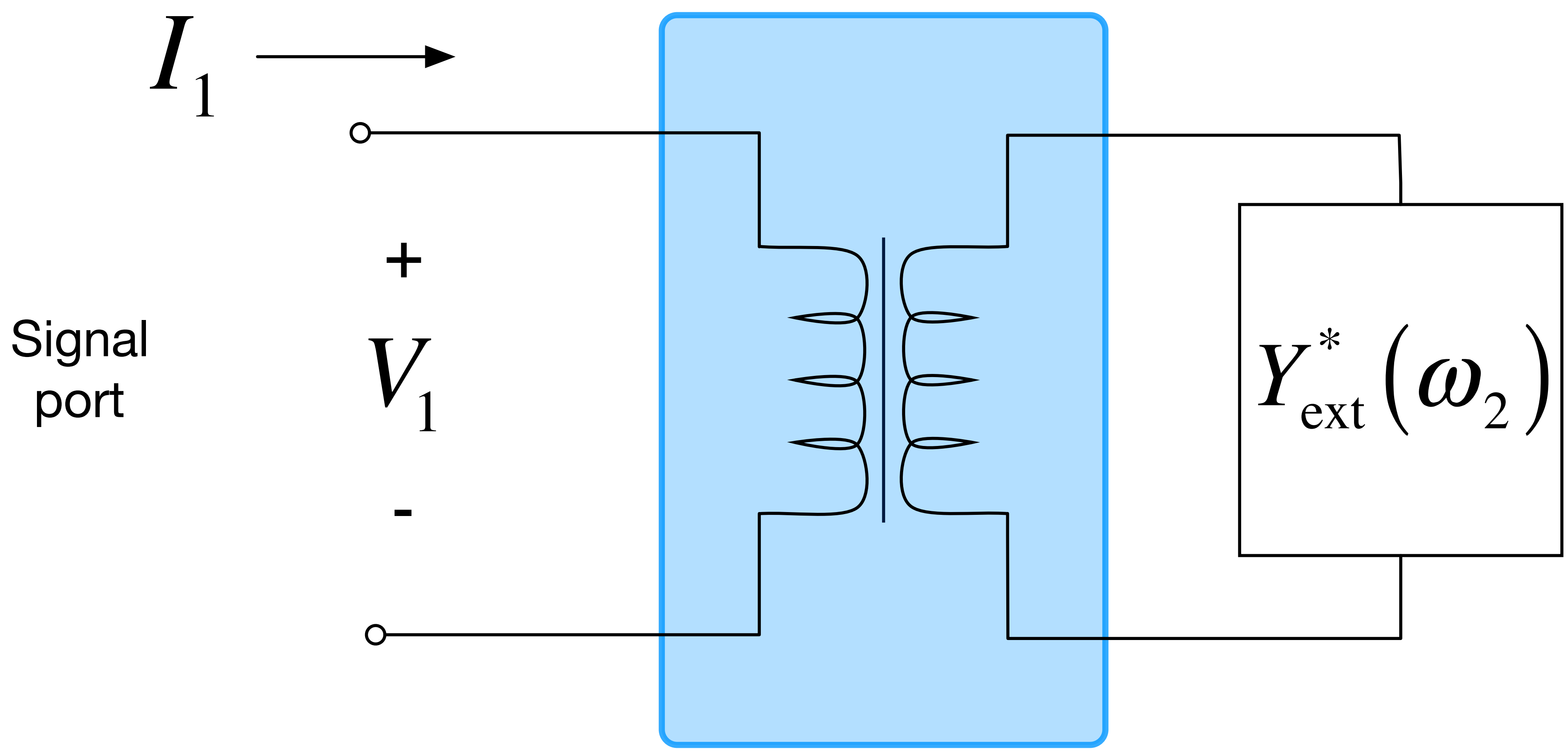
Table 1: Our convention for the frequencies involved in mixing effects

(Angular) frequency	Designation	Relation
ω_1	"signal"	ω_1
ω_2	"idler" (three-wave difference)	$\omega_3 - \omega_1$
ω_3	"pump"	ω_3
ω_4	"idler" (three-wave sum)	$\omega_3 + \omega_1$
ω_5	"idler" (four-wave difference)	$2\omega_3 - \omega_1$
ω_6	"idler" (four-wave sum)	$2\omega_3 + \omega_1$



We can refer **input impedance *across*** the transformer, which can supply gain.

$$\begin{pmatrix} I_1 \\ I_2^* \end{pmatrix} = \frac{1}{jL_J} \begin{pmatrix} \frac{\epsilon_0}{\omega_1} & -\frac{\epsilon_1^*}{\omega_2} \\ \frac{\epsilon_1}{\omega_1} & -\frac{\epsilon_0}{\omega_2} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2^* \end{pmatrix}$$



This understanding has allowed for a large gain-bandwidth, strongly-coupled lumped amplifier.

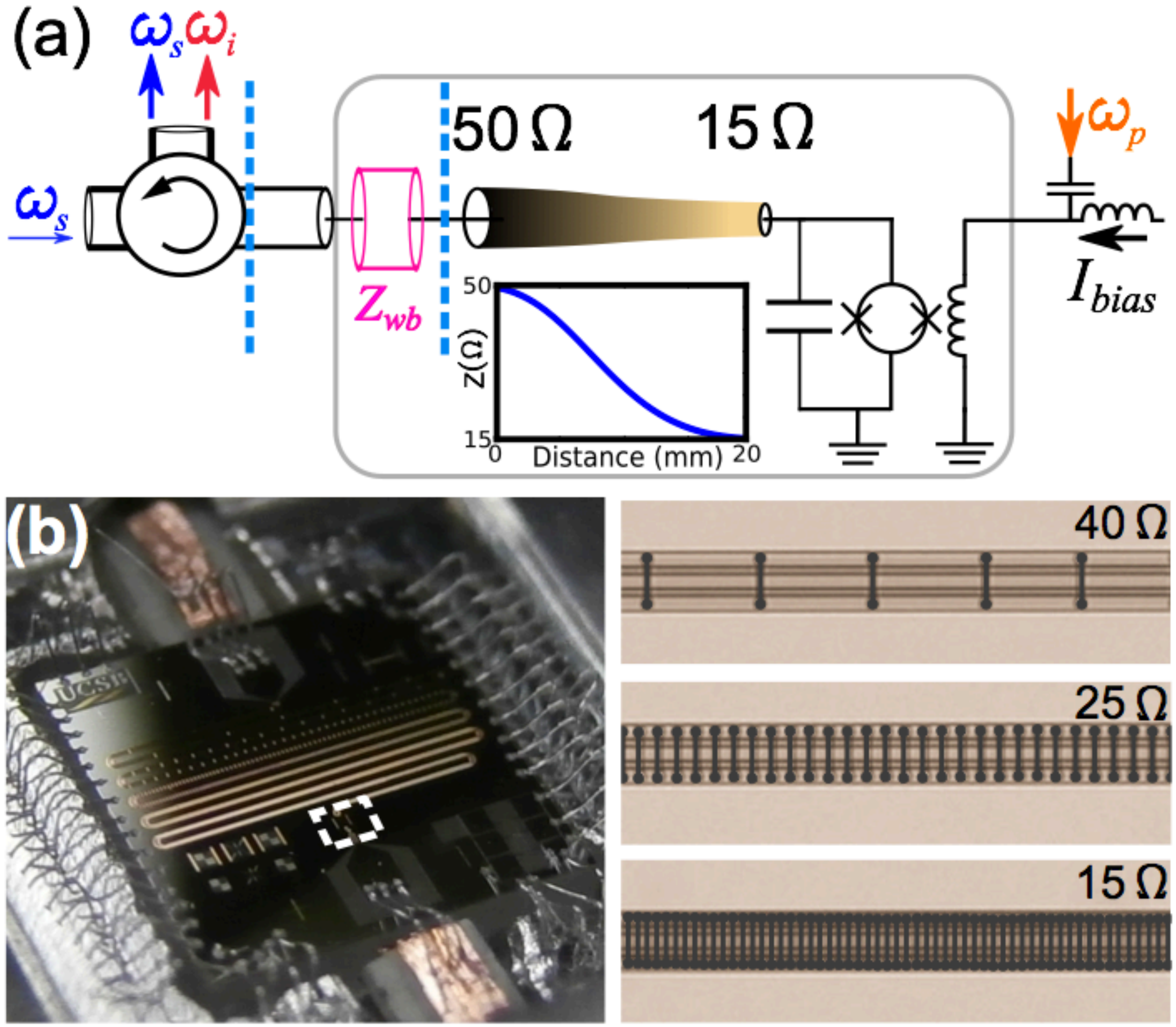
Strong environmental coupling in a Josephson parametric amplifier

J.Y. Mutus,* T.C. White,* R. Barends, Yu Chen, Z. Chen, B. Chiaro, A. Dunsworth, E. Jeffrey, J. Kelly, A. Megrant, C. Neill, P.J.J. O'Malley, P. Roushan, D. Sank, A. Vainsencher, J. Wenner, A.N. Cleland, and John M. Martinis†
Department of Physics, University of California, Santa Barbara, California 93106-9530, USA

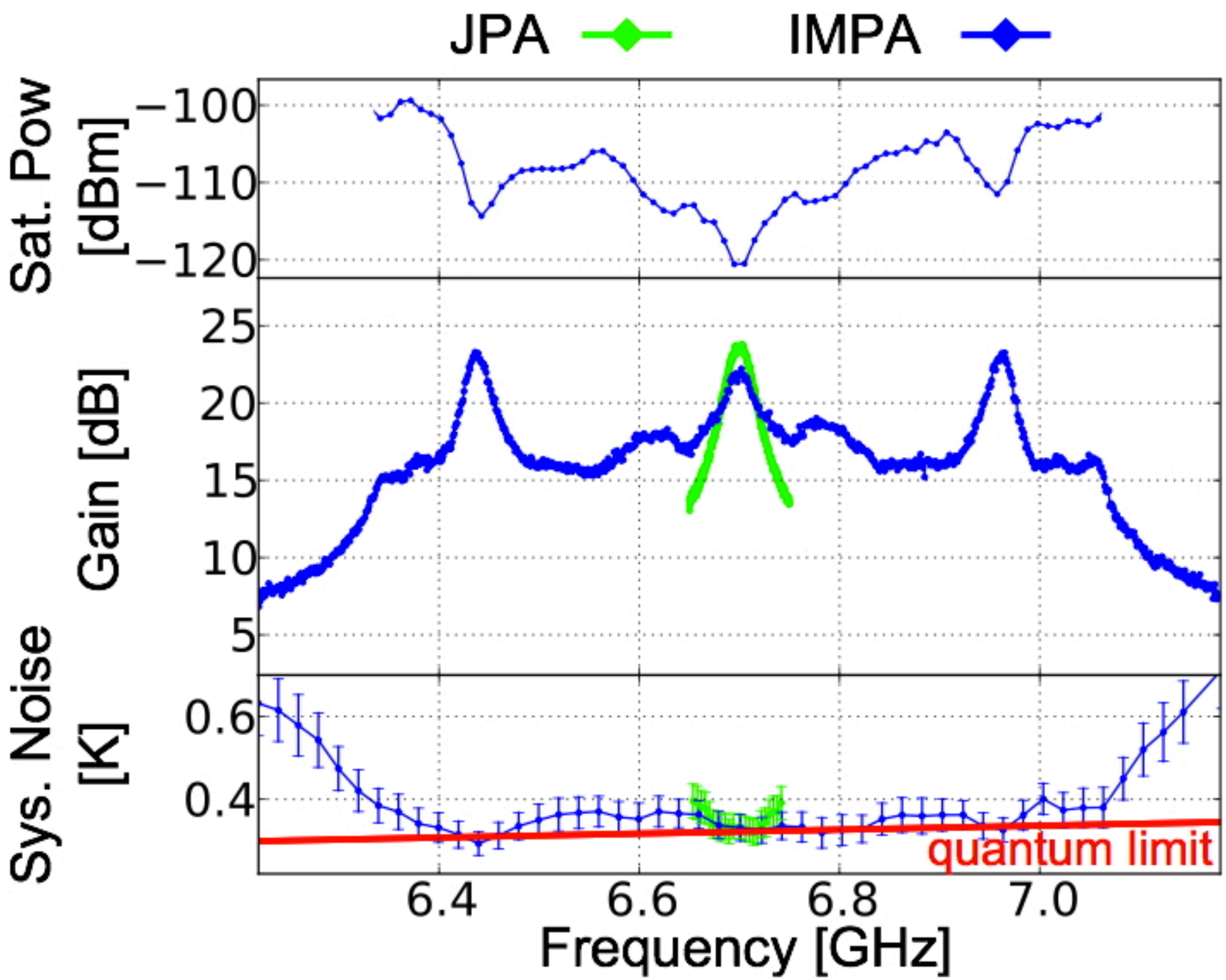
K.M. Sundqvist
Electrical and Computer Engineering, Texas A&M University, College Station, Texas 77843, USA
(Dated: January 20, 2014)

We present a lumped-element Josephson parametric amplifier designed to operate with strong coupling to the environment. In this regime, we observe broadband frequency dependent amplification with multi-peaked gain profiles. We account for this behaviour using the "pumpistor" model which allows for frequency dependent variation of the external impedance. Using this understanding, we demonstrate control over gain profiles through changes in the environment impedance at a given frequency. With strong coupling to a suitable external impedance we observe a significant increase in dynamic range, and large amplification bandwidth up to 700 MHz giving near quantum-limited performance.

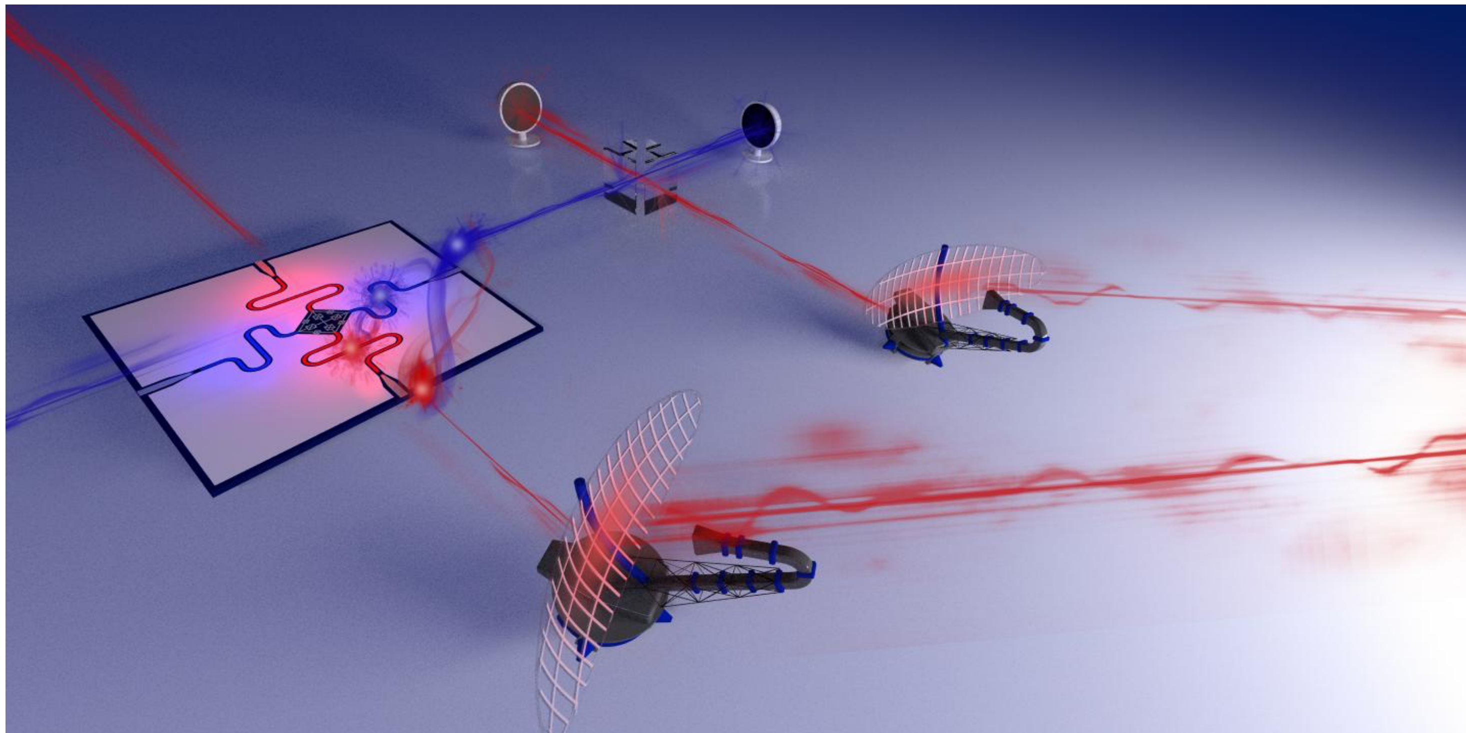
This implementation required air-bridge technology.

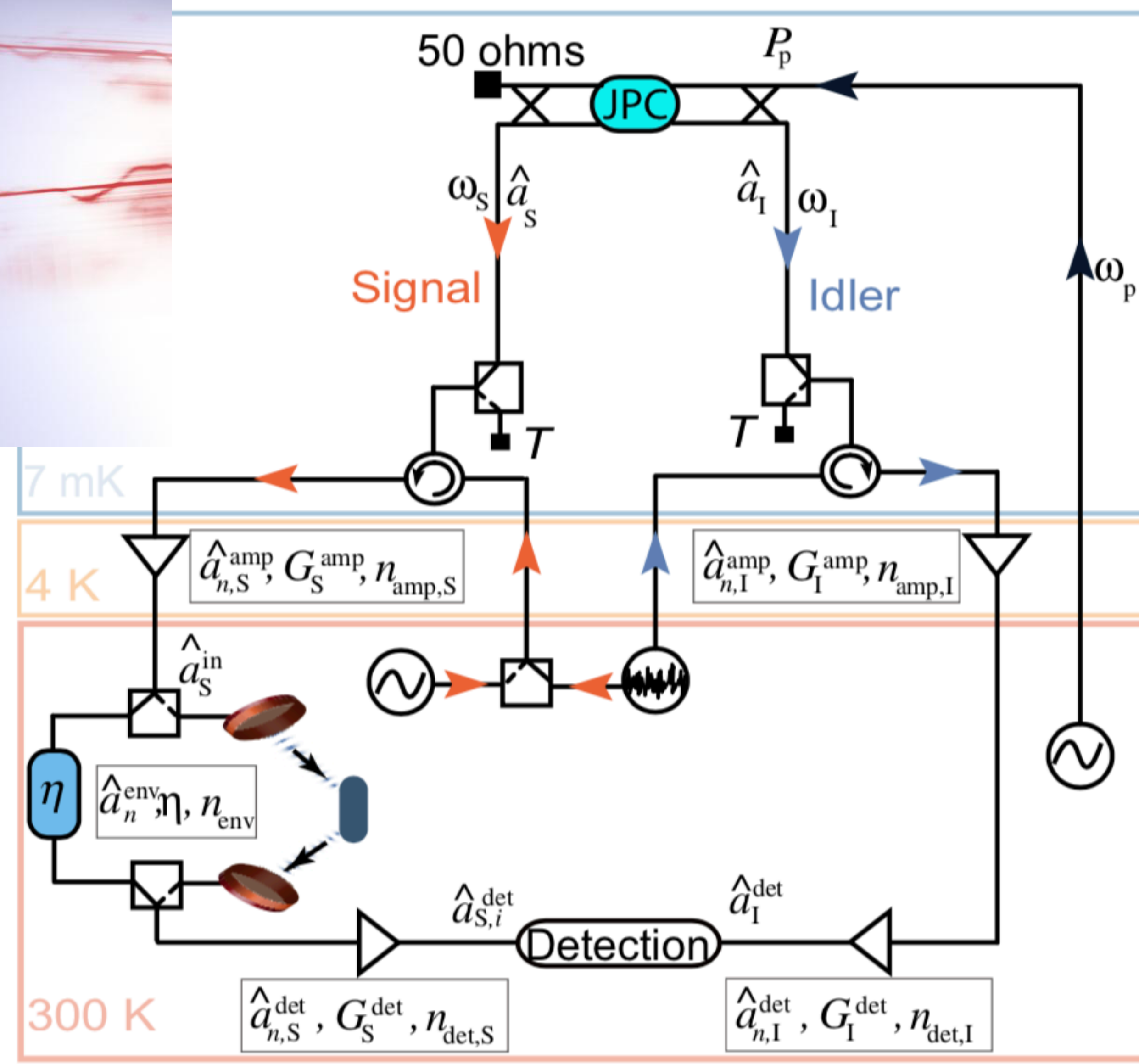


This produced the yet largest gain-bandwidth parametric amplifier for a lumped SQUID.



An Austrian group recently demonstrates a quantum radar prototype, using superconductive circuits.





- This group uses a **Josephson parametric converter (JPC)**, essentially a parametric amplifier to enable this prototype.

S. Barzanjeh, S. Pirandola, D. Vitali, J. M. Fink. **Microwave quantum illumination using a digital receiver**. *Science Advances*, 2020; 6 (19): DOI: 10.1126/sciadv.abb0451

IARIA

Panel 3

Trends on Minitiaturization

(energie, heat, optimisation, connections, accuracy, sensitivity, etc.)

NetWare 2020

Panelist Summary

FPGA-Based Obstacle Avoidance and Line Tracking System For Autonomous Mobile Robots

Sorore BENABID, ESEO, FRANCE sorore.benabid@eseo.fr

- Introduction & Previous work
- Robot Architecture
- Experimental Results
- Conclusion & Further work

→ Field-Programmable Gate Arrays (FPGAs)

→ Machine learning on FPGAs; Object detection; Synthesis; Real-time FPGAs; etc.

Electrical and Computer Engineering School

Aeronautical Engineering School

FPGA-Based Obstacle Avoidance and Line Tracking System For Autonomous Mobile Robots

Sorore BENABID[1] , Loïc LATOUR[2] , Solène POULAIN[3]

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Paris, France

The Thirteenth International Conference on Advances in Circuits, Electronics and Micro-electronics
CENICS 2020

Dr Sorore Benabid

An **Associate Professor in electronics and signal processing at Electrical** and **Computer Engineering School** (**ESEO**), in France, since **2019**. She held the same position from **2010 to 2019 at Aeronautical Engineering School (IPSA) in France**. From **2014 to 2018**, she was an **Associate Researcher** at **Sorbonne University** in System On Chip (SOC) department working on the design of a reconfigurable RF transmitter for the 5G wireless communication systems. Dr. Benabid received her **Ph.D** from the **University Paris Saclay in 2005**, on the design of sigma-delta ADC converters at the department of signal and electronic systems at **CentraleSupélec**. In **1999**, she received a **M.Sc. degree in Electronics** from the **Paris Diderot University** in France. She was born on August 11, 1974 in Algeria. She obtained an **Engineer degree in Electronics engineering** from **Setif University, Algeria, in 1995**. Her **research interests** include **embedded systems and information processing, FPGA, IA algorithms, cognitive radio, software defined radio, wireless communication systems, electronics IC design.**

Introduction & Previous work

- **Mobile robots** are expected to perform increasingly complex tasks in various application fields: space exploration, Intelligent Transport Systems (ITS), military, medicine, service robots, education, ..etc.
- The **Mobile robots use** different kinds of **sensors** to collect environmental information and a set of **actuators** for their motion and reaction to be able **to navigate** successfully in their environment.
- A **powerful and flexible device** is necessary **to control and manage the set of sensors and actuators** present on the mobile robot,
- The Field Programmable Gate Arrays (**FPGA**) are gaining popularity due to their **reconfigurability**, **parallel ability** and **real-time response** in a dynamic environment.

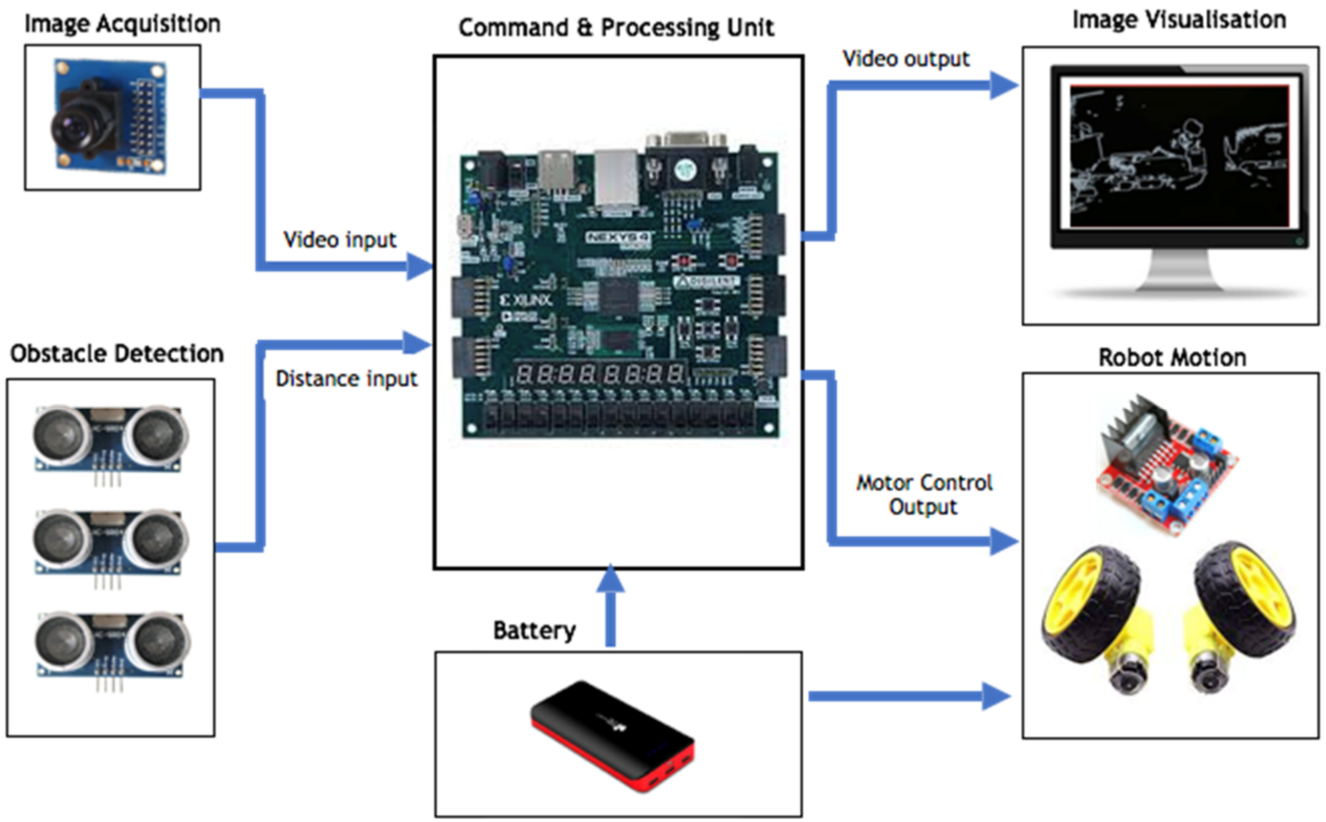
Introduction & Previous work

- Some **related work** on the FPGA-based mobile robot navigation

Reference	Proposed architecture
[2013], S. Boroumand and al., Iranian Conference on Fuzzy Systems (IFSC).	A fuzzy algorithm on FPGA-based mobile robot for line tracking and obstacle avoidance purposes
[2015], G. Velez and al., Journal of Real-Time Image Processing,	FPGA-based vision system for Advanced Driver Assistance Systems (ADAS) applications. The developed board contains a SOC composed of a programmable logic for parallel processing, and a μprocessor for serial decision making.
[2017], A. Irwansyah and al., Journal of Parallel and Distributed Computing.	An FPGA-based architecture for multi-robot tracking using multiple GigE Vision cameras. The proposed architecture was implemented comprising a multi-camera frame grabber and IP cores for image processing
[2019], S.Benabid and al., IEEE International Midwest Symposium on Circuits and Systems (MWSCAS)	An FPGA-based vision system for autonomous mobile robots. The proposed system evaluated in real-time the distance between a robot and an object or obstacle in front of it.

Robot architecture

Embedded system architecture



Robot Specifications

FPGA Board	*Nexys 4 DDR - Artix-7*
Board Dimension	10,9 x 12,2 cm
Logic Slices:	15 850
Block RAM	4,860 Kbits
DDR2 Memory	$128MiB$
Operating Frequency	$100MHz$
Power Supply	4.5V-5.5V
Camera	*CMOS Image sensor*
Photosensitive Matrix	640 x 480
Issuance formats (8)	RGB 565
Maximum rate:	30 fps in VGA
Pixel height	$3.6\mu m$
Output format	VGA
DC motor	*Decelerate motors ratio 1:48*
Drive voltage	12V
Ultrasonic sensor	*HC-SR04*
Operating voltage	5 V
Operating current	15 mA
Range of distance	2 cm to 400 cm
Battery	EC Technology
Capacity	$22400mAh$ / $82.8Wh$
Entry	$5V$ / $2A$
Max Output	$5V$ / $3.4A$ (AUTO)
Dimension	$160x80x23mm$
Weight	$462g$

Robot architecture

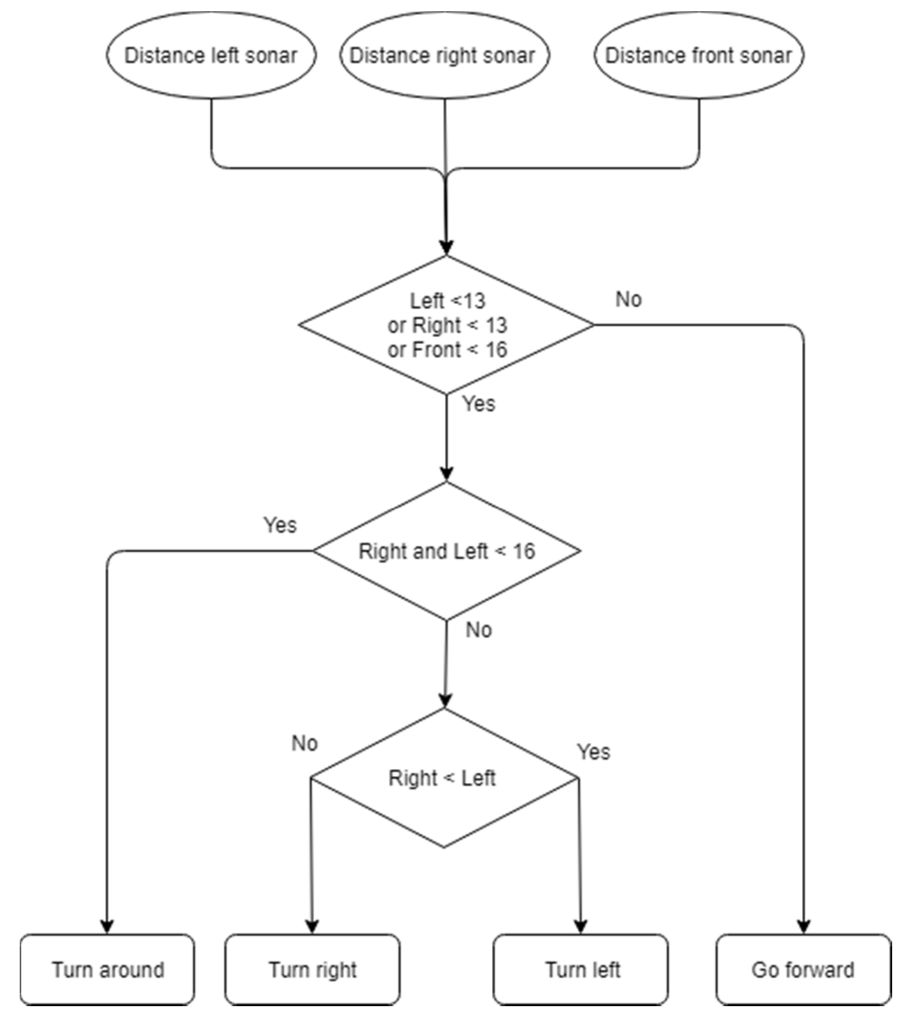
Robot Motion

The Pulse Width Modulation (**PWM**) principle is used **to control the speed of the robot**.

Obstacle Avoidance

This function was filled by 03 ultrasonic sensors placed at the front of the robot and oriented at different angles. Ultrasonic Sensors measure the distance (D) to the target object by measuring the time (T) between the transmitted and received wave.

$$D = \frac{T.S}{2}$$, S represents the sound speed

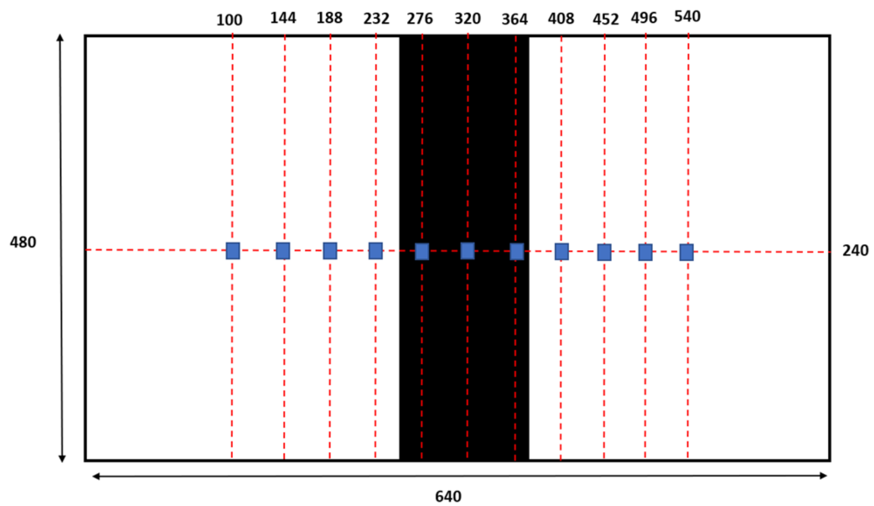


Robot architecture

Line Tracking

A single camera is used at the front of the robot. We have chosen to **track a white line on a black background** reversed by a black and white filter. We chose **11 pixels aligned horizontally**, **represented by an 11-bit binary vector.** Each bit of the 11-bits vector are set to ”1” (white) or to “0” (black) according to a filter threshold. **The line is modeled by 3 bits at the center of the 11-bits vector**.

Line modeling after black and white filter



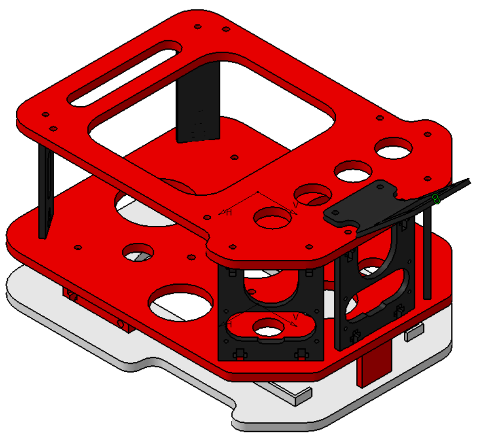
The motor control using the line model

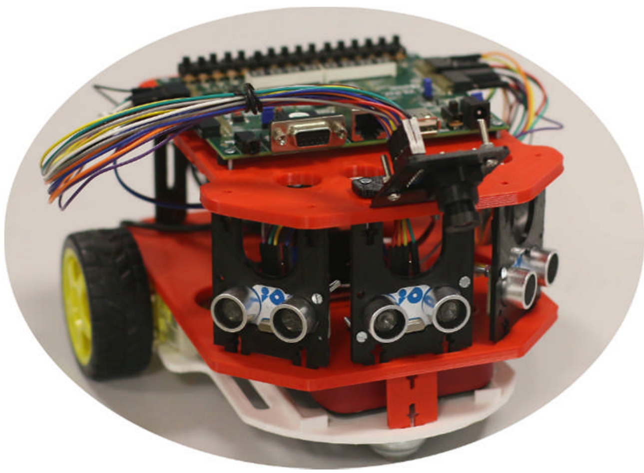
Binary vector	*Action on motor*	*Duty cycle (%)*
00111111111	Turn left	65
00011111111	Turn left	60
10001111111	Turn left	60
11000111111	Turn left	50
11100011111	Forward	50
11110001111	Forward	50
11111000111	Forward	50
11111100011	Turn right	50
11111110001	Turn right	60
11111111000	Turn right	60
11111111100	Turn right	65

Experimental Results

Robot Structure Design

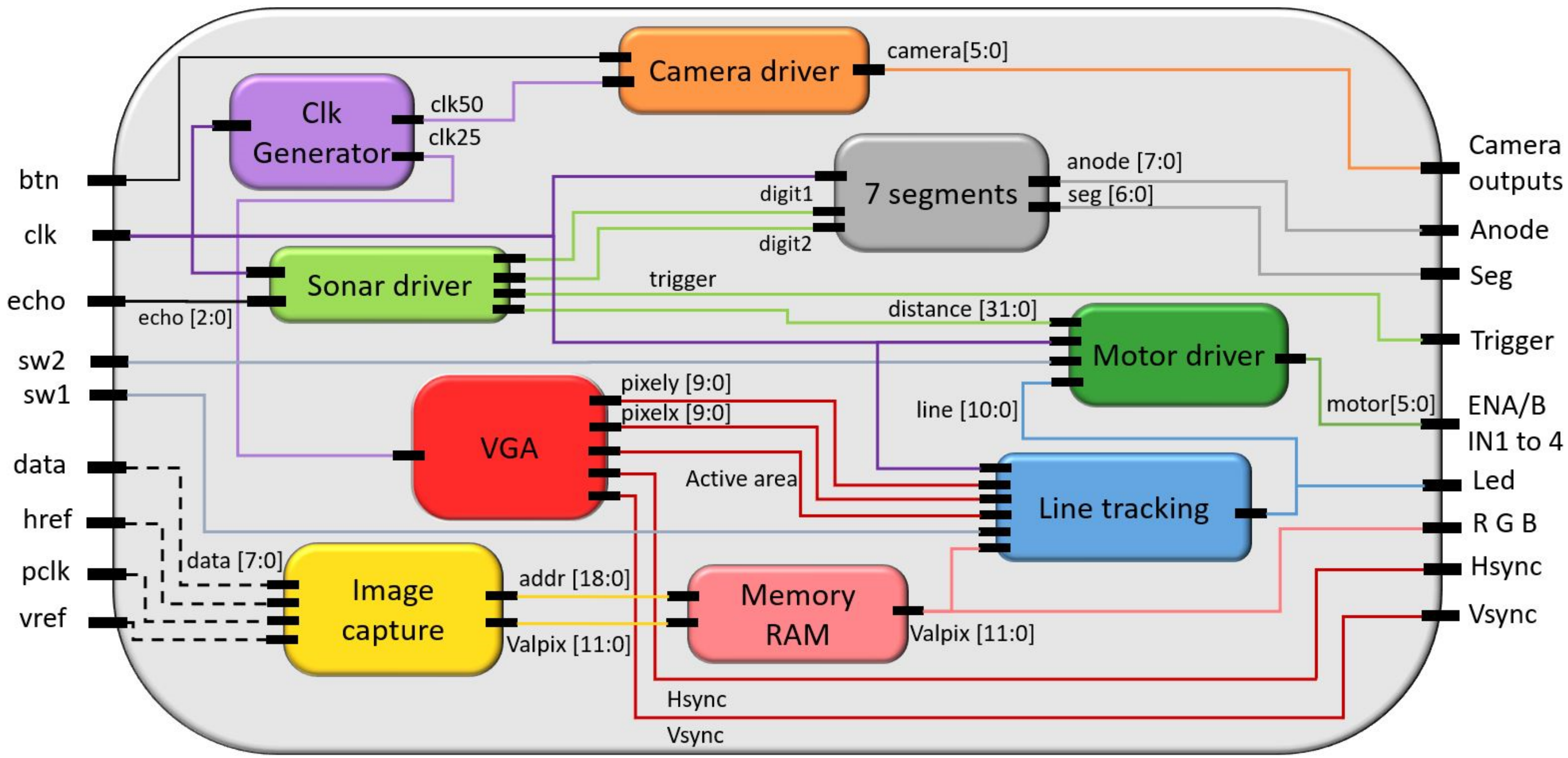
- The structure is designed on **CATIA software** (Computer Aided Three-dimensional Interactive Application), developed by the **french company Dassault Systemes**.
- The designed structure is printed by a **3D printer** available at the laboratory of the autonomous aerial systems at **IPSA.**





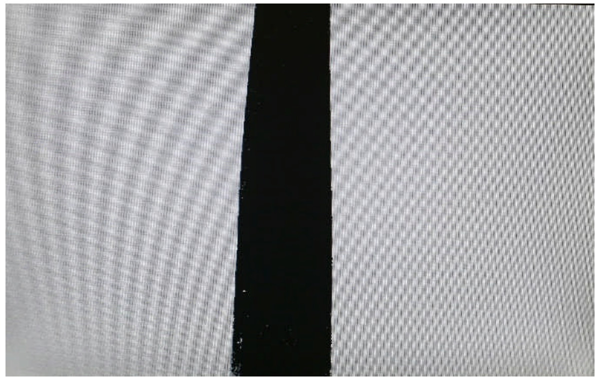
Experimental Results

The proposed architecture is synthetized only on **VHDL code** : robot motion, image processing, obstacle avoidance and line tracking



Experimental Results

Black and white filter for line tracking



FPGA resource usage of the proposed system

Resource	*Utilization*	*Available*	*%*
LUT	1107	63400	1,75
FF	481	126800	0,38
BRAM	104	135	77,04
IO	73	210	34,76
BUFG	5	32	15,63
MMCM	1	6	16,67

The **obstacle avoidance video**: https://youtu.be/tjWPFtim8CQ
The **line tracking video** : https://youtu.be/SjUswlInYgM

Conclusion & Further work

- An **FPGA-based embedded system navigation** for the **mobile autonomous robots** is proposed. The proposed system can **detect and avoid the obstacles** and **track a line**.
- The whole architecture is implemented **only in VHDL code.**
- The achieved robot provides a good experimental **platform for academic environment** in collaboration with industrial partners.
- This platform will be further improved and extended for other tasks such as path planning and object recognition algorithms.
- The engineering students will learn and test **AI algorithms** for mobile robots. They will also be able to propose a new AI techniques for several applications: Intelligent Transportation Systems (ITS), medical application, environmental protection,..etc.

Panelist Summary

Miniaturization Challenges and Potentials

Sazzadur Chowdhury, University of Windsor, Ontario, Canada, sazzadur@uwindsor.ca

- From Nano to Pico to Femto
- Physics, materials, and processes
- Modeling challenges (*Ab initio* (first principles) simulations)
- Diverse functionality integration
- Challenge of testing
- New applications: Computing-Life science-manufacturing, and more

  - Hybrid systems made of MEMS, Nano, and Pico clusters with new synthetic materials
    - Risk, validation, and reliability challenges
      - Research and technology roadmap

Trends on Miniaturization

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NetWare 2020 Congress
November 21, 2020 to November 25, 2020 - Valencia, Spain

From Nano to Pico to Femto

- Nanotechnology – Cluster of molecules
- Picotechnology – Atomic level
- Femtotechnology – Degenerate matter

10^{-15}	10^{-12}	10^{-9}	10^{-6}	10^{-3}
femto	pico	nano	micro	milli

- Physical properties can be radically different in micro, nano, pico, and femto scales
- Fabrication methods are possible to realize new devices

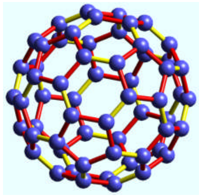
- Nanoscale technologies are evolving but are not scalable to pico and femto devices

- Opportunity of exploiting fundamental constituents of materials and fundamental forces to develop new artificial materials and devices with unprecedented level of speed, resolution, and functionality

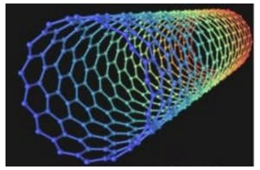
Physics of Miniaturization

- Physics of surface, atomic, and subatomic sciences is governed by coulombic, atomic, and nuclear forces, respectively
- In nanotechnology, structure determines the behavior
- In pico, single or composition of atoms determine the behavior
- In femto, degenerate particles determine the behavior
- Modification of the size or new building blocks of fundamental particles can result in new type of physical properties
- Orders of magnitudes better than corresponding properties of conventional molecular matter can be achieved
- New kind of excitation mechanisms instead of depending on coulombic or surface forces can be used

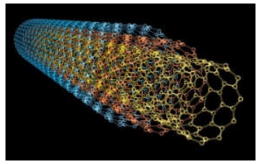
New Materials and Building Blocks



- Nanoscale:
  - AI designed new artificial materials with improved physical properties



  - Building Blocks: Nanotubes: SWNTs, MWNTs, nanoribbon, buckyballs / buckypapers, fullerene



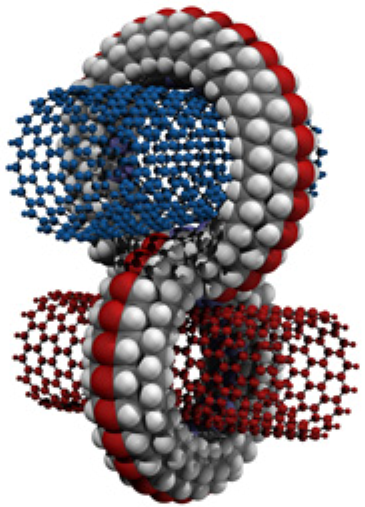
- Pico/Femto scale:
  - Artificial small masses of synthetic atomic (pico) / degenerate matter (femto)

  - Building Blocks: Various shapes, such as strings, single wall femtotube (SWFT), multiwall femtotube (MWFT), femtobeams, femto membranes, etc., constructed out of neucleons (neutrons, protons and electrons)

Possible New Material Properties

- Zero friction
- Superconductivity over a large range of temperatures
- Programmable extreme dielectric strength
- Programmable extreme high magnetic intensity
- Super mirror reflectivity
- Programmable extreme stiffness
- Programmable extreme thermal conductivity
- Programmable extreme hardness
- Super transparency

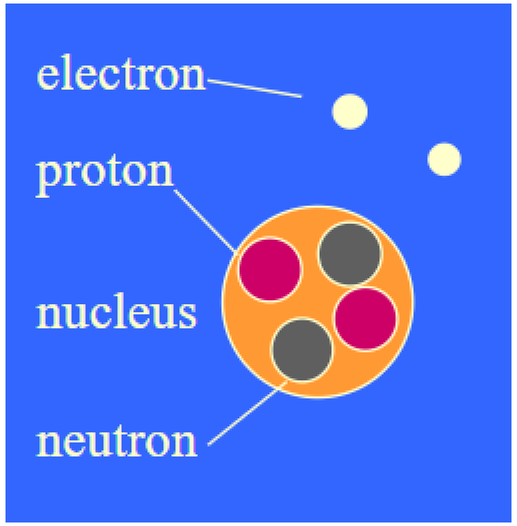
Orders of magnitudes better than corresponded properties of conventional molecular matter



Source:
http://www.somewhereville.com

Scientific Motivation for Femto Technology

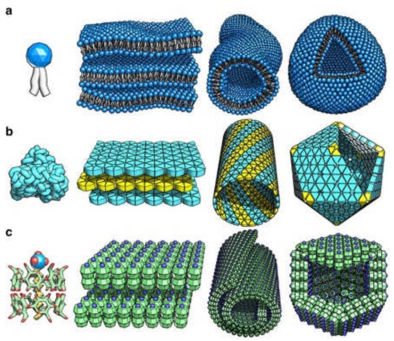
- Three initial particles to deal with:
  - Proton
  - Neutron
  - Electron
- Fewer forces:
  - Electrostatic
  - Strong
  - Weak



- In conventional technology including micro, most common molecules exist in tens of thousands and interactions between them are very complex (e.g., Van der Waals force)
- Multi-technology cluster (nano, pico, and femto)
- Multi-domain interaction / translation / energy conversion

Processing Challenges

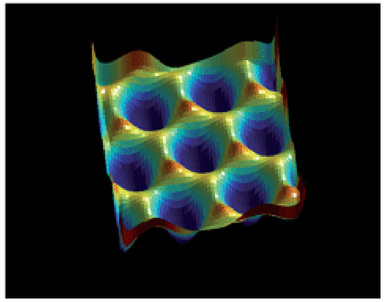
- Conventional fabrication or manufacturing processes comprised of deposition-lithography-etching will not be possible in pico or femto scale
- No tools are available now for pico patterning or femto patterning to realize the building blocks
- A total change in fabrication technology will be necessary
- Self-Assembly as a possible solution:
    - Particles shot at a specific force in a target geometry can assemble together due to atomic or subatomic forces to shape the geometry
    - Strong force manipulation in femto scale, while capillary force manipulation in nano or pico scale
    - Determination of appropriate self-assembly mechanism / force (coulombic, Van der Waals, Casimir, Strong) which may be case specific depending on the level of self-assembly: nano, pico, or femto will be crucial



Source: Wikipedia

Modeling Challenges

- New modeling techniques capable of simulating 1D, 2D or 3D materials using atomic and subatomic nuclear forces need to be developed
- Simulation of forces and interactions in the nano, pico, or femto scale geometries will require significant improvement on currently available computational platforms
- Some *Ab initio* (first principles) simulation tools are available for etching simulations, but simulation of self-assembly at nano, pico or femto scale to realize devices is a formidable challenge and no tools are available now
- Significant development is necessary
- Without proper modeling tools, these advanced devices can not be realized



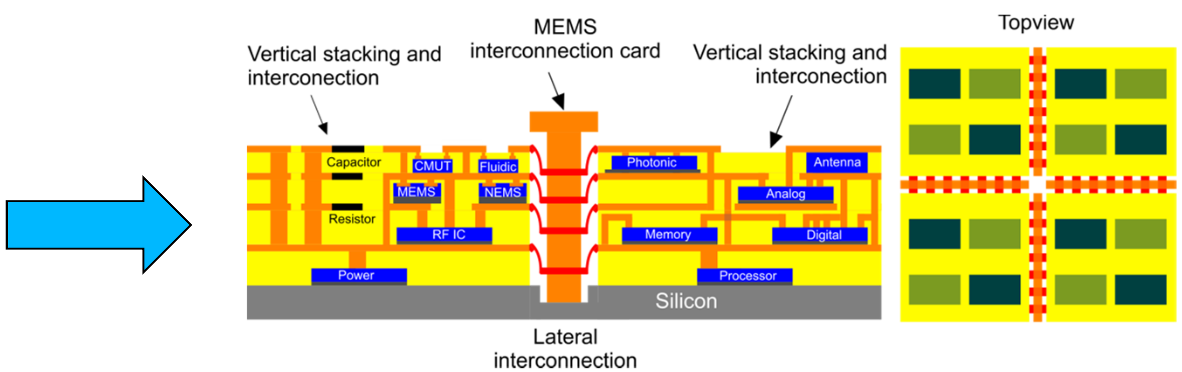
Sub-picometer resolution data from a 50 pm image of graphene

Source: Royal Society of Chemistry

Diverse Functionality Integration

- It can be anticipated that some of these new nano, pico, or femto scale structures will provide active functionality (computation, sensing, actuation) and some may just be providing passive support, surface modification, or interconnection functionality
- Heterogeneous integration and interaction of such devices constructed out of different building blocks will pose a technological challenge
- While multi-functional, multi-material, and multi-scale integration can realize new devices, stand alone pico-coating or femto-coating of surfaces can provide totally dramatic functionality to existing macro, micro, or nano structures

Heterogeneous integration of Micro / nano / pico / Femto devices



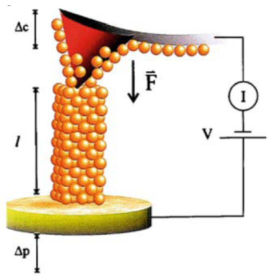
Sensing / actuating / processing / power

Vertical + lateral integration

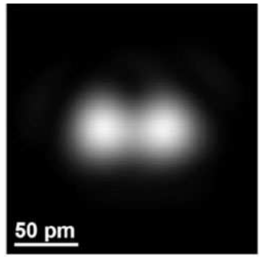
Source: University of Windsor

Challenges of Testing

- Current test equipment does not have the capability to test complex devices made of pico or femto scale devices while some nanoscale testing capability exists
- Without testing, such devices cannot be deployed in real world
- Extensive research is necessary to develop testing capabilities of such devices
- It is necessary to develop test signals (vectors) to probe these new devices and make a proper low-loss, low-noise connection to capture the response, analyse signal waveforms, noise, etc.
- It remains to be determined what kind of testing could be done on a pico or femto scale device and how to interpret those test data, e.g., how to test zero friction or super reflection, property
- A complete new set of testing definitions and protocols need to be developed



Source
Northwestern
University, IL



Source: Lawrence
Berkeley National
Laboratory

New Applications

- Nano-pico-femto scale devices will be able to provide information not possible with conventional microsystems technology
- This data can provide more fundamental information in areas such as biological cell clusters, disease pathogens, material structure and behavior, etc.
- Such data can revolutionize the current technology development and solution approaches for life sciences, manufacturing, computing, printing, chemical catalysis, materials synthesis, psychology, and many other fields
- A major challenge may be how to incorporate the new functional blocks into existing systems. For example, a femto scale degenerate material based hardness coating on a turbine impeller
- It may take several decades to be able to incorporate the new capabilities of miniaturization to enhance the functionality of evolving devices or systems

Conclusions

- Miniaturization will offer the potential to make devices with unprecedented functionalities
- Advanced technologies will be necessary to model, manufacture, test, validate, and integrate pico / femto systems
- Many new technology segments need to be developed
- Self-assembly techniques have the potential to lower the cost of fabrication
- Diverse global stake holders are involved
- A comprehensive roadmap is necessary to create synergy among the stakeholders