Development of RF Front-End Chip for Wireless Communications

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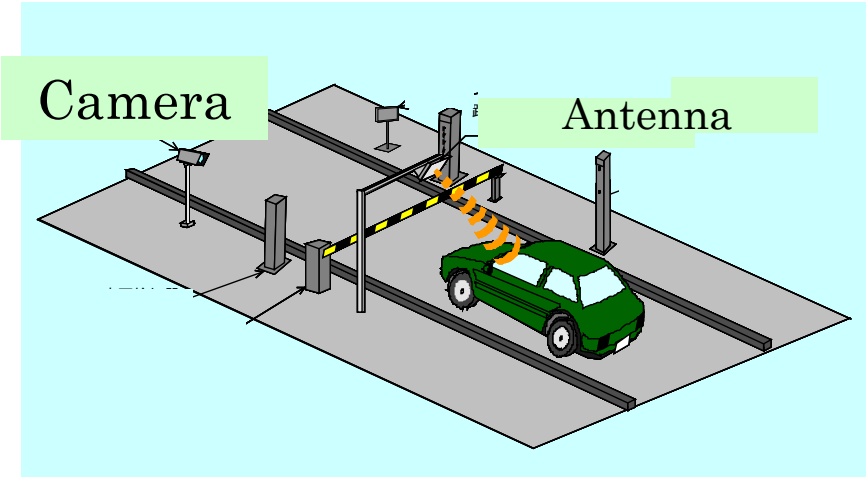
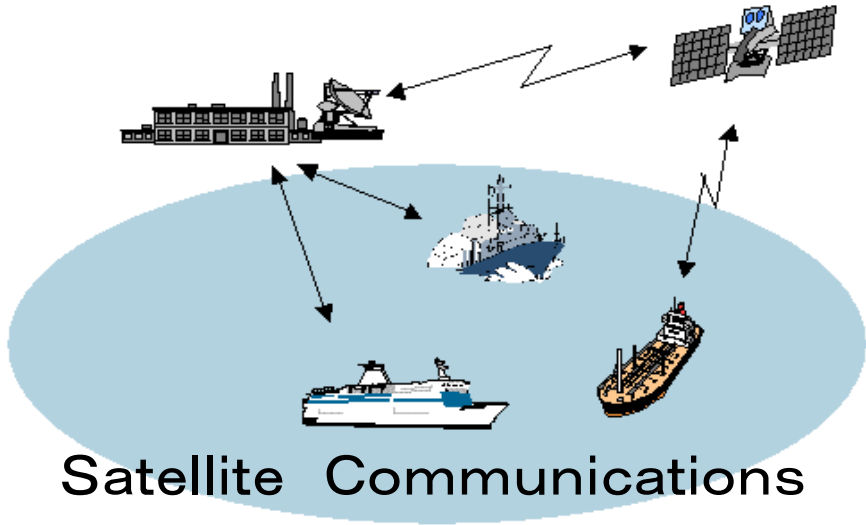
http://yossvr0.ed.kyushu-u.ac.jp

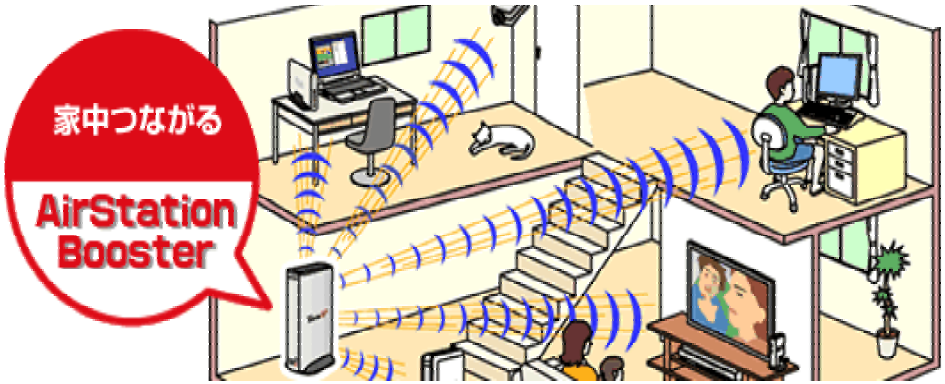
Driving Force: Wireless Technologies

Wireless LAN、Cell Phone、Cordless Telephone、IC Card, ITS, DSRC



Electronic-Toll Collection System.





Wireless LAN

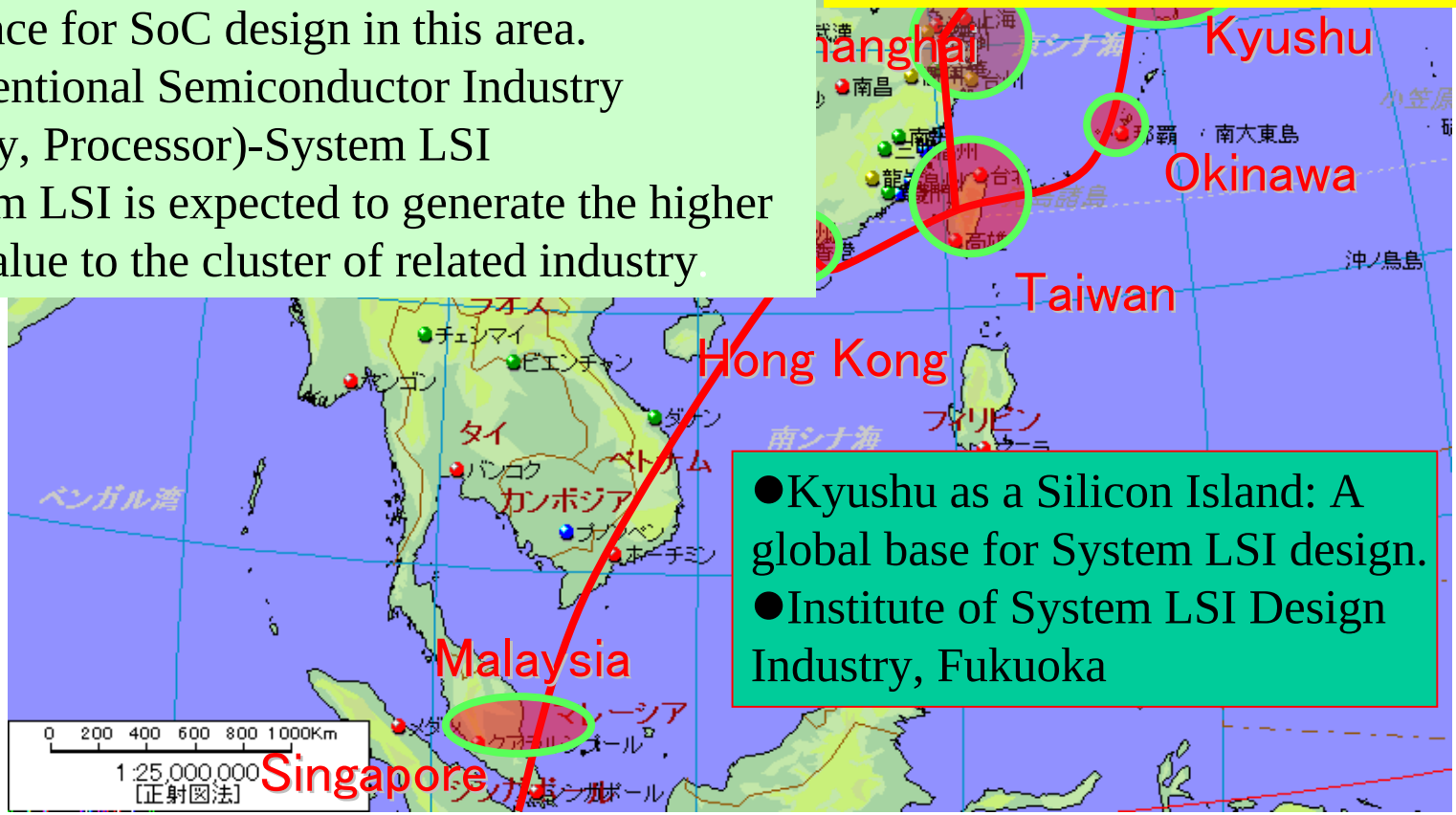
Cell Phone

Cordless Phone

Silicon Sea Belt Fukuoka Project

＊Center of Semiconductor design.
＊Semiconductor Industry: Driving force for the growth.
＊ Fukuoka is addressing to establish a center of Excellence for SoC design in this area.
＊Conventional Semiconductor Industry (Memory, Processor)-System LSI
＊System LSI is expected to generate the higher added value to the cluster of related industry.

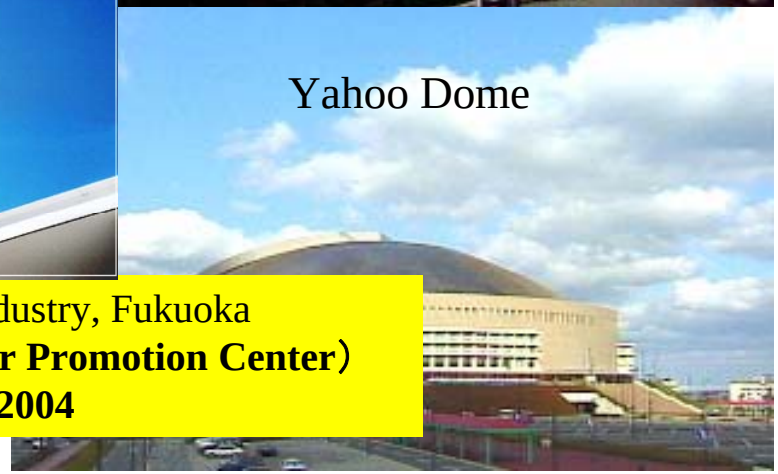
Silicon Sea Belt Fukuoka Project
＊World production: 50%
＊Large consumption region



●Kyushu as a Silicon Island: A global base for System LSI design.
●Institute of System LSI Design Industry, Fukuoka

Fukuoka Soft Research Park

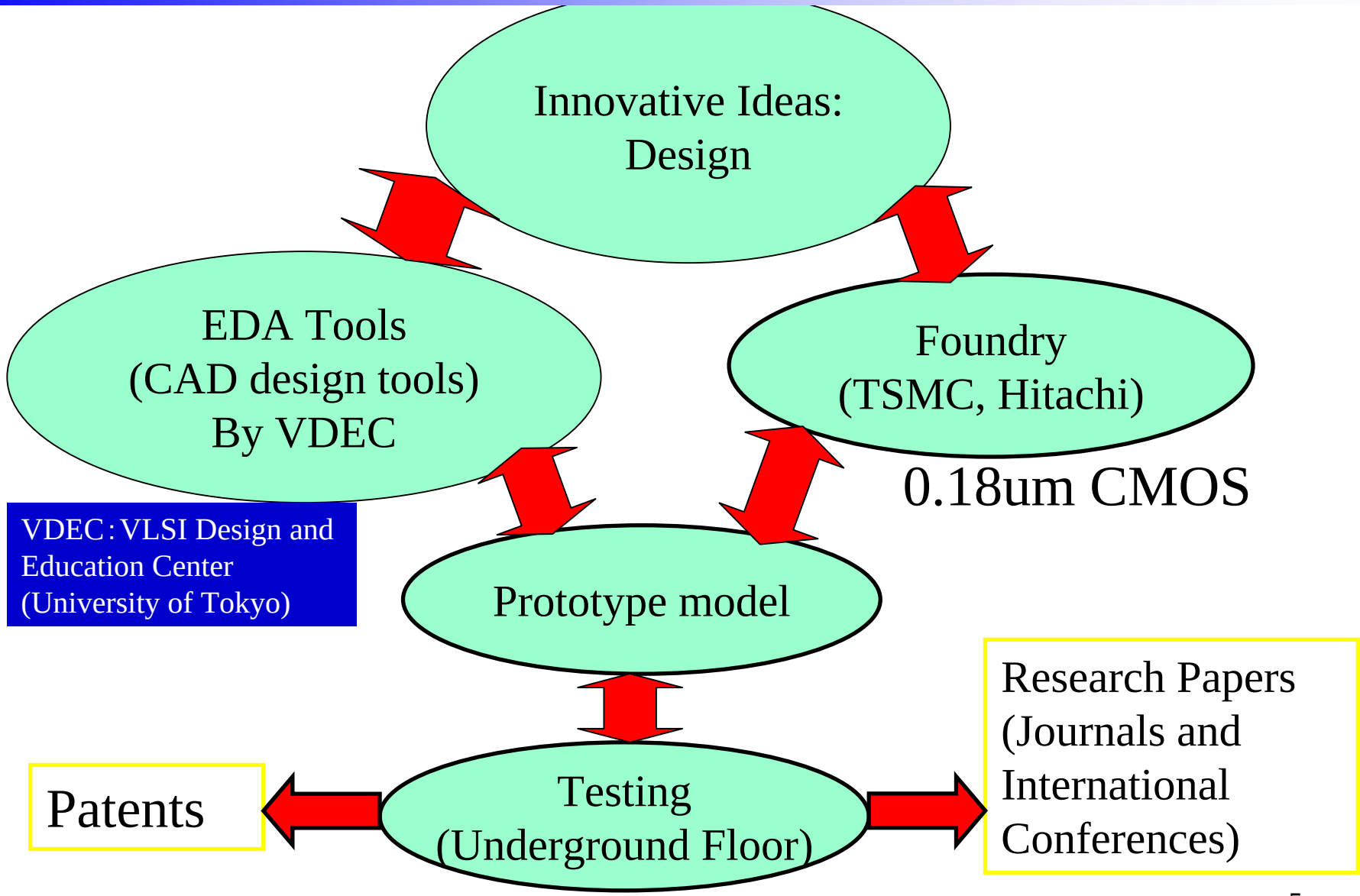
Momochi Hama District



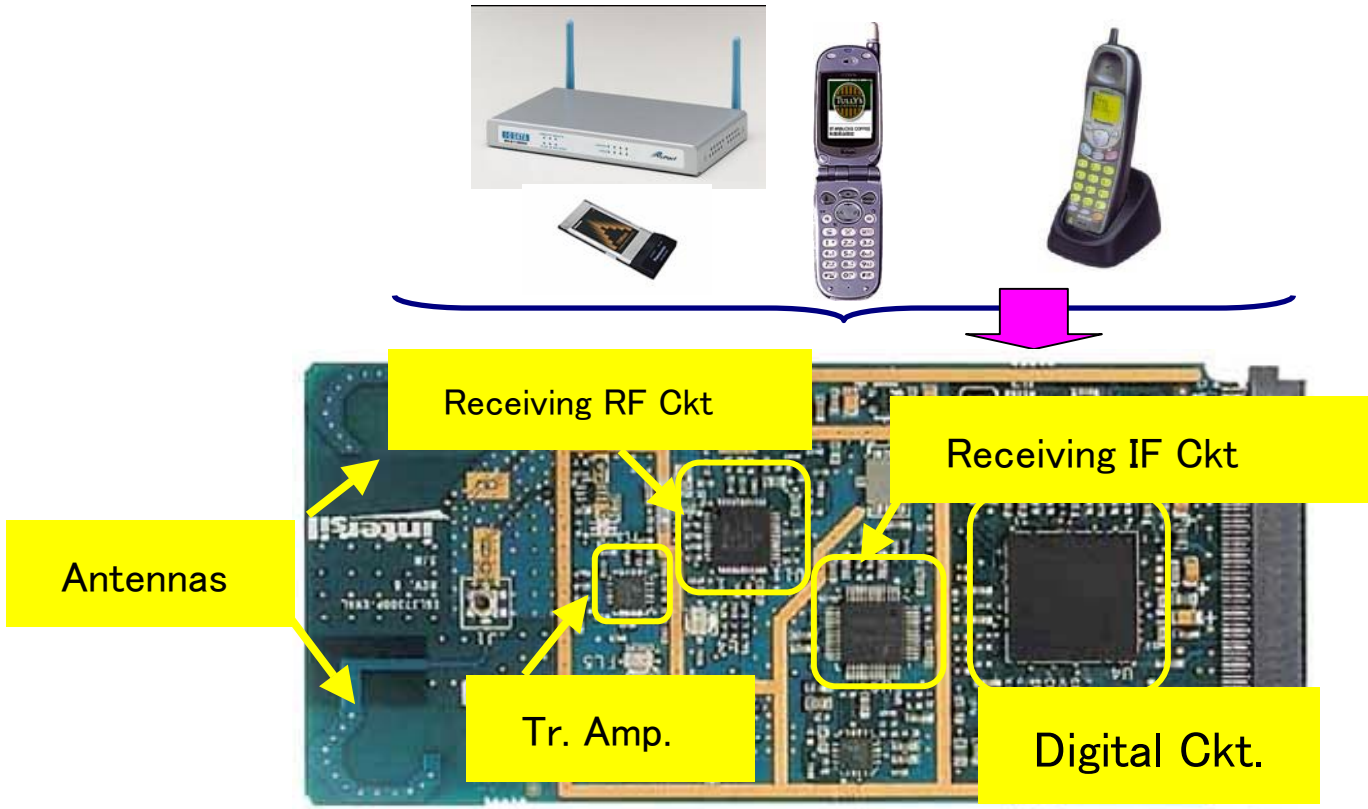
Institute of System LSI Design Industry, Fukuoka
（Kyushu University:Entrepreneur Promotion Center）
Established on 2004

World Class Companies of Japan and Korea:Toshiba, Sony etc

System LSI Research and Development



Prof. Yoshida's Lab Introduction



Intersil 2.4GHz PCMCIA Card (PRISM 2.5)

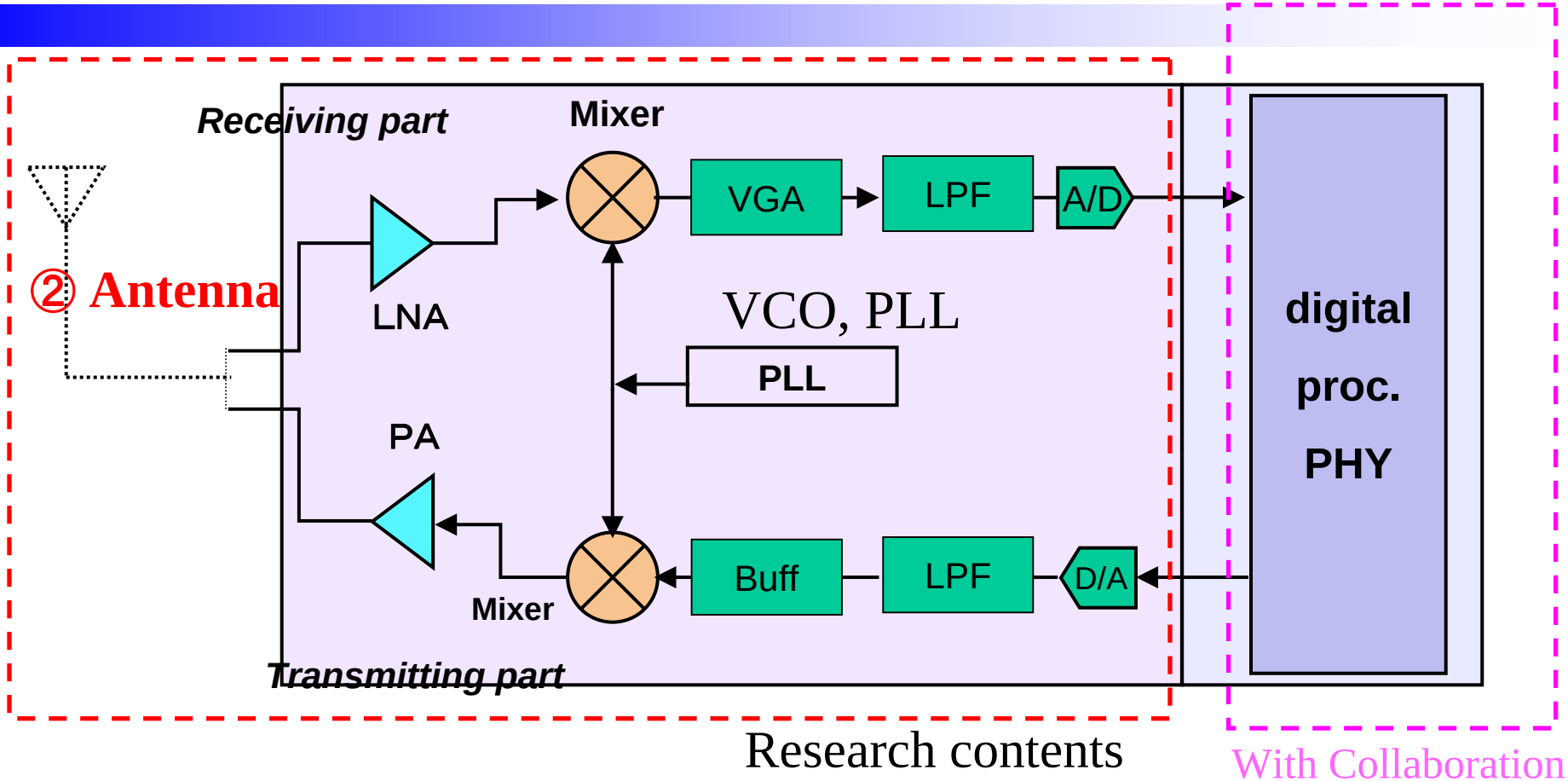
<u>Key Words of Our Research</u>

Miniaturization & Low Power

⇒ ① SoC (System on Chip)

⇒ ② Antenna

Block diagram of CMOS-LSI for Wireless Communications

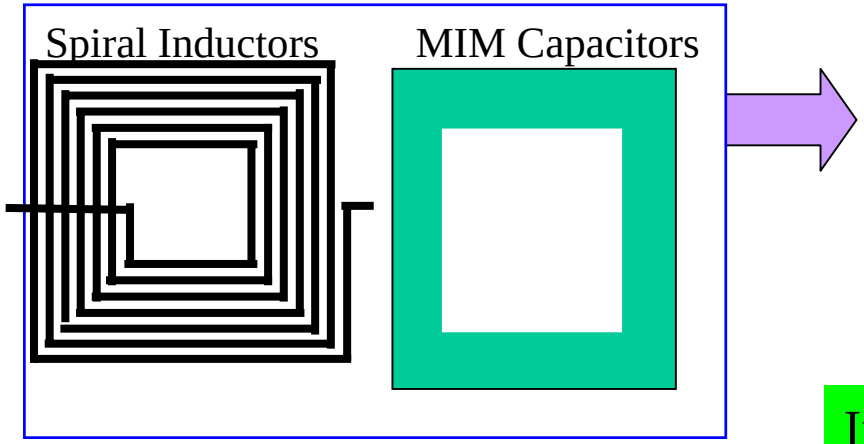


Direct Conversion Receiver Type

①1-Chip:SoC Implementation (System on Chip)

① Proposal of New Design Methodologies for RF Parts

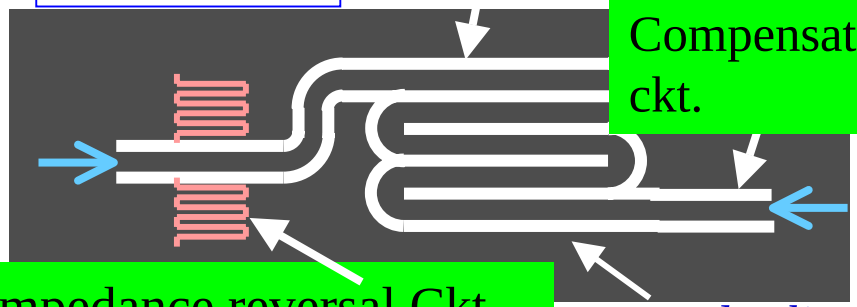
Lump Elements



Spice Models

Transmission line

Matching Circuits

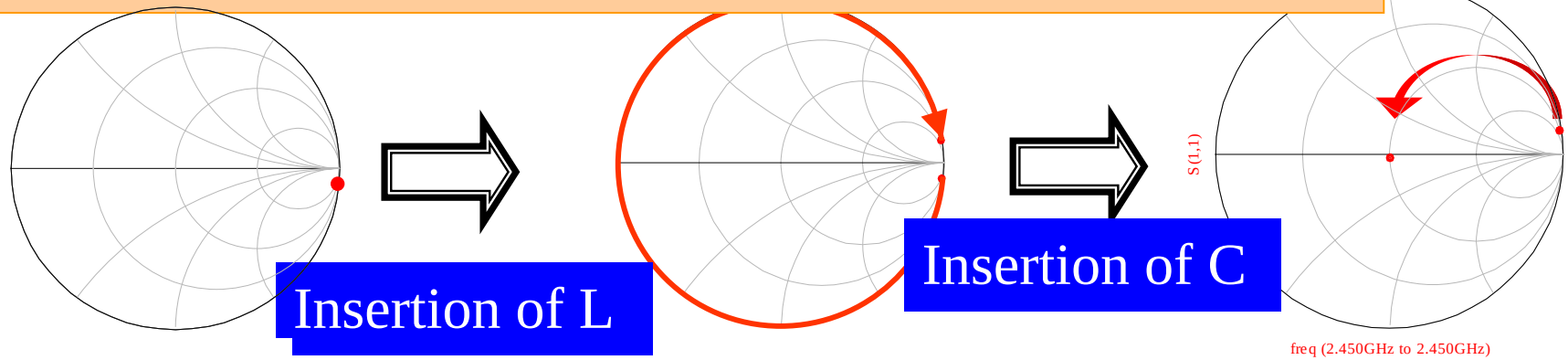


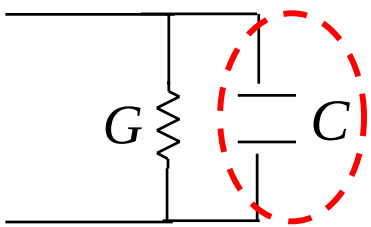
Freedom of Design

■Size is about 40% and the shape can be adjusted to exploit the vacant space in the chip.

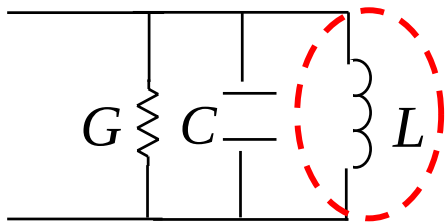
Matching by Lumped Elements

High Impedance（Say:100-j1000)Ohm is matched to 50-Ohm

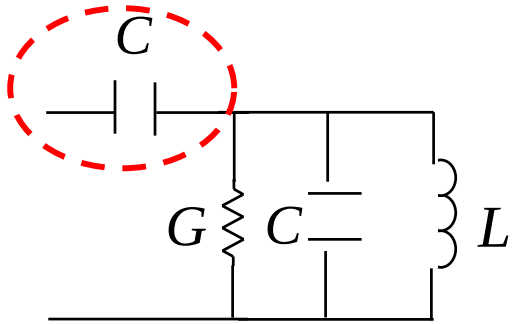




Very small C



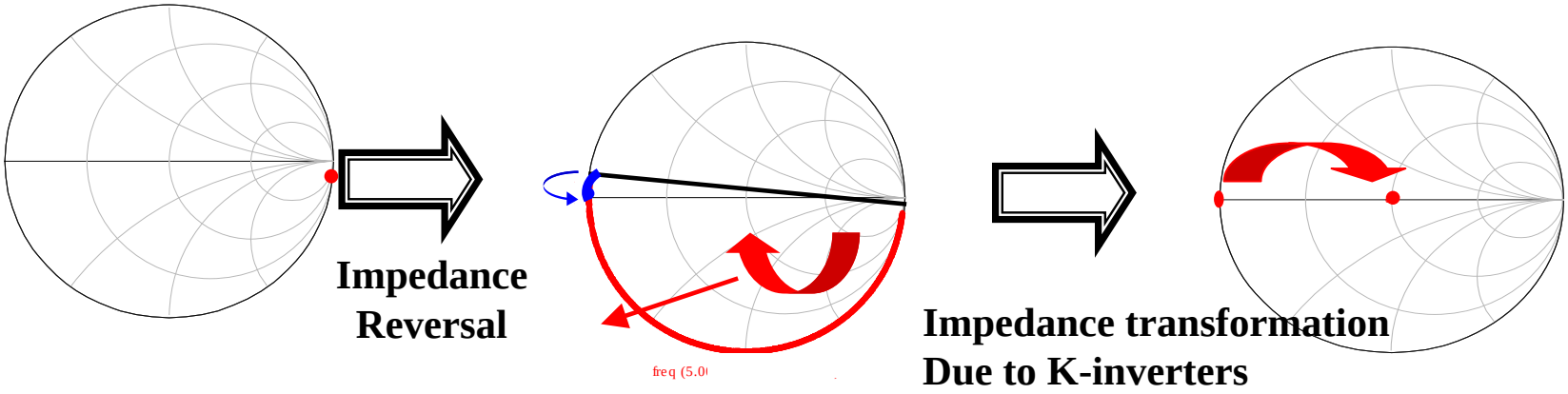
High L is necessary.

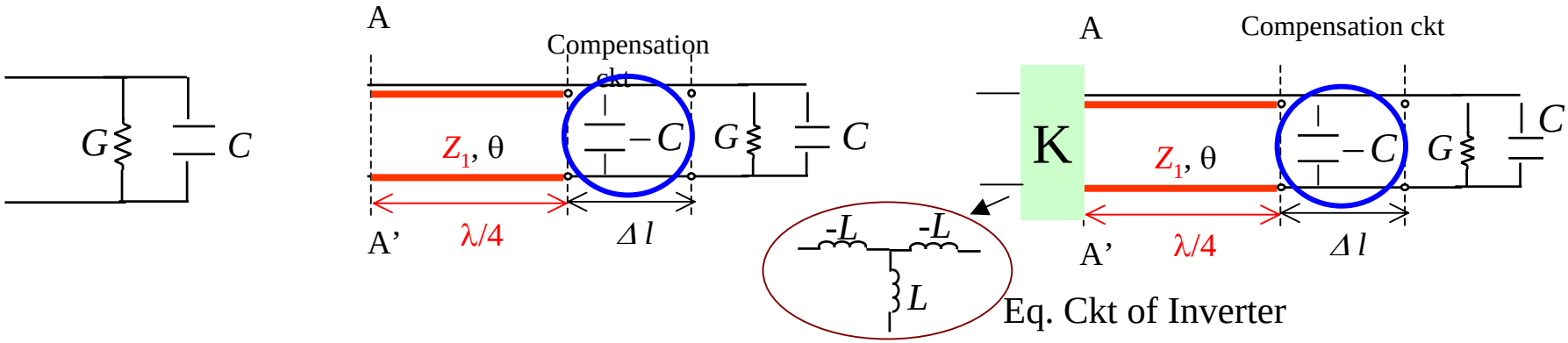


Insertion of Series C

（0.09pF）

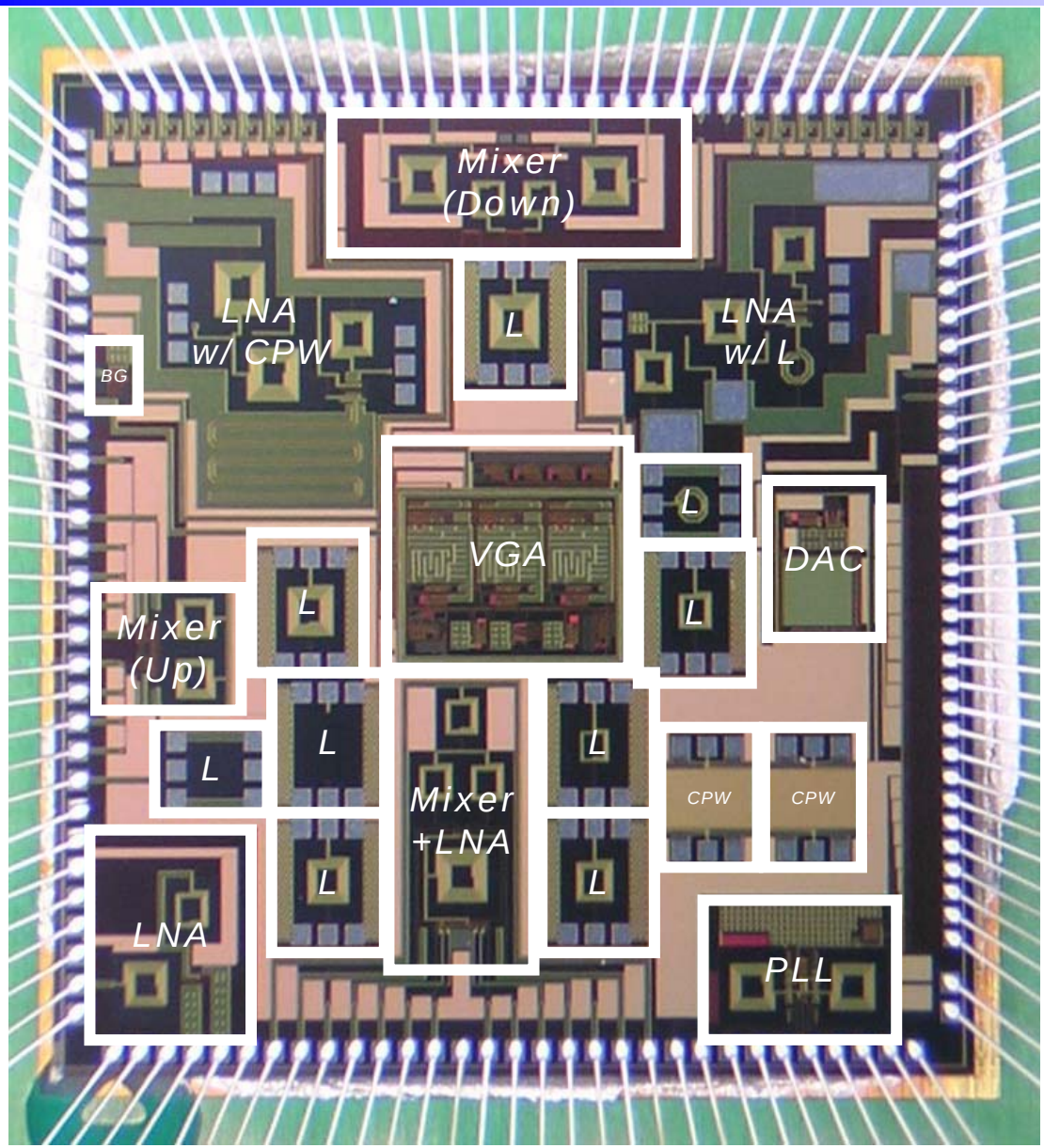
Theory of Matching Circuit





- Presented at IEEE RFIC2006.

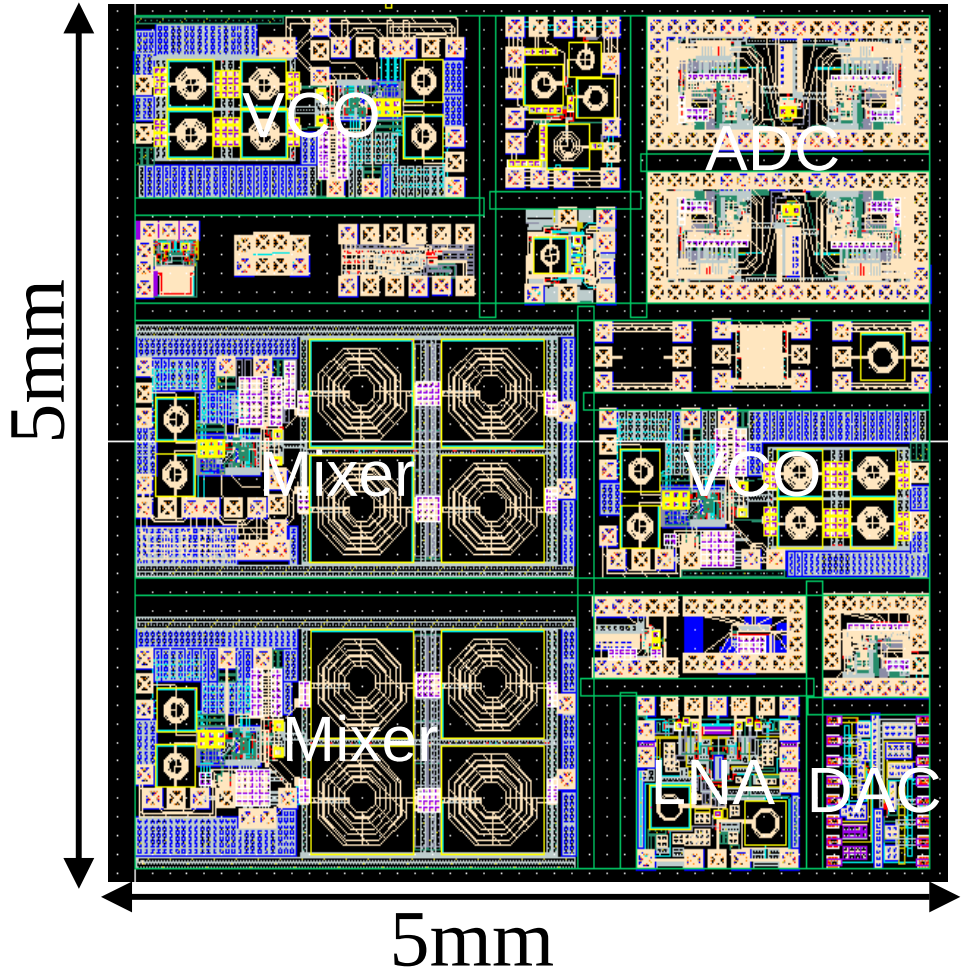
Prototype Design [I]



TSMC 0.25μm CMOS (1P5M)
Chip size=5mm x 5mm

- LNA; Cascade, w/ CPW, w/ L
- Mixer; Up, Down
- **Down Mx +LNA**
- PLL
- BG
- VGA
- DAC
- Inductor TEG
- CPW TEG

Prototype Design [II]



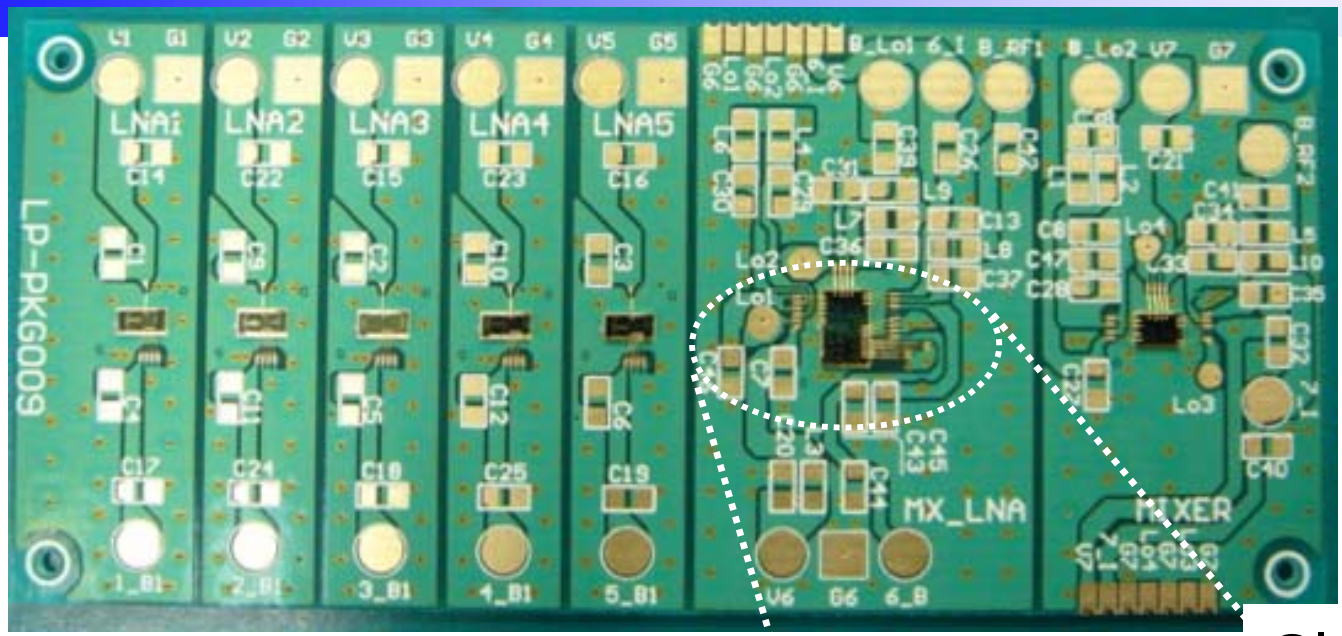
TSMC 0.18μm CMOS (1P6M)
Chip size=5mm x 5mm

- UWB-LNA, mixer, ADC, DAC
- Test chips.

For MIMO-MESH Project

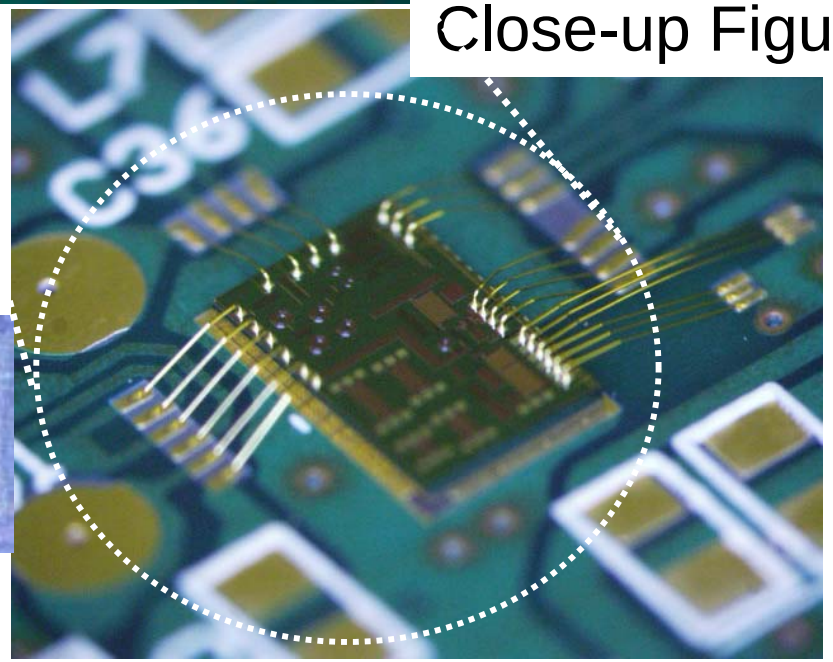
- Mixer, VCO, 1-bit ADC

TEG Chip Photo

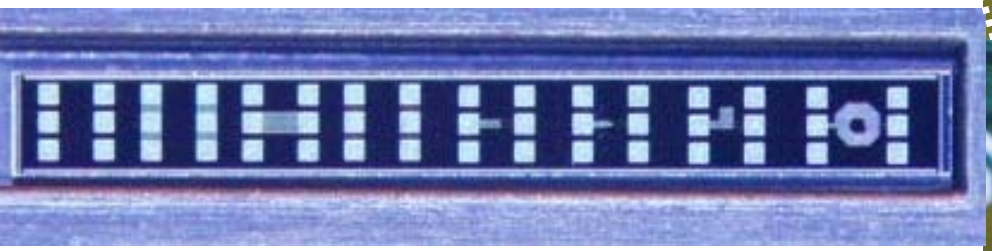


PKG Substrate

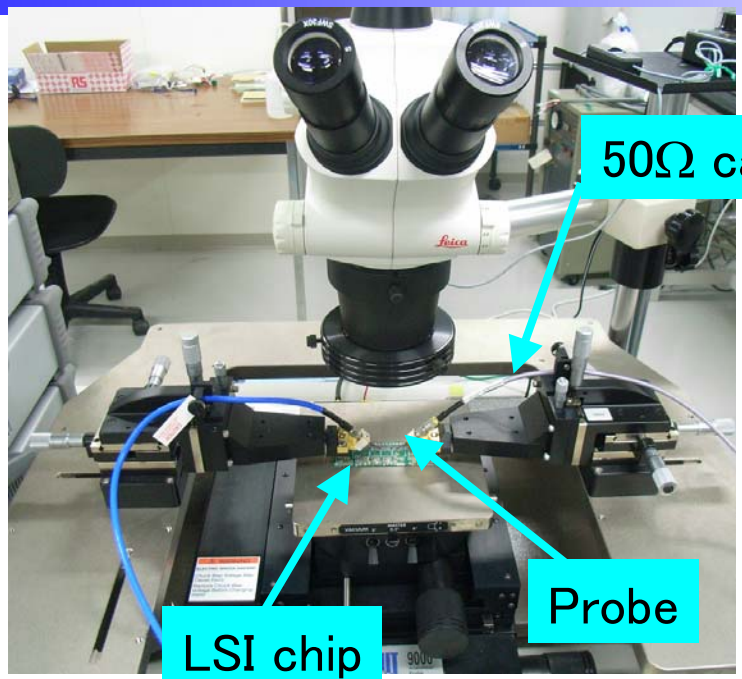
Close-up Figure

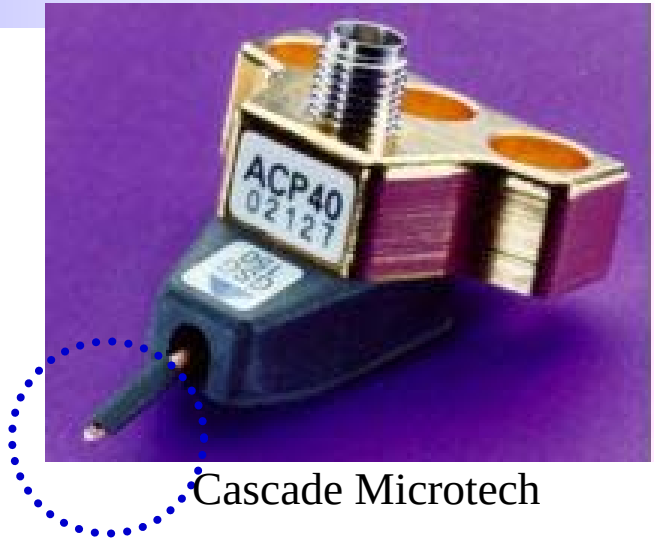


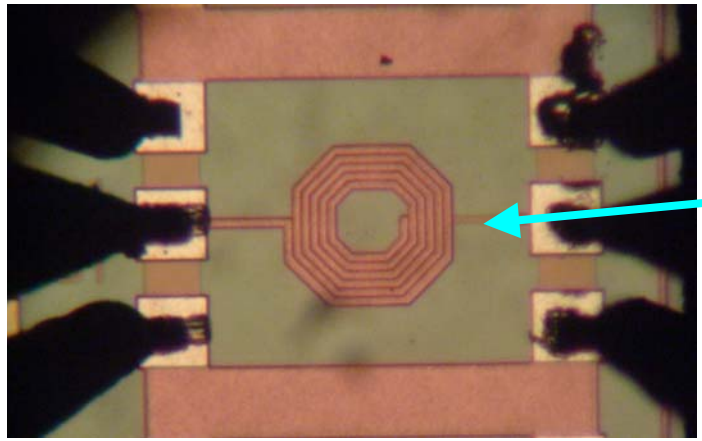
Cal. patterns



Lab Facilities of Testing







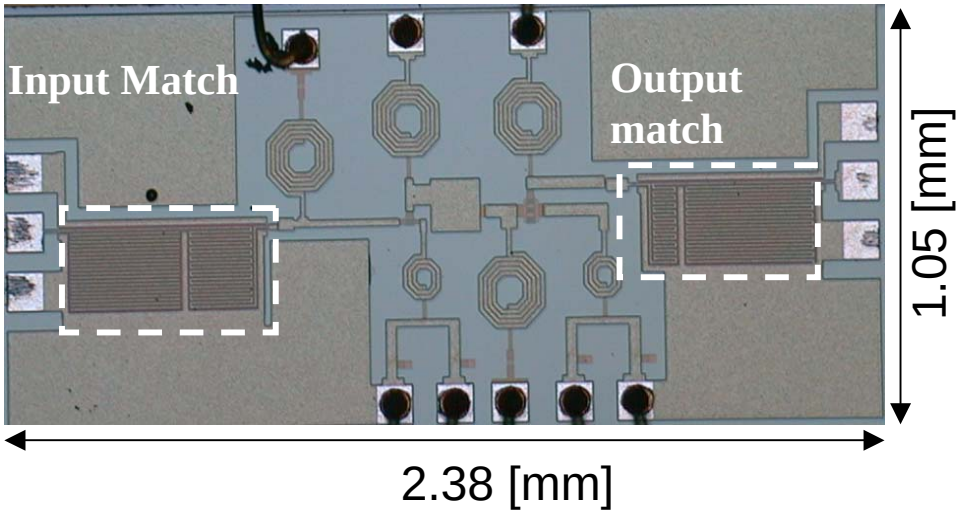
Results [1]

- Power Amp. (IEEE .11b)
- LNA (UWB)
- VCO & DCO (IEEE .11a)
- LNA + Mixer (IEEE .11b)
- Ring Oscillator

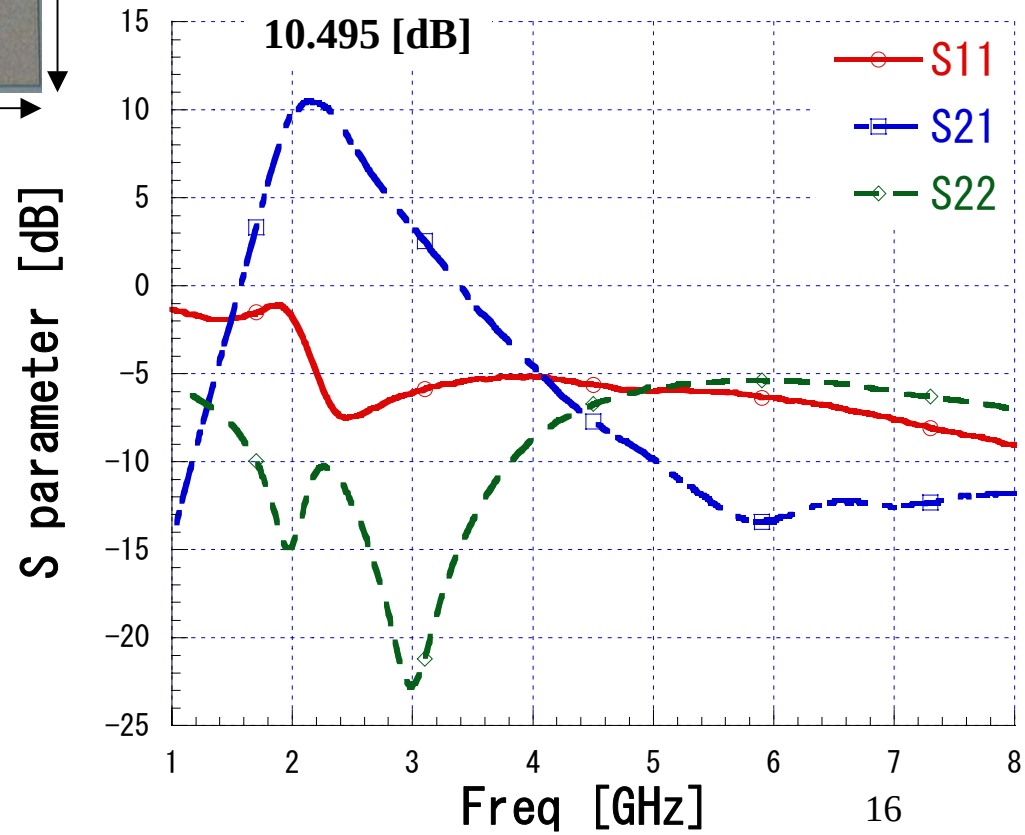
TSMC:

0.35um Bi-CMOS, 0.25um CMOS & 0.18um CMOS

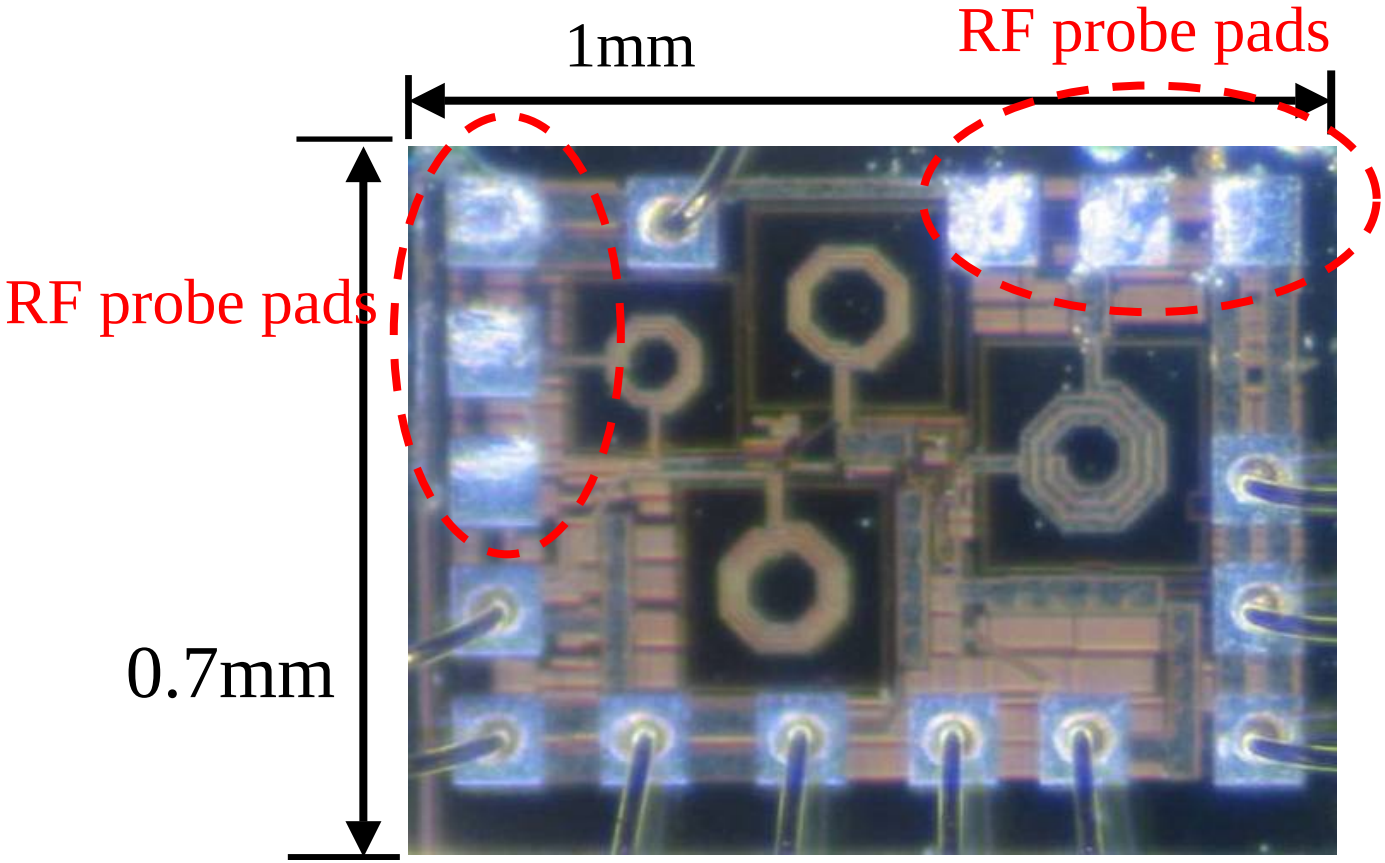
Power Amp.



TSMC0.35μm Bi-CMOS process

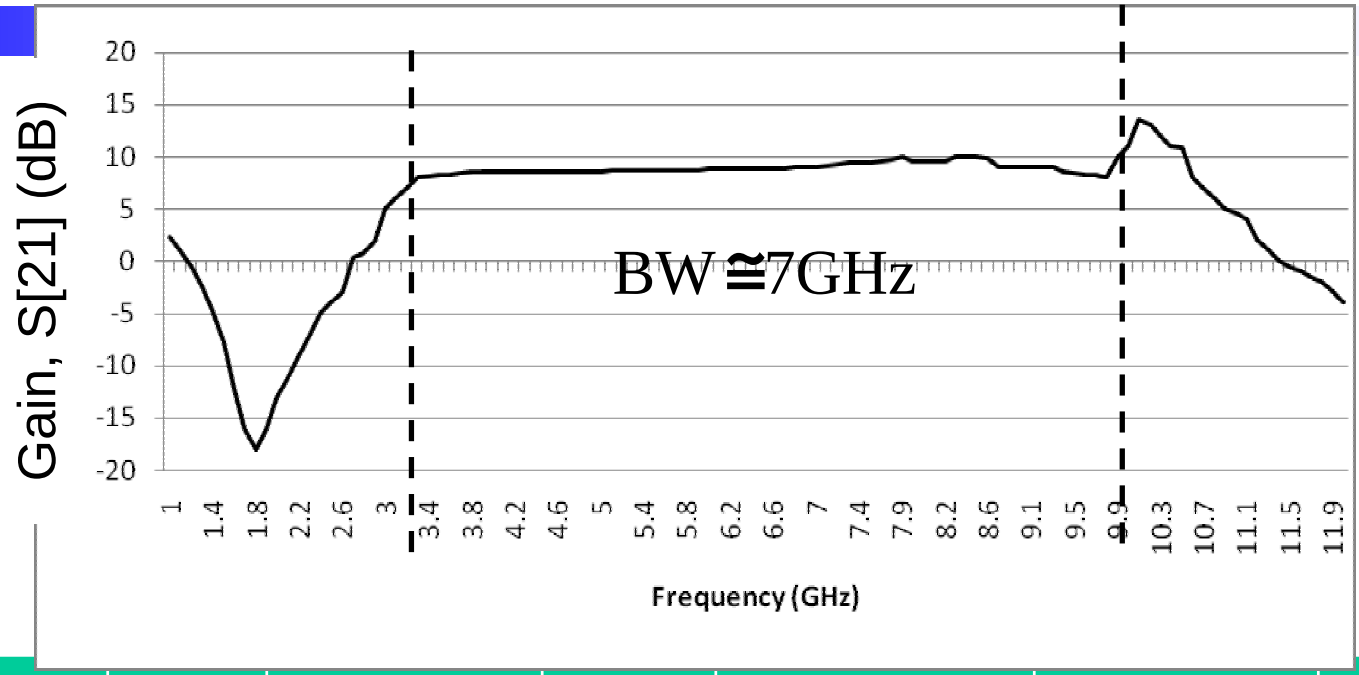


Ultra wideband (UWB) Low noise Amp. (LNA)



Chip photo of the designed UWB LNA in 0.18um CMOS.

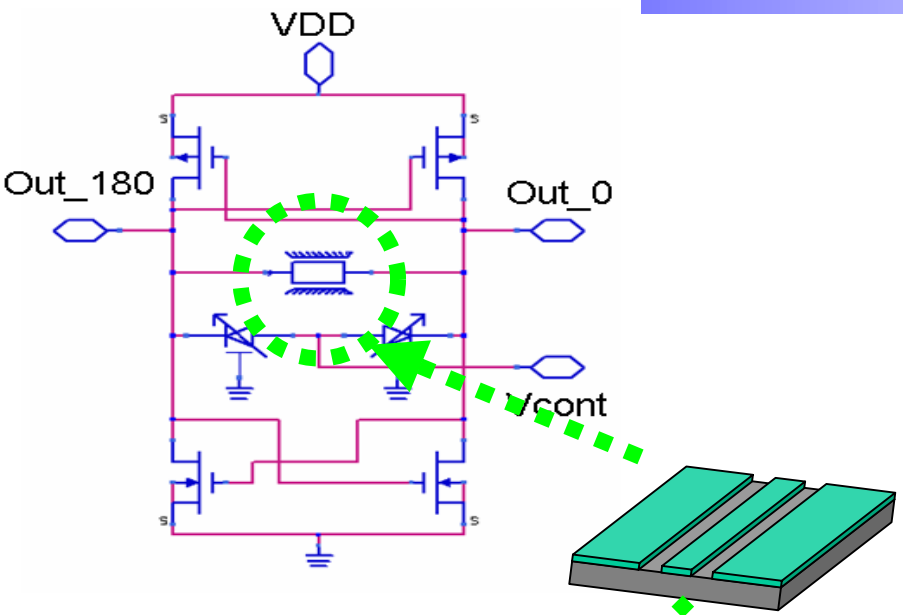
Measurement results

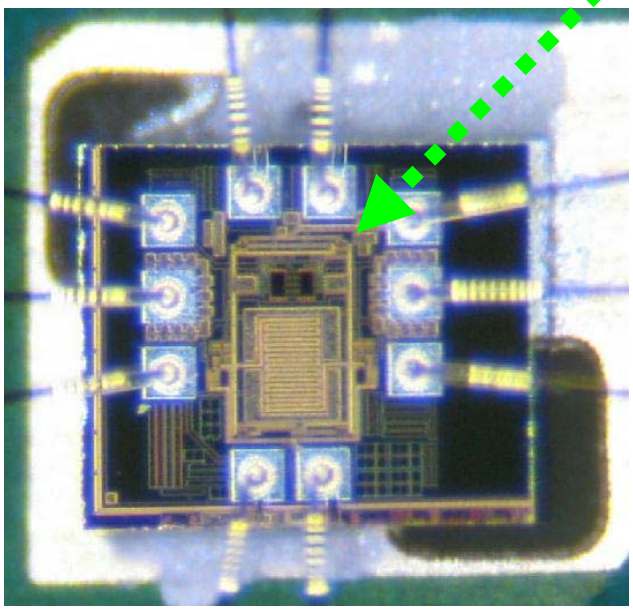


Reference	S21	NF(dB)	S11 (dB)	Freq. (GHz)	IIP3 (dBm)	Technology
JSSC[1]	9.7~7	4.5~5.1	<-11	3.1~10.6	-6.2	0.18µm CMOS
JSSC [2]	13	3.3 (max 6.5)	<-7	2~10	-7	0.18µm BiCMOS
Ref. [3]	9.5	5 (max 5.6)	<-10	3-11	-13	0.18µm CMOS
This work (Post-layout)	16.5 (flat)	<3.7 (flat)	<-9	3.1~10.6	-8	0.18µm CMOS

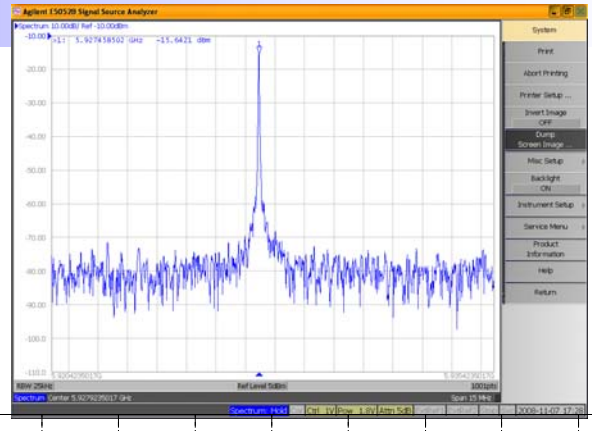
-> Presented at IEEJ Analog VLSI symposium, Aug, 2008.

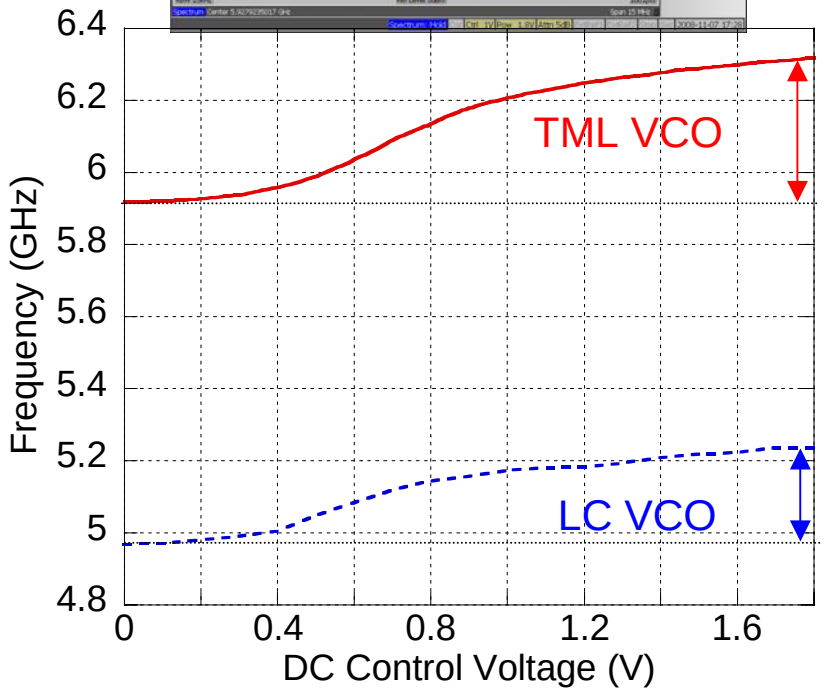
VCO (Voltage controlled Osc.) with TML





100μm



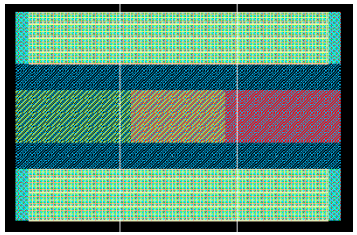


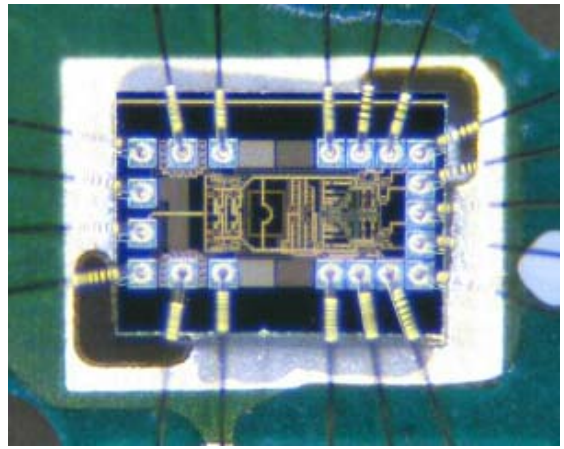
TML VCO= -112dBc/Hz @1MHz
LC VCO= -110dBc/Hz @1MHz

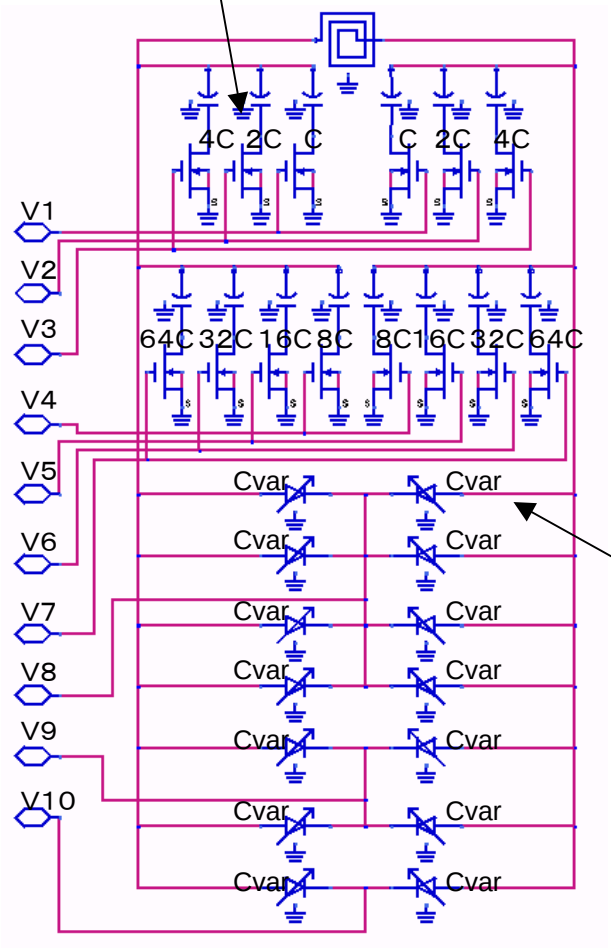
TSMC0.18μm CMOS process

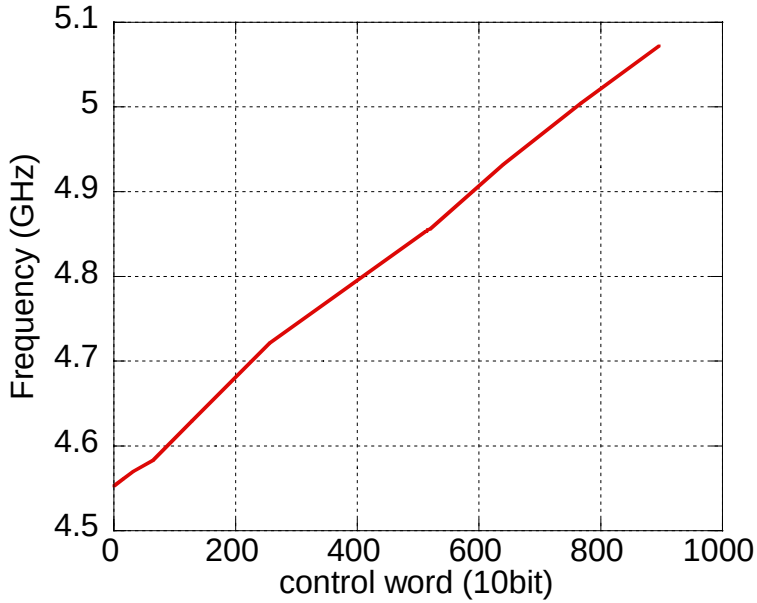
LC-DCO (Digitally controlled OSC)

TML Capacitor





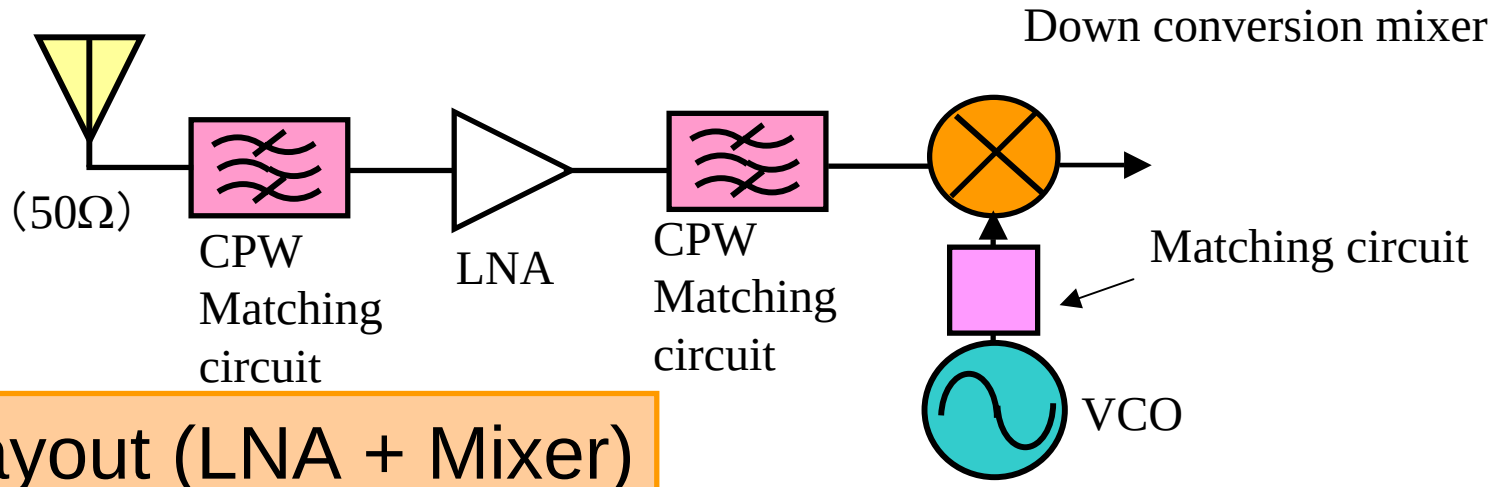




LC VCO= -119dBc/Hz @1MHz

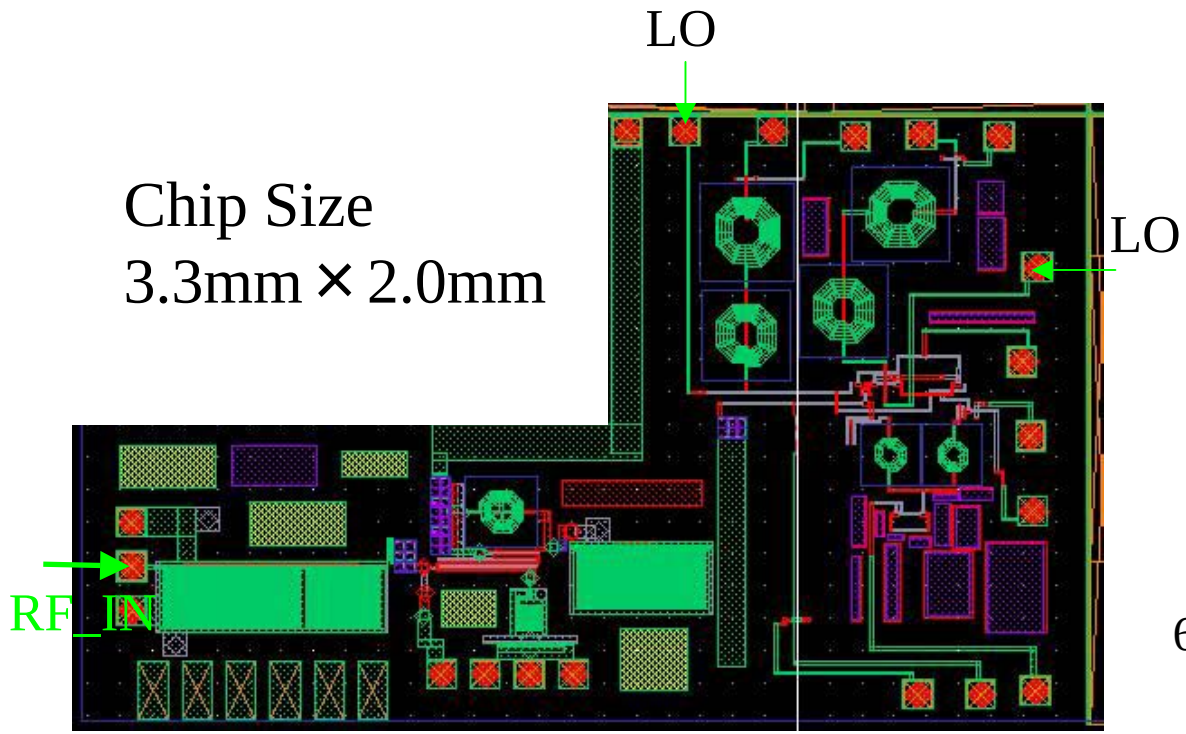
TSMC0.18μm CMOS process

LNA + Mixer (Down converter)



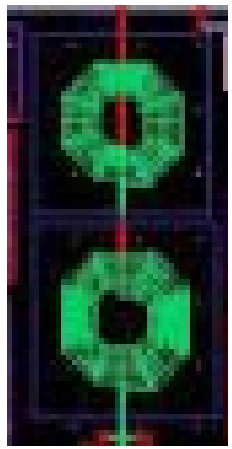
Layout (LNA + Mixer)

Chip Size
3.3mm × 2.0mm



Size

Lumped element

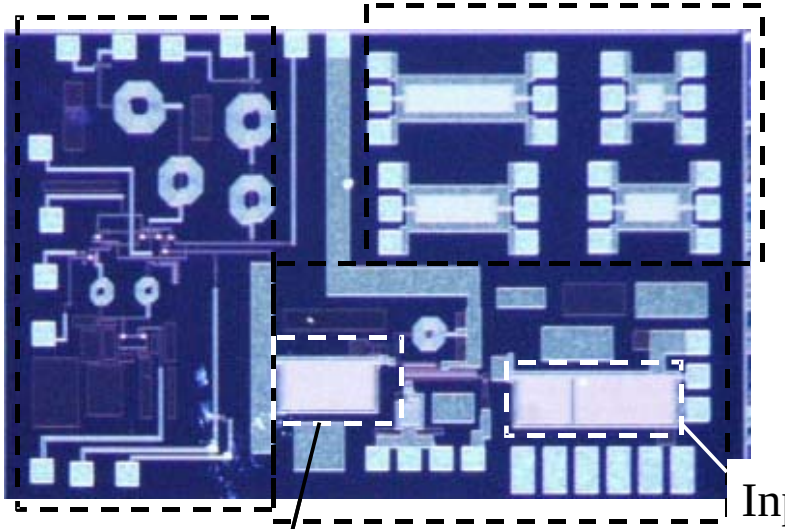


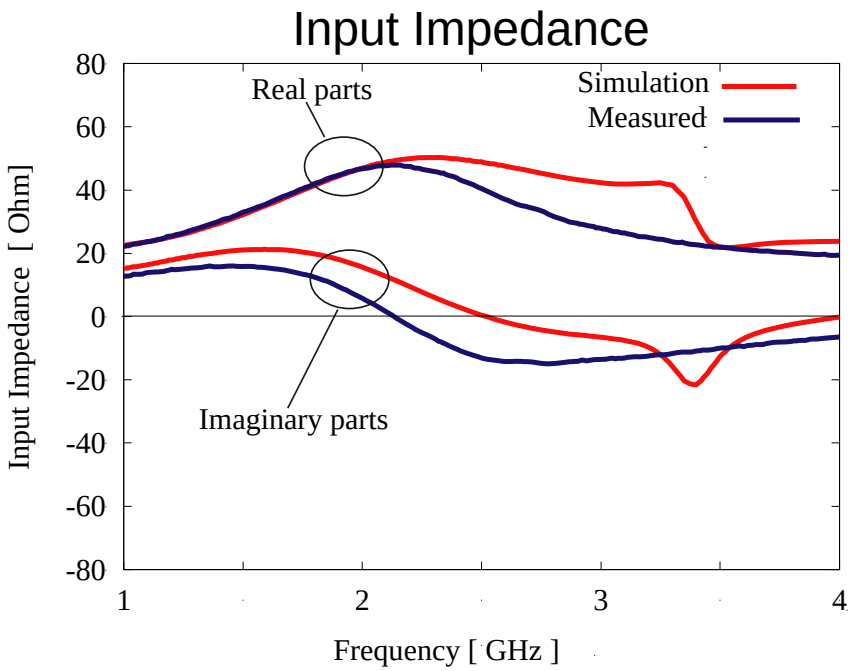
600 μm × 300 μm
（約14.0nH @2.45GHz ）

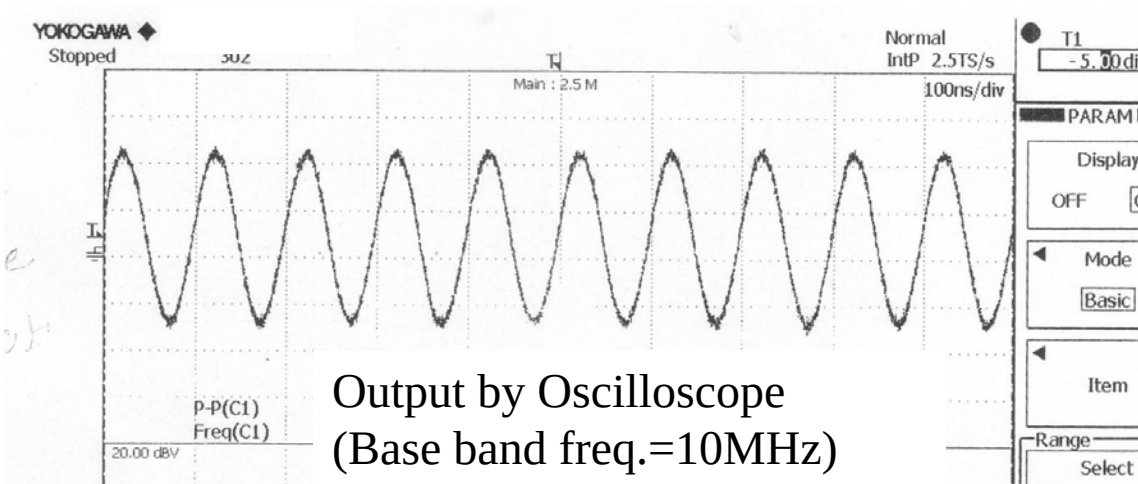
TML

480 μm × 250 μm

LNA + Mixer (Down converter)







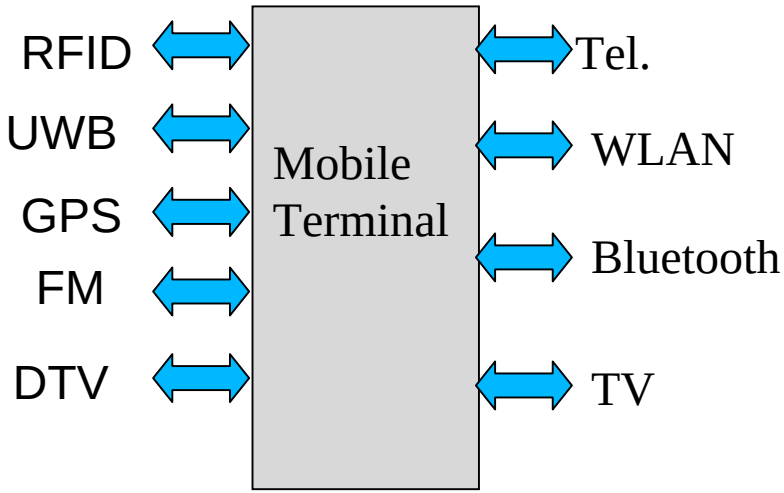
Output by Oscilloscope
(Base band freq.=10MHz)

Ring-Oscillator

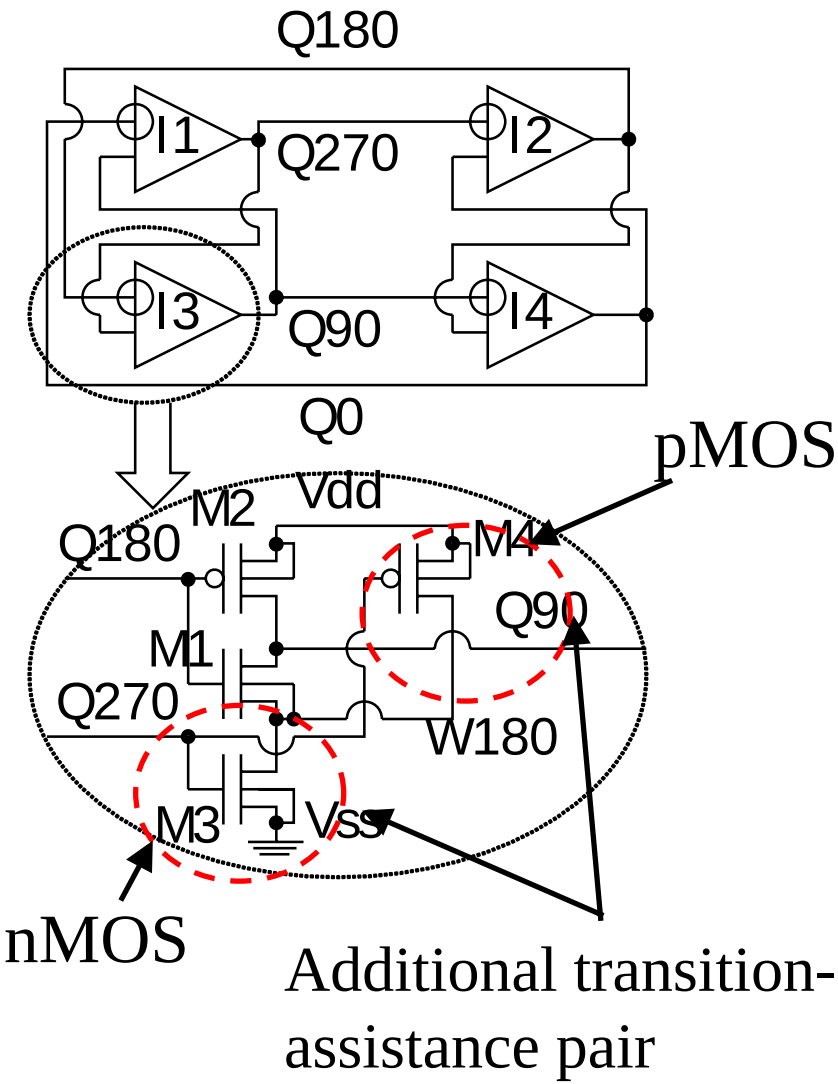
Demand of Wideband Systems

WLAN(.11a,.11b), WCDMA, GPS, PHS, GSM, IMT2000 …

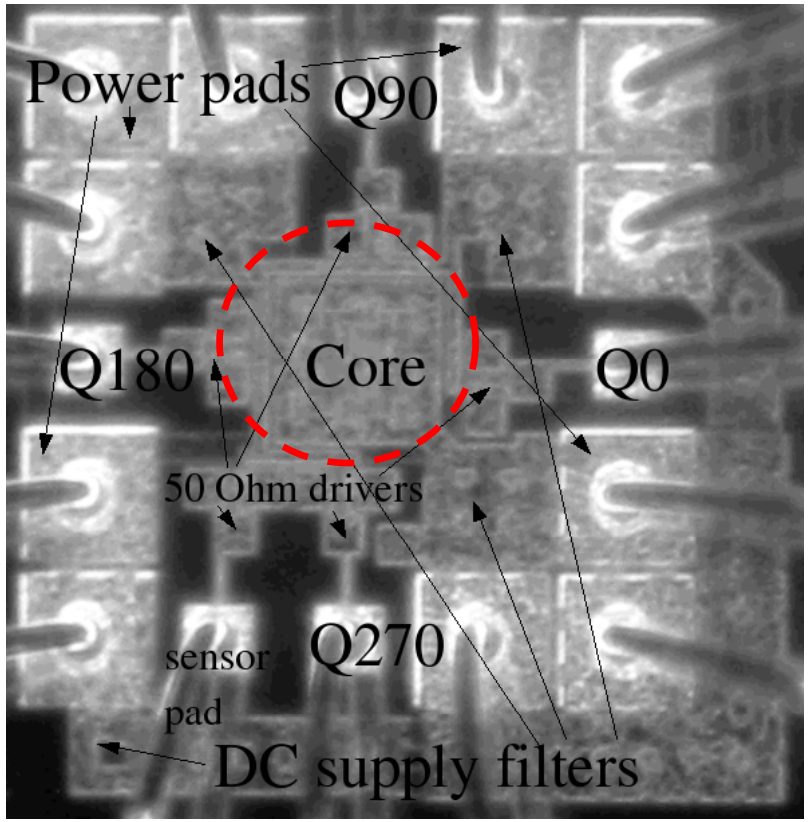
- Reconfigureable RF circuit.
- Multi-standard systems in one terminal.



Proposed Quadrature Ring Oscillator



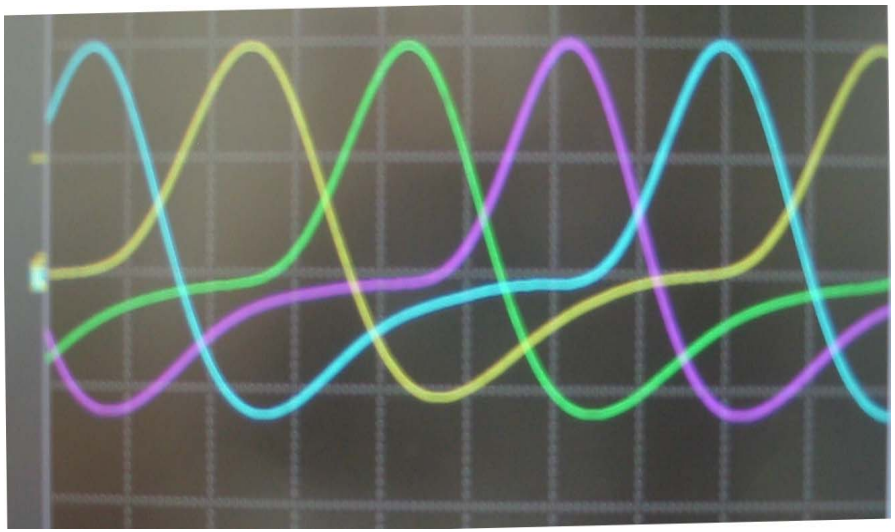
Chip photo
TSMC 0.18um CMOS Process



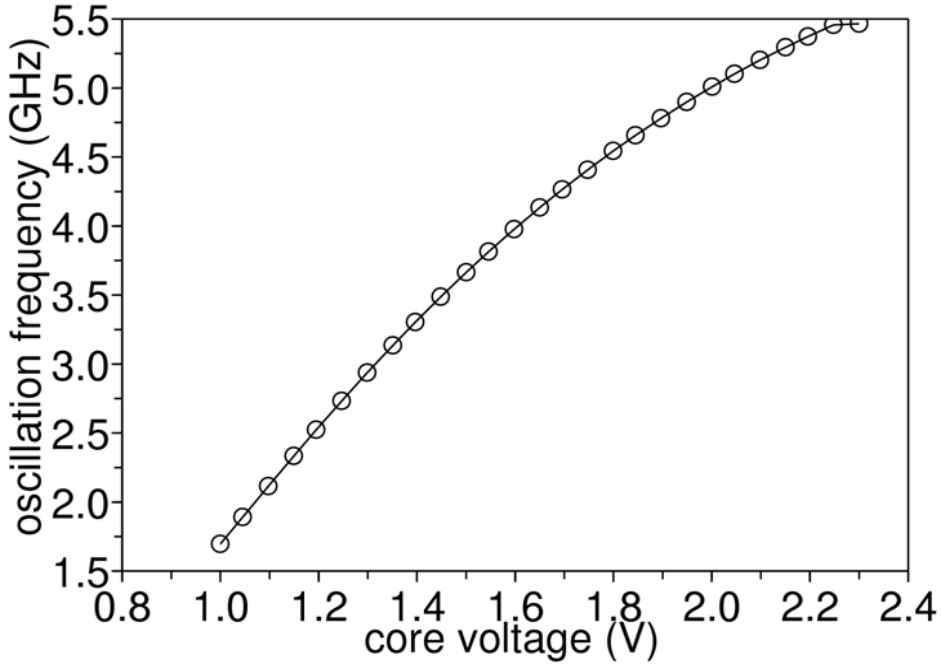
Size:0.30 mm^2 with bonding pads.
Size: 0.01 mm^2 without bonding pads.

Measurement results

Time-Domain



Tuning Range

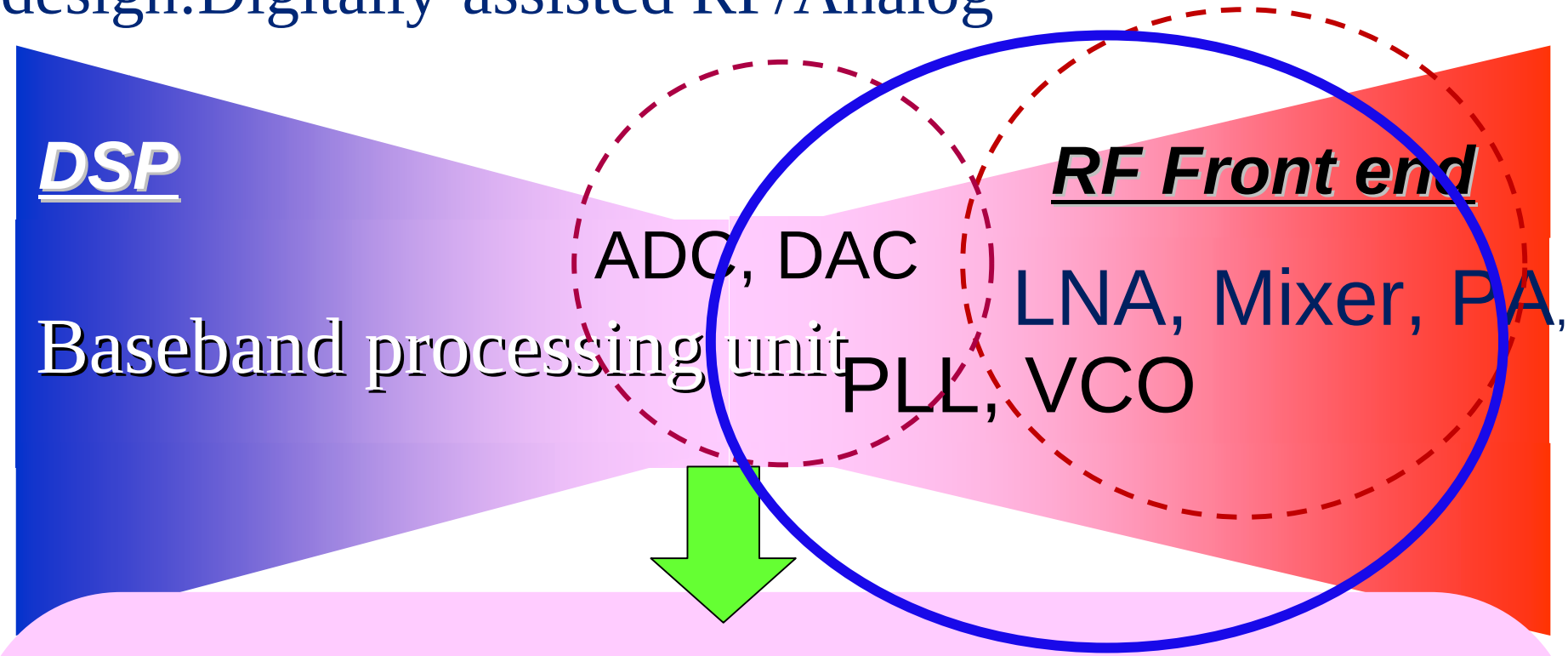


- Tuning Sensitivity = 2.9 MHz/mV
- Tuning range = 1.7 GHz ～5.5 GHz
- FOM= -162.2 dBc/Hz

Figure of Merit: $$FOM = -20\log\left(\frac{F_{osc}}{F_{off}}\right) + PN + 10\log\left(\frac{P_{diss}}{0.001}\right)$$

Wireless System LSI

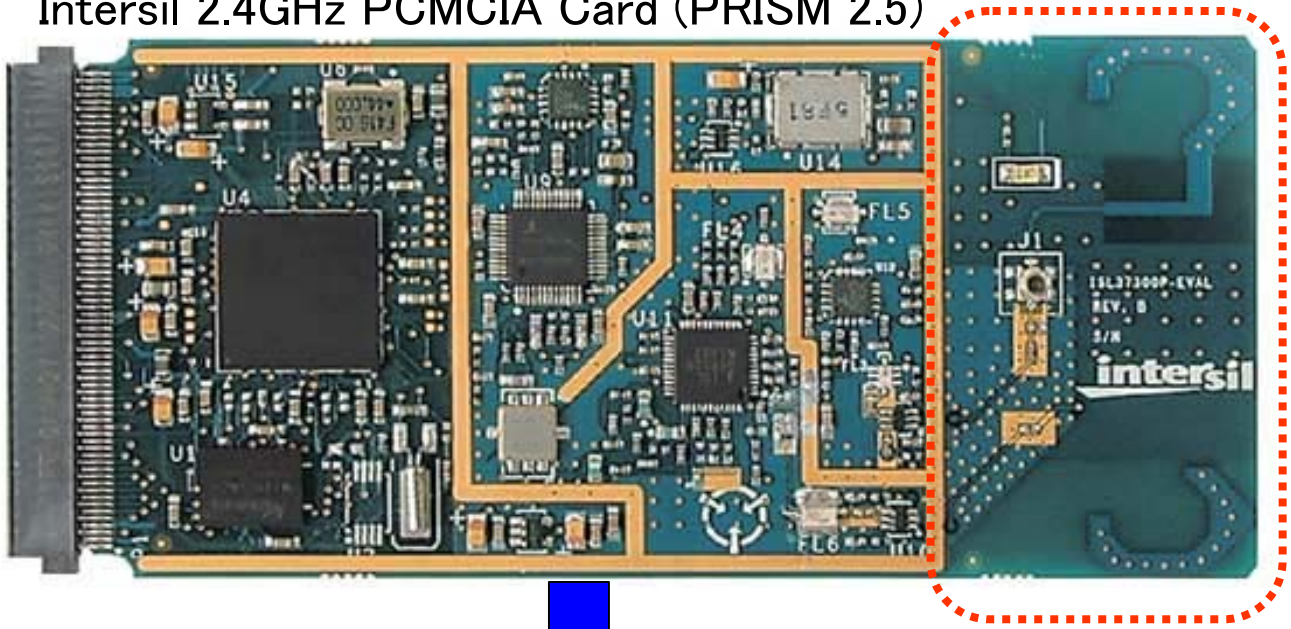
Digital techniques: a New Concept in RF circuit design:Digitally-assisted RF/Analog



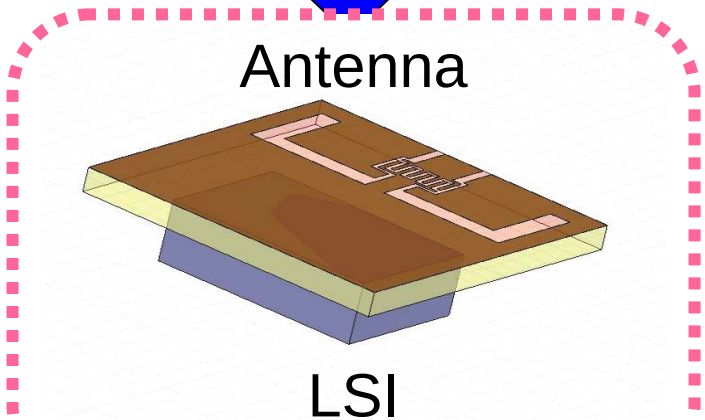
Key word: RFIC (Digitally-assisted RF/Analog)

② Development of Miniaturized Integrated Antennas

Intersil 2.4GHz PCMCIA Card (PRISM 2.5)



5cm



Small size, thinner and one-sided directional antennas are necessary!

Antenna Applications

- *One-sided directional antenna*

  300MHz, UHF, 2.4GHz (.11b), MIMO (.11a), UWB

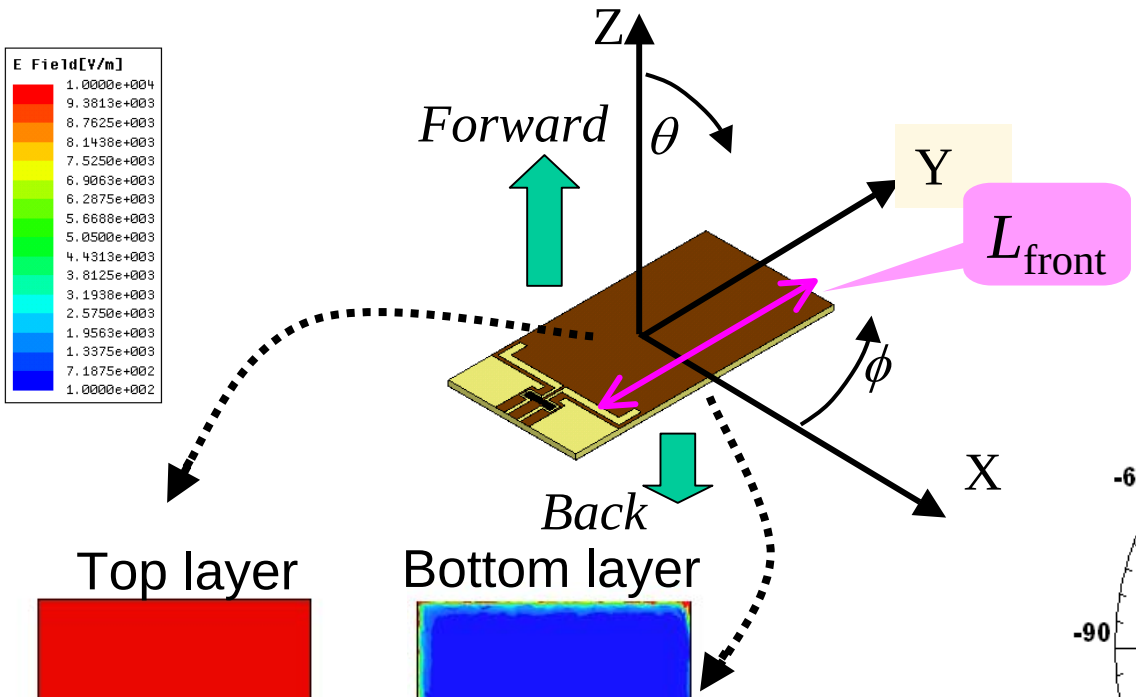
- *Electrically small antenna with matching circuit*

  UHF, 2.4GHz, 5GHz

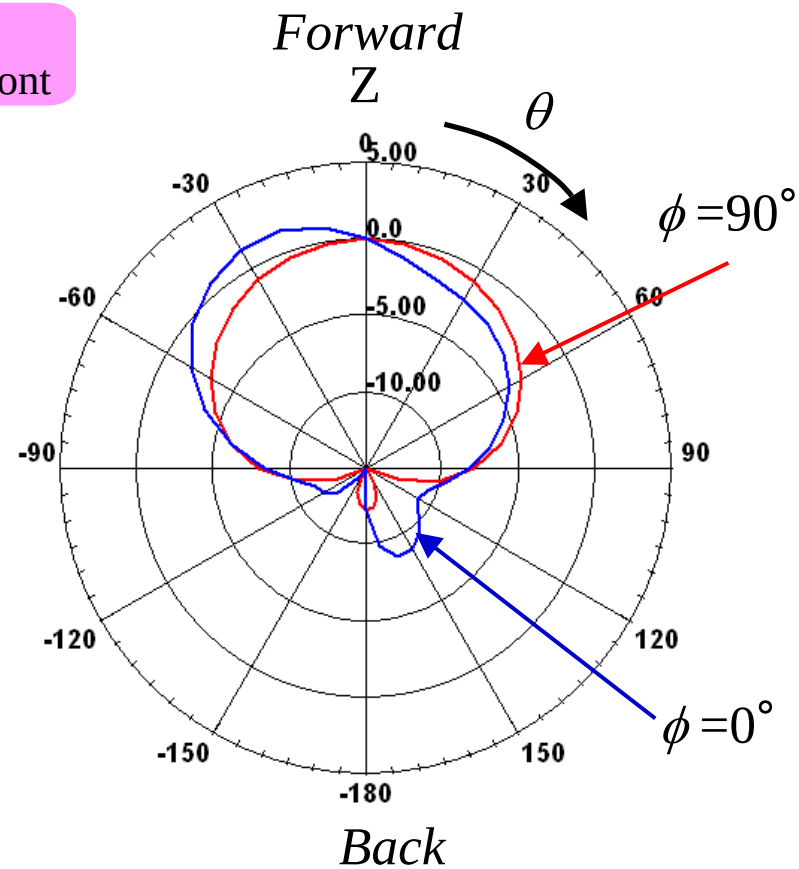
- *Dual band antenna*

  PDC + 3G (800MHz + 2GHz)

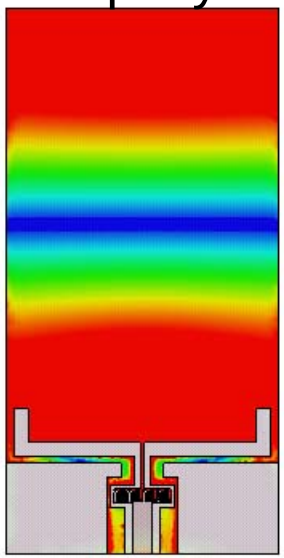
Simulated field pattern and radiation pattern of the one-sided directional antenna



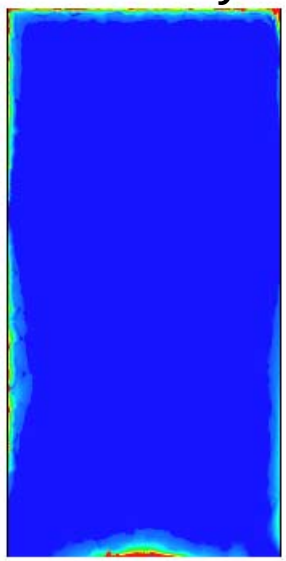
HFSS@2.4GHz



Top layer

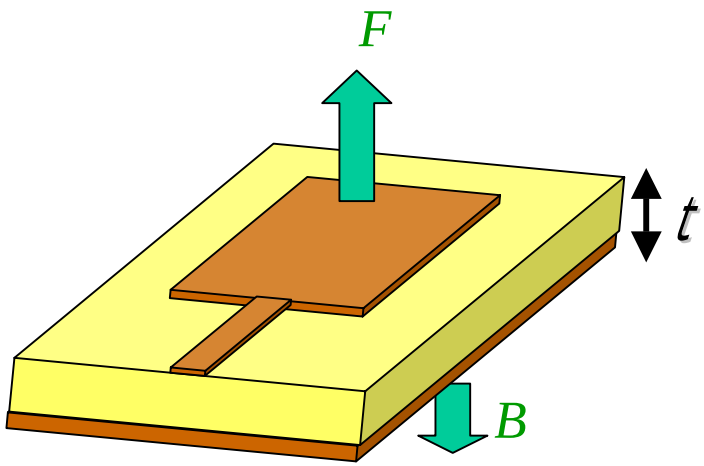


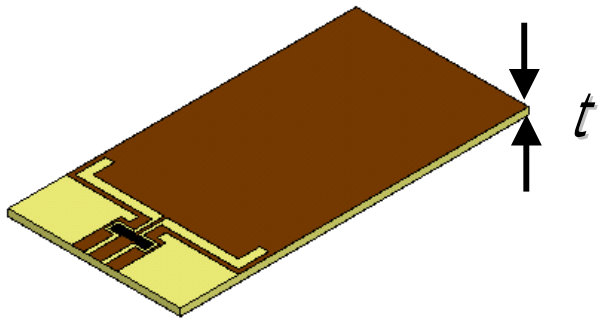
Bottom layer



E- field
Near field

Advantages of Proposed Theory:Gain can be realizable at thinner Substrate





	Thickness of the substrate t [mm]	1.6	0.8	0.4
One-sided slot	Gain[dBi]	1.177	0.81	-1.516
Patch antenna	Gain[dBi]	1.254	-1.057	-4.145

○

×

….advantage for multiplayer MMIC circuit.

By 3D-EM Simulation

Electrically small antenna (ESA)

An antenna that dimension is much smaller than quarter wavelength…

⇒Antenna length $< \lambda/4$

- Small Radiation Resistance
- Narrow bandwidth
- Sensitive to the conductor resistance

Impedance Matching

+

Design of Bandwidth

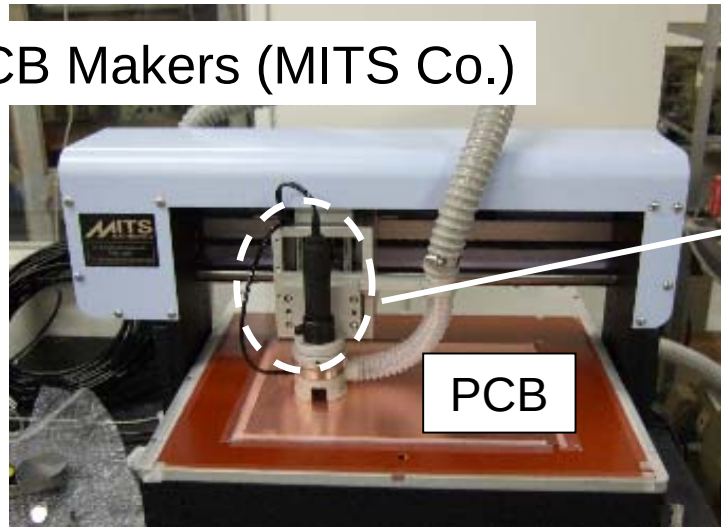
+

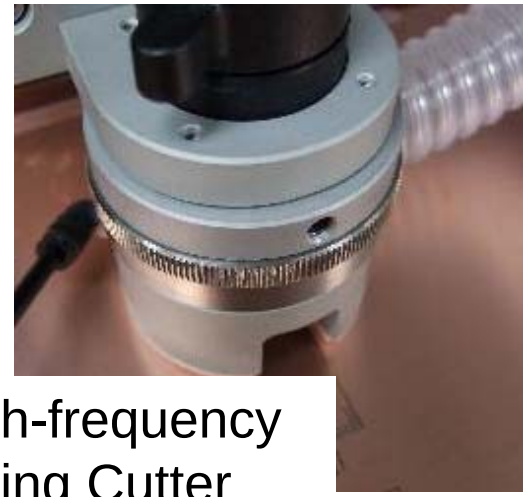
One-Sided Directional Antenna

⇒ ***Proposed Antenna***

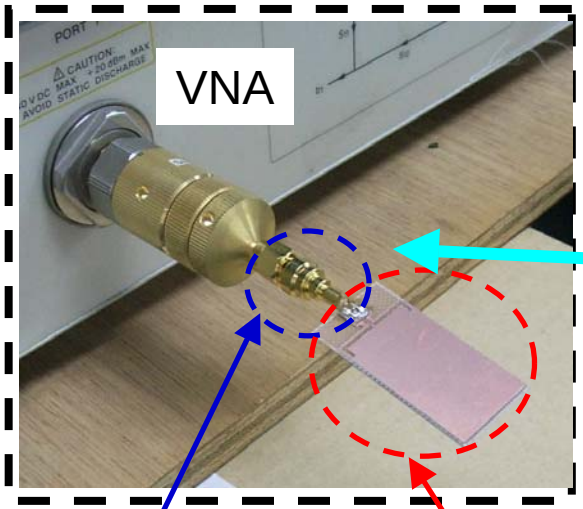
integrates

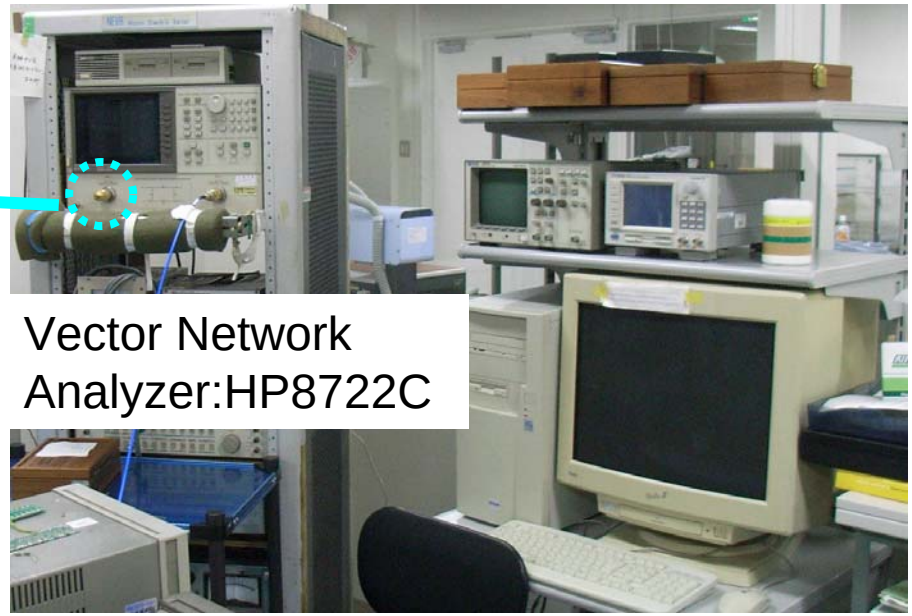
Antenna Fabrication and Measurement System





High-frequency Milling Cutter





Vector Network Analyzer:HP8722C

MMCX-SMA Connector

Antenna

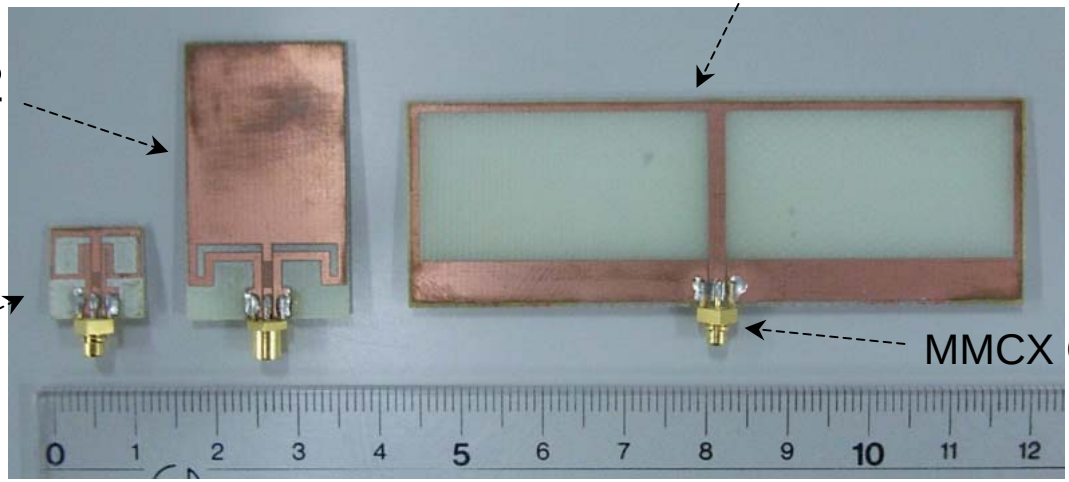
Photograph of the ESAs

Size comparison of the antennas

standard slot dipole antenna
(size:74.0mm × 24.0mm,gain:3.92dBi)

ESA2

ESA1

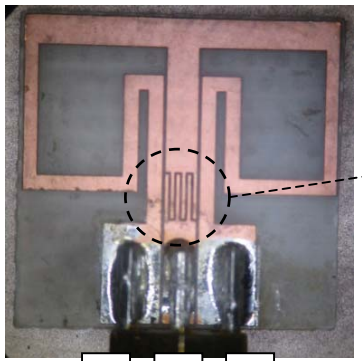


MMCX Connector(50Ω)

(unit : mm)

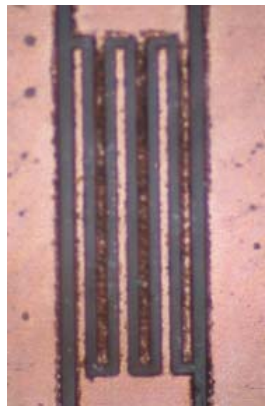
Enlargement of the ESAs

J-inverter



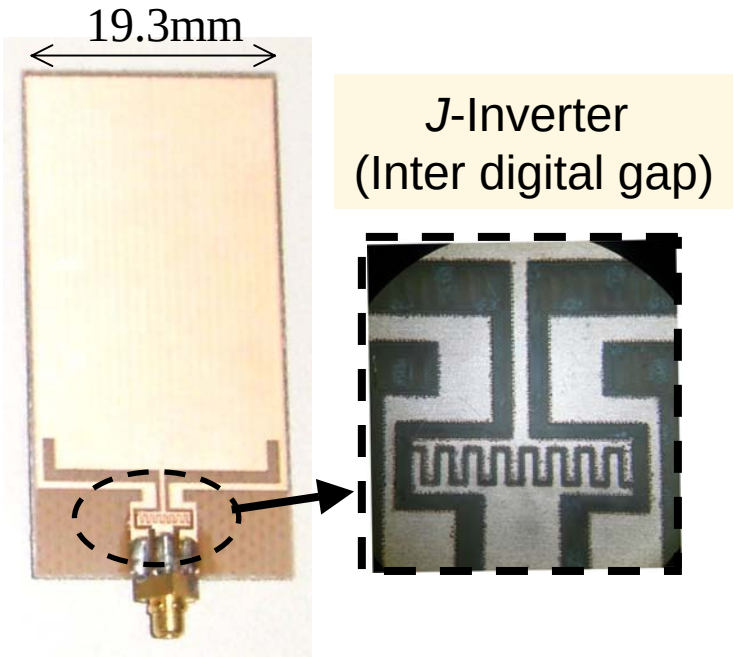
G S G

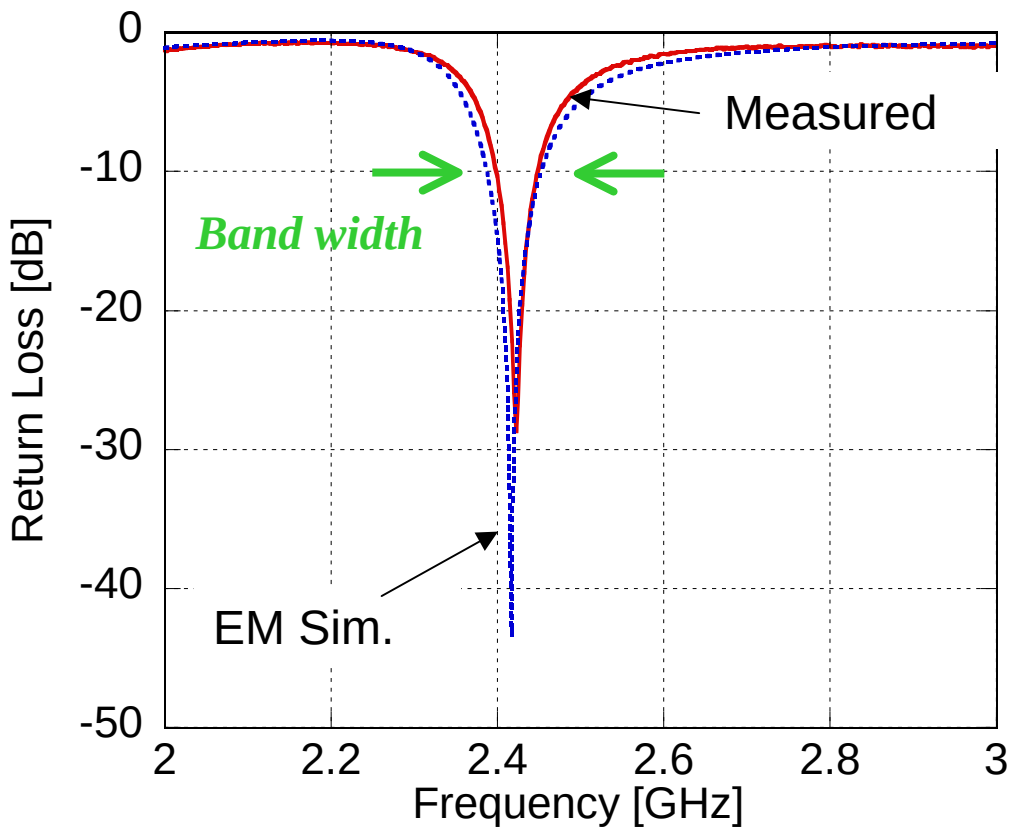
J-inverter



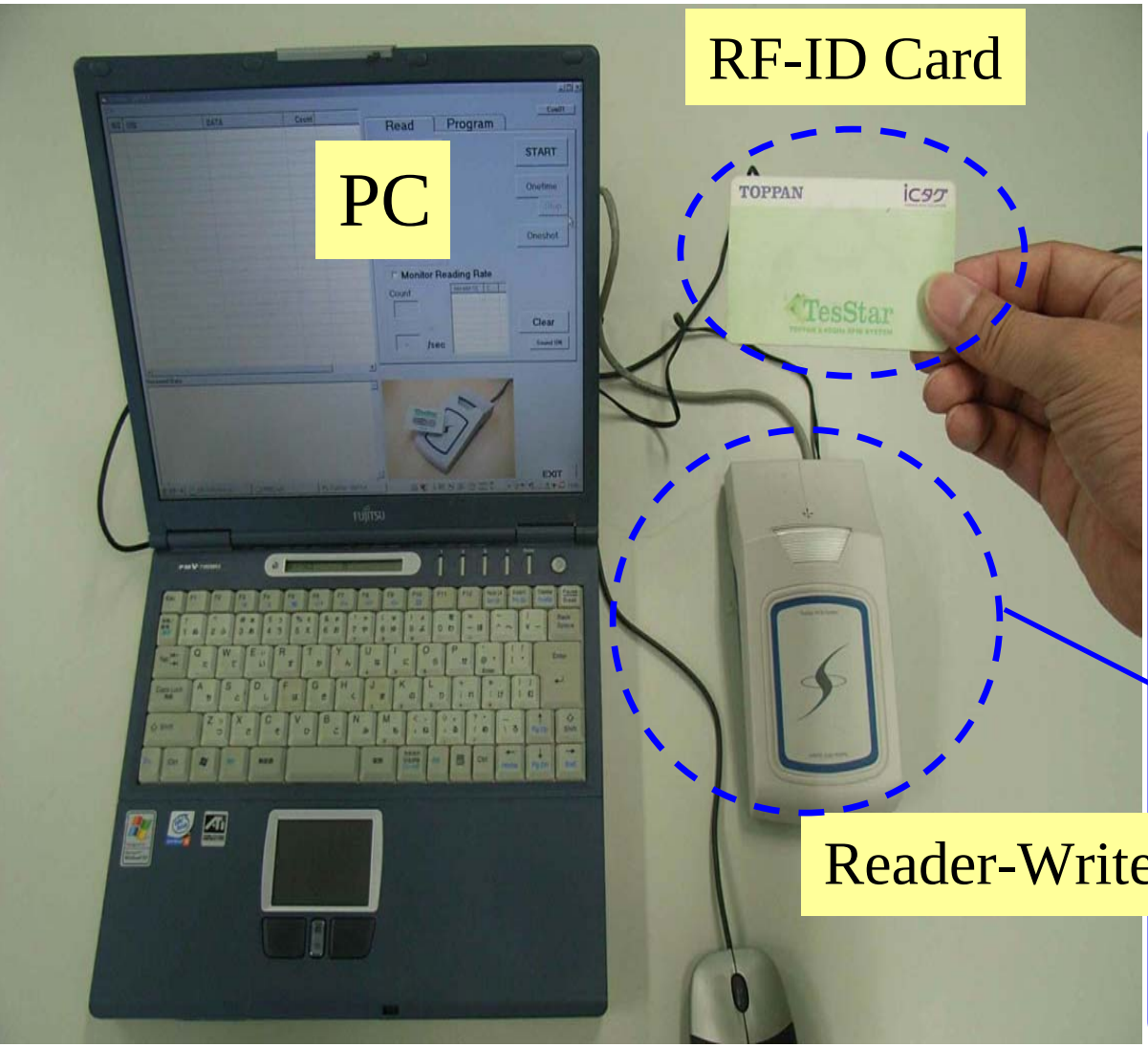
Experimental results of the one-sided directional ESA with CPW matching circuit

Photographs of the antenna

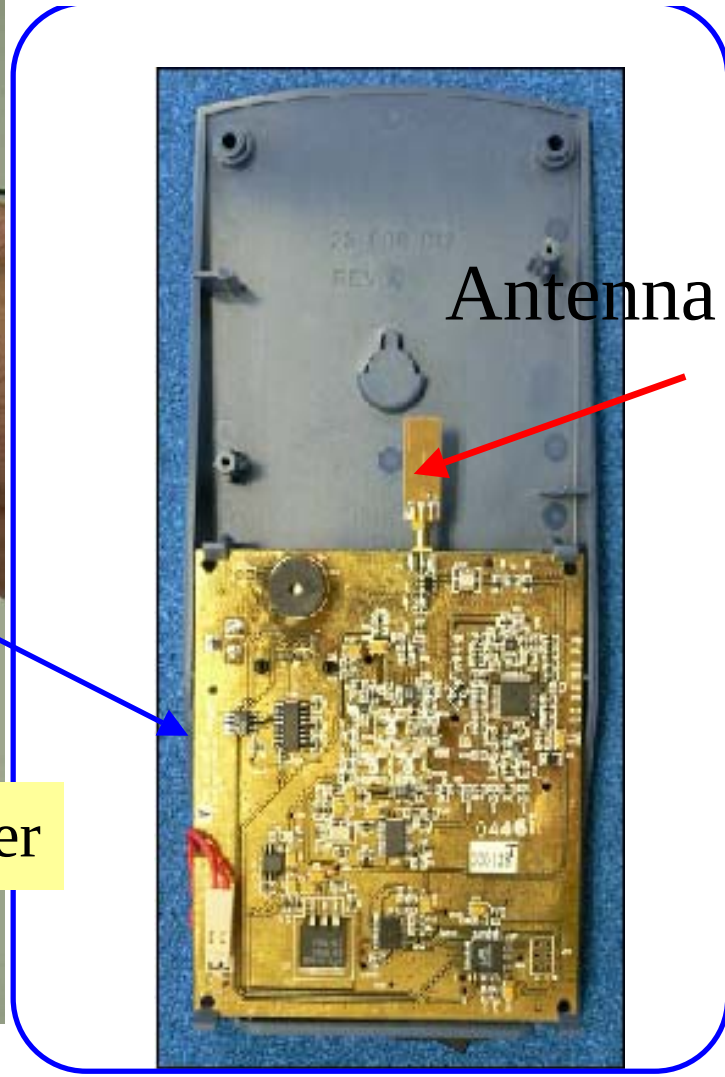




Experimental results of the one-sided directional ESA with CPW matching circuit



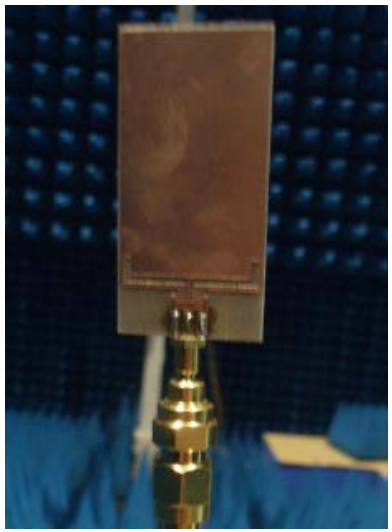
@2.45GHz (IMS band)

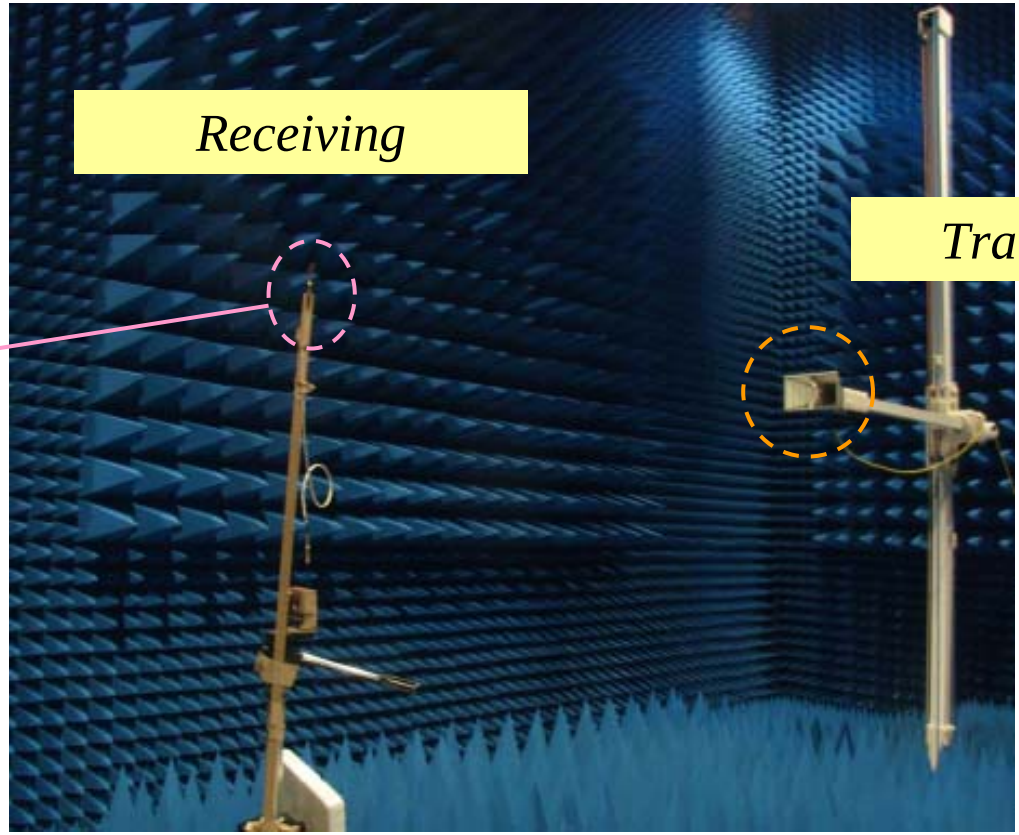


Setup of Radiation Pattern Measurement

In the anechoic chamber

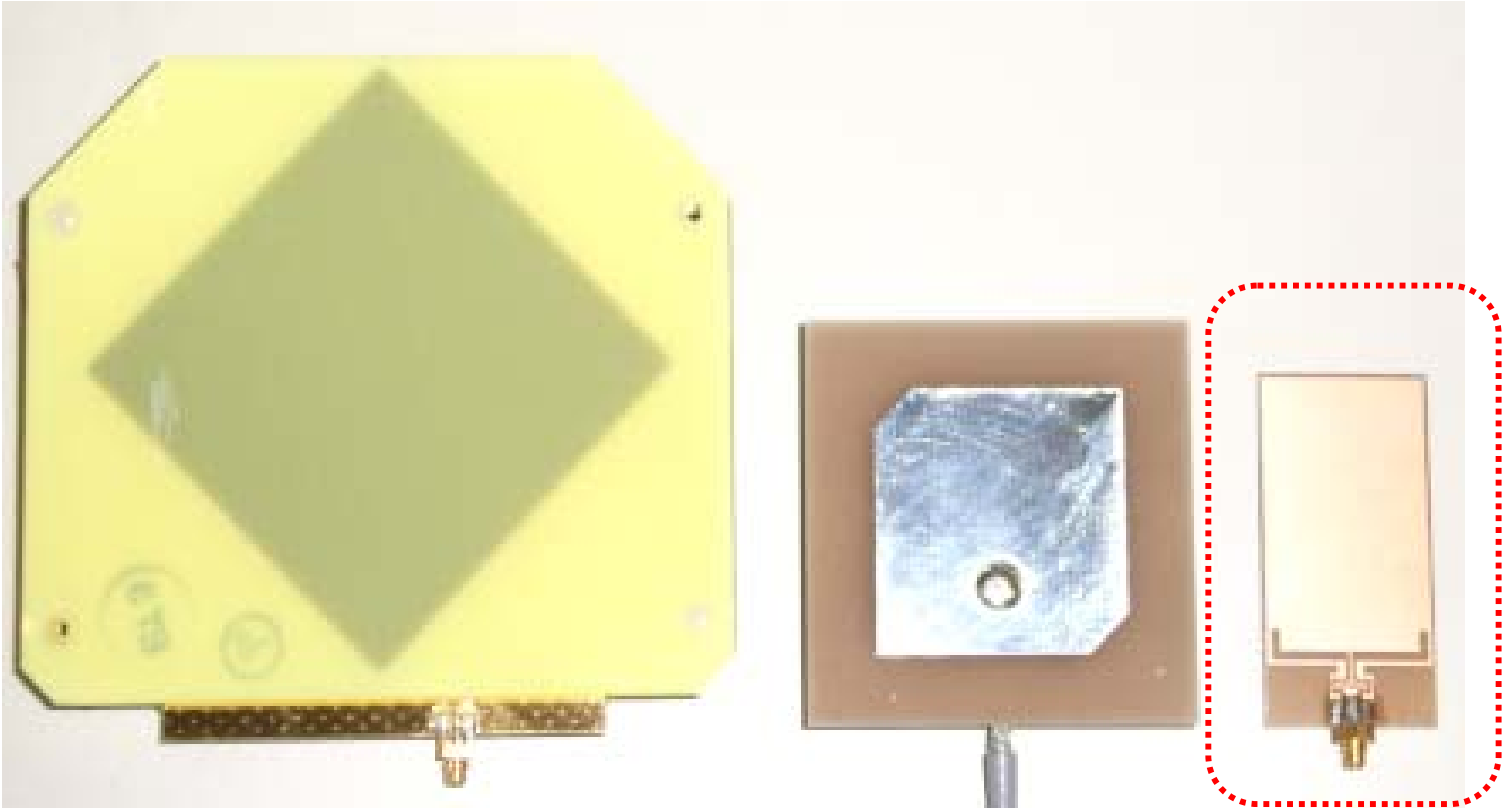
Test antenna





Turn table

Comparison of the sizes of the one-sided directional antenna

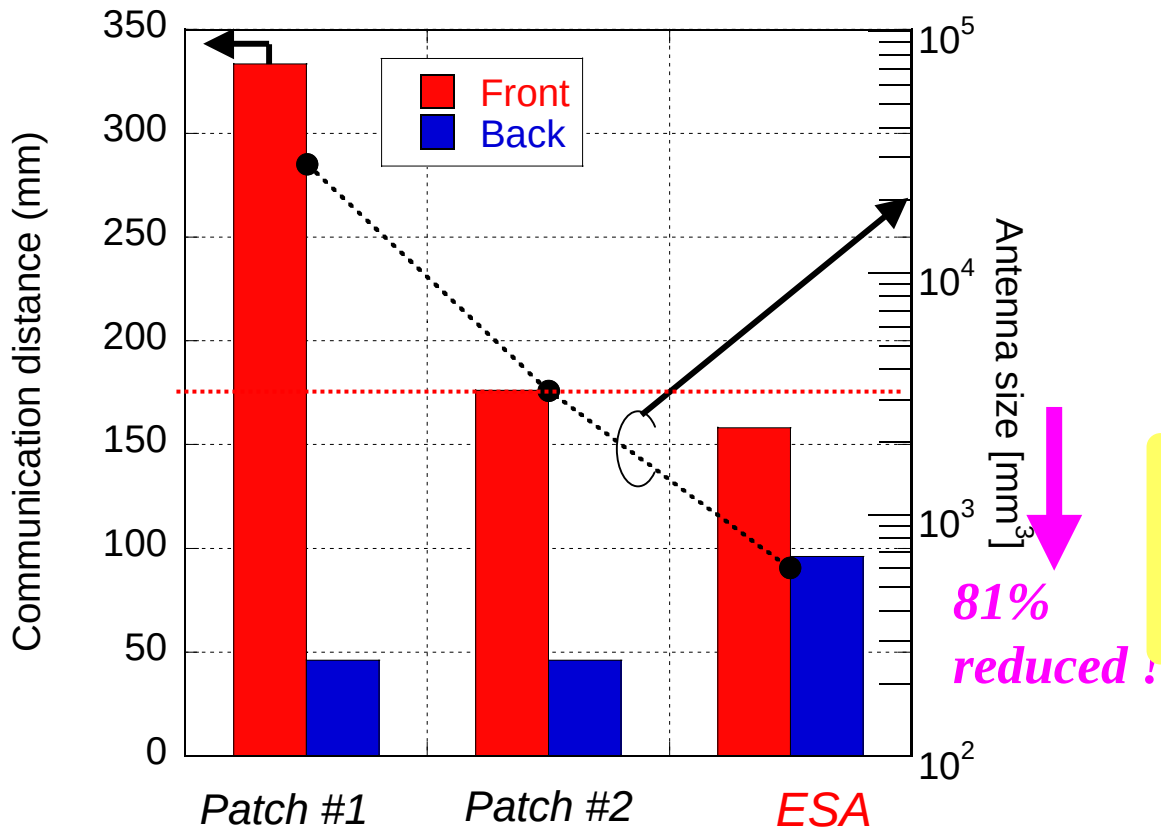


Patch antenna #1
75mm□×t5mm

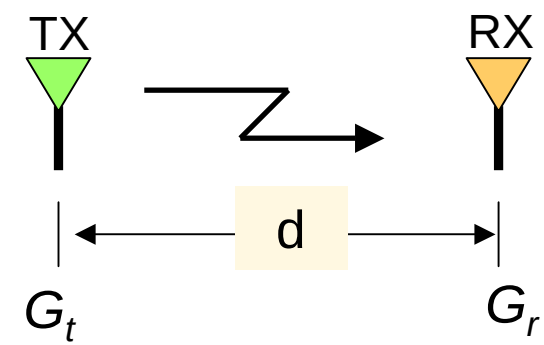
Patch antenna #2
45mm□×t1.6mm

ESA
39×19×t0.8mm

Measured communication distance and antenna size of the patch antenna and ESA



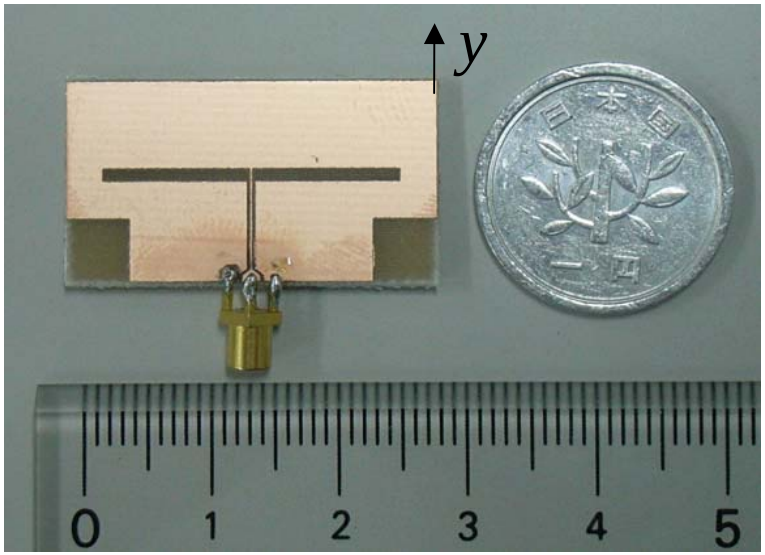
Friis' Transmission Formula

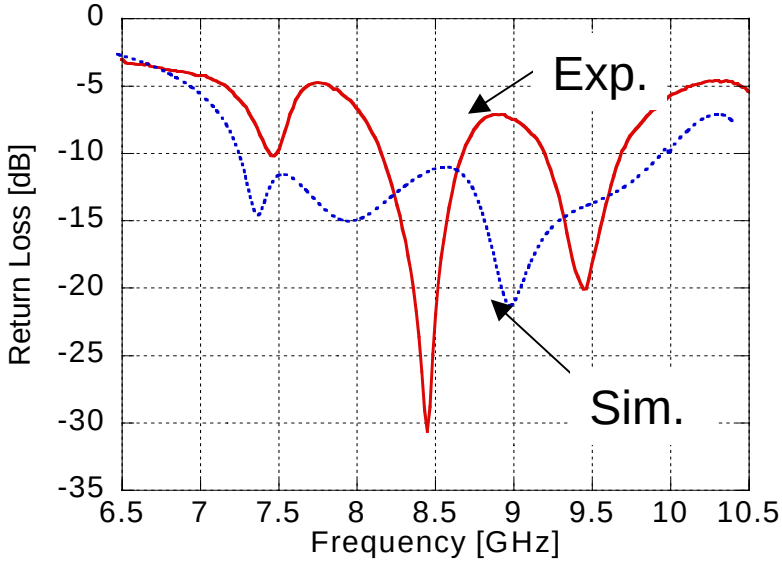


Power received by the RX antenna

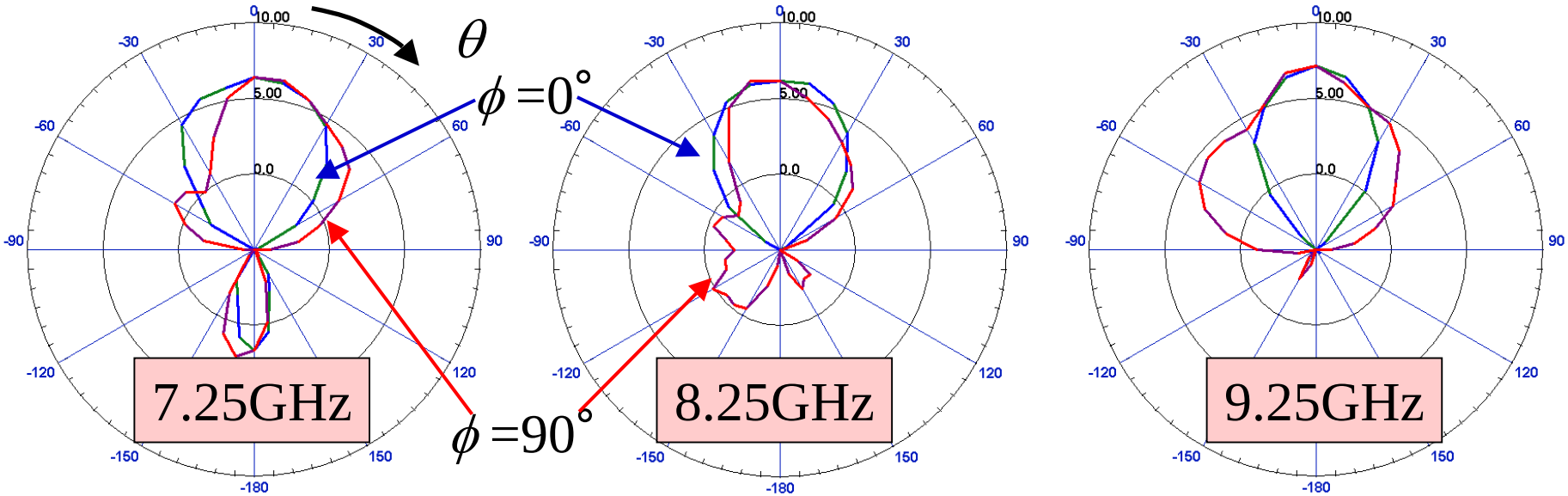
$$Wr = \left(\frac{\lambda}{4\pi d}\right)^2 GtGrWt$$

UWB High Band one-sided directional antenna

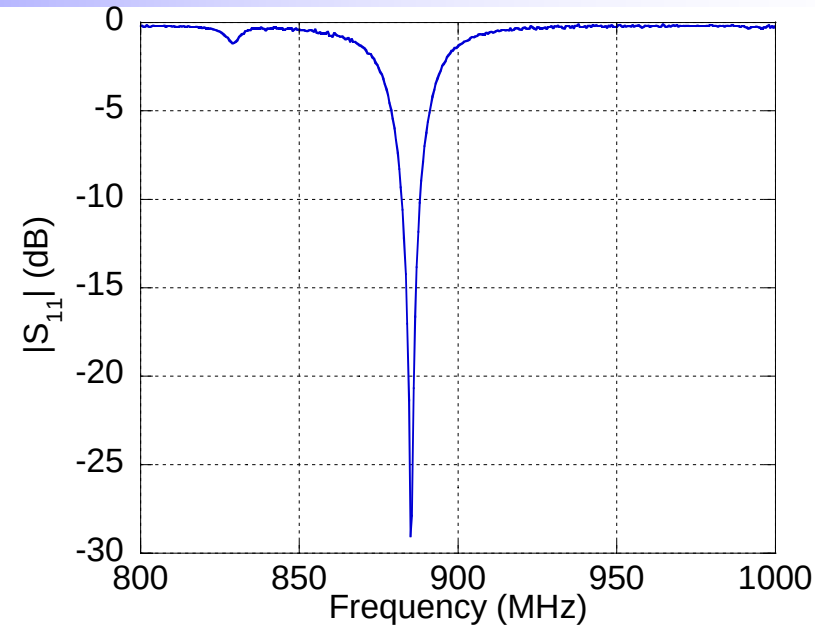




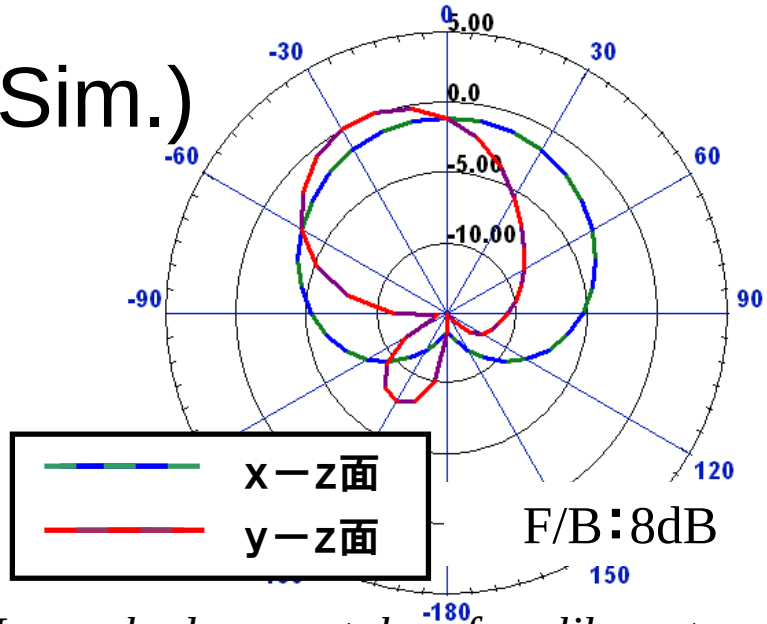
Three resonance—broad band

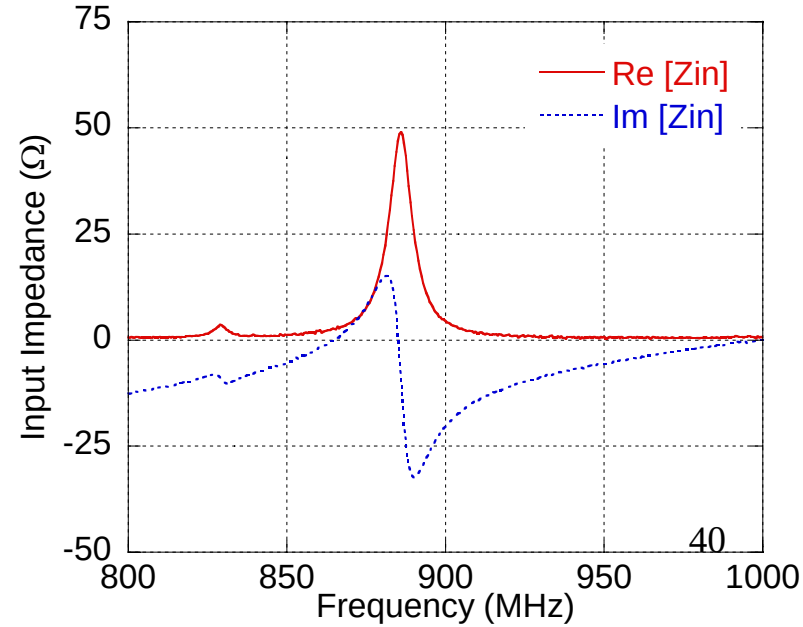


UHF visiting-card size one-sided directional antenna



(Sim.)





Human body or metal surface like auto mobile.

New national project (PICO, MIMO) MESH Network

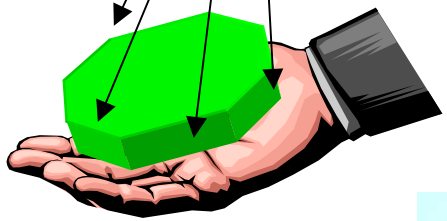
MIMO-MESH, Pico-MESH

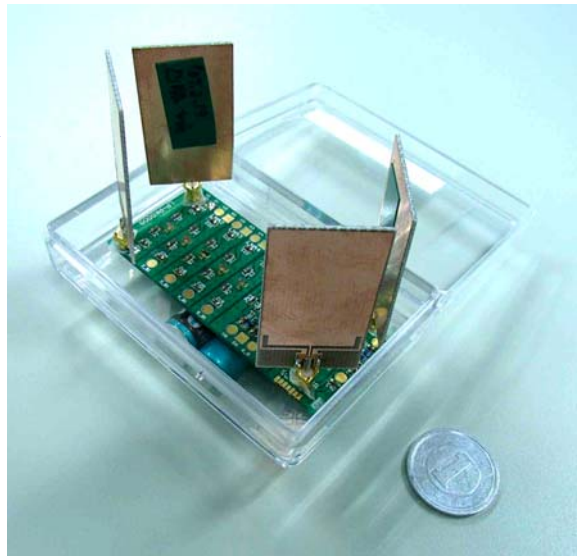
Conventional MESH Device

More than 10kg
Limitation= 2~3 hubs

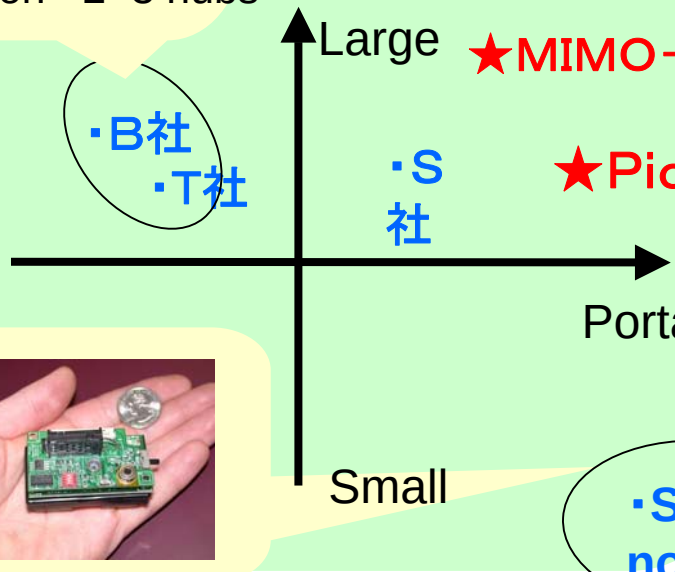
One-sided directional planar antennas

MESH Point

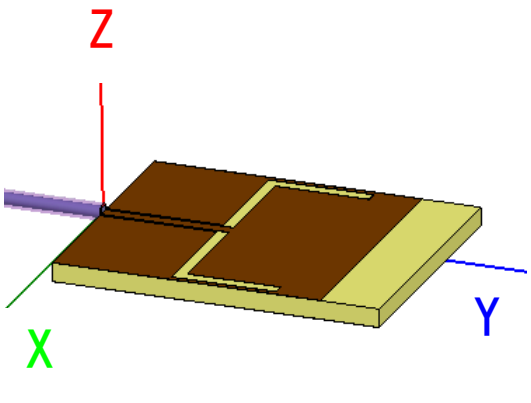


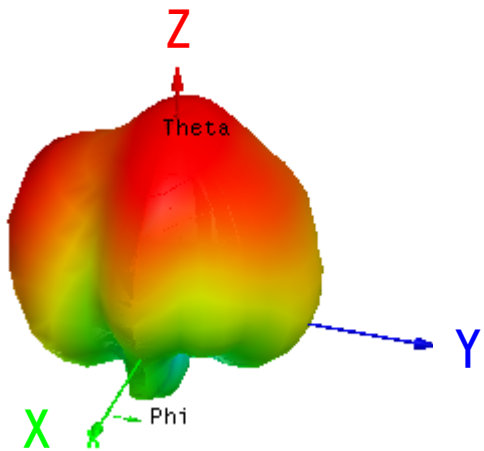


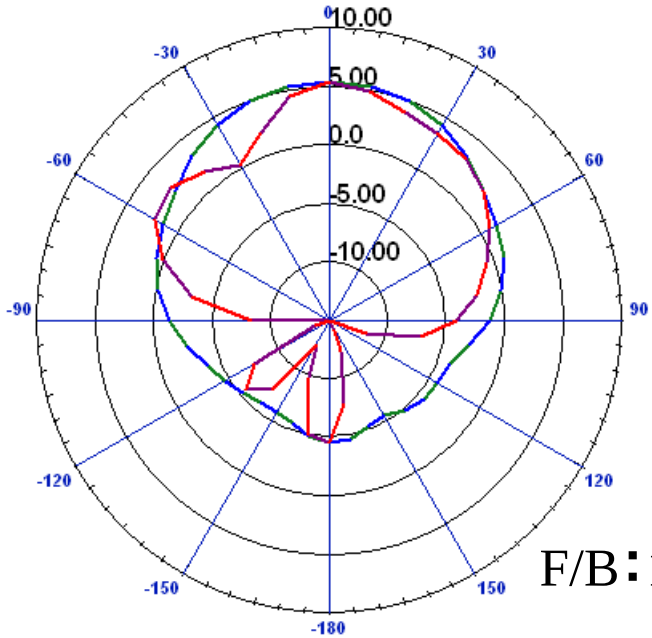
RF front end + IP Core



MESH Antenna @5GHz







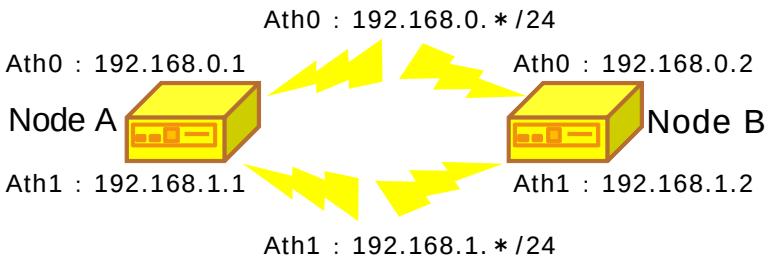
F/B：10 dB

Conventional
H:15.7mm×
D:1.1mm
5dBi

New Antenna
22mm×28mm
5dBi（One-sided directional）

Measurement system of communication distance

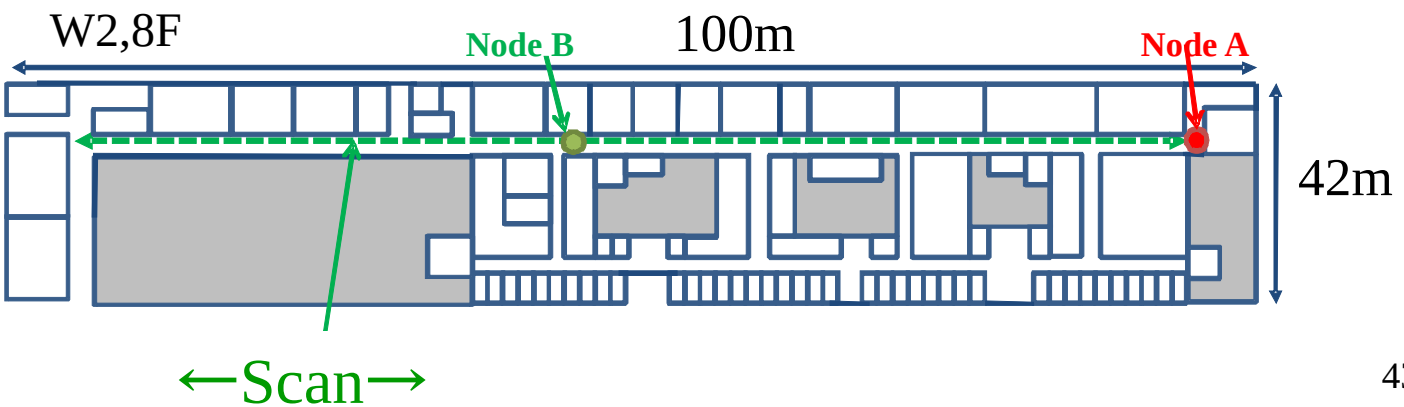
Node



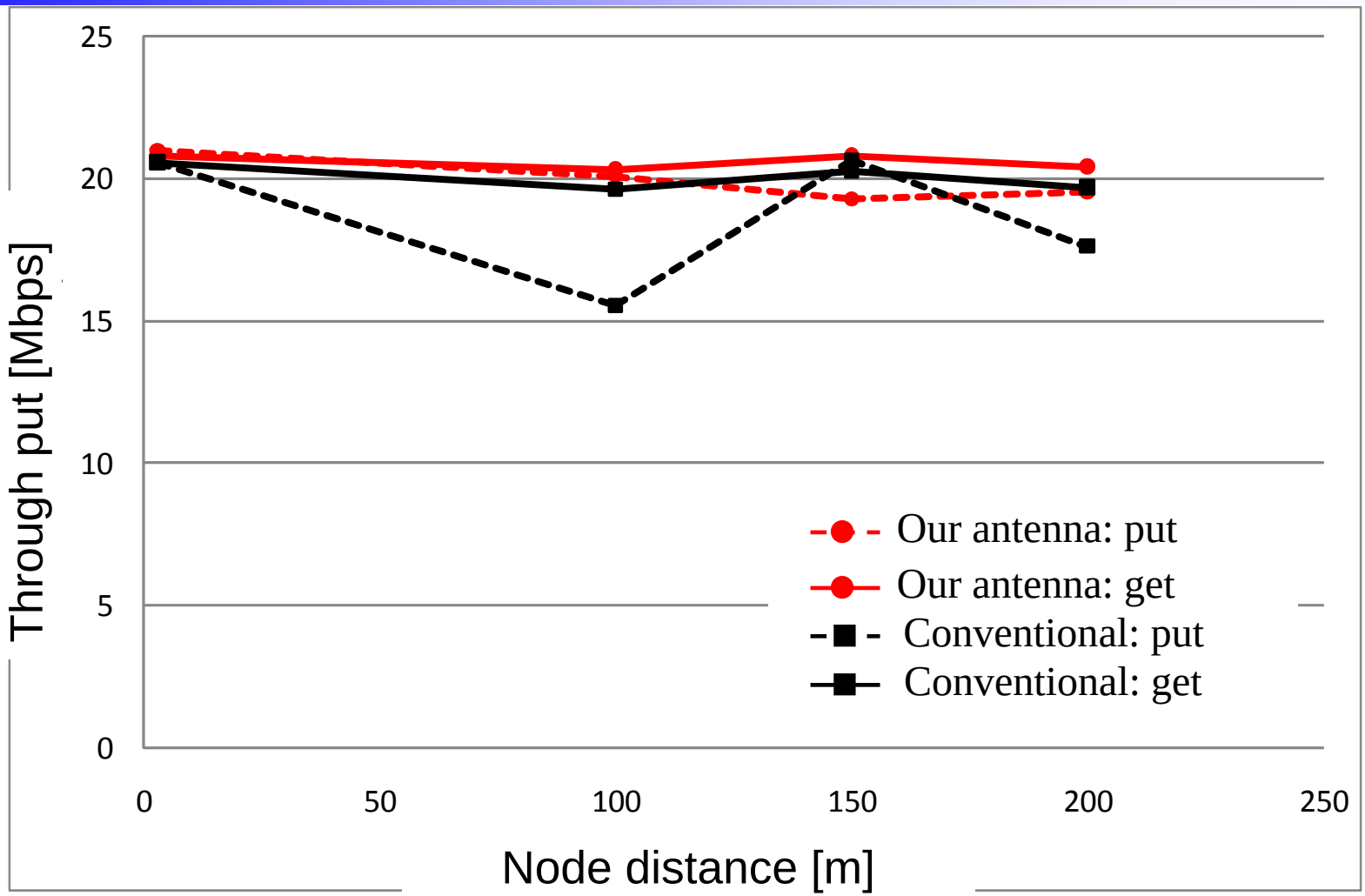
Node Photo

※Speed：36Mbps,　Frequency：52ch(5.26GHz),　Amp. output：17dBm(50mW)

Field: Building

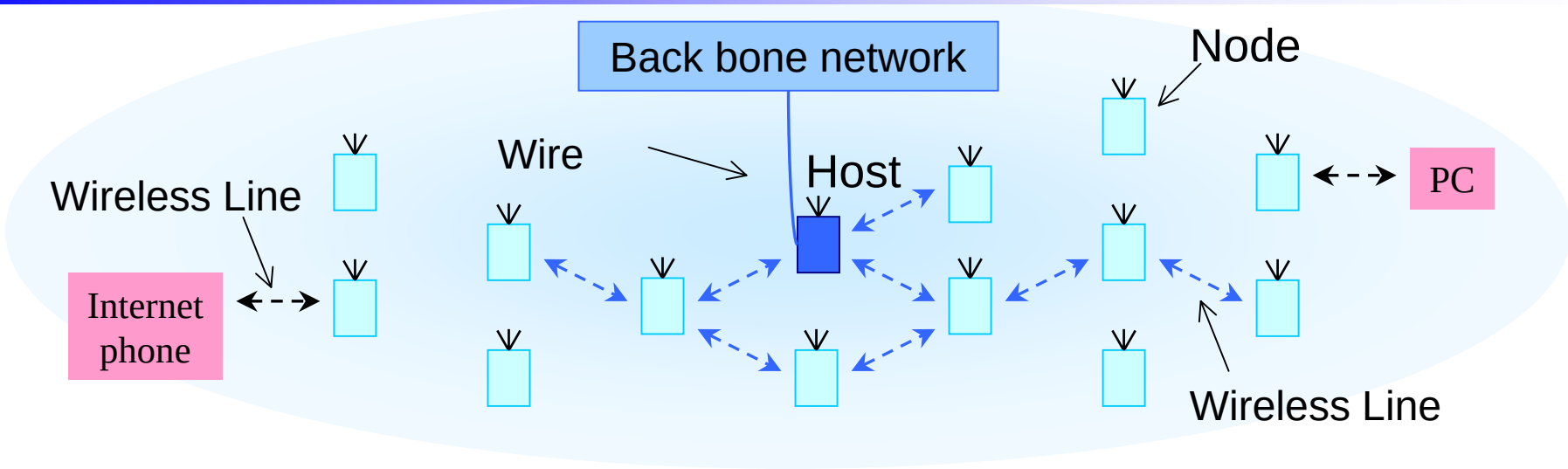


Measured communication distance



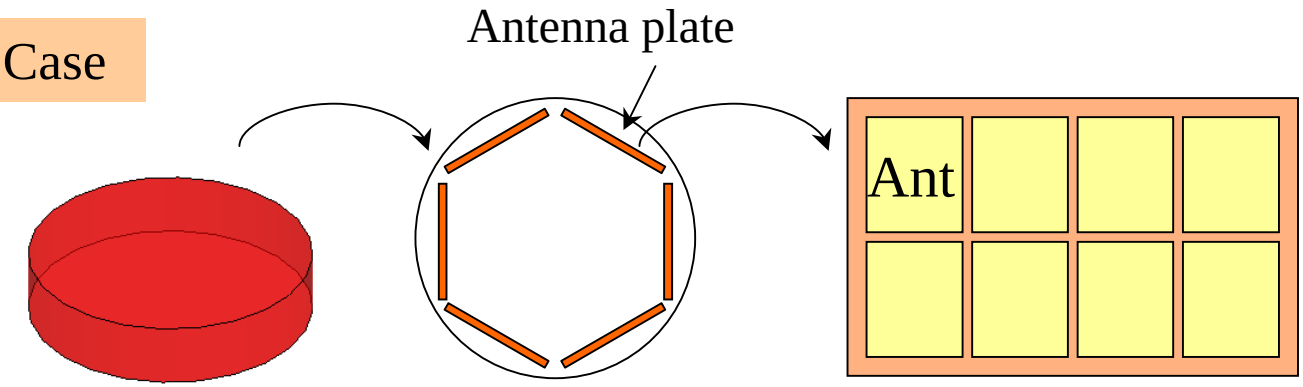
communication distance ＞ 200m

MIMO-MESH Point



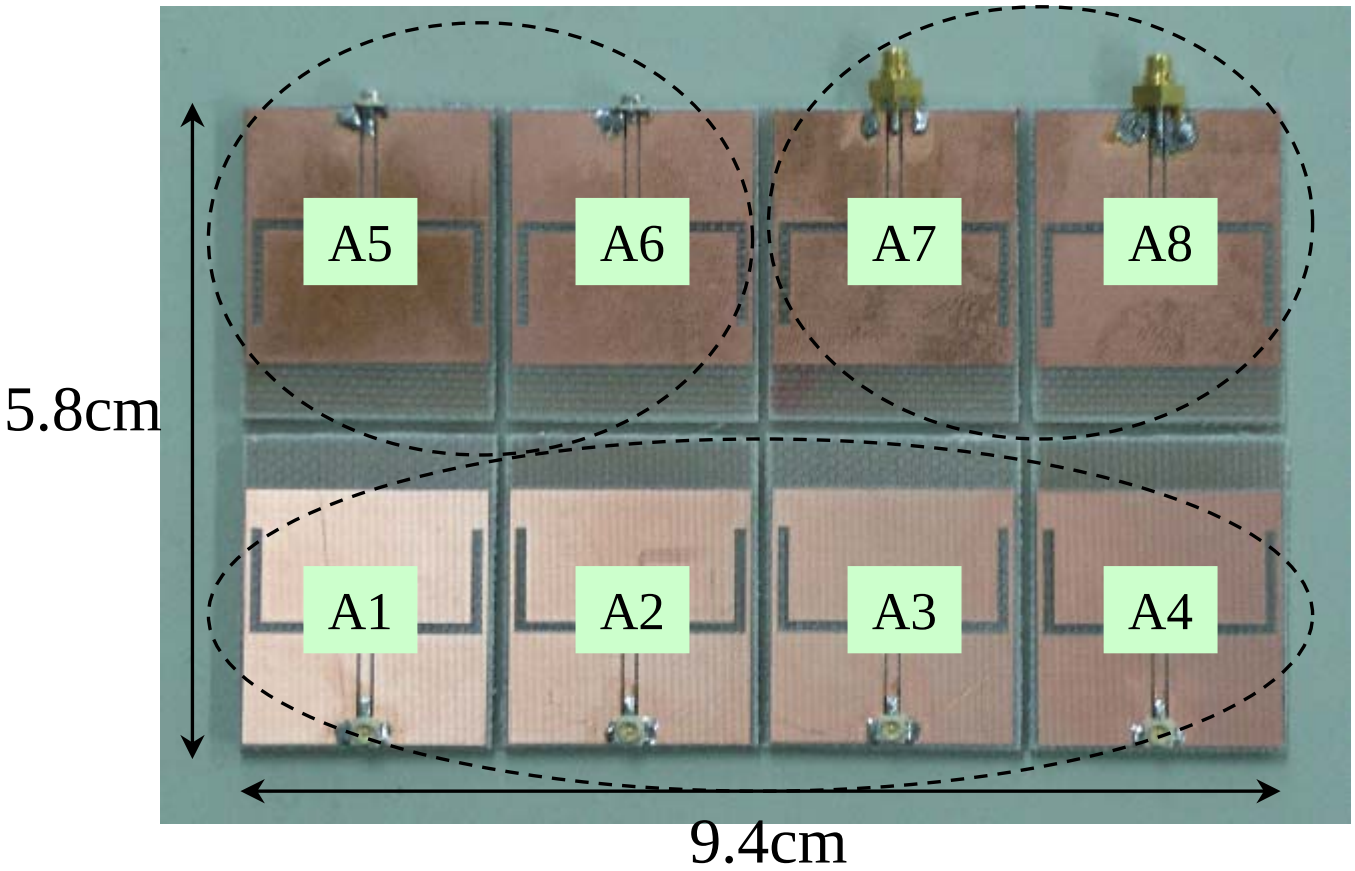
A small antenna is necessary !!

Case



- Small size
- One sided directional
- Wide band (4.9GHz～5.7GHz)

Antenna plate



Conclusion

- RF COMOS Front-end (RFIC)
- Planer type small antenna

Applications:3G, .11a,b &g, MIMO,PICO and UWB

Detail:

RFIC Japan

Thank you for your Attention!