EE719: Mixed Signal VLSI Design

Spring Semester Graduate Course

2014-2015 Session

by

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EE 719: Mixed Signal VLSI Design, Spring Semester 2015 (2014-2015 session)

- Professor: Prof. A.N.Chandorkar,
- EE Dept Office (E-Mail: anc@ee.iitb.ac.in)
- Class Time: 1105 AM – 12.35 PM
- Class Hrs: Wednesday and Friday (GG 401: CDEEP studio)
- Credits: 6 credits
- Objectives:
- To expose students to Mixed Signal Circuit Design which has revolutionized the world in every sphere. The Course emphasizes on Techniques one needs to adopt for implementation of Mixed Signal System as Integrated Circuit. It presents a detailed information on various Blocks of such a system required and their conflicting demands on Technology. Analog, Digital and RF circuits form part of most modern systems and their coexistence on a single chip, presents a tough challenge to Chip Designers.
- This Course highlights Design of some important system blocks like Filters(Continuous, Discrete and Digital) , Data Converters (ADC and DAC), Basic RF Modulators, Phased lock Loops , Interconnects in such systems and Mix signal Circuit Layout technique.

Course Text & Materials:

- CMOS Mixed-signal circuit design by R. Jacob Baker, Wiley India, IEEE press, reprint 2008.
- Design of Analog CMOS integrated circuits by Behzad Razavi, McGraw-Hill, 2003.
- CMOS circuit design, layout and simulation by R. Jacob Baker, Revised second edition, IEEE press, 2008.
- RF Microelectronics by Behzad Razavi, Mc Graw Hill
- CMOS Integrated ADCs and DACs by Rudy V. dePlassche, Springer, Indian edition, 2005.
- Electronic Filter Design Handbook by Arthur B. Williams, McGraw-Hill, 1981.
- Design of Analog filters by R. Schauman, Prentice-Hall 1990 (or newer additions).
- An introduction to Mixed-signal IC test and measurement by M. Burns et al., Oxford university press, first Indian edition, 2008.

Examination Schedules

Spring Semester Exam Dates:

Quiz/Cum Test -1: 1st Week in February 2015

Test - 2 : 3rd Week in March 2015

Mid-Semester Exam: February 2015(Institute Time table or as decided by us)

End-Semester Exam: Mid- April 2015

All Examinations except

Mid-semester and End semester ones will be from 8.45 to 10.45 PM slot in GG 001 OR GG 002

Home assignments/Project submission as per announced dates , time to time.

Mixed-signal systems

- **Analog/mixed-signal chips are those** :
  that at least partially deal with input signals whose precise values matter
- **This broad class includes RF, Analog, Analog-to-Digital and Digital-to-Analog conversion**

&

- **More recently, a large number of *Mixed-Signal chips* where at least part of the chip design needs to measure signals with high precision.**
  These chips have very different Design and Process Technology demands than normal Digital circuits.

Mixed Signal VLSI is possible in SoC form

- What is a System-on-Chip?

  ---------------These days, It is a Mixed Signal Chip in real life

- • Whatever marketing department believes to be more complex than the usual state-of-the art

- • As a general rule today's 'SoC's will be components of tomorrow SoC

- General characteristics:

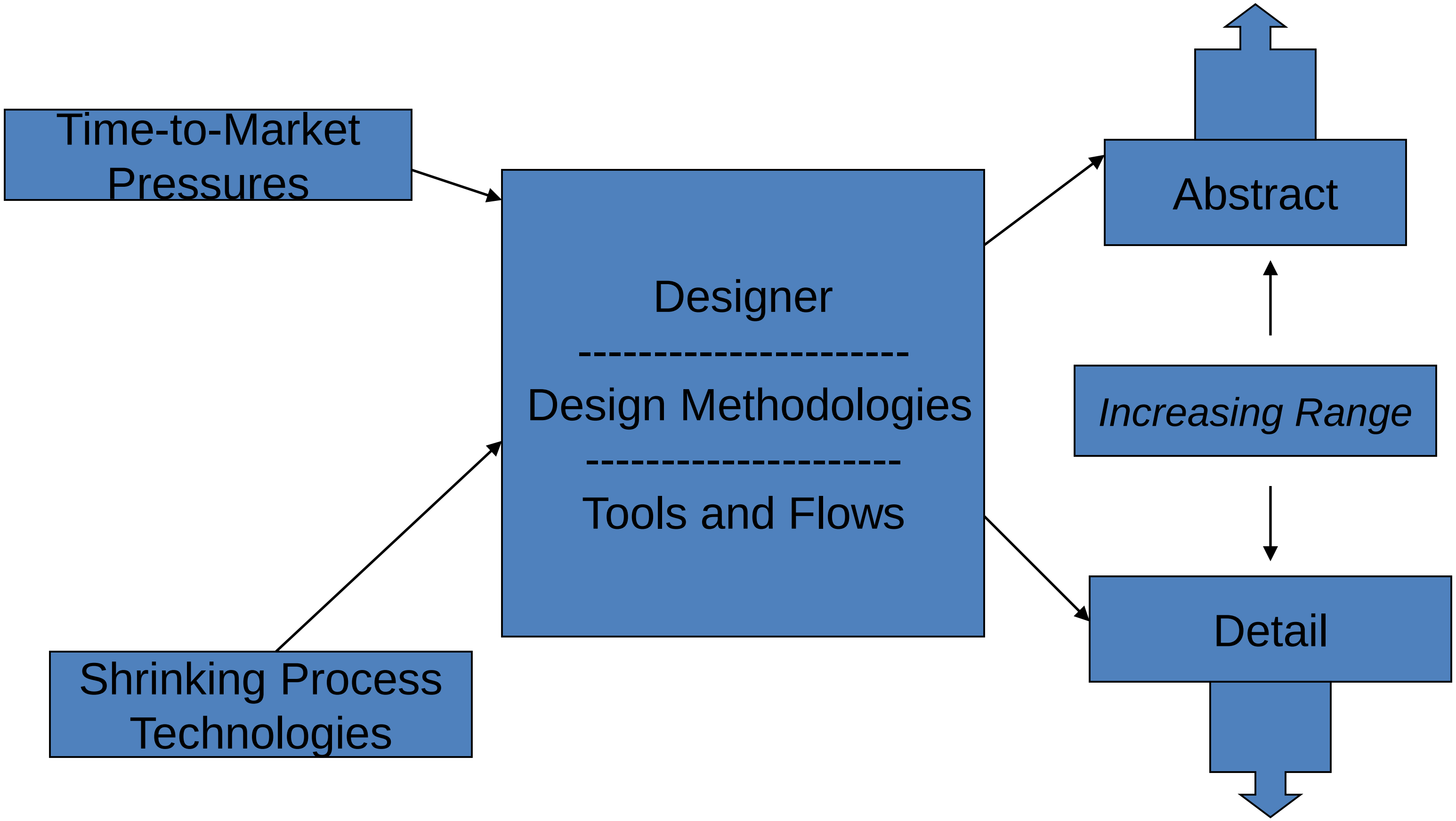
  – High complexity

  – Heterogeneity

  _ Of Blocks (Logic, Analog, µC, +DSP, +memory, +software....)

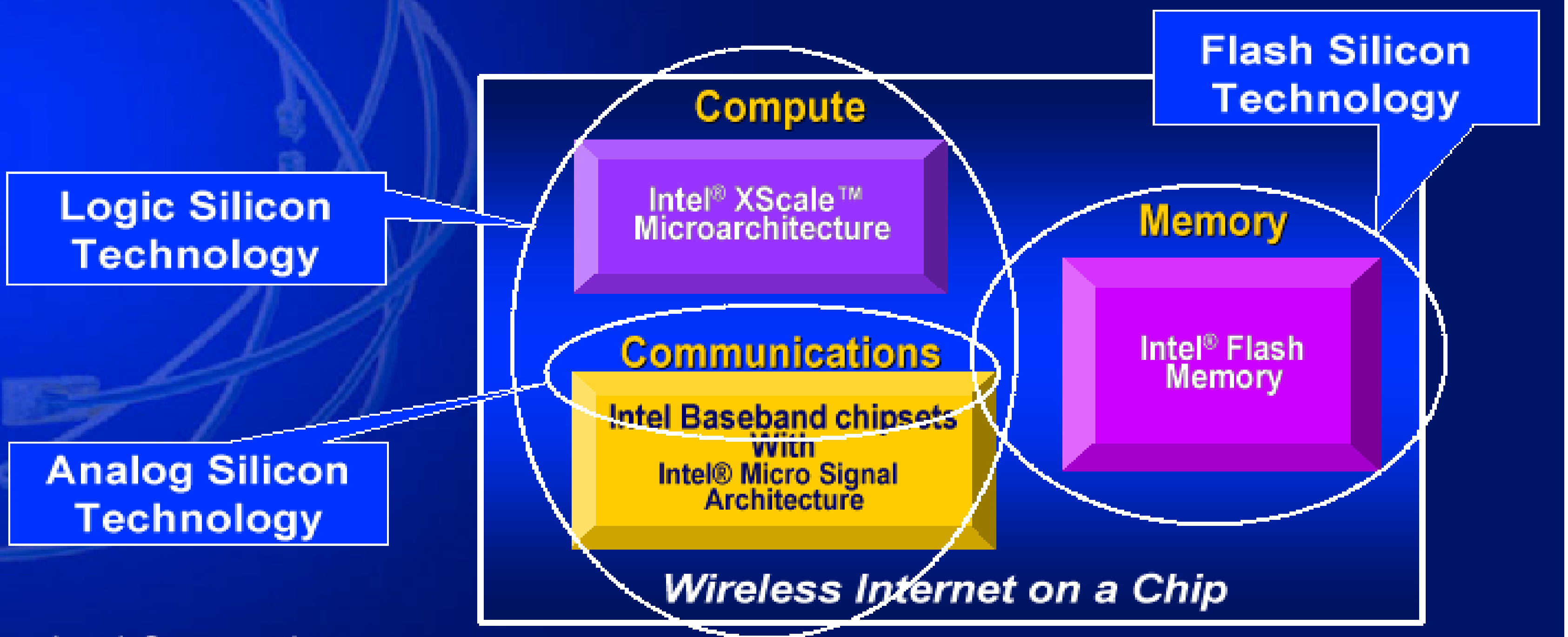
  __ Of Technology (logic, +RF, +DRAM, +NVM...)

Design Drivers and Design Methodology Gaps.



Compute, Communications and Memory Integration: Intel Core Silicon Technology Strengths

- Industry leaders in flash + Industry leaders in logic = Industry highest performing integrated silicon.

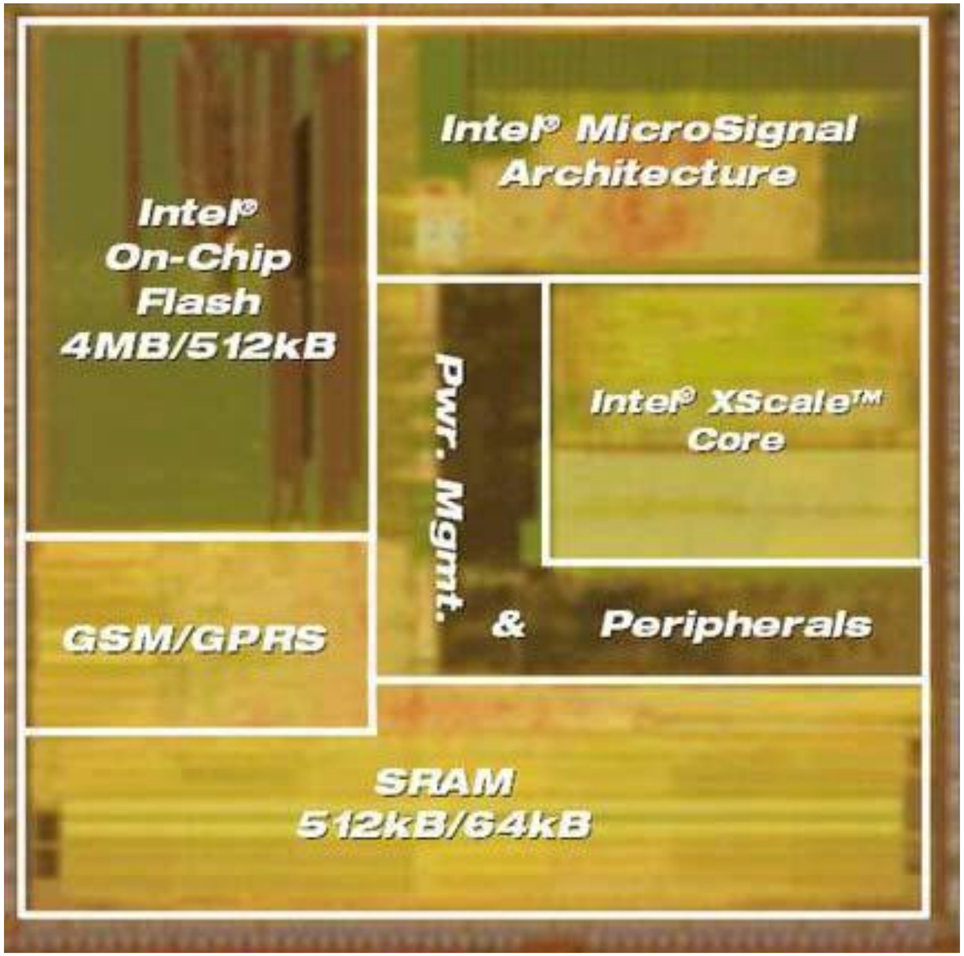


Intel Corporation

Typical Application: Intel PXA800F

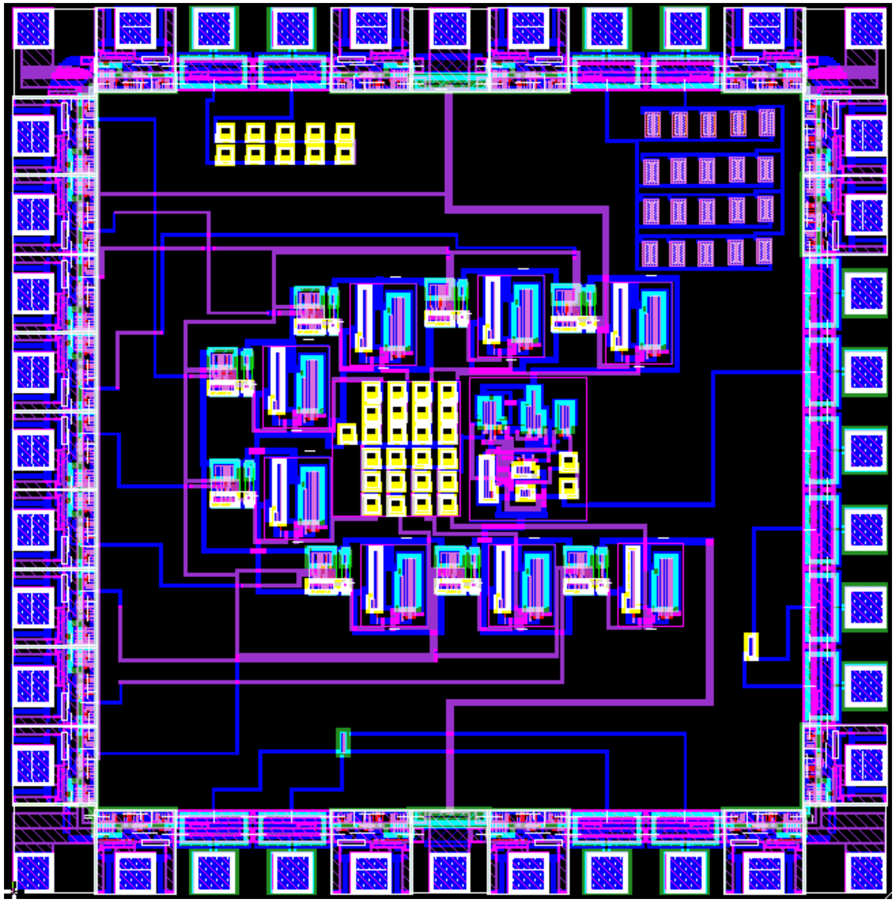
Industry's First Complete GSM/GPRS Class solution

- **Intel® XScale ™ Core**
- **Intel® Micro Signal Architecture**
- **Intel® On-Chip Flash Memory**
- **GSM/GPRS Communications Stack, RTOS and applications code for a single-chip mobile solution**



8-bit DAC

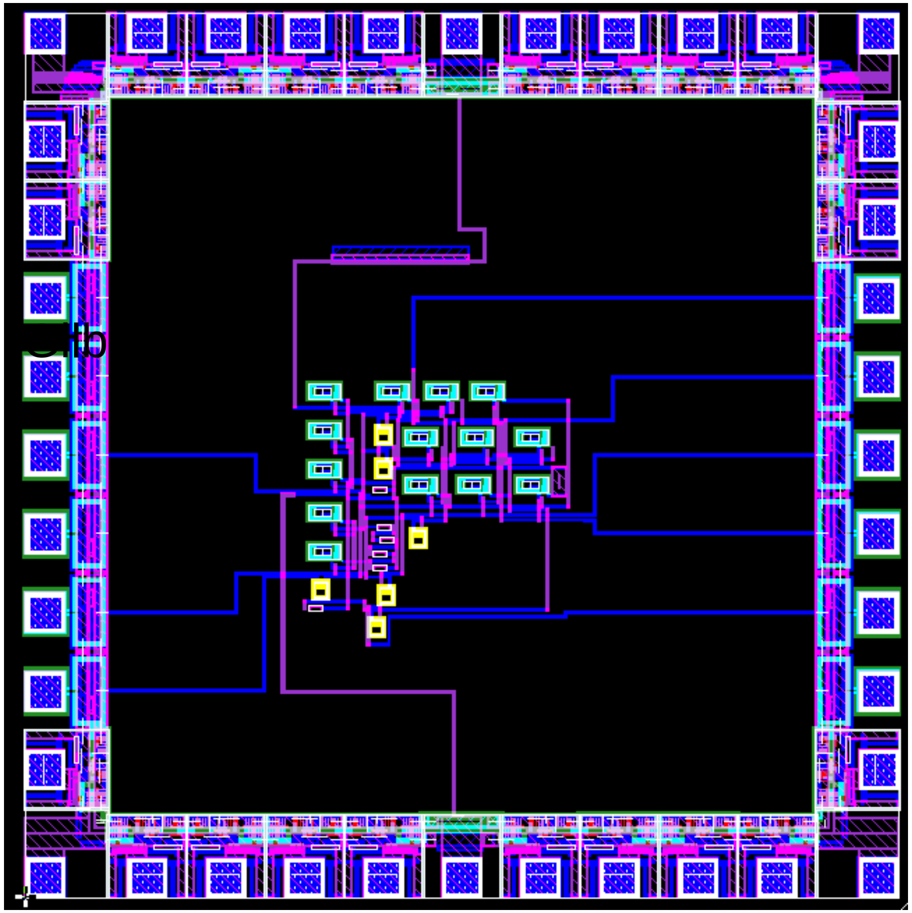
Specifications:
5 V supply
2 micron CMOS
50 M samples/second
8 bit resolution
0-5 V out



http://wws2.uncc.edu/tpw/mixsig/gilbjt.html

Gilbert Cell

Specifications:
5 V supply
2 micron BJT
100+ MHz operation

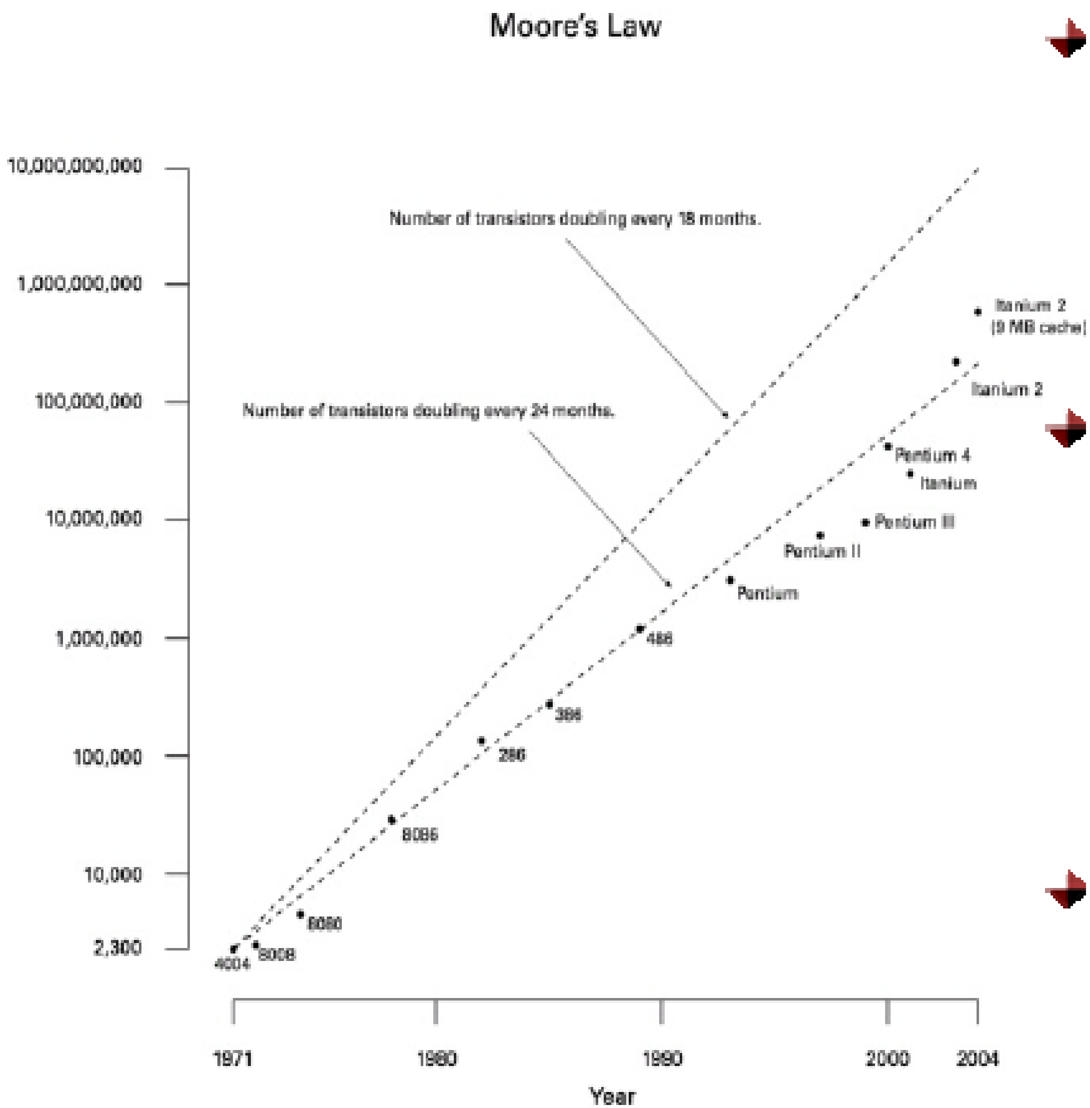


http://wws2.uncc.edu/tpw/mixsig/gilbjt.html

RF VLSI Design: Issues and Applications

- Motivation
- Market drivers for single chip transceiver
- RF Integration Challenges and solution trends
  - Front-End Integration
  - Multi-mode integration
  - Integration with the baseband
  - RF SoC Design and Methodology
- Conclusions

Motivation



- Discuss the trends and challenges of single chip radio frequency integration
- An overview of current solutions and today challenges to keep up with Moore's law in RFIC integration
- Engineering Innovation overcomes the RFIC integration challenges

RF Systems for VLSI Design

Global System for Mobile communications (**GSM**: originally from *Groupe Spécial Mobile*) is the most popular standard for mobile phones in the world.

GSM is a cellular network, which means that mobile phones connect to it by searching for cells in the immediate vicinity. GSM networks operate in four different frequency ranges. Most GSM networks operate in the 900 MHz or 1800 MHz bands. Some countries in the Americas (including Canada and the United States) use the 850 MHz and 1900 MHz bands because the 900 and 1800 MHz frequency bands were already allocated.

The rarer 400 and 450 MHz frequency bands are assigned in some countries, notably Scandinavia, where these frequencies were previously used for first-generation systems.

In the 900 MHz band the uplink frequency band is 890–915 MHz, and the downlink frequency band is 935–960 MHz. This 25 MHz bandwidth is subdivided into 124 carrier frequency channels, each spaced 200 kHz apart. Time division multiplexing is used to allow eight full-rate or sixteen half-rate speech channels per radio frequency channel. There are eight radio timeslots (giving eight burst periods) grouped into what is called a TDMA frame. Half rate channels use alternate frames in the same timeslot. The channel data rate is 270.833 kbit/s, and the frame duration is 4.615 ms.

RF Systems (Continued)

Code division multiple access (**CDMA**) is a channel access method utilized by various radio communication technologies.

W-CDMA (**Wideband Code Division Multiple Access**) is a type of 3G cellular network. W-CDMA is the higher speed transmission protocol used in the UMTS system.

Universal Mobile Telecommunications System (**UMTS**) is one of the third-generation (3G) cell phone technologies. Currently, the most common form uses W-CDMA **.**

Wi-Fi is a Wireless technology brand owned by the **Wi-Fi** Alliance intended to improve the interoperability of wireless.

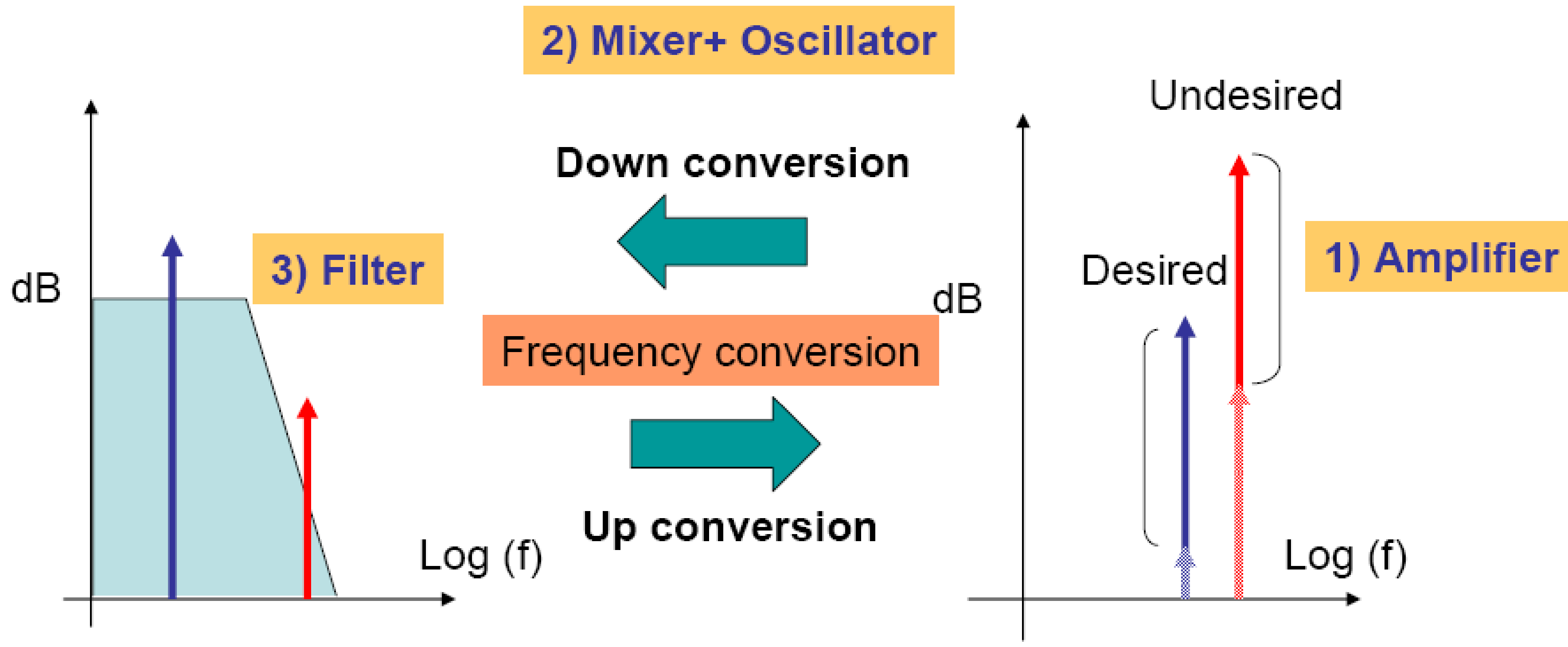
WiMAX, the **W**orldwide **I**nteroperability for **M**icrowave **Acc**ess, is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways, from point-to-point links to full mobile cellular type access. It is based on the IEEE 802.16 standard, which is also called WirelessMAN..

A wireless LAN or WLAN is a wireless local area network, which is the linking of two or more computers without using wires. WLAN utilizes spread-spectrum or OFDM modulation technology

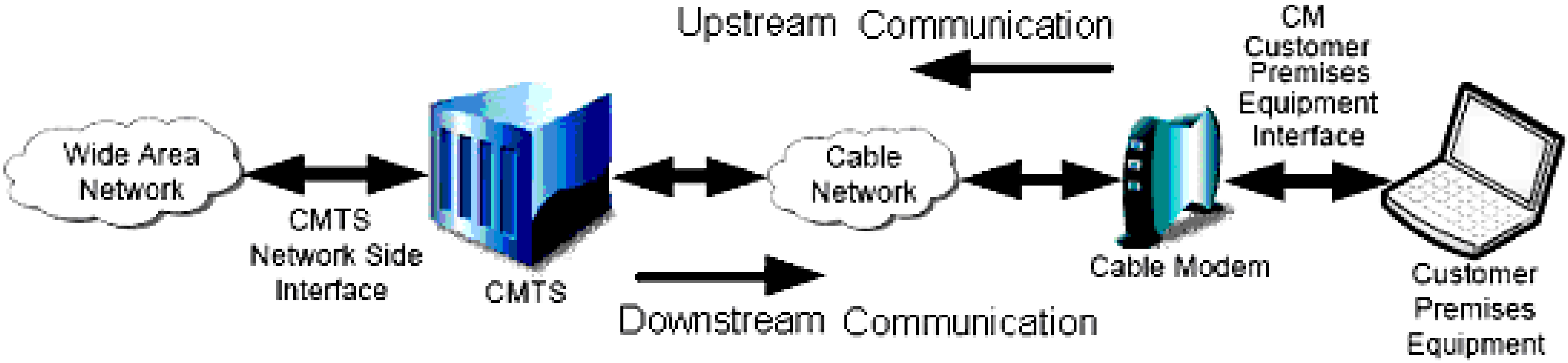
DCS1800 - Digital Cellular System 1800MHz. Digital Cellular System 1800MHz is a term given to what is now known as GSM1800

Basic functions of RF building blocks

Amplifier, frequency converter (mixer +oscillator), and filer are basic function blocks in RF system.

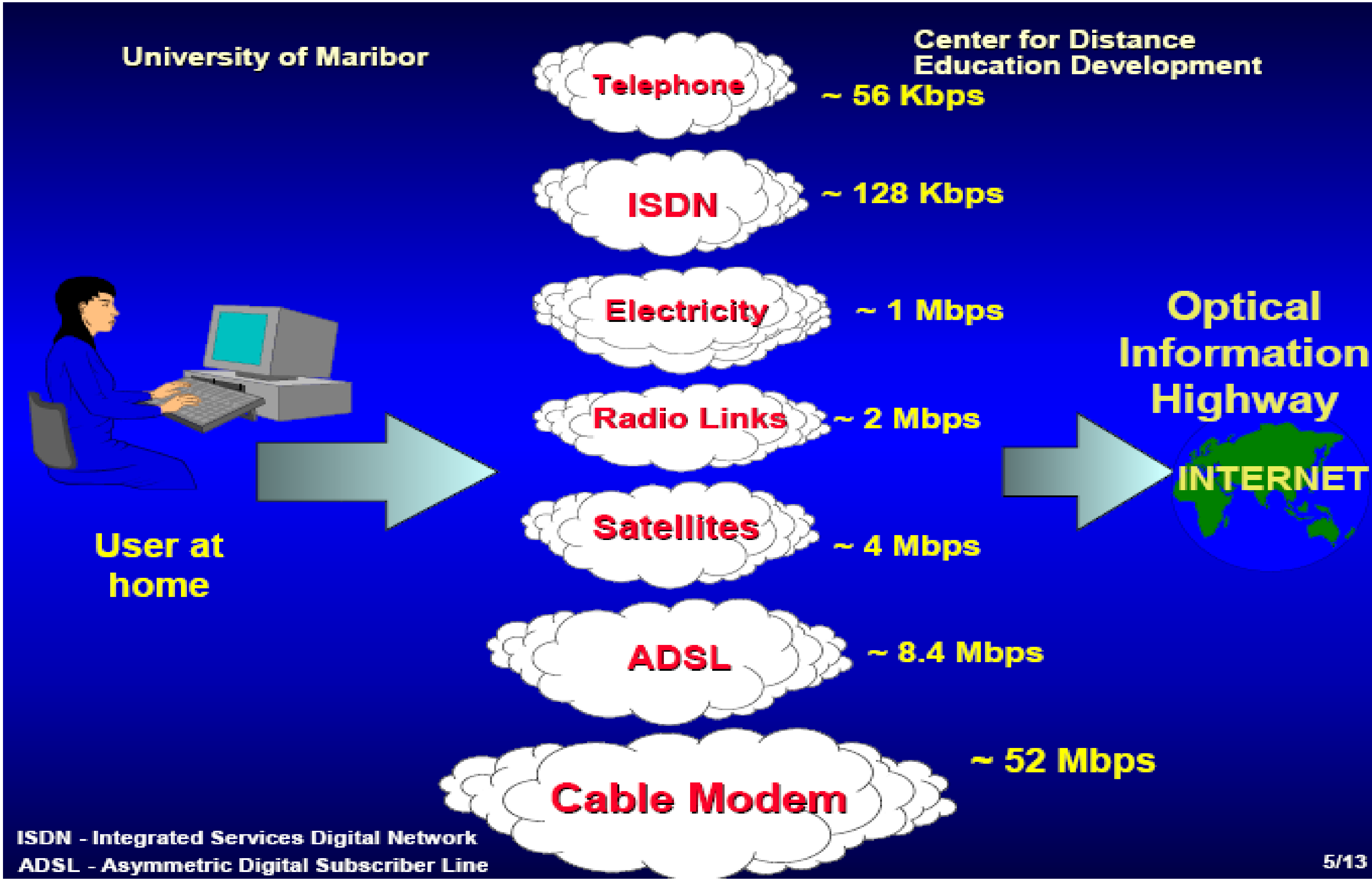


Application…. CABLE MODEM

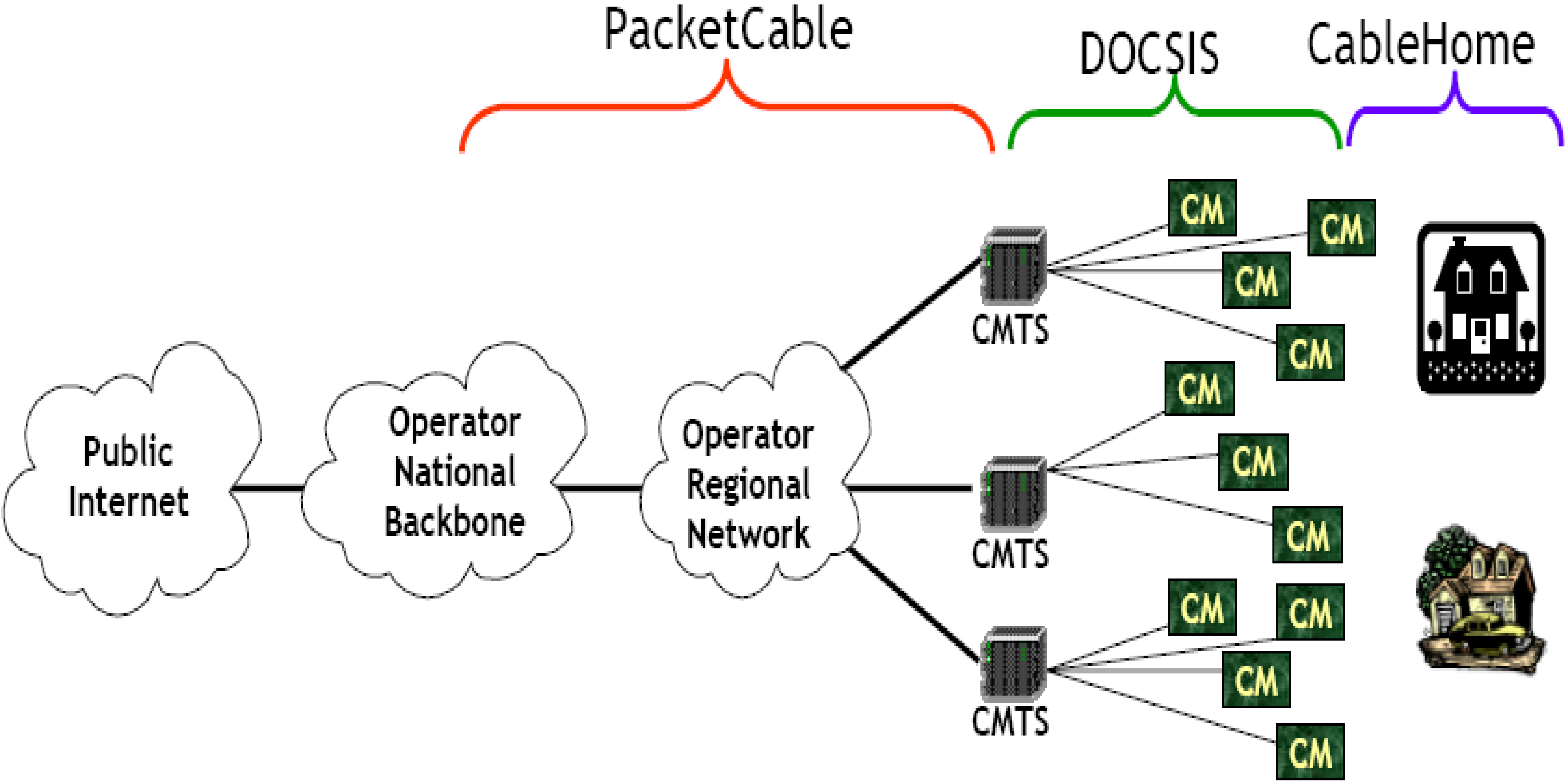


Block Diagram Of Cable Network

Data rate :Home to Internet



CableHome Architecture



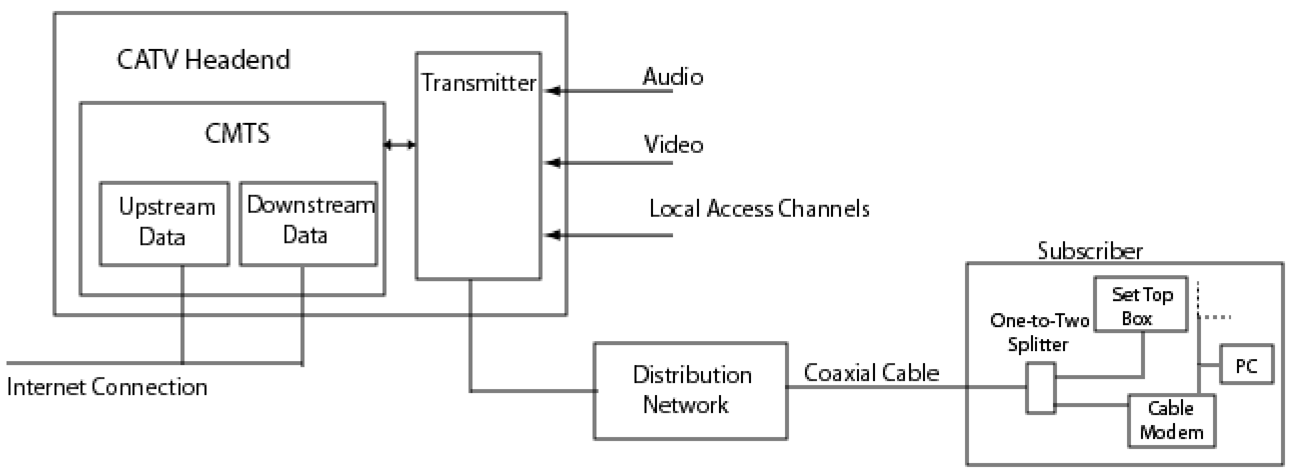
Cable Modem Basics

- Cable TV (CATV) Network serves as the Internet Service Provider (ISP)
- Cable Modem modulates/transmits and demodulates/receives to/from a CATV channel
- Downstream: data received at the modem is communicated to one or more PCs on a LAN via Ethernet, USB, PCI Bus, etc.
- Upstream: data requests from the PC are transmitted through the modem to the CATV network via coaxial cable, phone line or wireless.
- CATV data service interfaces to the Internet via Cable Modem Termination System (CMTS)

Gina Colangelo

Cable Modem Network Overview

- **Headend: DOCSIS-certified CMTS (Cable Modem Termination System)**
  - **One Headend supports @ 2000 Cable Modem Users on a single TV Channel**
  - **CMTS interfaces the CATV network to the Internet**
- **CMTS output channel combined with TV video signals**
- **CATV Network to Subscriber via coaxial cable**
- **One-to-Two splitter: One signal to Set Top Box (STB), other to Cable Modem**
- **Cable Modem**
  - **One Modem can support up to 16 users in a local-area network**
- **PC/Ethernet Card**
  - **Cable Modem connected to PC via Ethernet, USB, PCI Bus, etc**

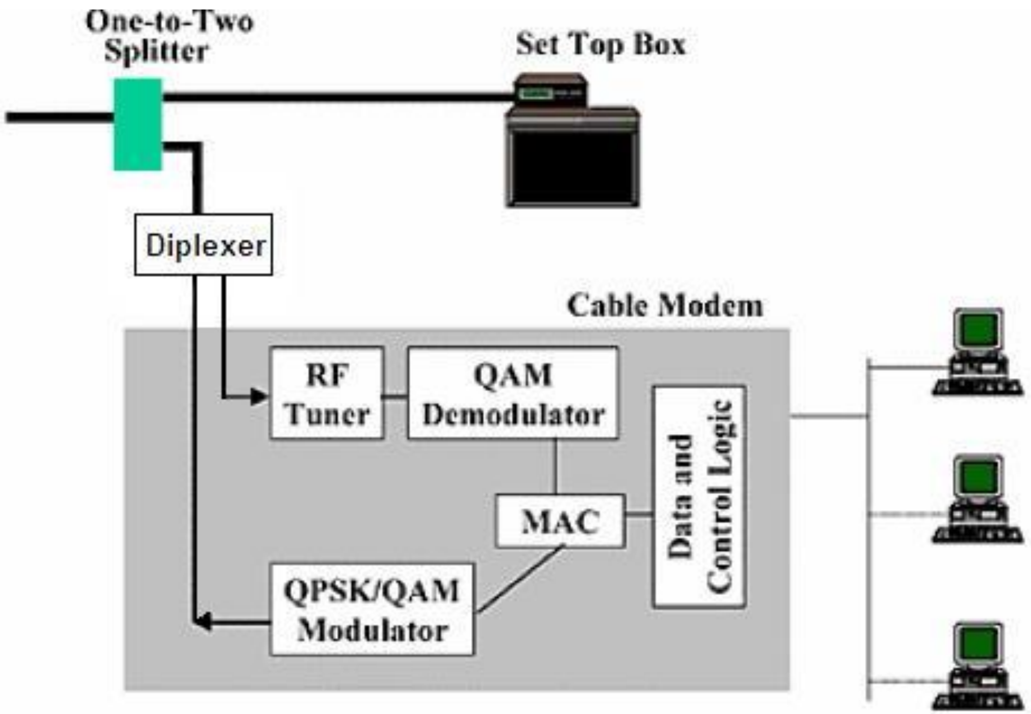


Data Over Cable Service Interface Specifications (DOCSIS) is an international standard

Gina Colangelo

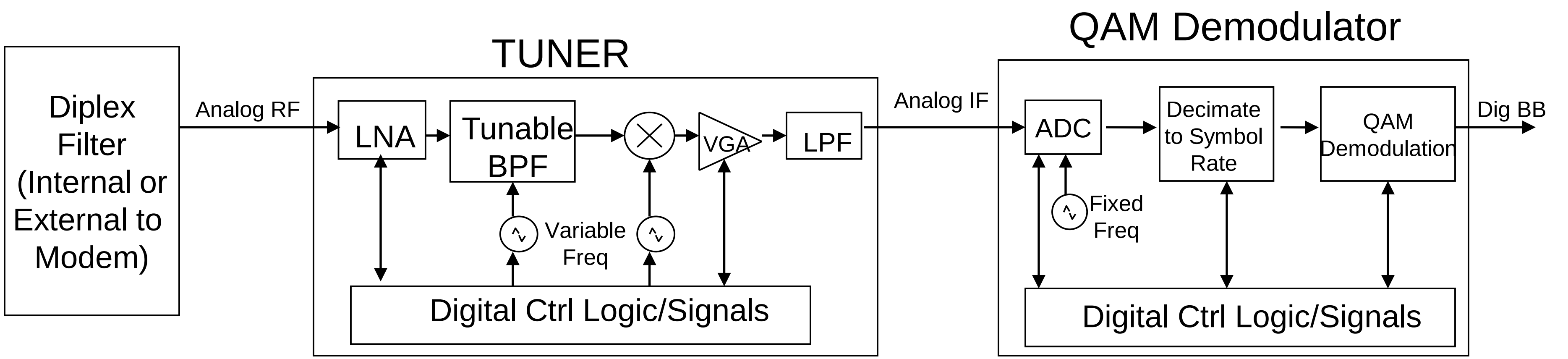
Cable Modem Architecture

- Transmit/Upstream
  - QPSK/QAM Modulator performs:
    - QPSK/QAM-16 modulation
    - Reed-Solomon Encoding
    - D/A Conversion
    - Up-conversion to the selected frequency/channel
- Receive/Downstream
  - RF Tuner
    - Converts TV Channel to a fixed lower frequency (6-40MHz)
  - QAM Demodulator performs:
    - A/D conversion
    - QAM-64/256 demodulation
    - MPEG frame synchronization
    - Error Correction (Reed-Solomon)
- MAC - Media Access Control
  - Implemented partially in hardware and software
- Data and Control Logic



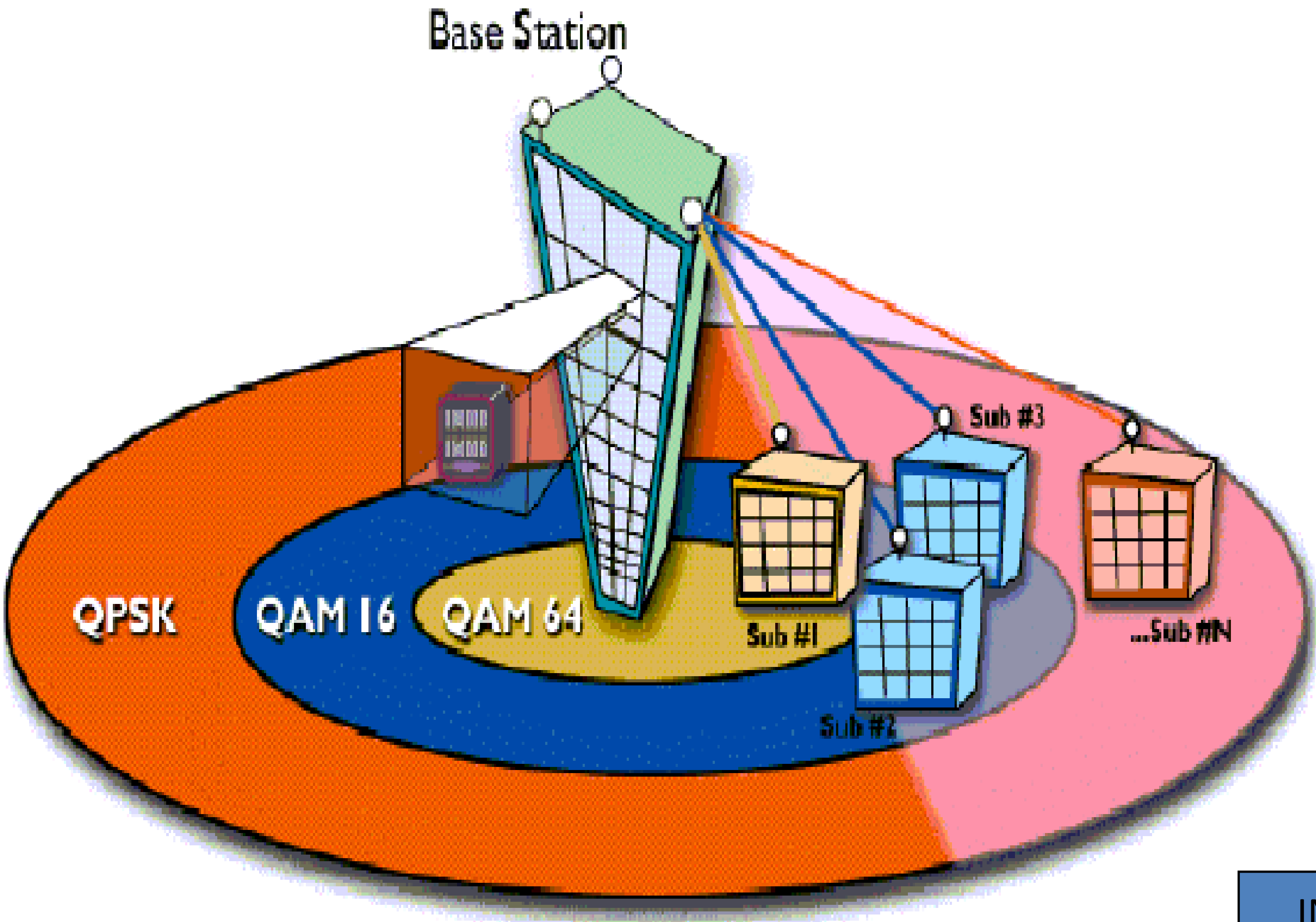
Receive Path

- Diplex Filter – splits/combines bands for 2-way capability on CATV systems
- Tuner – isolates TV channel and mixes it down to Analog IF (6-40MHz)
- Analog to Digital Conversion
- Decimation Filters to down-sample to the symbol rate (e.g. CIC)
- QAM Demodulator
  - MPEG Frame synchronization
  - Automatic Gain Control (AGC)
  - Equalizer – removes distortions, and cancels echoes or multi-path conditions
  - Carrier Removal
  - Automatic Frequency Control (AFC)



Generic Receive Path of a Cable Modem

Adaptive Digital Modulation



INTEL

Cable vs. DSL

- *Bandwidth/Data Rates*
  - Cable
    - Faster theoretical speeds (@ 30+ Mbps)
    - Average Plan: 6 Mbps down, 384 Kbps up ($43/mo + cable plan)
    - Scales by the number of subscribers using a particular channel
    - This problem can by resolved by the cable company adding more channels
  - DSL
    - Slower data rates (< 10 Mbps, except for the unpopular VDSL)
    - Average Plan: 1.5 Mbps down, and 128 kbps up ($35/mo + phone line)
    - More consistent speeds

- *Performance/Quality*
  - Cable: designed to provide digital signals at a particular quality (variable gain on upstream provides proper signal strength)
  - DSL: quality depends on distance from central office

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Mixer

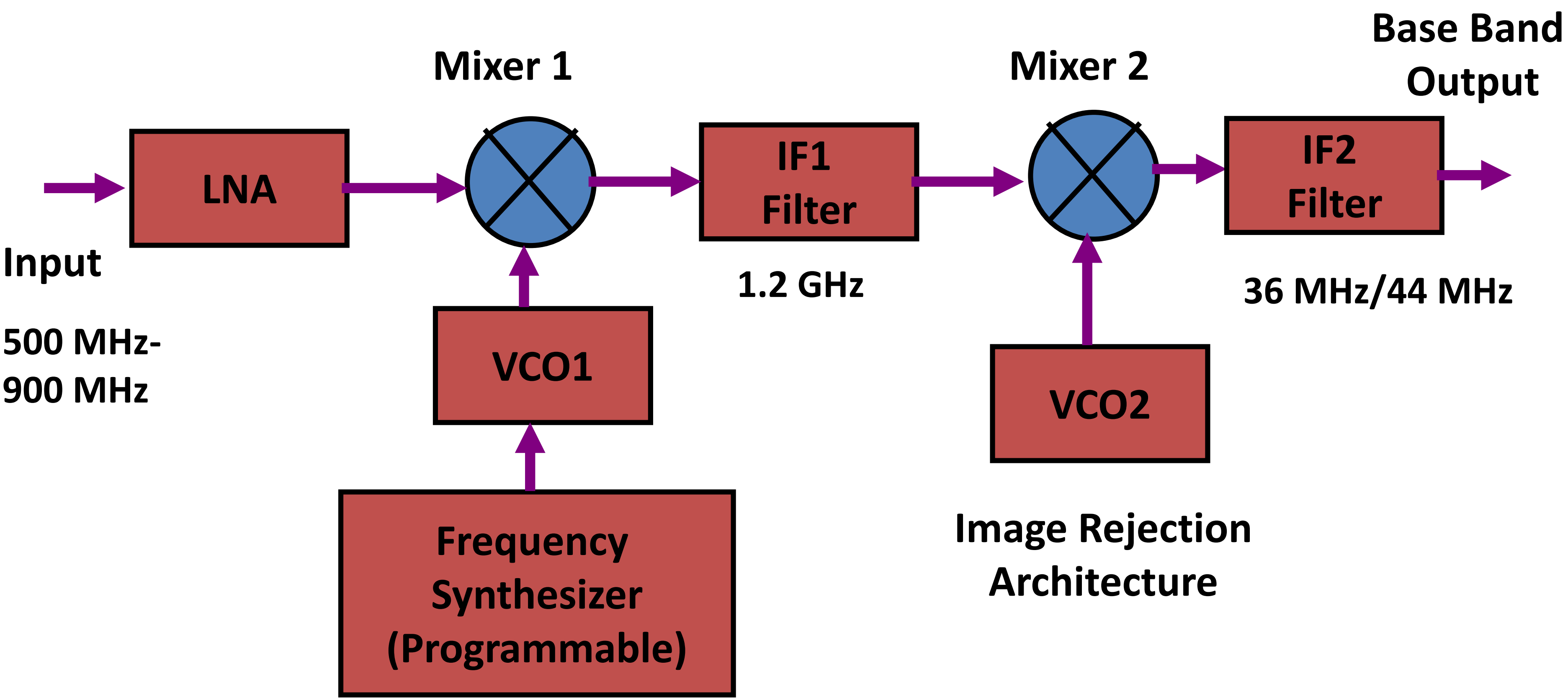
- **Single Stage**

1. Converts input frequency to intermediate frequency in single stage
2. Problem of reverse isolation
3. Image rejection is poor

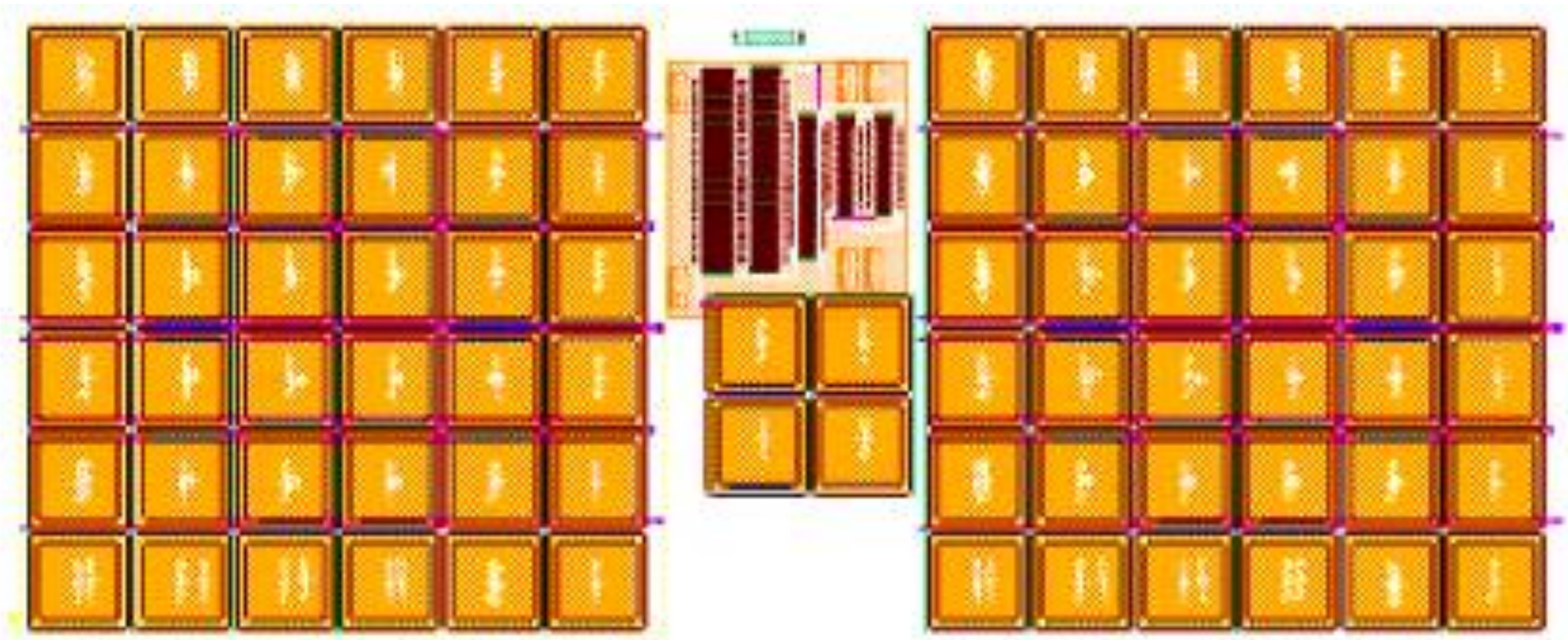
- **Multi Stage**

1. Converts input frequency to intermediate frequency in multiple stage
2. Image rejection is good with better selectivity and flat IF response

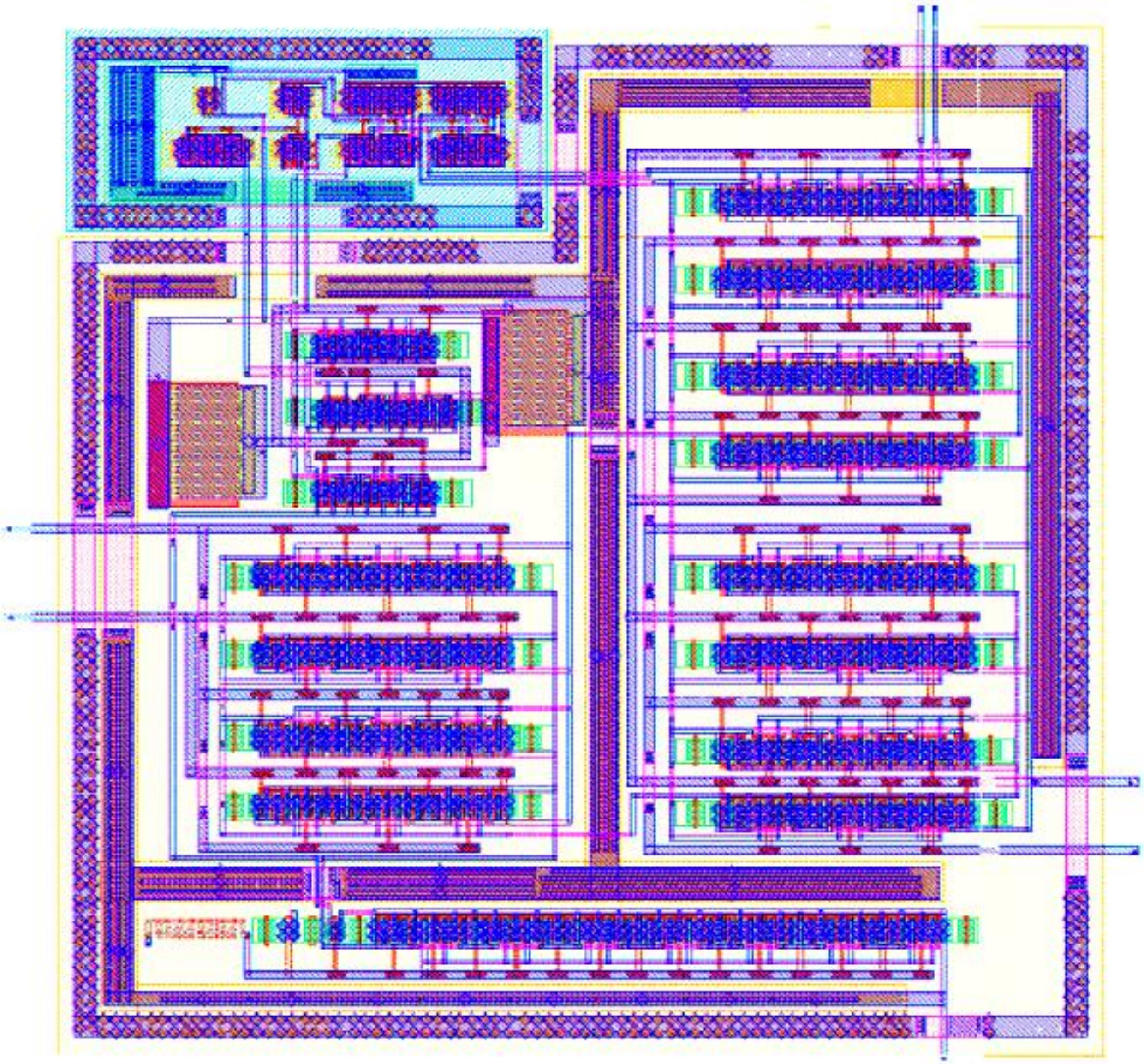
Block Diagram of RF Tuner



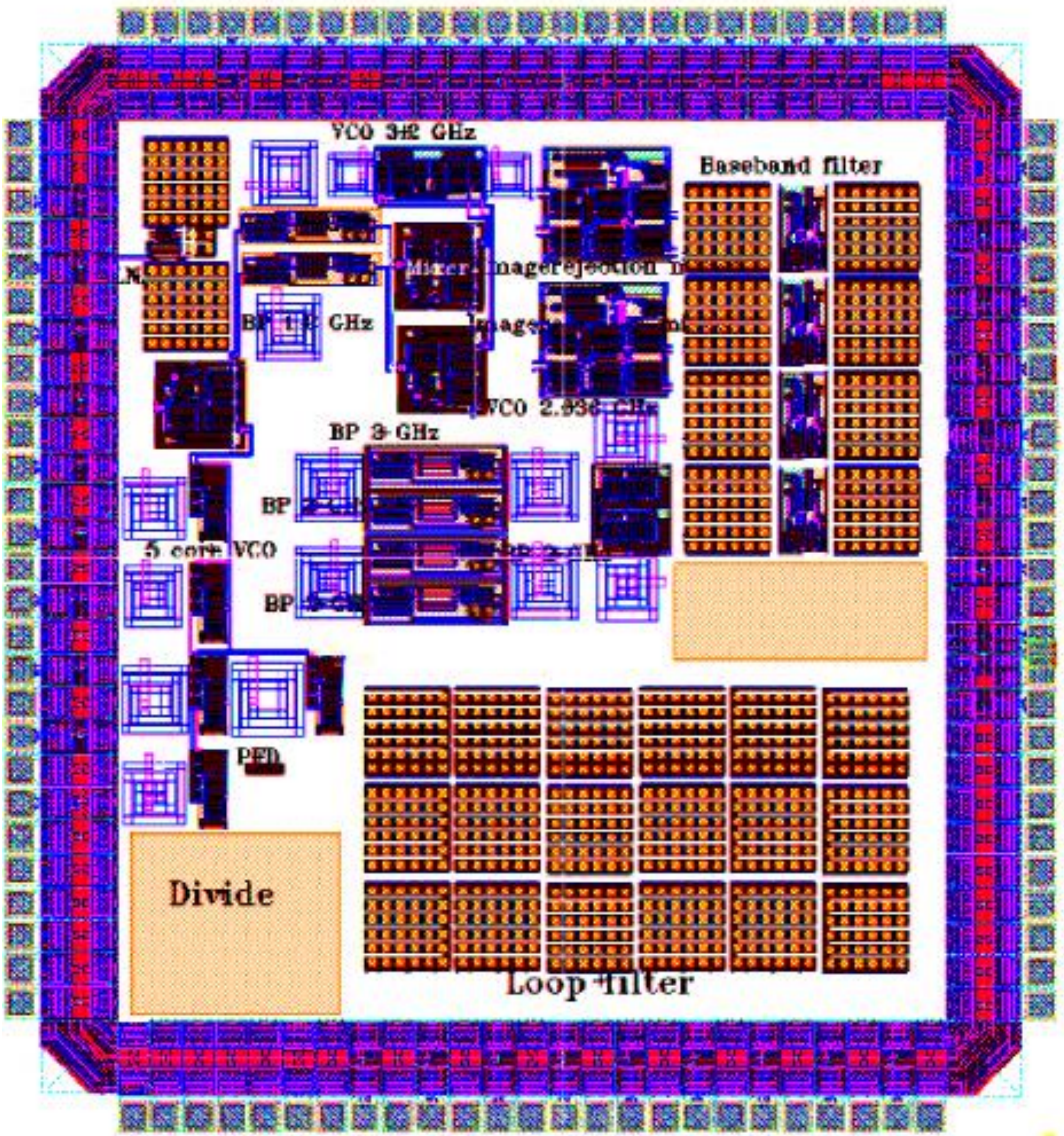
LNA Layout



Mixer Layout



Complete RF Tuner Layout



Chip Area
3mm X 3mm

A Multi-Standard ADC for GSM/WCDMA/Bluetooth

Presentation Overview

- **Need for multi-standard receivers**
-
- **Theory of sigma delta ADC**
- **Proposed sigma delta modulator architecture for multi-standard receivers**

Need for Multi-standard Receivers

- **Need for higher data rates**
- **Third generation wireless standards to support higher data rates over long range**
- **Bluetooth for short range wireless information transfer**
- **Third generation mobile devices need to support second generation**
- **Single chip integration to keep costs low.**

Multi-standard ADC

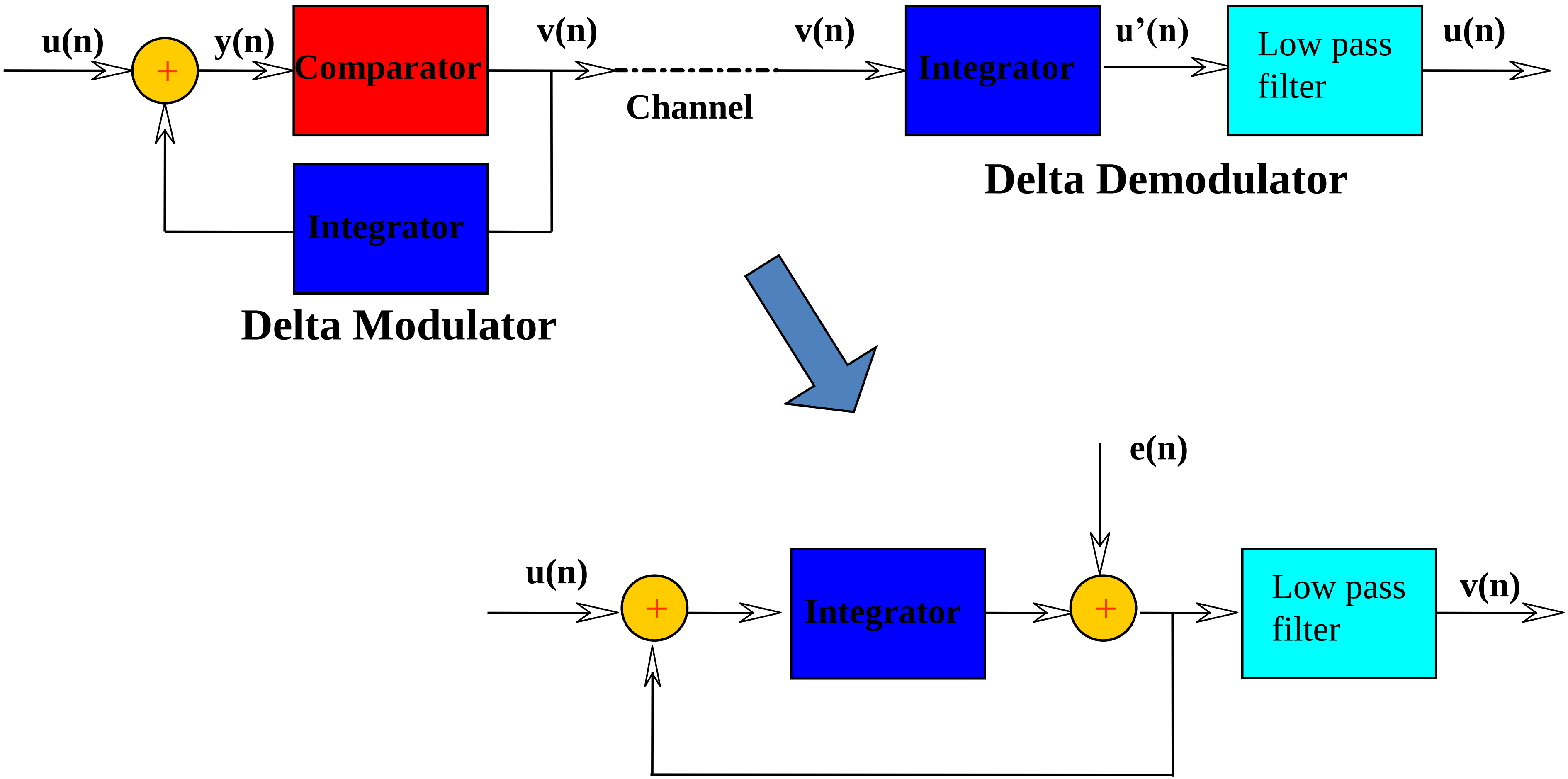
Multi-standard ADC requirements

Parameter	WCDMA	Bluetooth	GSM
Bandwidth	3.84MHz	2MHz	100kHz
Dynamic Range	55dB	50dB	86dB

Why sigma delta ADC?

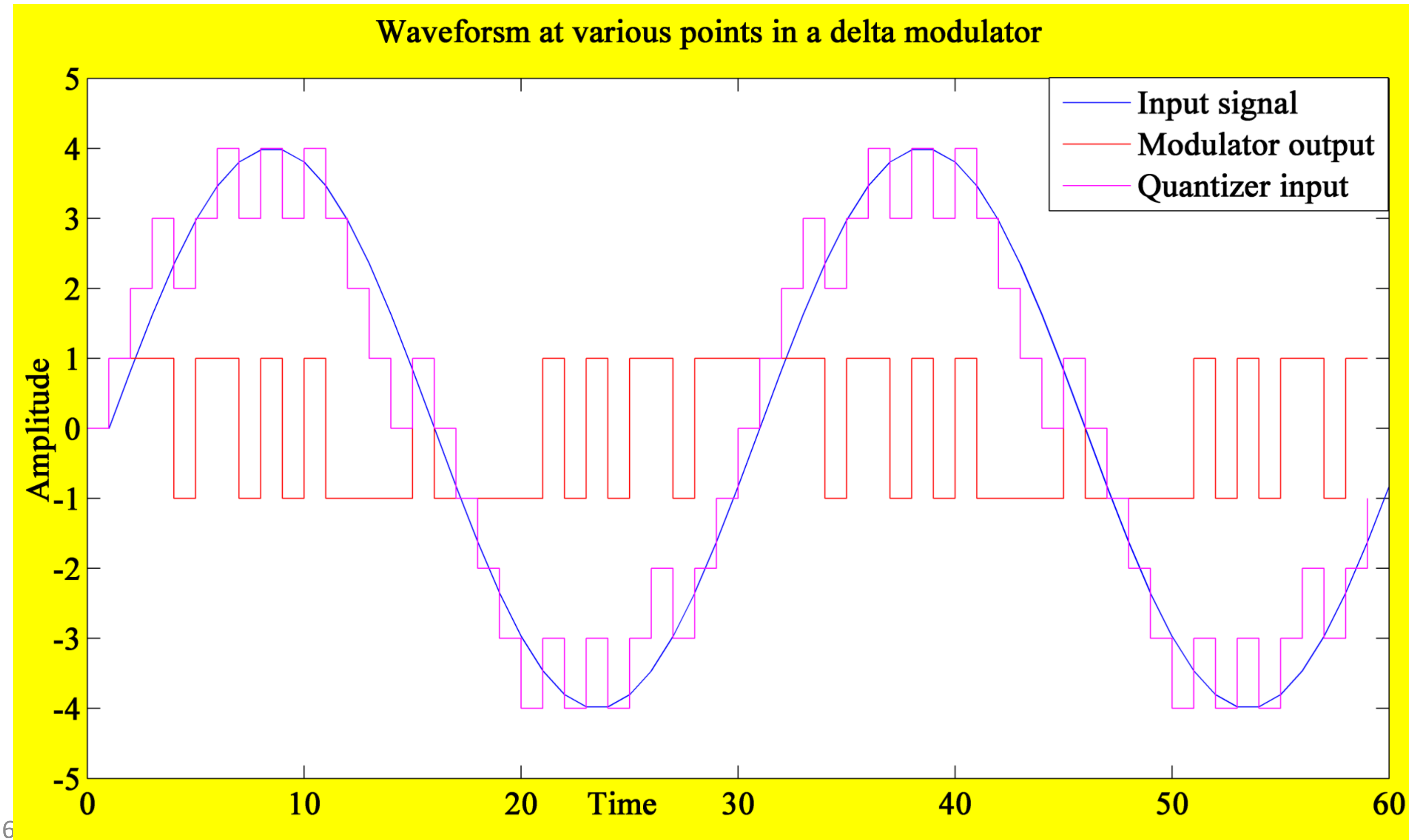
- **Allows trade-off between bandwidth and dynamic range**
- **Less sensitive to circuit imperfections**
- **Relaxed anti-alias filtering requirements suitable for multi-standard operation**

Theory of Sigma-delta ADC

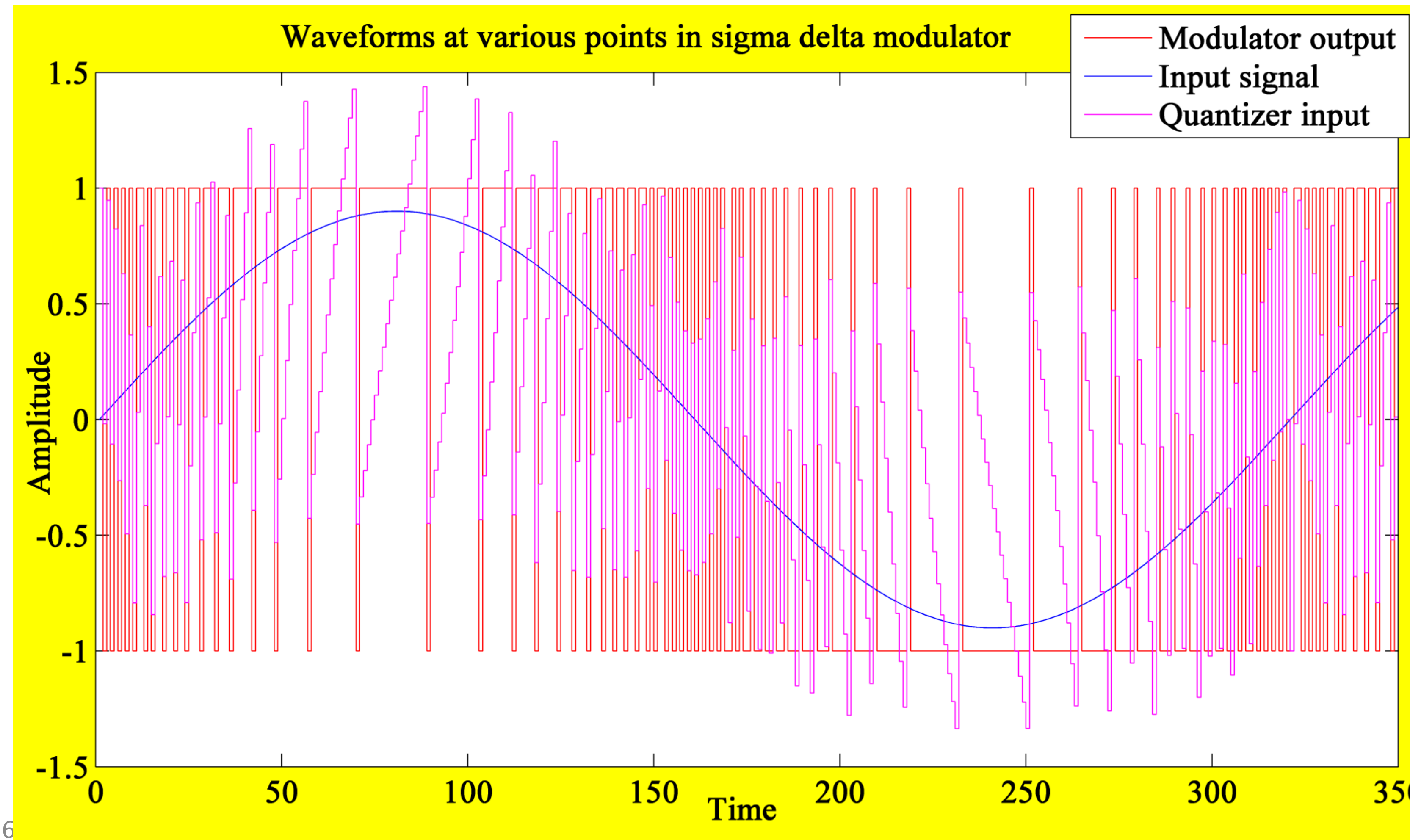


Sigma delta modulator

Signals in Delta Modulator



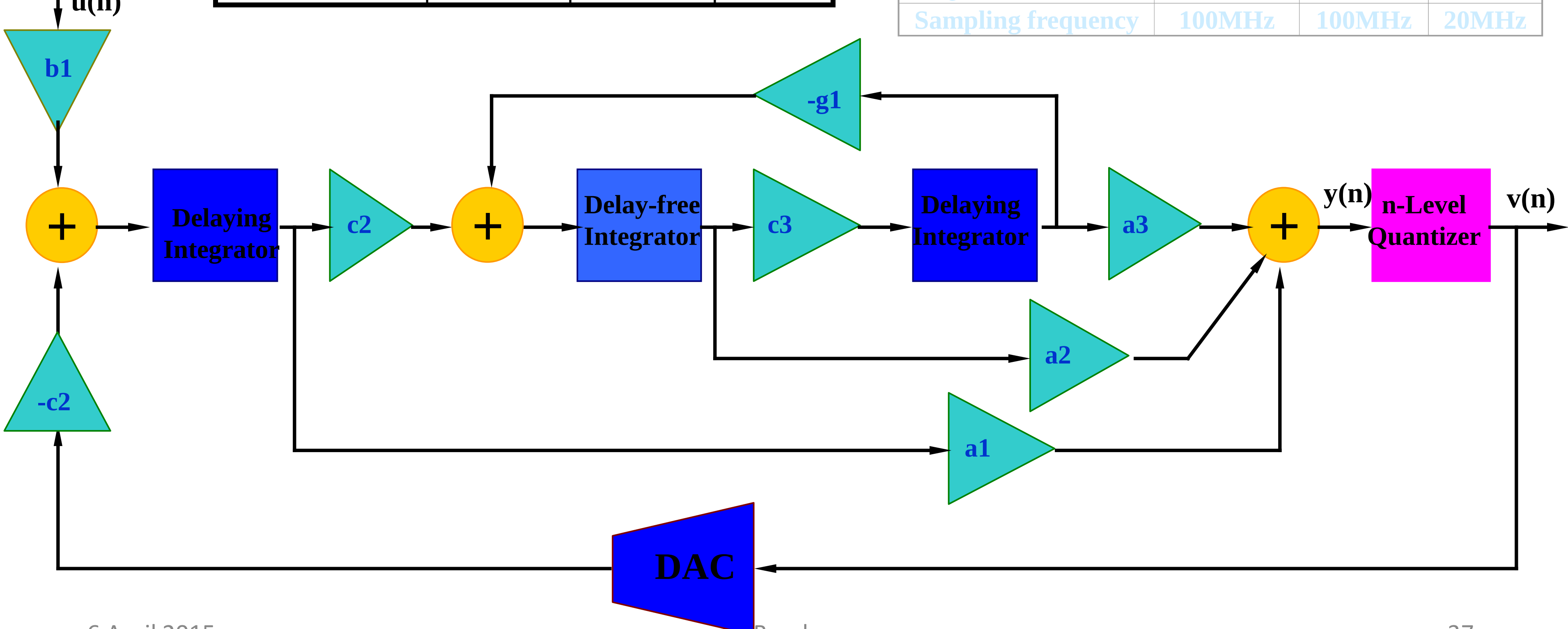
Signals in Sigma-delta Modulator



Architecture of the Proposed Modulator

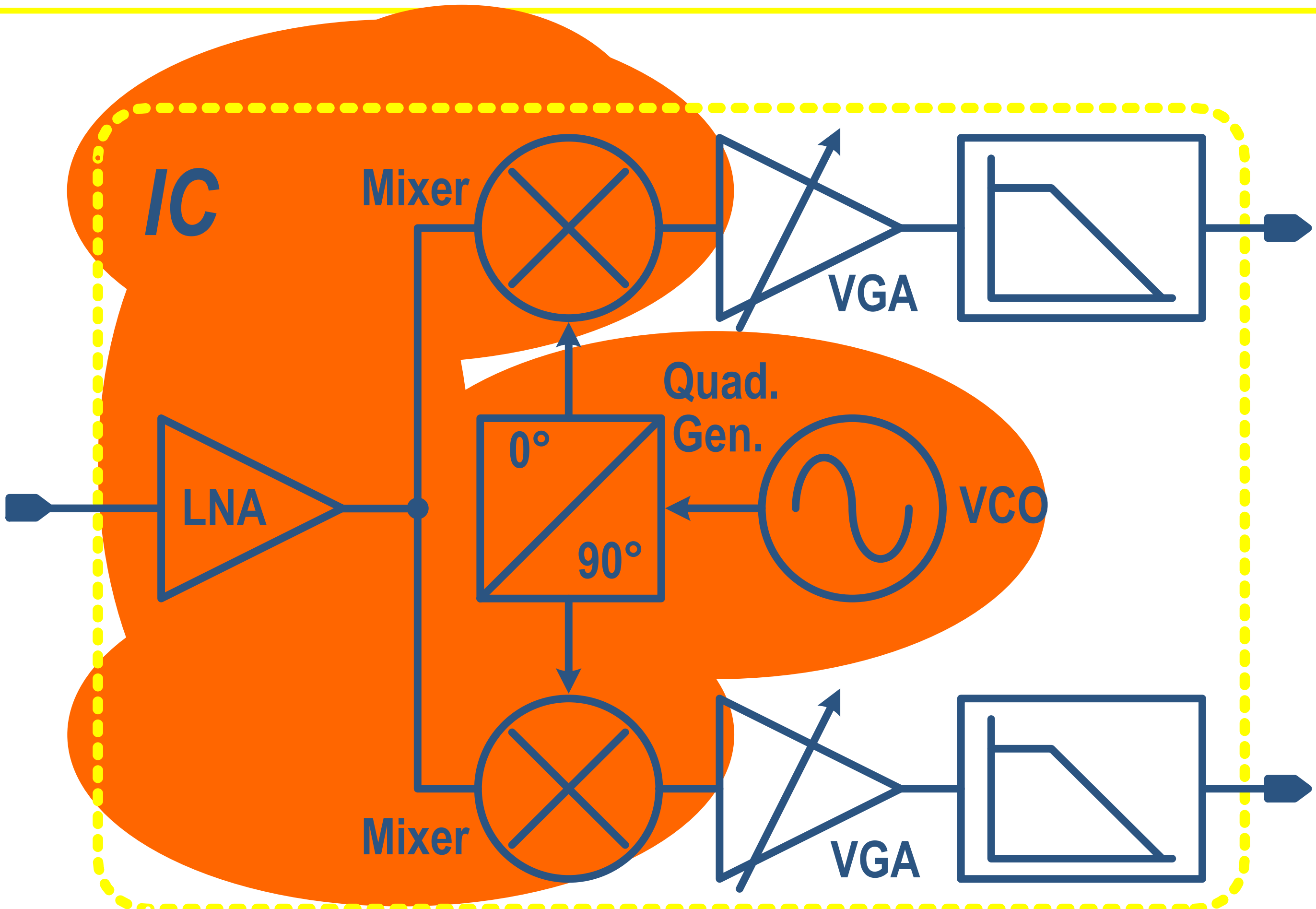
Parameter	WCDMA	Bluetooth	GSM
a1	0.8	0.8	0.8
a2	1.0	2.0	2.0
a3	1.0	4.0	4.0
b1	1.0	0.5	0.5
c1	1.0	0.7	0.7
c2	1.0	0.2	0.2
c3	0.1	0.1	0.1
g1	0.3	0.1	0
Quantizer levels	8	2	2
Sampling frequency	100MHz	100MHz	20MHz

Parameter	WCDMA	Bluetooth	GSM
Bandwidth	3.84MHz	2MHz	100kHz
Dynamic Range	55dB	50dB	86dB



RF Systems as products (Applications)

This Talk



A CMOS Direct Downconverter with +78dBm Minimum IIP2 for 3G Cell-Phones

A 750mV 15KHz 1/f Noise Corner 51 dBm IIP2 Direct Conversion Front-End for GSM in 90nm CMOS

Injection Locked dividers for Quadrature Generation in Direct Conversion Receivers

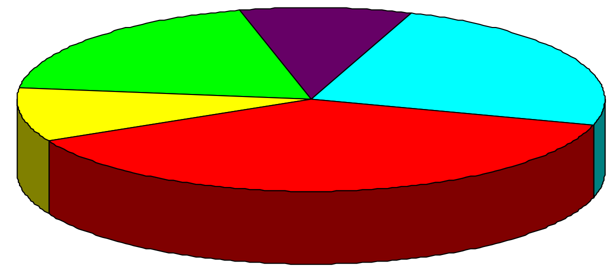
CMOS Direct Conversion front-end

- **Fully Differential Topology**
- **DC offset cancellation loop**
- **0.18μm CMOS Technology**
- **Double Frequency VCO**
- **Second-Harmonic Injection Locking Dividers**

Servo-loop around the VGA implements a 3kHz high pass filter

Performance Summary

NF	4.2dB * 5.6dB **
IIP3 out-of-band	-2dBm
Minimum IIP2	+44.8dBm
Gain	47dB
PN@135MHz	-155dBc/Hz
Power	38mW
Active Area	16mm^2
Technology	0.18µm 6M CMOS



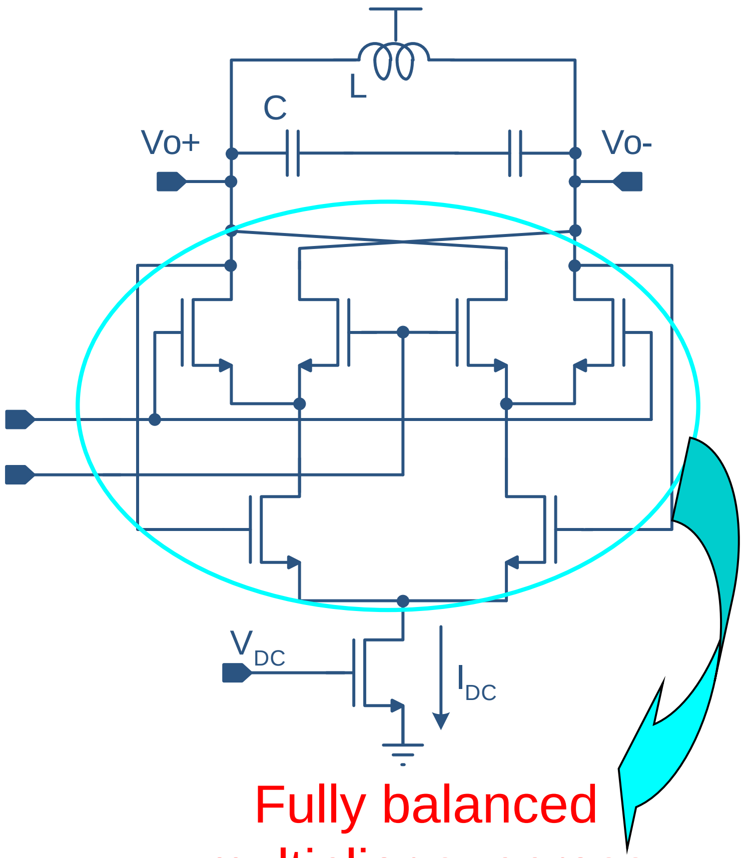
Injection Locked Balanced Dividers

VCO
@
$2\omega_0$

LO_I

ω_0

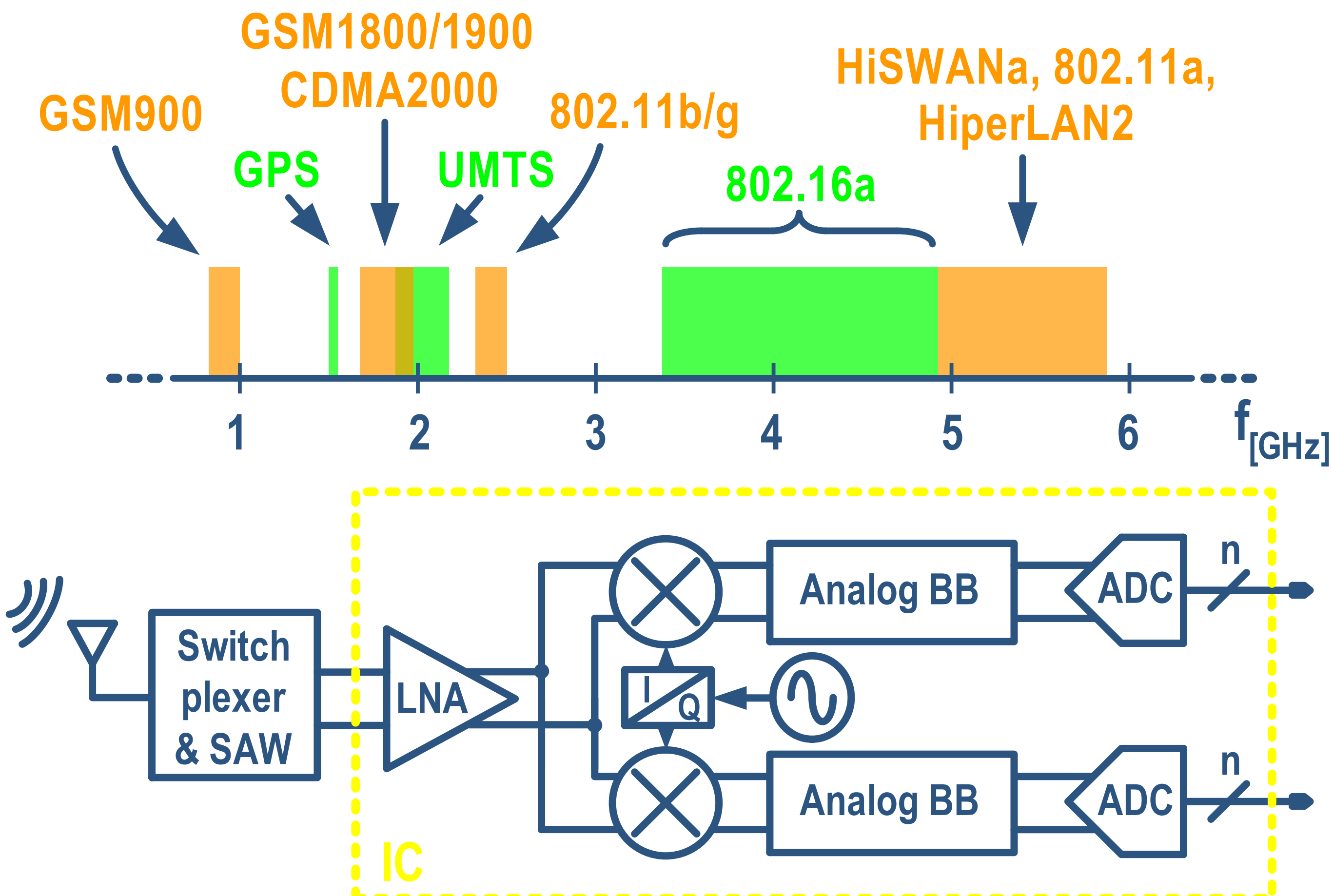
LO_Q



Fully balanced multiplier suppress the DC current

42% measured locking range with $Q_{tank} = 14$

Universal Mobile Terminals



Ultimate solution: Zero-IF fully integrated Multistandard RX

- **Mixer and analog base-band blocks are easily re-configurable**
- **LNA is the most critical block for multistandard operation**

WLAN PA Module

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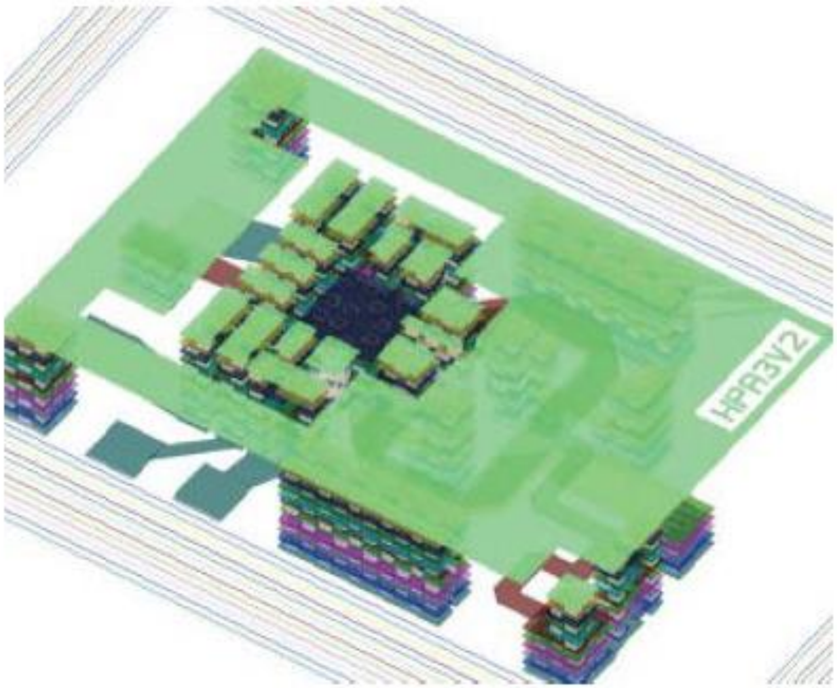

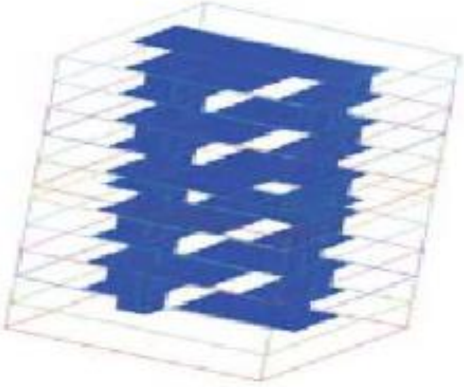

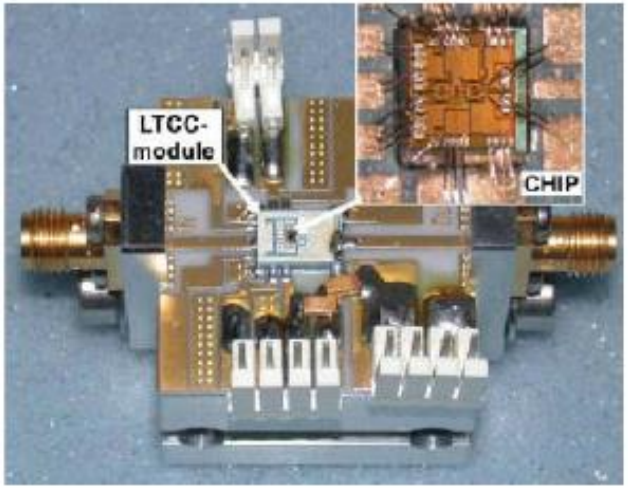

Source: Infineon

Forum on SiP Integration for Wireless Applications, SIMTech Auditorium, 3 May 2004

RF SiP

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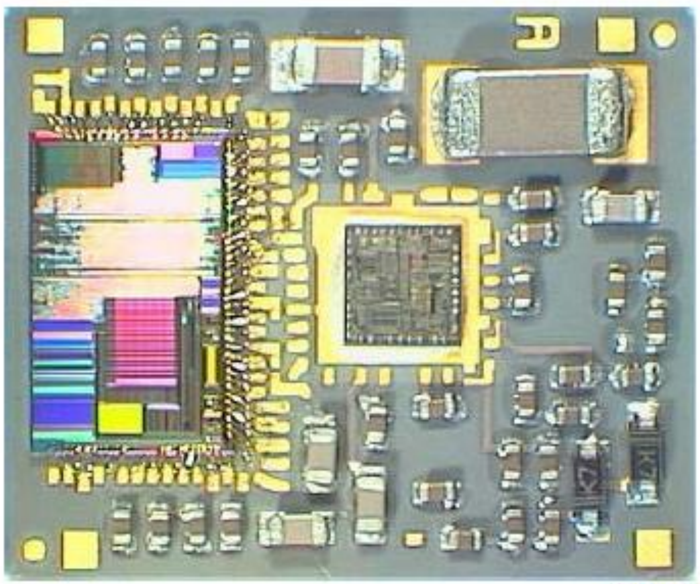
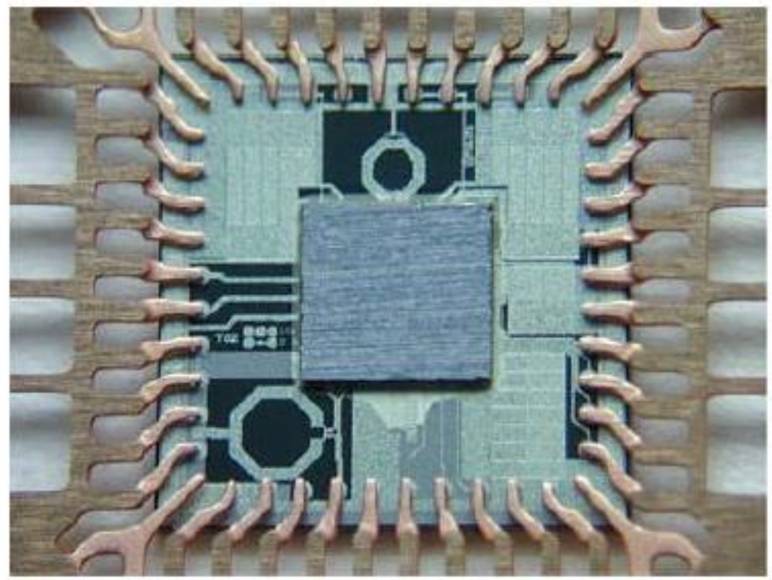
- **Module**
  - RF + BB + application
  - 9 x 11 mm^2, 1.8 mm high
- **SiP**
  - RF + application
  - 5 x 5 mm^2, 1 mm high

BGB202





Source: Philips

Forum on SiP Integration for Wireless Applications, SIMTech Auditorium, 3 May 2004

SiP with Antenna Integration

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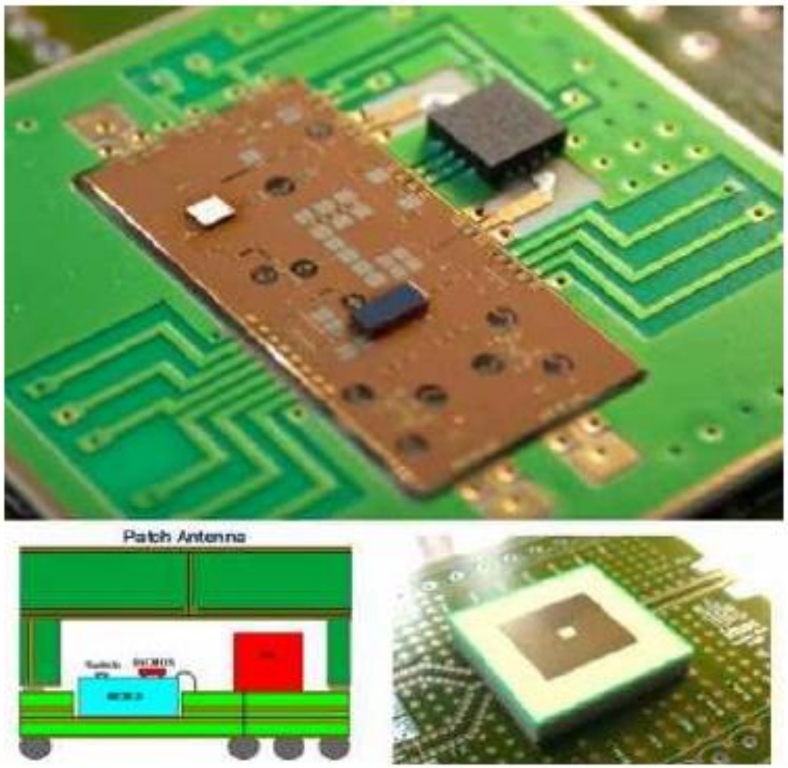
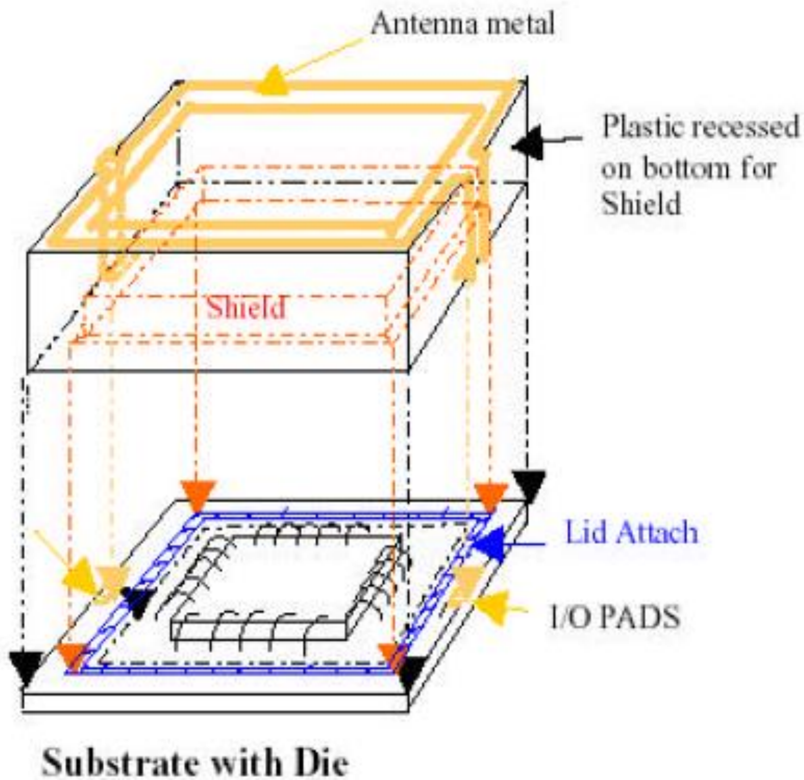
802.11 a/b/g



Source: IMEC

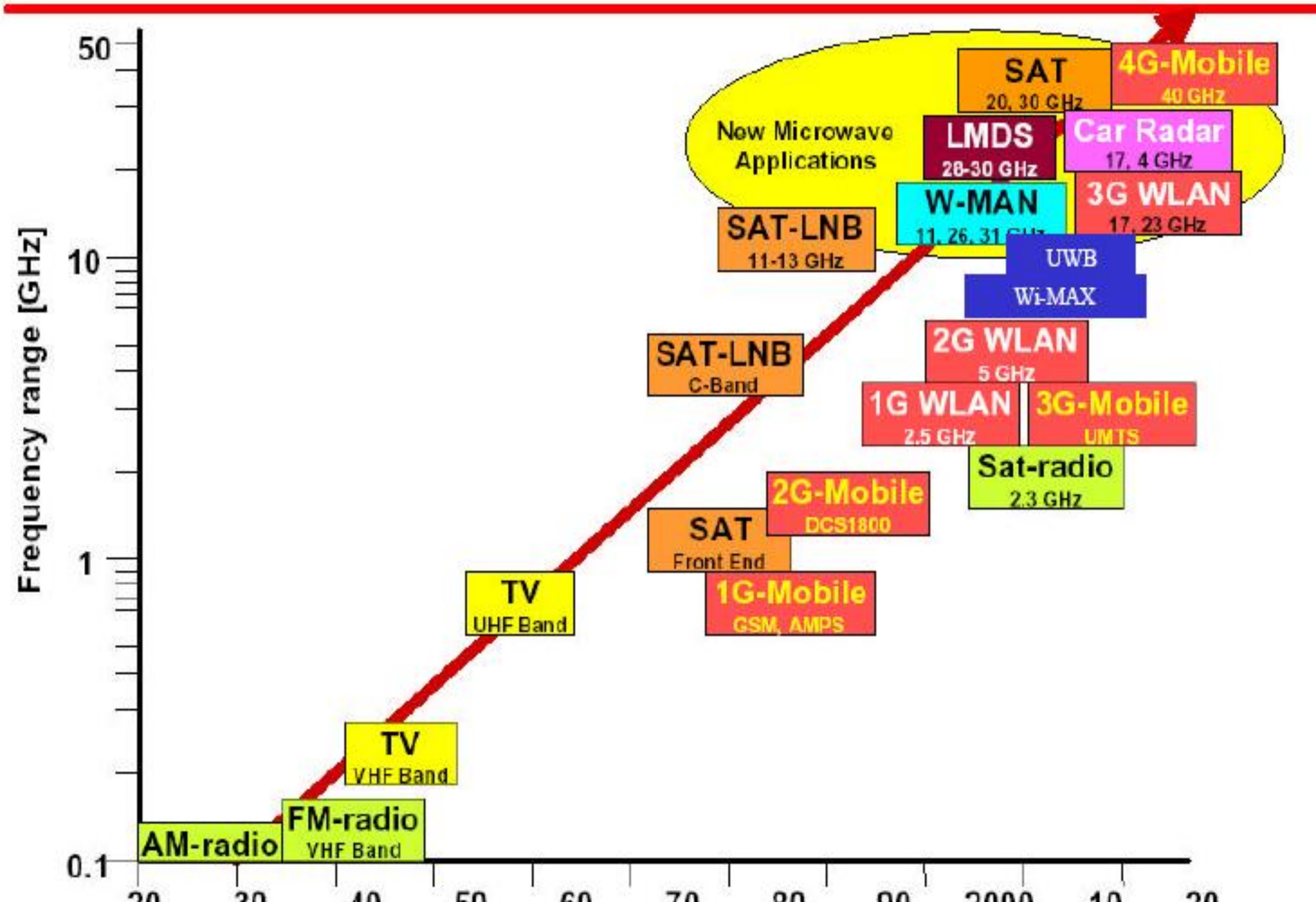
Bluetooth



Source: Amkor

Forum on SiP Integration for Wireless Applications, SIMTech Auditorium, 3 May 2004

Wireless Applications Roadmap



Source: Philips

SMART Phones

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O2 Xphone

- **Multi-Band : GSM 900/1800/1900 MHz**
- **Baseband: 144 MHz ARM Processor**
- **Bluetooth**
- **Wireless Modem**

Emerging Applications

Wireless Standards

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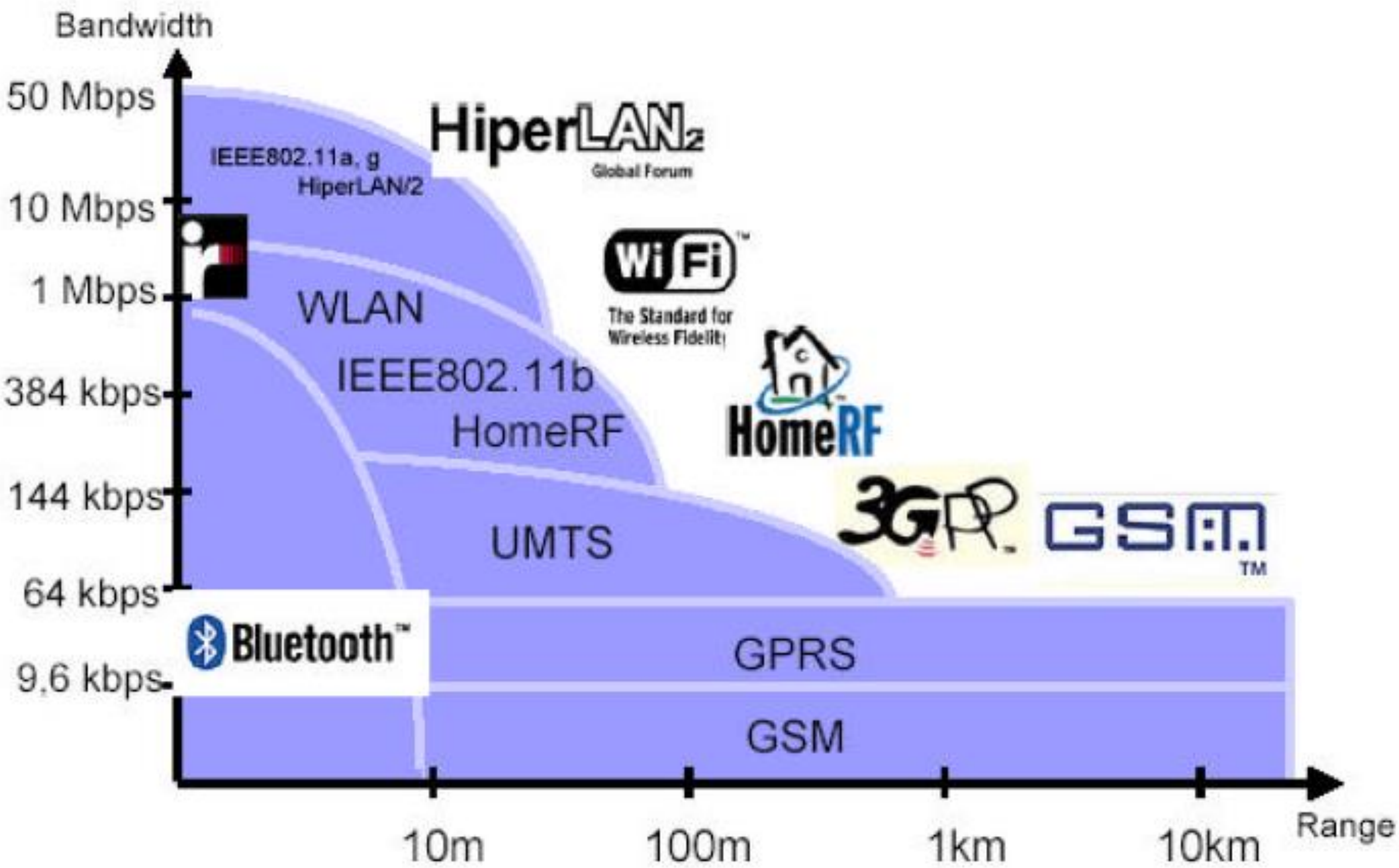

Wireless Broadband

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Strategy Analytics
... Insights for Success

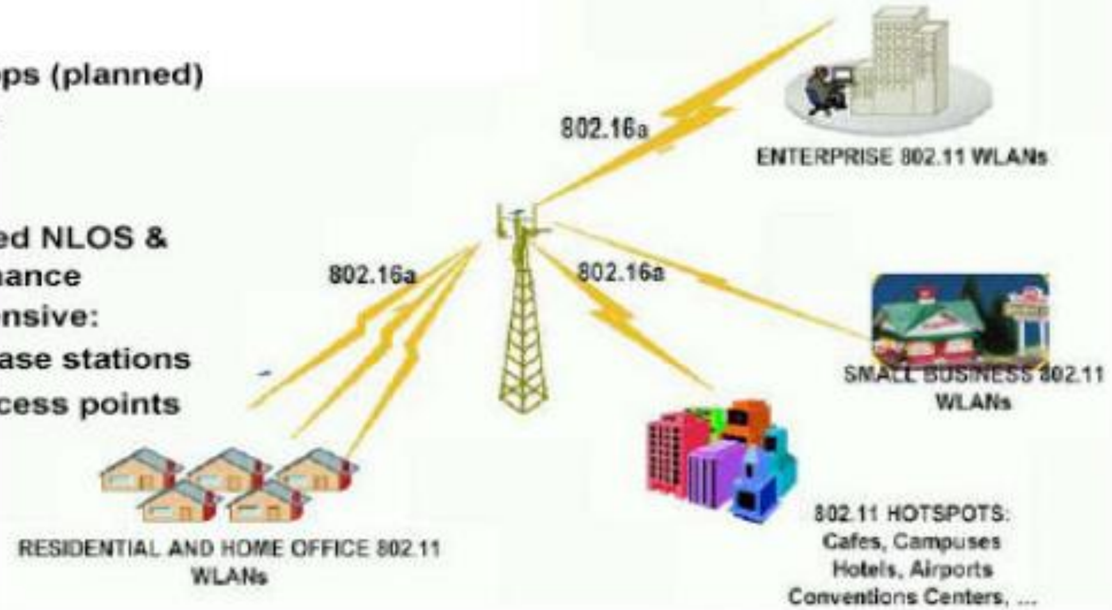
Wireless Broadband

Will further stimulate wireless mobility

Will succeed where wireline unavailable or uneconomical

- **MMDS, LMDS, or**
- **802.16**
  - **63 Mbps – 368 Mbps (planned)**
  - **2 GHz – 11 GHz & 10 GHz – 66 GHz**
  - **Range ~ 40 km**
  - **OFDM for improved NLOS & multipath performance**
  - **Potentially inexpensive:**
    - **$10 k - $20 k base stations**
    - **$300 - $500 access points**

802.16 Worldwide Potential at least 500,000 Units



Source: WiMAX Alliance

WLAN & UMTS / 3G Interoperability

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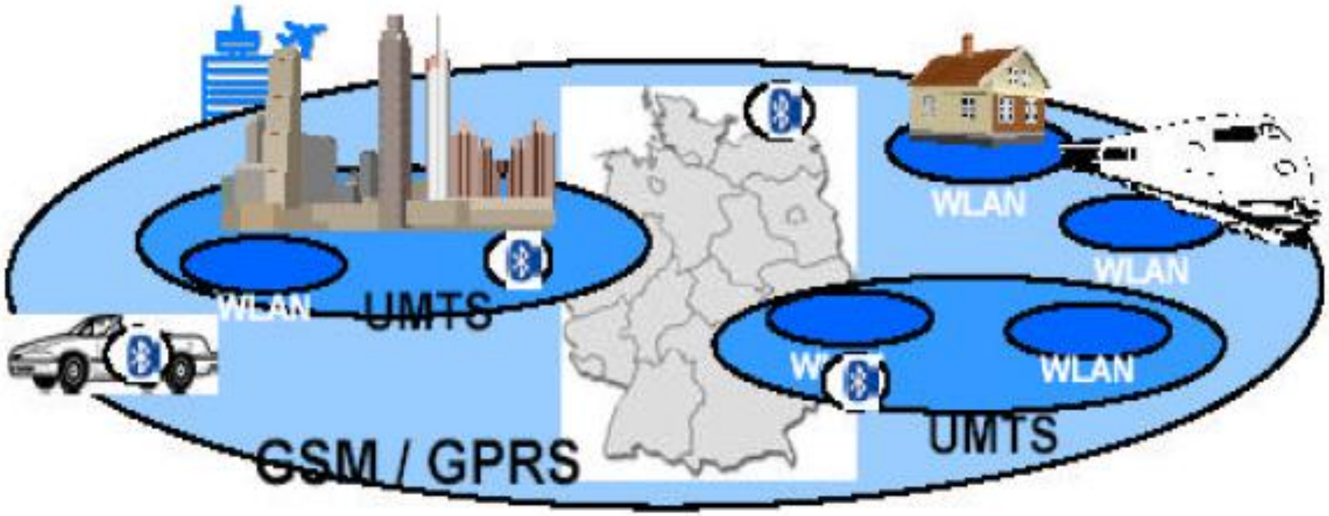

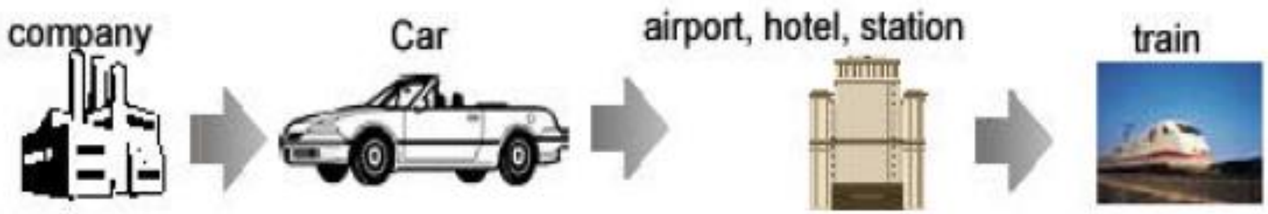

WLAN to the intranet

Bluetooth PAN in the car, via GPRS to PLMN (e.g. sync of Outlook)

e.g. send PPT via pulbic **WLAN**

e.g. e-mail via **GPRS**

Strong need for interoperability between LAN and Cellular standards

WLAN Trends

802.11 – The Future

Developments to watch:

- WLAN + Cellular Data (e.g. SiRiFIC)
- QoS for video distribution in the home
- WLAN telematics (ITS)
- High Throughput Study Group
  - Atheros "Turbo Mode" 108 Mbps (5UP)
  - MIMO antennas, multiple receivers
  - New channel assignments
- Mesh networking (not limited to 802.11)
- WLANs connected via 802.16

WLAN and Bluetooth Coexistence

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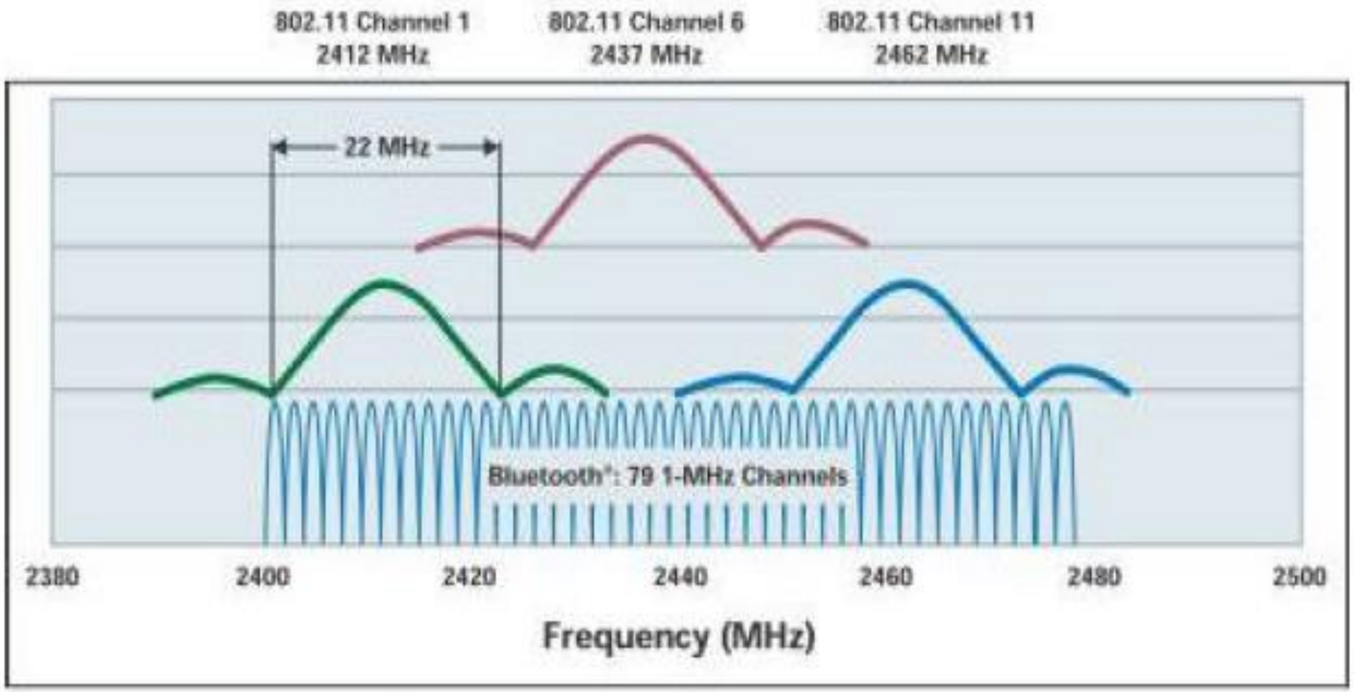

- 802.11b/g and Bluetooth* occupy the same 2.4 GHz band
- 802.11b/g has a stationary 16 MHz width
- Bluetooth hops over the entire band typically 1600 hops/sec, occupying 1 MHz at a time
- Collisions in time and frequency cause Bluetooth and WLAN to drop packets

Strong need for co-existence between LAN and PAN standards

UWB (Ultrawideband)

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Impulse radio implementation

Traditional design approach for UWB communication system using narrow time-domain pulses that occupy a very wide spectrum

- encodes information using impulses
- impulses can be modulated either with position, or with amplitude or with phase
- especially effective for radars systems
- difficult to be realized in CMOS
- application into niche markets such as radars, imaging, military communications

Pulsed multi-band implementation

In the Multi-band approach the information is encoded in multiple RF sub-bands at staggered time, each band occupying 500MHZ.

- use multiple frequency band to efficiently use the UWB spectrum
- transmits multiple UWB signal at different frequencies
- signals don't interfere with each other because they operate at different frequencies
- available spectrum is broken down in bands each of them occupying 500MHz bandwidth.
- can be realized in CMOS
- application in personal network area which requires speeds of 110,220 and 480Mbps at 10m with low power consumption

Wi-MAX

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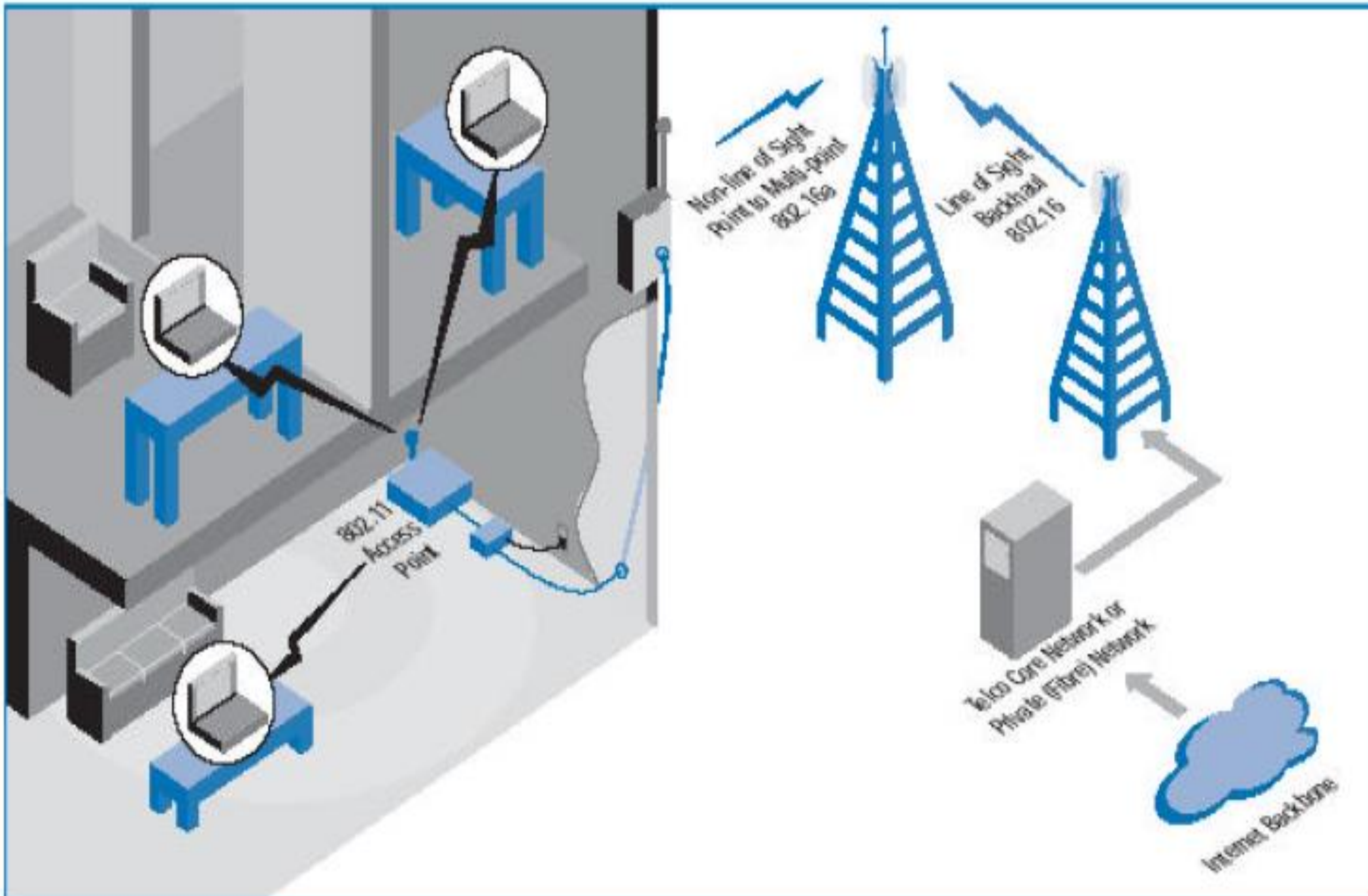

RF Module Integration Trends

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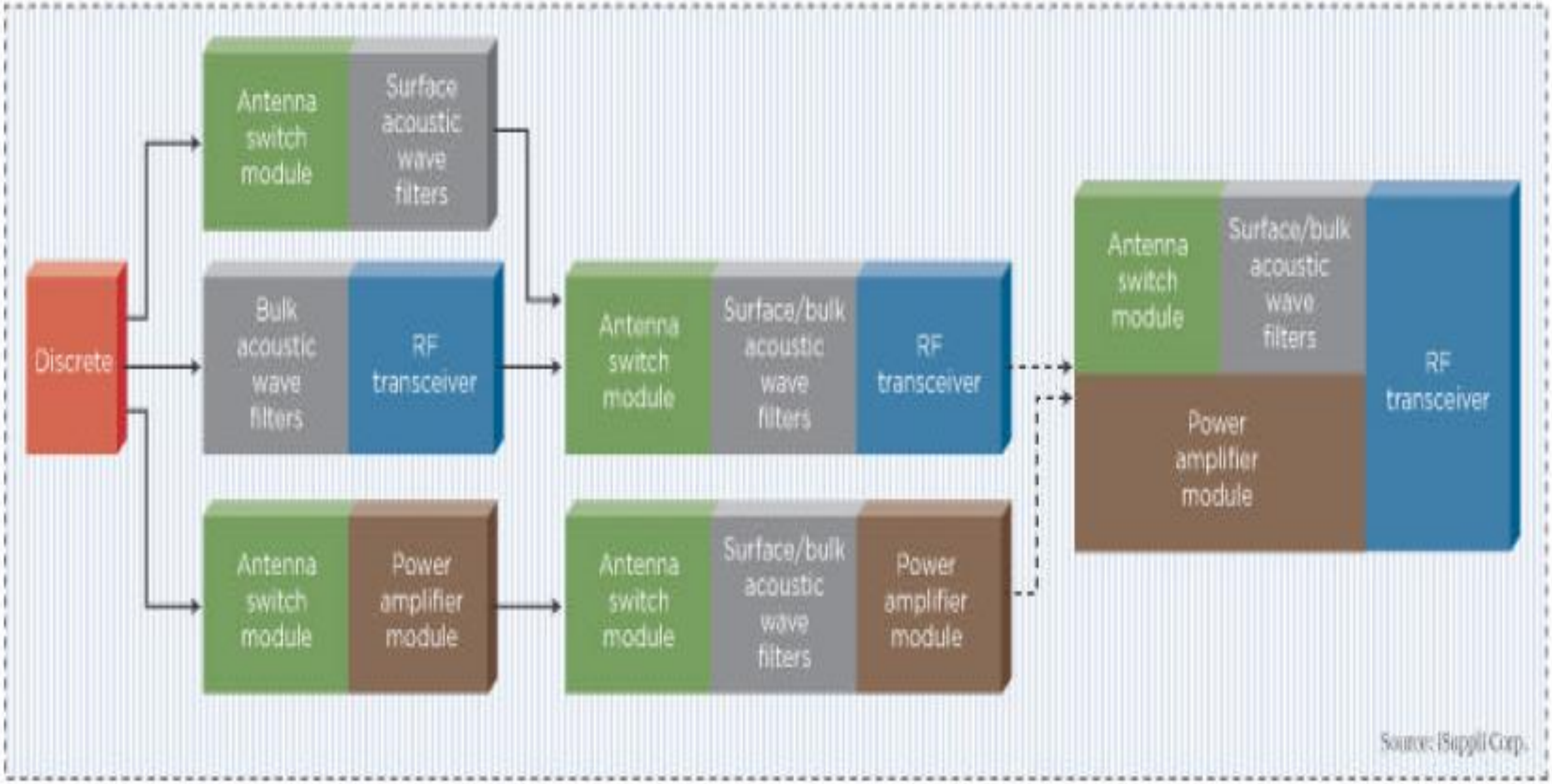

Separate RF Modules → **SiP RF Module**

RF Design Challenges

- Complexity surpasses the tool capability to verify performance
  - PA and VCO integration requires simulation engines to co-simulate Electromagnetic phenomena while predicting electric behavior
  - Verification and post-layout simulation complexity increases as new coupling mechanisms need to be addressed
    - Substrate couple between RF and High speed basedband processors
- Design Methodology and Simulation Methodology key to maintain development budget within reasonable limits
  - 90nm mask cost, 65 nm mask cost
- Cad tool engineers will meet the challenge

RF Design challenges

- Wireless connectivity proliferation into consumer products introduces new cost and time to market requirements for the RF IC design
- The level of integration along with performance challenges poses a continuous challenge for the RF design community
- Innovative approach in RF IC architectures, design and CAD tool solution are addressing the challenge

Summary

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Strong drive for integration of RF, Digital, Passives

- Mixed-signal (Baseband and RF) integration
- Multi-band and multi-mode functionality
- Higher frequency: Wi-MAX (up to 11 GHz), UWB (up to 11 GHz), LMDS (28 GHz)

System in Package (SiP) will provide

- Flexible and cost-effective integration of High-Q passives and antenna
- Faster time-to-market
- Enhanced interoperability between multiple wireless broadband standards

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AND
Many Websites as referred in the PPTs