



# **RF/RF-SoC Overview and Challenges**

Fang Chen  
May 14, 2004

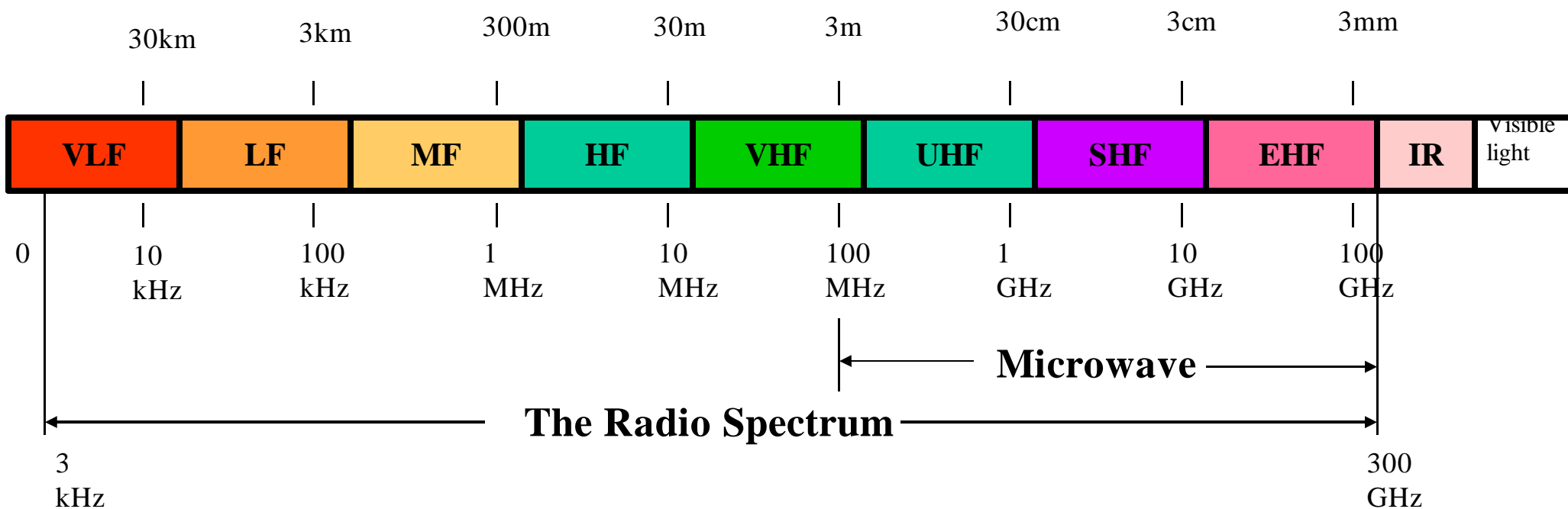


# Content

- **What is RF**
- **Research Topics in RF**
  - RF IC Design/Verification
  - RF IC System Design
  - Circuit Implementation
- **What is RF-SoC**
- **Design Methodology**
- **Design Flow**



# Allocation of Radio Spectrum in United States



Reference: <http://www.ntia.doc.gov/osmhome/allochrt.html> April, 2004



# What is RF?

## ■ **Bandwidth-based definition:**

- RF circuits are necessarily narrowband circuits, having bandwidths that are a small fraction of the center frequency.

## ■ **Application-based definition:**

- For communication system engineers, RF signals are not information but are used as carriers of the information-bearing signals in wireless applications. RF becomes an antonym of the word “based-band”.

## ■ **Size-based Definition:**

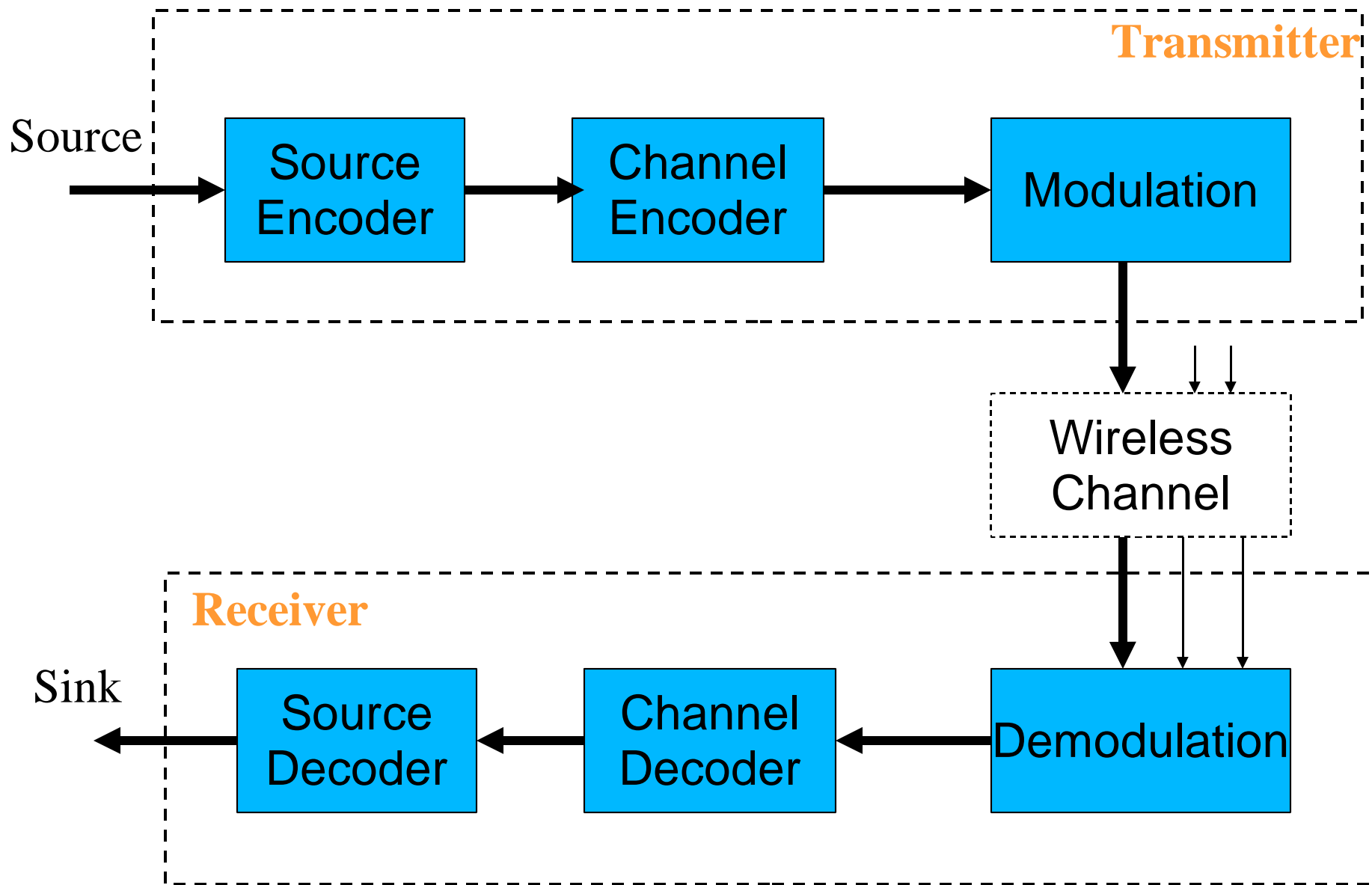
- The size of RF hardware is not negligible compared to the wavelength of the electromagnetic (EM) waves that they process.

## ■ **Definition Used by Electrical Engineers**



# What is RF?

## General Digital Communication Diagram



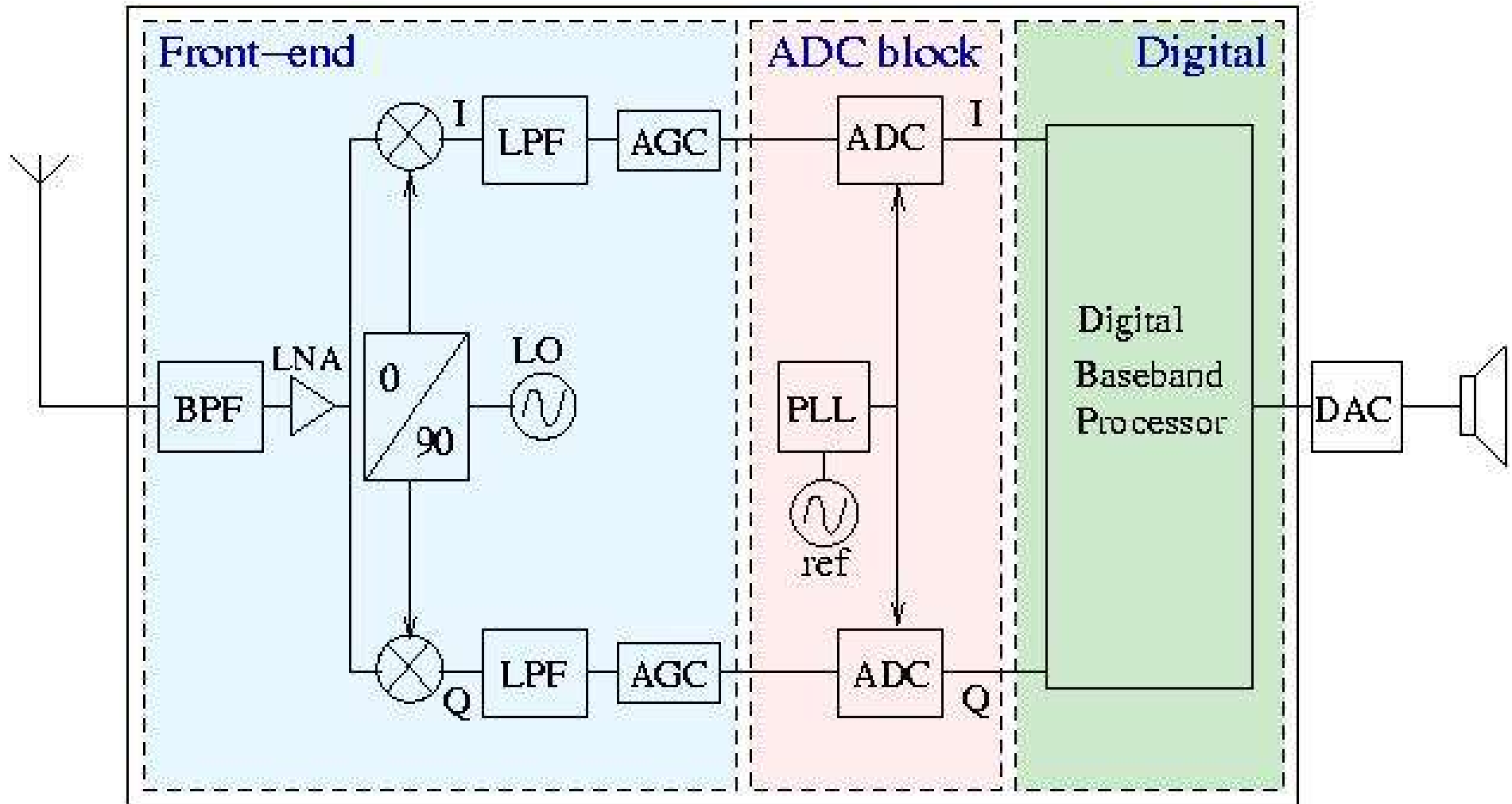


# Summary of Different Wireless Standards

<b>Wireless Standard</b>	<b>Access Scheme</b>	<b>Frequency Spectrum(MHz)</b>	<b>Channel Spacing</b>	<b>Modulation Technique</b>	<b>Date Rate</b>
<b>GSM</b>	TDMA/FDD	890-915(Tx) 935-960(Rx)	200kHz	GMSK	270kb/s
<b>UMTS</b>	CDMA/FDD	1920-1980(Tx) 2110-2170(Rx)	5MHz	QPSK	2Mb/s
<b>Bluetooth</b>	CDMA/FH	2400-2480	1MHz	GFSK	1Mb/s

# An Example of RF IC

## A Receiver System for 3G Mobile



**Reference:** "A triple-mode continuous-time sigma-delta modulator with switched-capacitor feedback DAC for a GSM-EDGE/CDMA2000/UMTS receive" *IEEE Journal of Solid-state Circuits*, Vol. 38, No. 12, Dec. 2003



# Research Topics in RF IC for 3G Mobile

## ■ **System-level Design**

- Architecture Design for higher integration of the system.
- Architecture Exploration for Multi-Standard Receiver.

## ■ **Computer Aided Design**

- Device Modeling.
- Simulation Algorithm.

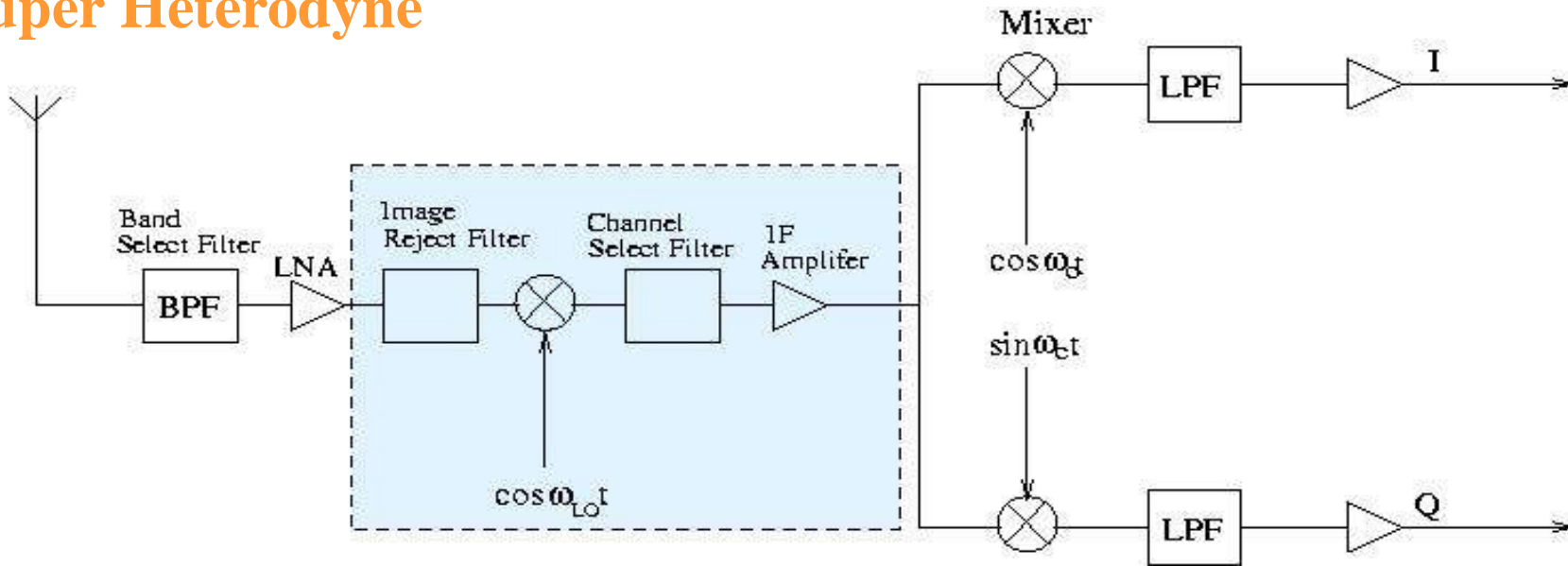
## ■ **Circuit Implementation**

- Circuit implementation using certain technology for better performance or higher integration.

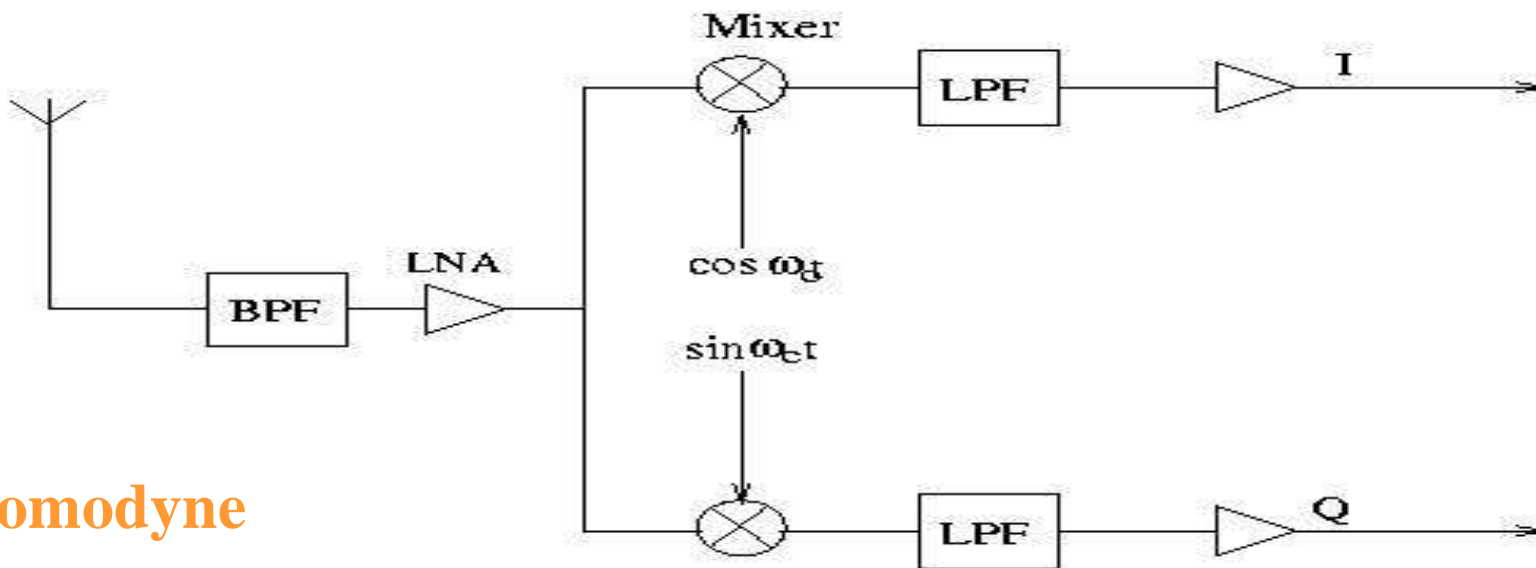


# System-level: Front-end Architectures

## Super Heterodyne

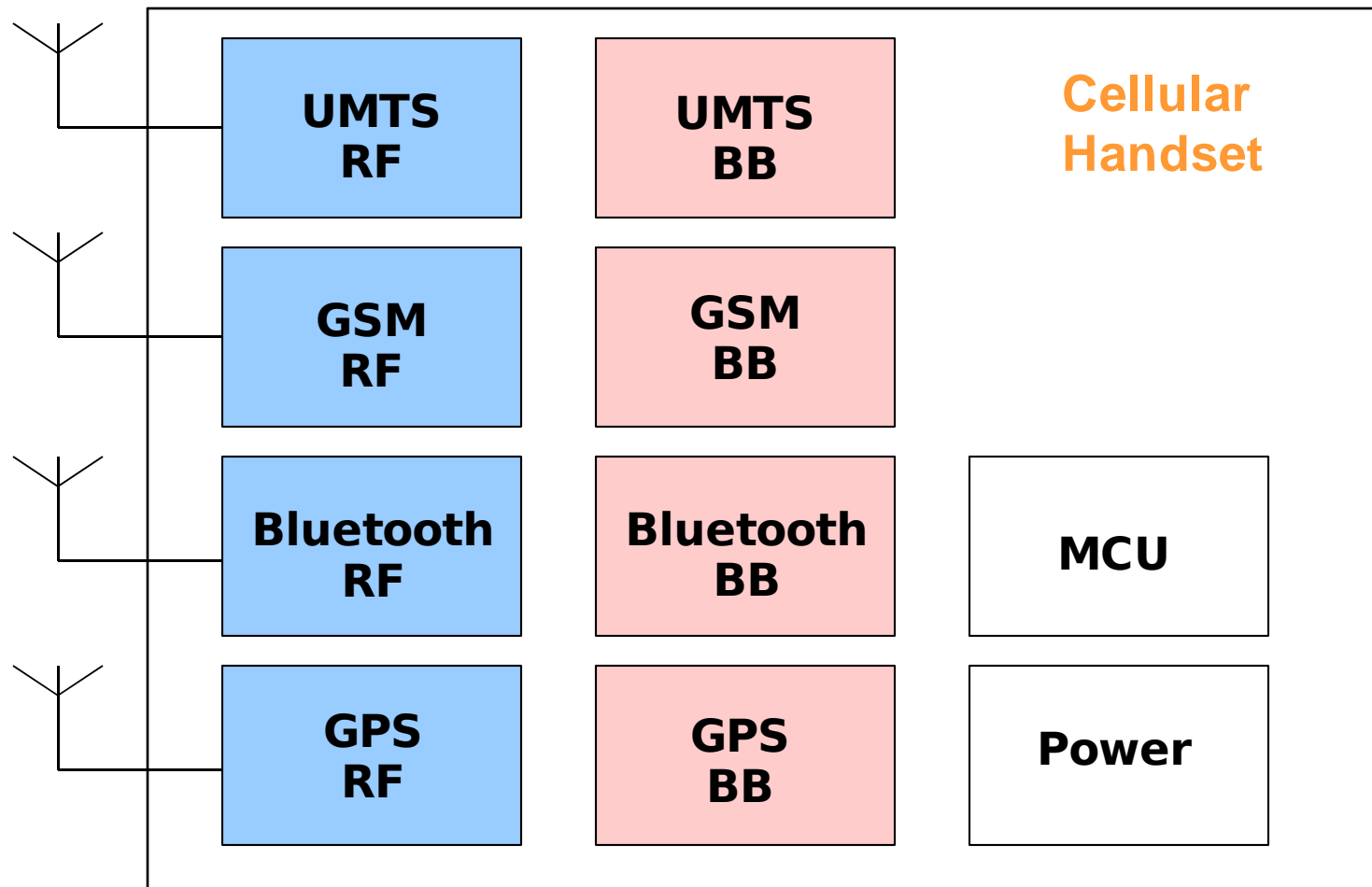


## Homodyne



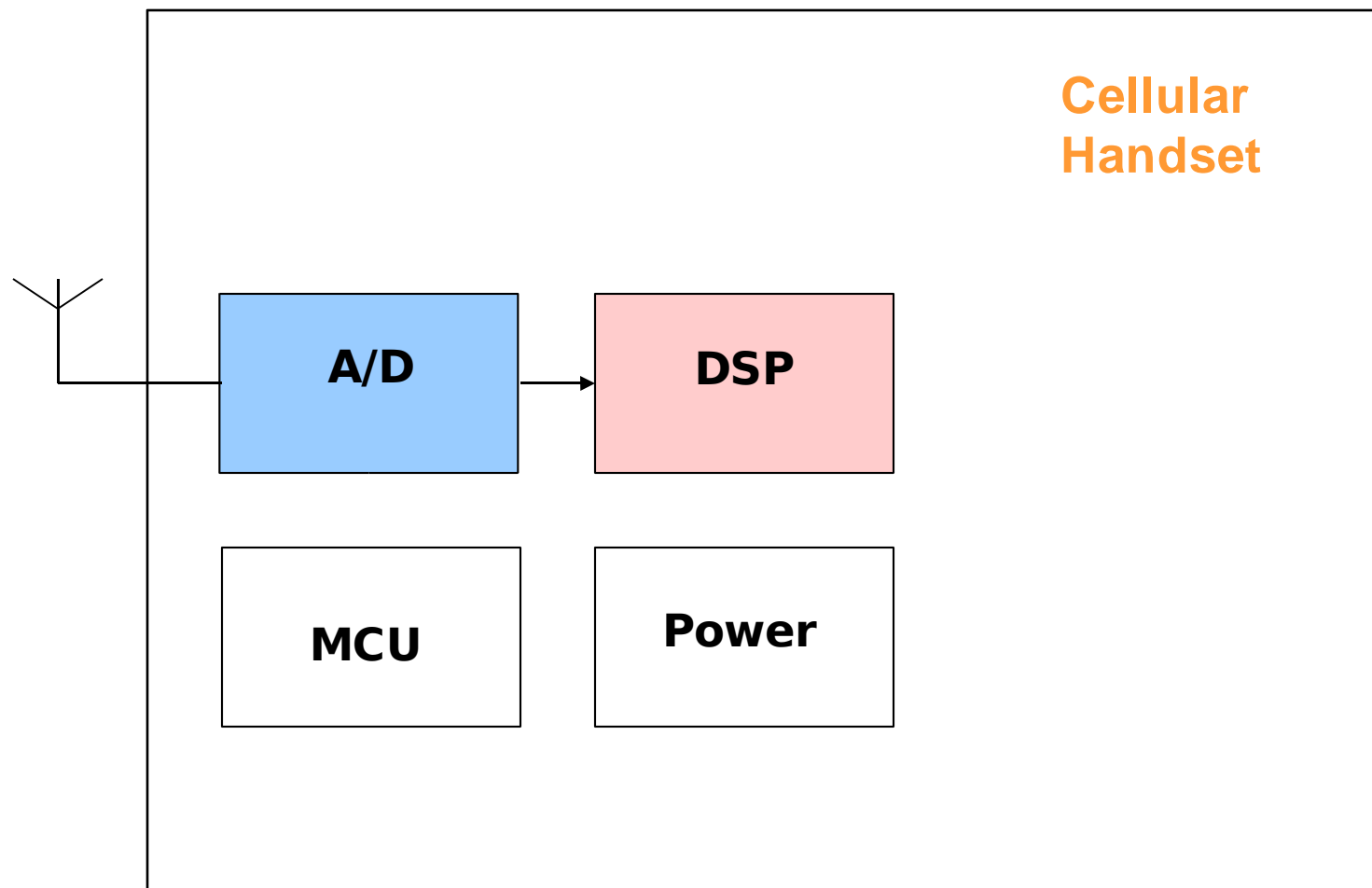


# System-level: Multi-Standard Receiver





# System-level: Software Radio





# Computer Aided Design: RF IC Design

- **Two Circuit Design Methodologies**
  - Digital Design Methodology.
  - Analog/Mixed-signal Design Methodology.
  
- **RF Design Methodology**
  - Analog/Mixed-signal Design Methodology.



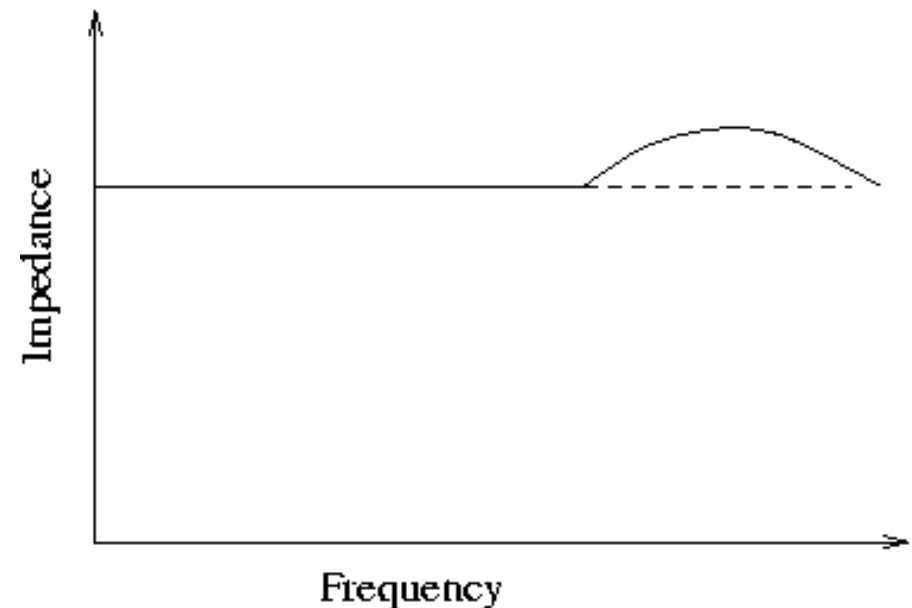
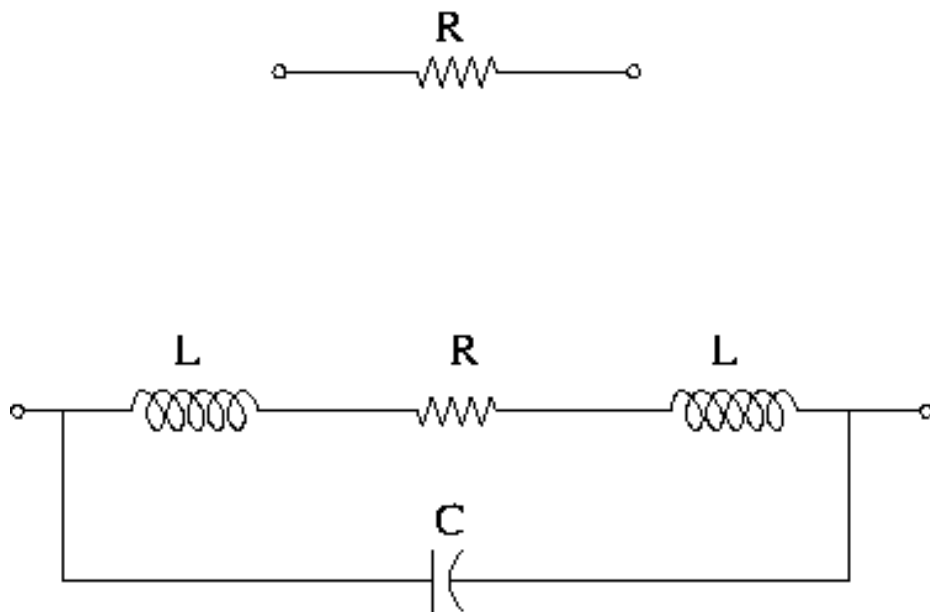
# Computer Aided Design: RF IC Verification

- **SPICE (Simulation Program with Integrated Circuit Emphasis) Simulation Program**
  - Simulator.
  - Device Model.
  
- **Accuracy and Speed of the Simulation:**
  - Critically dependent on device model and simulation algorithm implemented by the simulator.



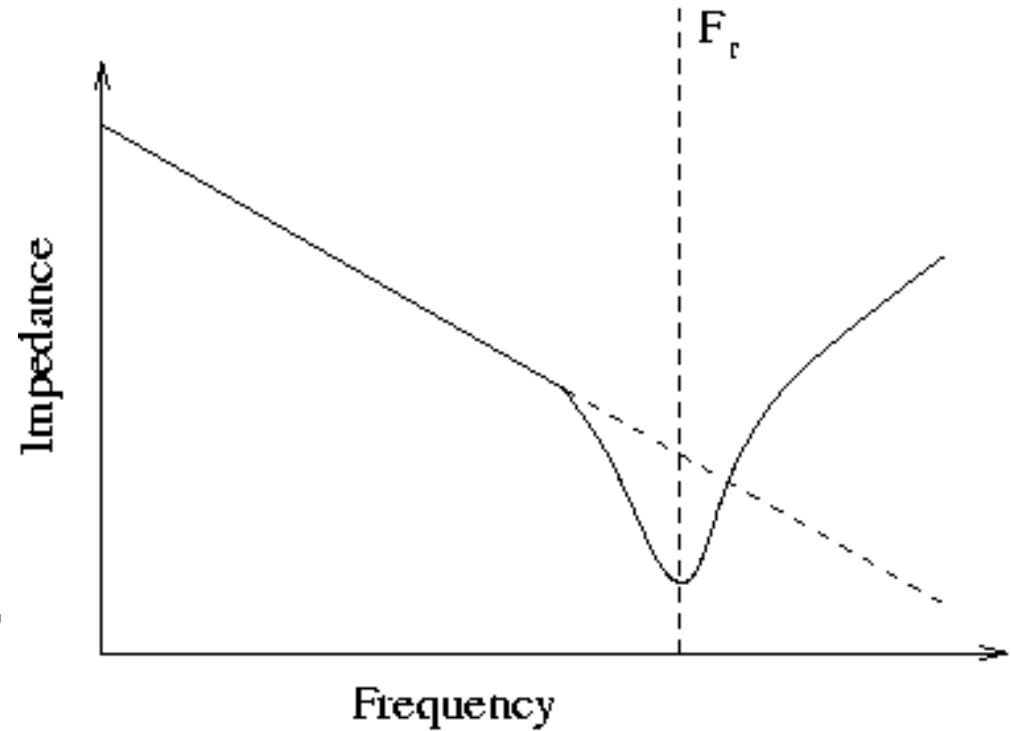
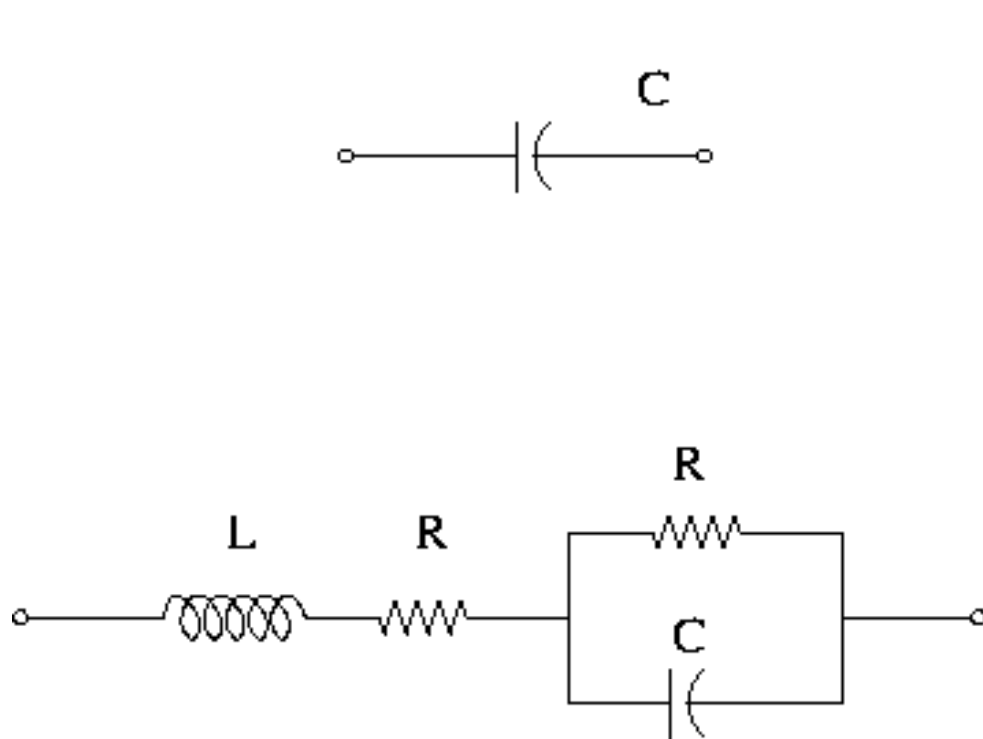
# Computer Aided Design: RF IC Verification

- RF device models are different from analog ones due to the very high operating frequency(1-5GHz).



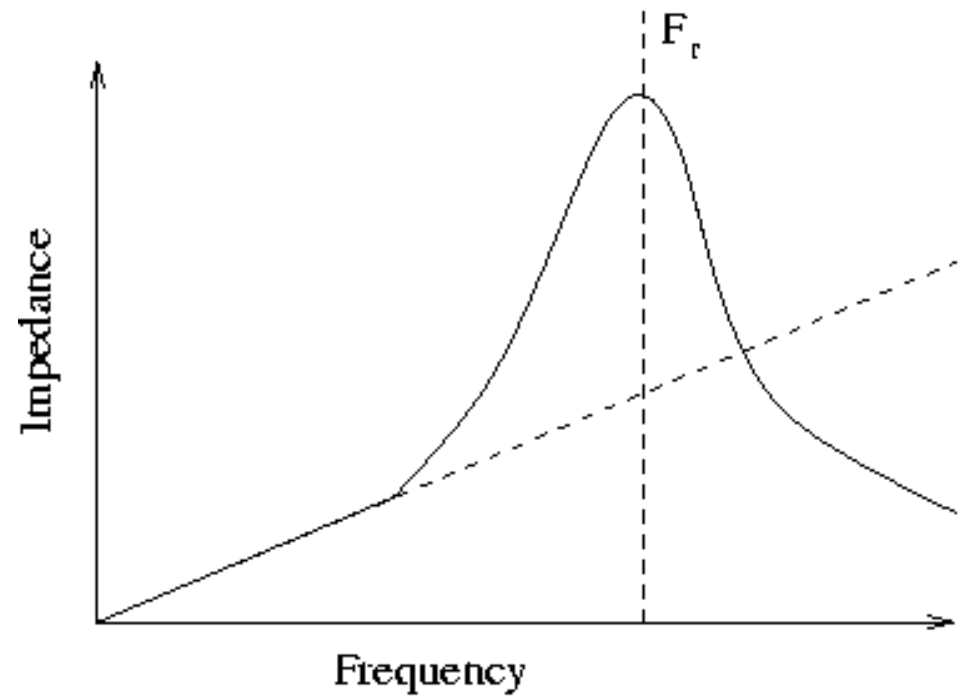
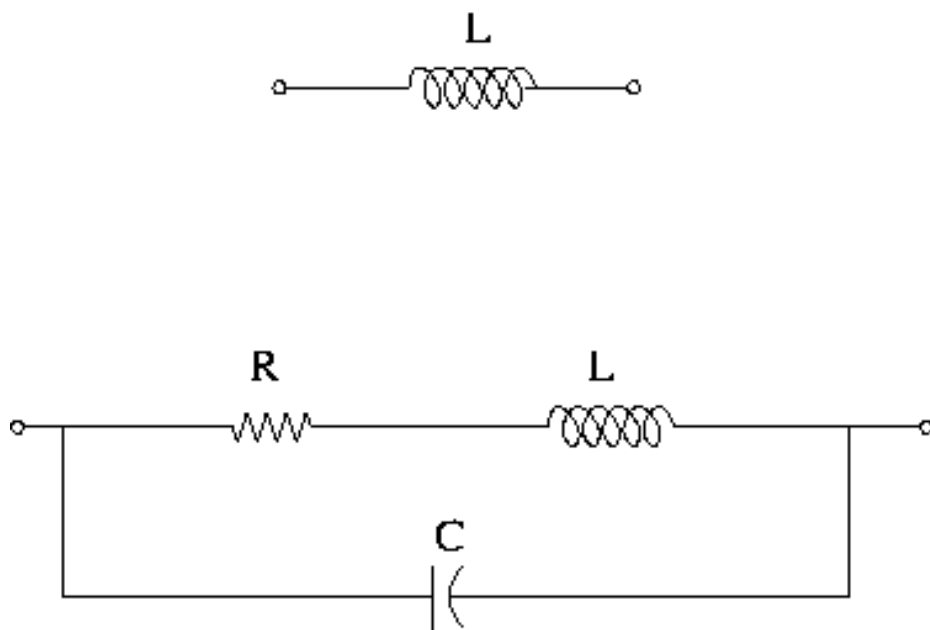


# RF IC Verification





# RF IC Verification





# Computer Aided Design: RF IC Verification

- RF signal: High frequency carrier with relatively low frequency information signal.
- High frequency carrier needs a small time step.
- Low frequency modulation requires a long simulation interval.
- SPICE is not effective and efficient enough for RF circuits.



# Circuit Implementation

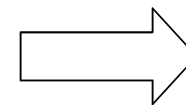
## Comparison of Semiconductor Technologies

<b>GaAs</b> (Gallium-Arsenide)	<ul style="list-style-type: none"><li>◆ Highest frequency coverage</li><li>◆ <b>Best RF Performance</b></li><li>◆ Best passive RF component Integration</li></ul>
<b>SiGe</b> (Silicon-Germanium)	<ul style="list-style-type: none"><li>◆ Higher frequency coverage than Si</li><li>◆ Better RF performance than Si</li><li>◆ Good mixed-signal capability</li><li>◆ Higher levels of integration possible</li><li>◆ Lower cost than GaAs</li></ul>
<b>Si</b> (Silicon)	<ul style="list-style-type: none"><li>◆ <b>Lowest cost</b></li><li>◆ <b>Best mixed-signal capability</b></li><li>◆ <b>Highest level of integration possible</b></li><li>◆ Consistent process</li></ul>

# Circuit Implementation

## ■ Hand-held products demand for

- Low power consumption
- High level of integration
- Low cost



**CMOS**

## ■ State-of-the-art CMOS RF IC

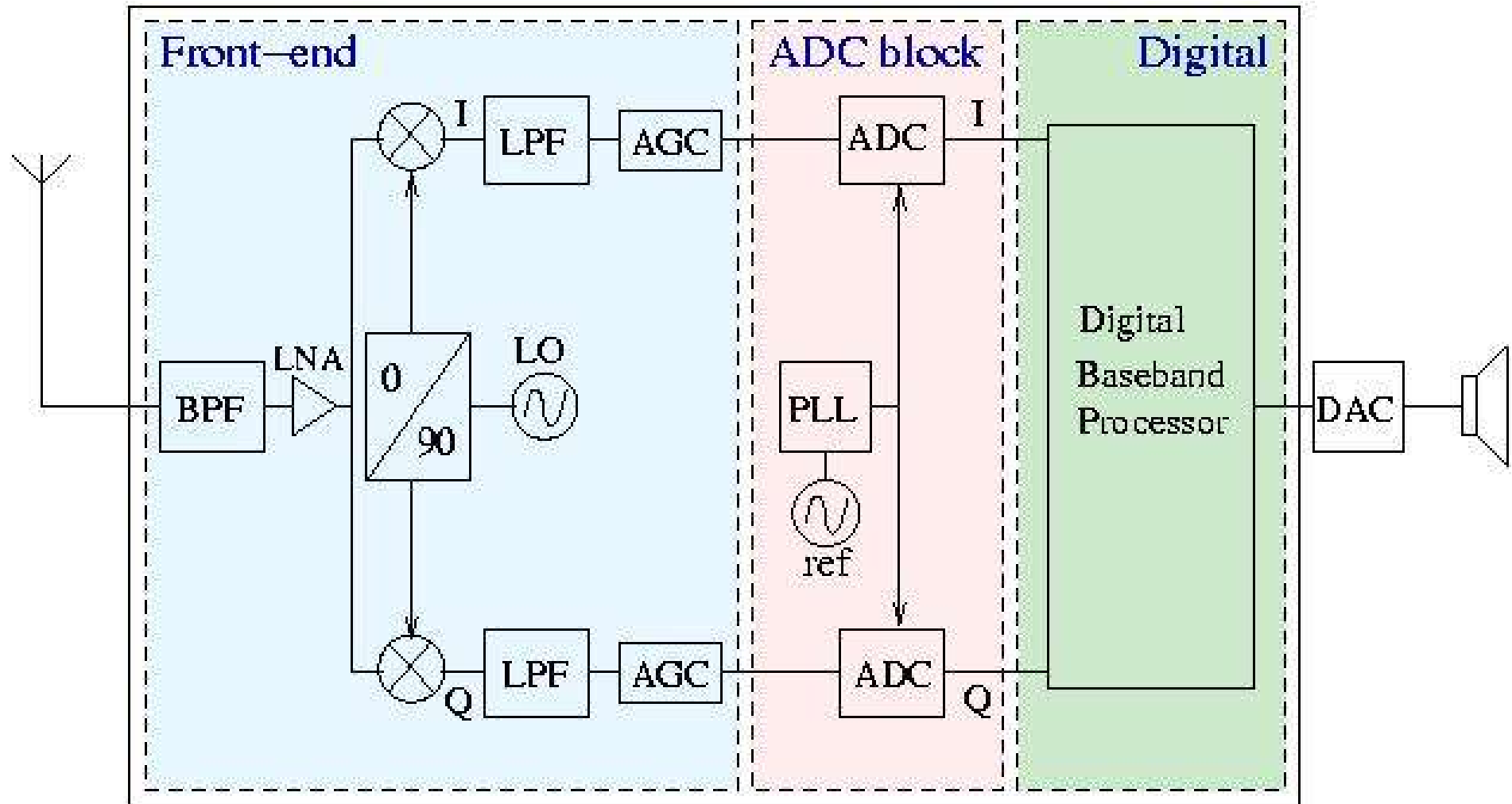
- A fully integrated 0.18 CMOS direct conversion receiver front-end with on-chip LO for UMTS (published on “IEEE journal of solid-state circuits”, Jan. 2004)



# What is RF-SoC ?



# What is RF-SoC ?



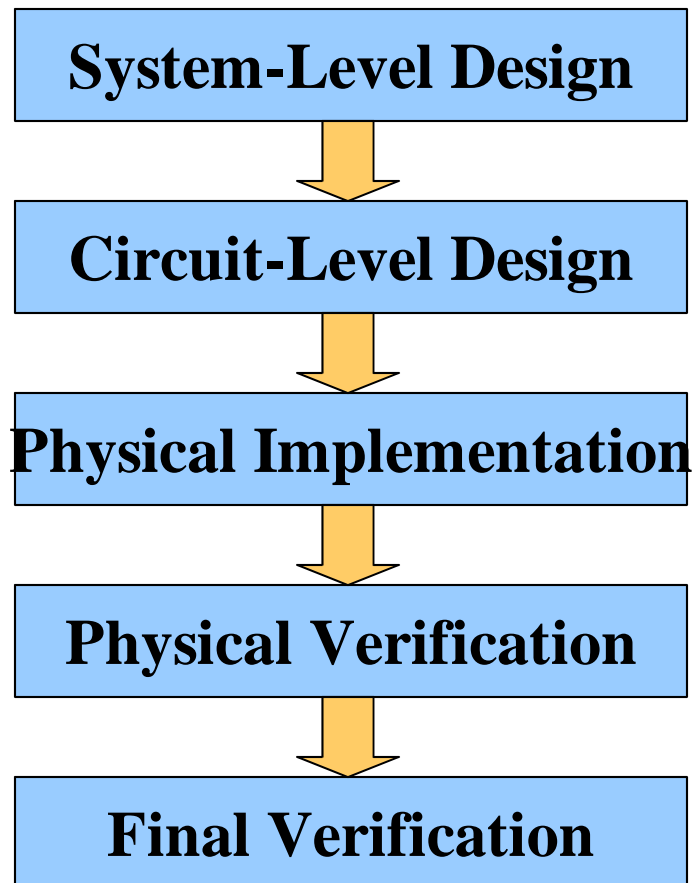


# Challenges

- Only a single technology can be used.
- RF section can be very sensitive to the interference from digital portion.



# RF-SoC Design Methodology: Top-Down Design, Bottom-up Verification

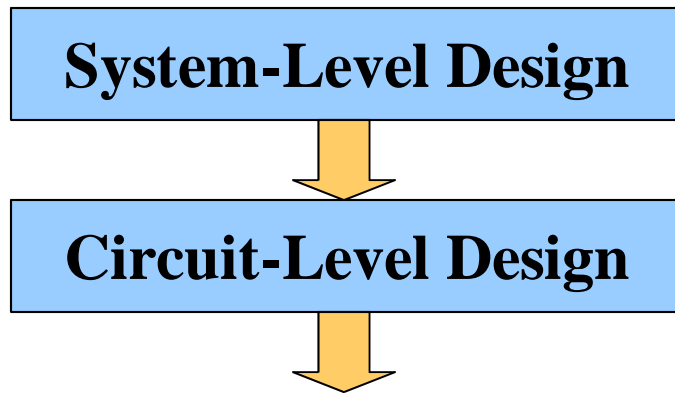


## Basic Idea:

- Architecture of a chip is defined, simulated, and optimized as a block diagram.
- Requirements for the individual blocks are derived.
- Individual blocks are designed and verified against the requirements.
- Entire chip is laid out and verified against the original requirements.



# RF-SoC Design Methodology: Top-Down Design, Bottom-up Verification



## **System-Level Design:**

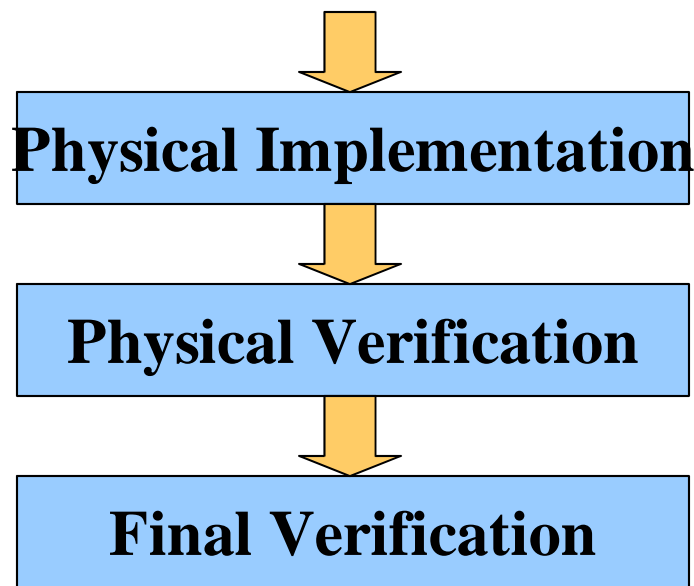
- Design is partitioned.
- Circuit blocks and Interfaces are modelled and verified.
- Requirements are derived

## **Circuit-Level Design:**

- Transistor-level circuit of each block is designed.
- Each block is simulated and verified against the specifications.
- Each block is also verified in the context of the entire system (Mixed-level simulation).



# RF-SoC Design Methodology: Top-Down Design, Bottom-up Verification



## **Physical Implementation:**

- Architecture is converted to floorplan.
- The blocks are laid-out and routed.

## **Physical Verification:**

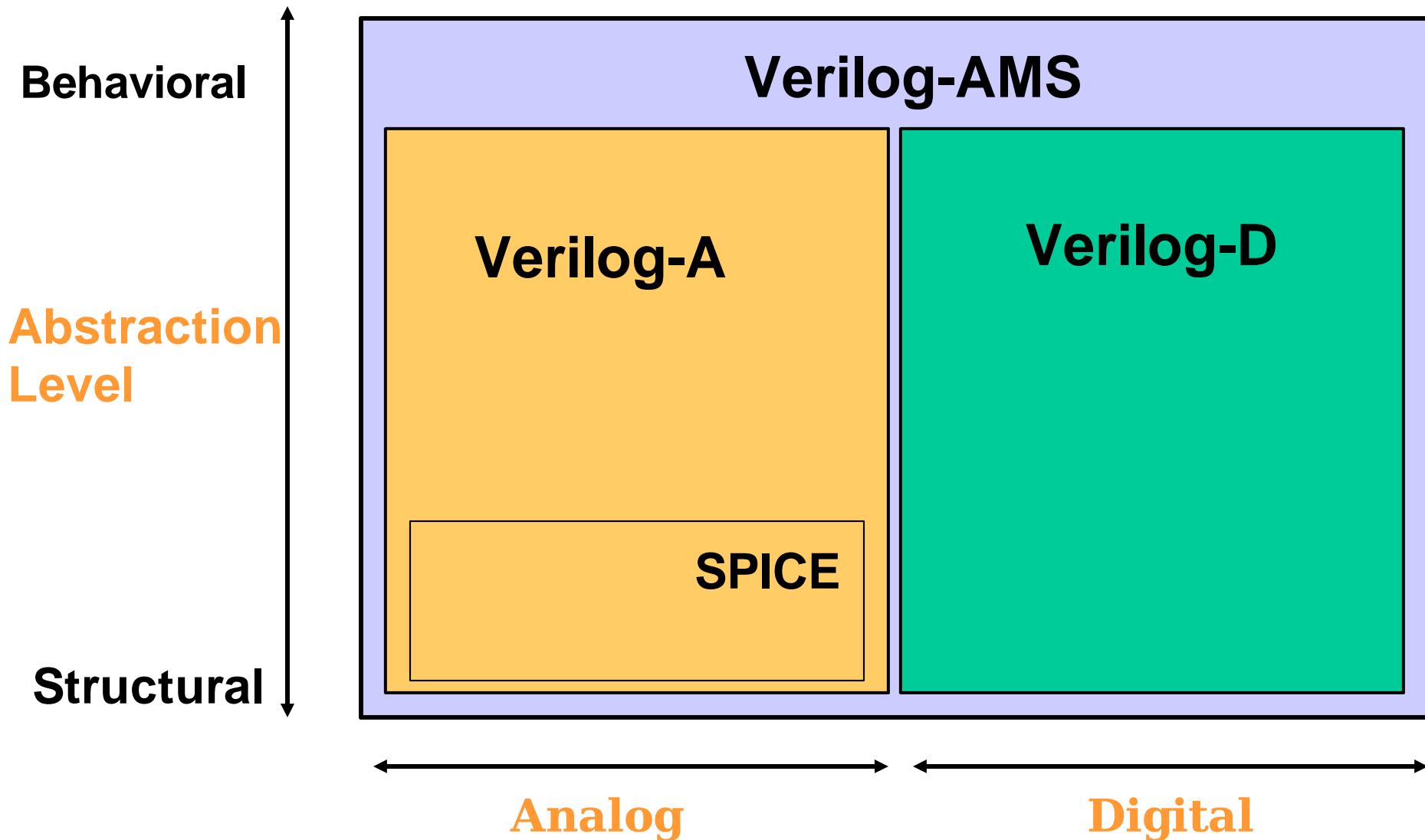
- LVS (Lay-out Vs Schematic).
- DRC (Design Rule Check).

## **Final Verification:**

- Extraction and characterization.
- Macro-models created for a fast high-level simulation.

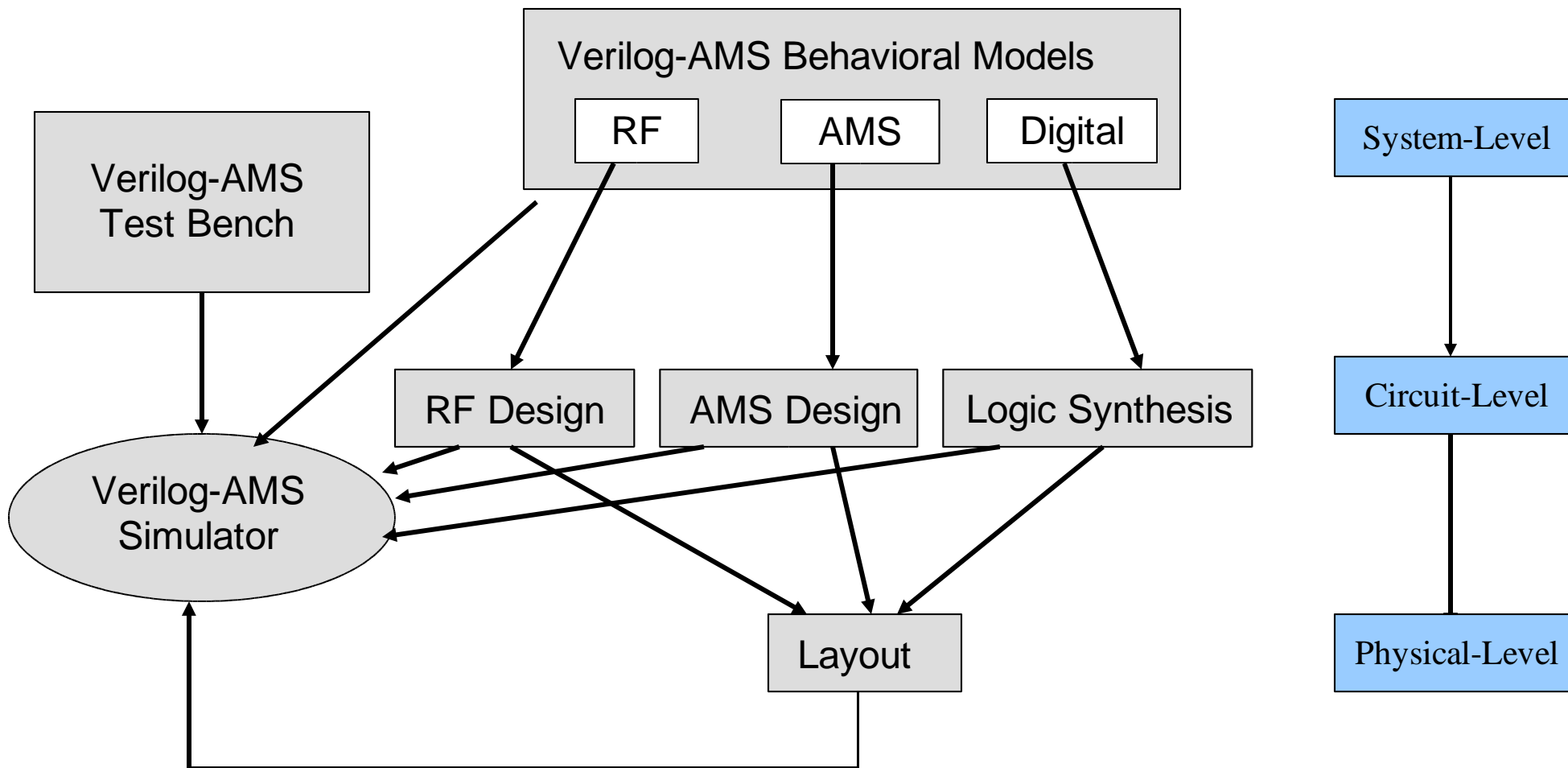


# Scopes of Tools for RF-SoC Design





# RF-SoC Design Flow: (Simplified)





# References for Receiver Architectures

1. "RF Microelectronics" B. Razavi 1998.
2. "Multi-standard CMOS wireless receivers - analysis and design" Li, Xiaopeng, 2002.
3. "A fully integrated 0.18um CMOS direct conversion receiver front-end with on-chip LO for UMTS" IEEE journal of solid-state circuits, vol 39, no.1, Jan 2004.
4. " A 1.5V 45-mW direct-conversion WCDMA receiver IC in 0.13um CMOS" IEEE journal of solid-state circuits, vol. 38, no. 12, Dec. 2003.
5. "A direct-conversion receiver IC for WCDMA mobile system" IEEE journal of solid-state circuits vol 33, no. 9, Sep. 2003.
6. " A highly digitized multimode receiver architecture for 3G mobiles" IEEE transactions on vehicular technology, vol. 52, no. 3, May 2003.
7. " A single-chip multimode receiver for GSM900, DCS1800, PCS1900, and WCDMA" IEEE journal of solid-state circuits, vol. 38, no. 4, Apr. 2003.
8. "A direct-conversion receiver for the 3G WCDMA standard" IEEE journal of solid-state circuits, vol. 38, no. 3, Mar. 2003.
9. "Full- CMOS 2-GHz WCDMA direct conversion transmitter and receiver" IEEE journal of solid-state circuits, vol. 38, no. 1, Jan. 2003.
10. "Direct conversion radio for digital mobile phone – design issues, status, trends" IEEE transactions on microwave theory and techniques, vol. 50, no. 11, Nov. 2002.
11. "Fully integrated W-CDMA IF receiver and IF transmitter including IF synthesizer and on-chip VCO for UMTS mobiles" IEEE journal of solid-state circuits, vol. 36, no. 9, Sep. 2001.
12. "A 2-GHz wide-band direct conversion receiver for WCDMA application" IEEE journal of solid-state circuits, vol. 34, no. 12, Dec. 1999.



## References for RF Design

1. "Practical RF circuit design for modern wireless systems" R. Gilmore, L. Besser, c2003.
2. "Device modeling for analog and RF CMOS circuit design" T.Ytterdal, Y. Chen, T.A.Fjeldly, c2003, Chapter 3.
3. "MOSFET models for SPICE simulation including BSIM3v3 and BSIM4" W.Liu, c2001, Chapter 4.5, 4.6.
4. "Computer-aided design of RF and Microwave circuits and systems" IEEE transactions on microwave theory and techniques, vol. 50, no. 3, Mar. 2002.
5. "Introduction to RF simulation and its application" IEEE journal on solid-state circuits, vol. 34, no. 9, Sep. 1999.



## References for RF-SoC

1. "CMOS technology for MS/RF Soc" IEEE transactions on electronic devices, vol. 50, no. 3, Mar. 2003.
2. "Computer-aided design of RF and microwave circuits and systems" IEEE transactions on microwave theory and techniques, vol. 50, no. 3, Mar. 2002.
3. "RF-Soc – expectations and required conditions" IEEE transactions on microwave theory and techniques, vol. 50, no. 1, Jan. 2002.
4. "Design of mixed-signal system-on-chip" IEEE transactions on computer-aided design of integrated circuits and systems, vol. 19, no. 12, Dec. 2000.
5. "Introduction to RF simulation and its application" IEEE journal on solid-state circuits, vol. 34, no. 9, Sep. 1999.
6. "CMOS technology characterization for analog and RF design" IEEE journal of solid-state circuits, vol. 34, no. 3, Mar. 1999.



**Questions?**