IC design for wireless system

Lecture 1

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Course Objective

- To bridge the gap between the circuit and system visions in wireless design.
- To build up low frequency integrated circuit operations increasing complexity to high frequency circuits such as Low-noise amplifiers, mixers, analog-to-digital converters, VCOs and local oscillators.
Administrative Rules

- Course schedule:
  - Lectures:
    - Thursday (1st slot), 8:30 - 10:00 (C5.206)
    - Thursday (2nd slot), 10:15:11:45
  - Office hours: Thursday (C3.221)
  - Teaching assistant: No TA

- Grading
  - Project & Quizzes & Assignments: 20%
    - Assignment of every lecture is due the following lecture
  - Final exam: 80%

References

- Scientific papers
- Or any VLSI and wireless systems references
Course outline

- Overview of Wireless communication systems
- Low-noise amplifiers
- Local Oscillators
- Mixers
- Analog to digital Converters
- Frequency synthesizer
- High-speed digital circuits

Wireless History

- Guglielmo Marconi invented the wireless telegraph in 1896
  - Communication by encoding alphanumeric characters in analog signal – continuous wave (CW)
  - Sent telegraphic signals across the Atlantic Ocean
  - “It is dangerous to put limits on Wireless” - Guglielmo Marconi, 1932
- Communications satellites launched in 1960s
- Advances in wireless technology
  - Radio, television, mobile telephone, communication satellites – initially RF based analog systems in the VHF/UHF spectrum
- More recently
  - Satellite communications, wireless networking, cellular technology – digital RF in the microwave spectrum
Wireless systems

- Tremendous growth in Wireless Applications
- Demands expertise from different areas (more integration of people)

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Wireless Broadband Systems Applications

- Many Wireless Applications and Gadgets (Multi-dimensional)
- More Functional Integration in 3G

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Typical technology for RFICs

Wireless Standards and Migration

**Push to 3G caused by:**
1. Demand for Higher Data Rates
2. Capacity
3. Global Roaming
Third Generation Cell Phones

- More Capacity
- Higher data rates
- More Functions
- Backward Compatibility
- Global Roaming
- Lower Cost
- Small Size
- Long Battery lifetime

Programmable CMOS Integrated Wireless Transceivers

- Multi-dimensional applications and Multi-standard support

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General RF Transceiver Architecture

- RF Section – analog high frequencies
- Baseband Section-mostly digital ICs working at low frequency

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General RF Transceiver

- RF Transmitter

Optimal RF Transceiver

- Single chip transceiver
- Minimum external components
- Inductors and capacitors integrated on chip
Types of wireless receivers

Wireless Receivers from a Digital/Analog Perspective

- Depends on ADC location in the Analog front End
- An All digital receiver demands RF-ADC (not practical with current technology)
- IF Sampling is currently an active research topic

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**Super Heterodyne Receivers**

- Discrete IR and IF filters not amenable for Integration
- Channel selection done at IF
- Low dynamic range baseband circuits
- Multi-Standard programmability in IF stage is difficult to achieve

**Integrated Receivers**

- Eliminates the need for discrete IR and IF filters
- Signal + Blockers are translated to baseband
- Channel selection done at baseband
- High dynamic range baseband circuits required
- Multi-standard programmability in baseband circuits
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Direct Conversion Receiver

- Digital servo loop implementation using DSP (for offset cancellation)
- Baseband Filter programmability for multi-standard support
- Digitally programmable variable gain amplifiers

programmable baseband chain for a multistandard receiver (ex.:GSM/DECT)

- Enables cell phones to be used as a cordless phone by supporting both GSM/DECT modes of operation
- Utilizes wide band double conversion technique to allow integration
- Focus set to develop the baseband section of the receiver chain
GSM/DECT multi-standard receiver

- DC offset cancellation in DSP
  - DC offset fed back to baseband section to be subtracted from signal
  - VGA with digital offset correction capability is preferred
- Channel selection to be performed using DSP
  - Relaxes filtering requirements
  - Software programmable FIR filters for multistandard operation
  - Requires the use of high dynamic range sigma delta converter
  - Baseband VGA to reduce the ADC dynamic range

Baseband Circuits for Integrated receivers

- Filtering/Amplification relaxes ADC dynamic range
- Low Noise/High Linearity
**Baseband Circuit Design**

“Integrated receivers lead to challenging demands on baseband circuits”

- Small gain in RF section
  - Wide gain control in baseband VGA
  - Low baseband input referred noise
- Out of Band Blockers translated directly to baseband
  - Good Linearity in Amplifiers/Filters
  - Most of Filtering operation done in baseband section
- DC offset problem
- Wide signal bandwidth (Low power??)

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**Challenges in the Wireless Comm. Revolution:**

- Power Consumption
- Multiplicity of Standards
- Requirement for Linear PA
- External Component Count
- Higher Frequency of Operation
- Time to Market

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Power Consumption

- Mobile applications require very low power
- Cellular transceivers burn ~ 100mW of power while power amplifiers burn several watts
- Talk time limited by PA and DSP to a few hours (today we can safely ignore transceiver power!)
- In the future the PA power will drop significantly (power control will regulate power to low levels)
- Transceiver power will thus become equally important
- Transceivers today designed for worst-case scenario of distant base station in presence of nearby interferers

Dynamic Transceivers

- High power consumption comes about due to simultaneous requirement of high linearity in RF front-end and low noise operation
- The conflicting requirements occur since the linearity of the RF front-end is exercised by a strong interferer while trying to detect a weak signal
- A dynamic transceiver can schedule gain/power of the front-end for optimal performance
Multiplicity of Standards

- Cellular voice: GMS, CDMA, W-CDMA, CDMA-2000, AMPS, TDMA...
- Same Standard over multiple frequency bands (4-5 GMS bands exist today)
- Data: 802.11b, 802.11a, Bluetooth, 3G
- A typical handheld computer or laptop should be compatible with all of the above standards

Universal Radio

- High Dynamic Range Broadband Front End
- High speed high dynamic range ADC
- Eliminate high-Q front-end filtering
- Design parallel or broadband amplifiers to cover major bands around 1 GHz, 2 GHz, 5 GHz, etc.
- Require dynamic operation to reduce power
- Employ broadband matching, filtering, and amplification (e.g. 500 MHz – 3 GHz)
Linear Power Amplifiers

- Today’s voice systems employ non-linear PA’s due to the use of constant-envelope modulation schemes
- Spectrally efficient modulation schemes require a linear PA
- Wi-Fi requires a linear PA (due to OFDM)
- Linear PA’s have relatively poor efficiency < 30%
- Efficiency especially problematic at lower power levels (CDMA systems have about 7% average eff.)
- Technology trends in the wrong direction (lower supply voltages and lower breakdown)
- PA’s typically realized in GaAs or V-MOSFET technologies (SiGe, GaN, GaC, others!)

Intelligent Power Amplifiers

- PA’s today are dumb. They should be more adaptive
- A dynamic matching network can compensate for antenna impedance changes due to near-field environmental changes and also due to process variations on the board and matching components.
- Power levels are dropping for dense urban env: Need separate PA’s optimized for both low power and high power; must co-exist and interoperate to maintain efficiency across entire power range
- Research Efforts:
  - Dual Mode Class A/F PA project
  - Dynamic Class A PA project
  - Linearized Class C Amplifier
High External Component Count

- Current trends in academia and industry have reduced component count at RF and IF.
- The Low-IF, Direct-Conversion, and Wideband IF radio architectures eliminate (reduce) external IF filters.
- Systems still heavily dependent on external components on the front end: SAW filters, switches, directional couplers, matching networks, diodes, duplexers ...
- Many of these components are expensive (high Q) and narrowband.

Reducing Front-End Components

- Front-end components are a major impediment to the design of a more universal filter.
- Integration of more passive elements on-chip or in the package.
- Broadband front-end with improved linearity to cover multiple bands eliminates high-Q filters.
- Integrated Matching Networks for PA and LNA.
- Need simulation tools to do co-simulation of chip, package, and board environment.
### Higher Frequency of Operation

- The typical Internet user is very bandwidth hungry: real-time high fidelity digital music requires ~ 100 kbps/s. Video will require several Mbps/s.
- New high frequency bands offer a healthy supply of bandwidth (5 GHz around 60 GHz)
- Current CMOS RF-ICs and design methodology is ill-equipped to move into these bands
- Traditional Microwave methodology also inappropriate (You want to use more than ten transistors?)
- Current Solvers are not capable of handling VLSI circuits (LSI?)

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### RF-ICs Time to Market

- RF expertise hard to find
- Typical IC manufacturer spend ~ 2 years in development, testing, and manufacture of an advanced RFIC
- The consumer market is hungry for products today! (Where’s my wireless USB port on my laptop?)
- RFICs are supposed to be cheap!
- CAD tools and a lack of expertise is a major detriment in fast implementation of today’s systems
Transceiver Optimization

- Typical transceivers designed by large groups of engineers
- Typically the transceiver is divided among several blocks: LNA, VCO, PA, mixer, etc.
- Optimizing individual blocks separately does not yield global optimum!
- Co-design of tightly coupled blocks (LNA+mixer+buffer)
- Dynamic power allocation requires a holistic viewpoint, not an atomistic approach to the optimization

Microprocessors are Becoming Microwave Circuits!

- Low jitter GHz clock lines difficult to implement and consume a lot of power
- Due to large capacitance of loads and line, must drive $C V^2 f$ power
- Take advantage of distributed nature of clock line: inductance of line and capacitance of loads form artificial transmission line
- Power drive to clock resonant network reduced significantly if network has high Q
- Reduce substrate parasitics, eddy currents, etc.
Thanks

References

- Dr. H.O Elwan PhD Presentations