ISSCC 2013 RF Highlights

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Outline

- 60th anniversary of ISSCC
- Paper Statistics
- RF Techniques
- Frequency Generation Techniques
Special Celebrations

- 60th anniversary of ISSCC (1954-2013)
- Lots of nostalgic anecdotes and statistics

![ISSCC Attendees Graph]

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of Attendees</th>
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<tbody>
<tr>
<td>2007</td>
<td>2000</td>
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<tr>
<td>2008</td>
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<td>2009</td>
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<td>2013</td>
<td></td>
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<td>2014</td>
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209 papers were presented
- About the same as last year (206)
- Organized in 27 sessions

Out of the 94 papers from industry, 16 were from the institutes

The papers were uniformly distributed
- Geographically
- Academy vs. industry

Number of papers from Asia is increasing appreciably
RF paper statistics

- **RF session titles:**
  - RF Techniques
  - mm-wave Techniques
  - High Performance Wireless
  - Wireless Transceivers for Smart Devices
  - Frequency Generation
  - Energy Efficient Wireless

- **US and Academia had a larger share**

- **RF Forums**
  - Advanced RF Transceiver Design Techniques
  - Mixed Signal/RF Design and Modeling in Next Generation CMOS RF Short courses
5.1: SAW-less Front-End for TDD/FDD

- Out-of-band interferes
  - Dynamic Range (De-sentization)
  - LO Harmonics
  - Reciprocal Mixing

- External SAW filter
  - Resolves the above issues
  - Single-ended to differential
  - Cost

- Current-mode signal processing
  - LNA acts as a V/I converter
  - I/V conversion after BB filtering
    - Blockers removed in current domain

![Diagram showing current mode operation and passive mixer](image-url)
5.1: SAW-less Front-End for TDD/FDD (cont.)

- The bottle neck is the LNA V/I
  - Linearity is set by this Gm

- CG for Wide-band Zin
  - No current gain
  - NF = 1 + Gamma = 3 (too high)

- On-chip transformers
  - Allows SE/Diff conversion
  - Provides maximum headroom
  - Provide current gain and negative Vin

- Use gate boosting
  - Apply the signal to the gate
  - Improve NF
LO Harmonics are still an issue

- One approach is harmonic-Rejection Mixer
  - Needs higher VCO frequencies

25% duty-cycle mixer is used

- The down converted mixer current is passed through an LC network
- Resonance at $4f_{LO}$
- Mixing at $f_{LO}$ converts the notches to
  - $3f_{LO}$ and $5f_{LO}$

Some debate though

- LO harmonic rejection seems to be limited
- Mixing also with $3f_{LO}$ and $5f_{LO}$

40nm CMOS process
5.2: Spatial and Frequency Filtering

- **N-path filtering**
  - High-Q tunable RF filters
  - High RF Imp. for $f_{RF} = f_{LO}$
  - Low RF Imp. for $f_{RF} \neq f_{LO}$

- **Better Linearity**
  - No active component at RF

- **Extend to phase-array**
  - $RC > T_{on}$
  - Antenna is a current source
  - Signals add up in $C_{BB}$
    - Constructively for in-beam
    - Destructively for out-of-beam
  - SNR improvement
    - Signals are correlated, noise is not
5.2: Spatial and Frequency Filtering (cont.)

- Combine the two ideas
  - Four antennas
  - 8-path filtering for each
  - 8-phase mixer
  - Steer the beam at N*90/8

- Harmonic rejection is still an issue
  - N*f_{LO} goes through

- In this case, 3*f_{LO} is targeted not f_{LO}

- Use base-band weights
  - 3*f_{LO} phase is three times that of f_{LO}
  - Apply BB weights
    - Constructively add for 3*f_{LO}
    - Destructively add for f_{LO}

- 65nm CMOS
5.3: Phase noise cancellation

- If Phase noise can be cancelled, then
  - Use R.O. instead of LC Osc.
  - But how?

- Use a replica path
  - But replica of what?

- Phase noise is symmetric
  - A copy of the phase noise exists
  - Extract it and subtract it
  - Let’s see how it is done
5.3: Phase noise cancellation (cont.)

- **Overall Concept**
  - Main path: Direct down conversion
  - Aux path: Down convert the image
  - Not very practical
    - Needs a second synthesizer
    - Phase noise of 2nd synthesizer

- **Use a limiter based approach**
  - Symmetric spurs $\rightarrow$ AM
  - Anti-symmetric spurs $\rightarrow$ PM
  - Limiter only allows PM through
  - Adjust gain and delay for proper cancellation
5.3: Phase noise cancellation (cont.)

- **Limiter acts as a PN mixer**
  - Sampling at zero-crossings ($2\Delta f_b$)
  - Folding and images will emerge
  - This will impact the PM subtraction

- **Use an N-phase approach**
  - With proper weighting the first N-2 images will be cancelled.
  - The first image is then at N-1 (smaller impact)
5.3: Phase noise cancellation (cont.)

- **Final Design**
  - All circuits are differential
  - Inverters are used for all TIA’s
  - Inv. Also act as limiters
  - What about gain calibration?

- **Digitize both paths**
  - Off chip LMS algorithm
  - $X_{RM}$ exists in both paths
    - Causes correlation
    - Provides proper G
  - Rest is uncorrelated
    - Long enough averaging will remove this extra signal

- **Blocker detector**
  - If no blocker, turn off Aux path

- **40nm CMOS**
5.4: Stacked Array PA

- **Array PA’s**
  - **Serial**
    - Too high an output impedance
  - **Parallel**
    - Too low an output impedance
  - Both inefficient due to large impedance ratios
    - High Q → High IL (for a given $Q_{comp}$)

- **Use arrays of S/P instead**
  - Can provide better matching
    - Lower impedance ratio
    - Better efficiency
Large swing is an issue
- Hot Carrier Injection
- Oxide dielectric breakdown

Use stacking
- Distribute the swing and supply across several series devices
- Too many transformers
- Hard to route

Merge transformers into one
- Simplify the design
- Enhance the power routings
- Use HV for the top most device
  - Needs to handle large V_{db}
- Parasitic S/D caps affect efficiency
5.4: Stacked Array PA (cont.)

- $C_p$ along with $R_{on}$ (when in triode) causes loss
  - During charge and discharge

- Often inductors are used to tune
  - Cost
  - Narrow band

- Use negative capacitors
  - Wide-band
  - But how?
  - Use Miller effect

- Transformers design
  - Low lateral and secondary caps

- 65nm CMOS
  - $P_{out} = 28\text{dBm}$, $PAE = 20.6\%$
5.5: Supply switching PA

- Efficiency degrades when PA B.O.
- What is supply drops when signal drops?
  - Needs DC/DC converters
  - Use stacked PA for Vdd/2 case
    - Mid point needs to be around Vdd/2
    - Use a keeper
- <2ns threshold detector (EVM Impact)
  - Some switching noise issues
5.6: TX leakage suppression

- **RFID system**
  - Back scatter and AM modulate an incoming CW
  - RX signal contaminated by the TX CW

- **Current techniques**
  - Active blocker injection
  - VCO cancellation

- **Proposed solution**
  - Non-linear amplification with a dead zone
20.1: Class-D VCO

- **Class-B VCO**
  - Large swing (+-Vdd)
  - Need Tail current source (or resistor)
    - Due to $R_{on}$ losses

- **What if we have very low $R_{on}$?**
  - Go for even higher swings
  - Loss in $R_{on}$ is negligible (good switch)
  - Lower Vdd, hence lower power

![Diagram of Class-B VCO with time-invariant and time-variant tanks, showing high impedance and good switches.](image)
20.1: Class-D VCO (cont.)

- **Operation**
  - T1: The $I_{La}$ charges up
  - T2: $La$ resonates with C

- **Circuit equations**
  - Continuous $I_{La}$ and its derivative
  - $T1 = T2$ (due to symmetry)
    - $V_{peak} = V_{dd} \left( 1 + \sqrt{\frac{\pi^2 \alpha^2}{4}} + 1 \right) \approx 3.27V_{dd}$
    - $\omega_D = \frac{1}{\sqrt{LC}} \sqrt{\frac{2}{\alpha}} \quad \alpha = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{4}{\pi^2}} \approx 1.3$

- **Note that the tank is time variant**
  - Makes phase noise calculation even more difficult

- **Very large (1.35mm) switches were used**
  - Poor $1/f^3$ and supply pushing
20.2: Class F VCO

- **Motivation: Reduce power**
  - Larger tail current help PN
  - Until the devices go in triode

- **Basic idea: Improve ISF**
  - Noise injection when V is flat
    - Not during zero crossing
  - But how?

- **Make the tank to have high impedance at** $f_0$ **and** $3f_0$

- **Make** $Z(3f_0) = \frac{Z(f_0)}{x}$
  - A more advanced tank is required
A transformer-based tank will provide two pair of complex poles

By setting the proper coupling factor, the intended impedance can be achieved

Oscillation at higher frequency
- Lower loop gain
- Injection locking to 3f₁

Very large gate voltages
- Use thick-oxide devices

Transformed based tank has two resonance frequency for imperfect coupling factor:

\[ Z_{in} = \frac{s^3(L_pL_sC_2 (1-K_m^2)) + s(L_p)}{s^4(L_pL_sC_1C_2 (1-K_m^2)) + s^2(L_sC_2 + L_pC_1) + 1} \]

Forth-order polynomial:

\[ [Z_{in}]Ω \]

Lower Q, higher BW

Fine tuning capacitors (C₁)

Coarse tuning capacitors (C₂)

M₁ & M₂ thick oxide devices ➔ More than 10 years operation