A 402/433 MHz Low Power, Direct Conversion Medical Implant Communication FSK Receiver Front End

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Group 7
Outline

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- Applications
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- Specifications
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  - Single to Differential Converter
  - Mixer
  - VCO
  - Low Pass Filter
- Performance Measures
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Motivation

- To move from reactive healthcare based methods to active and prevention based healthcare solutions.
- To aid in monitoring health based parameters in real time
- Remote access to patient’s data
- Reduce the healthcare cost and improving access to better healthcare to wider population
  - To develop low power low cost radio frequency receiver front end for medical applications
  - Eliminating replaceable components with highly reliable and long life term mechanisms (i.e. batteries with energy harvesting mechanism)
- Provide external control of functionality/measurement of implanted/ embedded devices
Applications

- **Personal Healthcare System**
- **Wireless Bio-signal Acquisition**
- **Implantable Devices**
  - Pacemaker
  - Neurostimulators
  - Cochlear Implants
  - Retinal Prosthesis
  - Implantable Cardioverter/ Defibrillator (ICD)
- **Embedded Measurement/Control/ Other Devices**
  - Drug Infusion & dispensing
  - Implanted sensors for measuring body parameters
  - Artificial Heart & Organ Assist devices
MICS BAND

- Medical Implant Communication Service (MICS)

- Why introduce MICS?
  - Removes limitations associated with existing short range inductive links (low data rate, very short range requires body contact)
  - Opportunity for improved healthcare and new applications

- Why 402-405 MHz?
  - Reasonable signal propagation characteristics in the human body
  - Compatibility with incumbent users of the band (e.g. weather balloons)
  - General world-wide acceptance (US, Europe, Japan, Australia etc)

- Why allocate separate band?
  - Need for higher data rates
  - Need for longer range/ broader applications
  - Required by medical industry
Architecture

- Direct Receiver (Zero IF Architecture)
Specifications

- Frequency of Operation: 402-405 MHz (10 channels MICS)/ 433-434 MHz (2 channels ISM)
- Data Rate: ~20 Kbps
- Modulation Scheme: Non-coherent FSK with index m=0.25
- Adjacent Channel Rejection: 50dB
- Sensitivity: -110 dBm @ 0.1% BER
- Power Consumption: ~1mW
- Range: ~2m
- Minimum Detectable signal (MDS): -91dBm
- Technology: 0.13 um
- NF = 174 -10logB - SNR + MDS = 26 dB (at demodulator input for MICS band)
## Biological Signal Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement Range</th>
<th>Signal Frequency (Hz)</th>
<th>Standard Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrocardiography (ECG)</td>
<td>0.5 ~ 4 mV</td>
<td>0.01 ~ 250</td>
<td>Skin electrode</td>
</tr>
<tr>
<td>Electroencephalography (EEG)</td>
<td>5 ~ 300 uV</td>
<td>dc ~ 150</td>
<td>Scalp electrode</td>
</tr>
<tr>
<td>Electromyography (EMG)</td>
<td>0.1 ~ 5 mV</td>
<td>dc ~ 10000</td>
<td>Needle electrode</td>
</tr>
<tr>
<td>Electronerography (ENG)</td>
<td>0 ~ 100 uV</td>
<td>250 ~ 5000</td>
<td>Surface or Needle electrode</td>
</tr>
<tr>
<td>Electroretinography (ERG)</td>
<td>0 ~ 900 uV</td>
<td>dc ~ 50</td>
<td>Contact electrode</td>
</tr>
</tbody>
</table>
LNA & Single to differential stage
LNA

Design Challenge:

• High Gain
• Return loss
• Noise Figure
• Impedance matching at input
Single to Differential Stage

Cascaded Common Gate Common Source Balun
## Performance

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain (S21) LNA</td>
<td>11.22 dB</td>
</tr>
<tr>
<td>Gain (S21)</td>
<td>16.45 dB</td>
</tr>
<tr>
<td>Return Loss (S11) LNA</td>
<td>-10.28 dB</td>
</tr>
<tr>
<td>Return Loss (S11)</td>
<td>-9.65 dB</td>
</tr>
<tr>
<td>Noise Figure (LNA)</td>
<td>2.71 dB</td>
</tr>
<tr>
<td>Noise Figure</td>
<td>8.03 dB</td>
</tr>
<tr>
<td>Power Consumption (LNA)</td>
<td>9.87 uW</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>44.91 uW</td>
</tr>
</tbody>
</table>
Low Power
Low Noise
Self Mixing Free
I-Q down-conversion
Zero-IF Receiver

Merits:
- Low complexity, cost, power

Susceptible to:
- LO Leakage (DC offset)
- 1/f noise
- I/Q Mismatch
- Even order distortion
DC OFFSET at Mixer output

- LO radiated, reflected and received, mixed with itself
- Hard to remove time varying DC offset
- Removing by root:
  - Oscillator running at half the signal frequency
  - Frequency doubling within the mixer by employing phase shifted LO signals.
  - Oscillator frequency mixed to half the RF frequency

\[ \text{flo}=\text{frf}/2 \]

\[ \text{fswitch}=2\text{flo} \]
Flicker Noise

- **Main contributor:**
  - Switching pairs
    - $\ln(DC) \sim I_b, 1/Area, 1/frf$

- **Bleed current**
  - decrease switch current
  - reused in driver stage for large gm
  - Makes signal more sensitive to parasitic capacitances
IQ mismatch and low power

- Amplitude and phase of I/Q channels need to match
- Combine trans-conductor for both channels
  - Process variation shared
  - Half power
Mixer Summary

- Power: combined IQ 550 µW
- $f_c=25$ kHz
- NF: 17.5 dB
- Conversion Gain: 23 dB
VCO
Voltage Control Ring Oscillator

Design Challenge:

• Phase Noise
• Low Power
Voltage Control Ring Oscillator
Frequency Spectrum
Phase Noise
Filter
Low Pass Filter Characteristic
Layout

Area: 
~ 1124 X 879 \text{um}^2
Performance Summary

- **LNA**
  - NF=2.75 dB  Gain=11.22 dB  Power= 9.87µW

- **Balun**
  - NF=5.28 dB  Gain=5.23 dB  Power=35 µW

- **Mixer**
  - NF=18 dB  Gain=20 dB  Power=550 µW

- **VCO**
  - Phase Noise= -102dBc/Hz at 1 MHz
  - Power=19µW

- **LPF**
  - 3 dB cutoff = 200kHz
  - Tunable gain upto 40 dB

- **System**
  - Overall Gain:76.45 dB (calculated)
  - NF after mixer = 9dB (calculated)
Summary
References

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Questions?