EECS 522

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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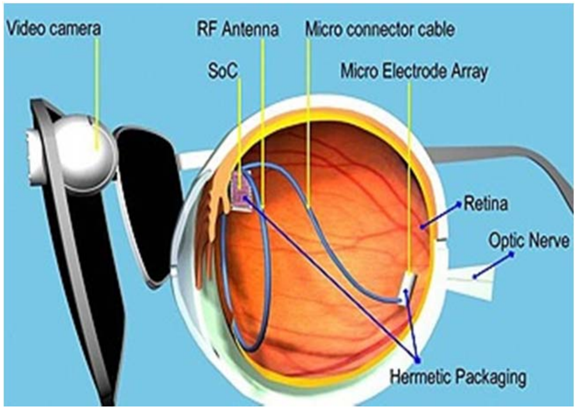
- **Summary**
- **References**

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)



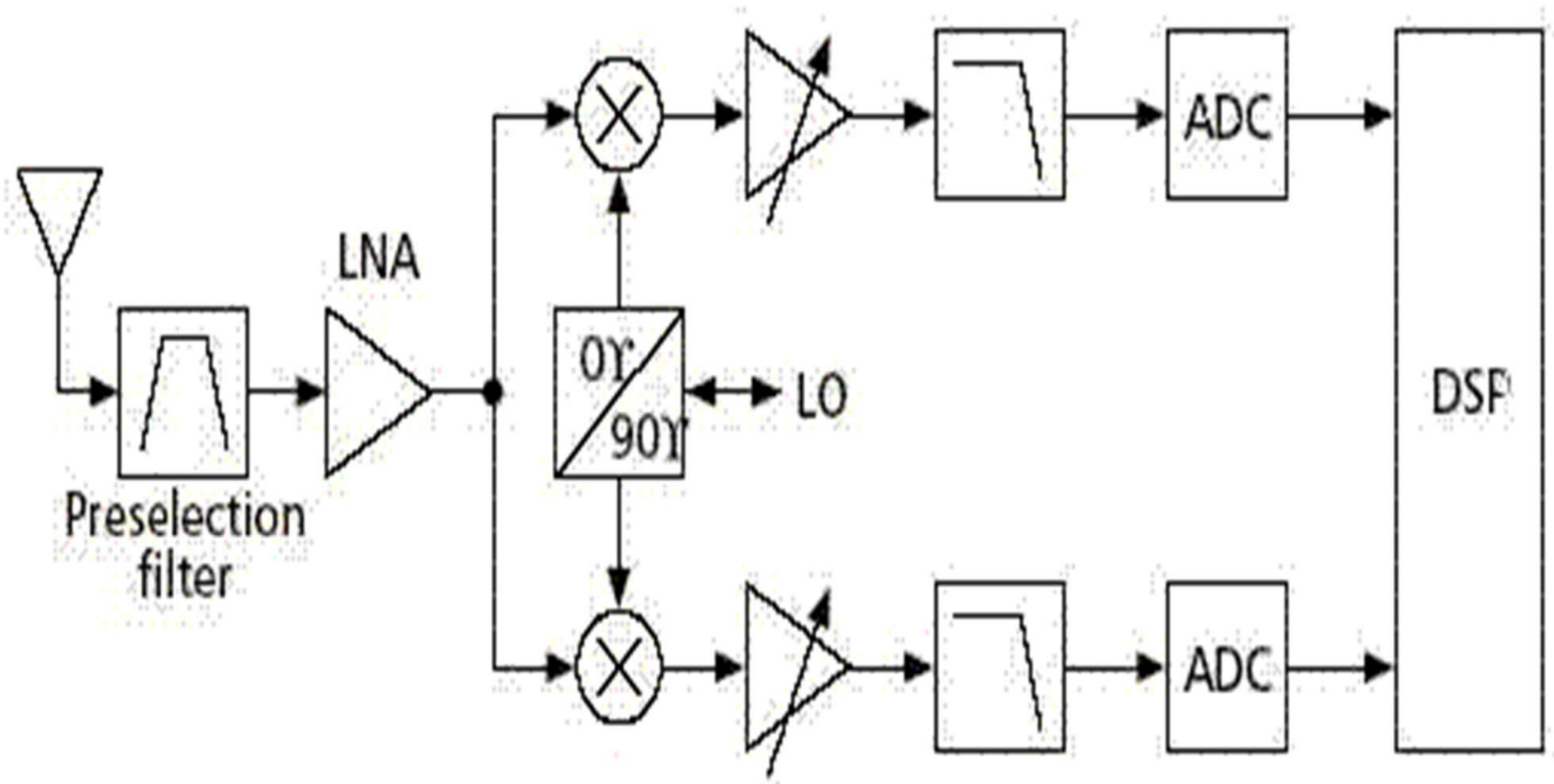
- **Embedded Measurement/Control/ Other Devices**
  - Drug Infusion & dispensing
  - Implanted sensors for measuring body parameters
  - Artificial Heart & Organ Assist devices

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

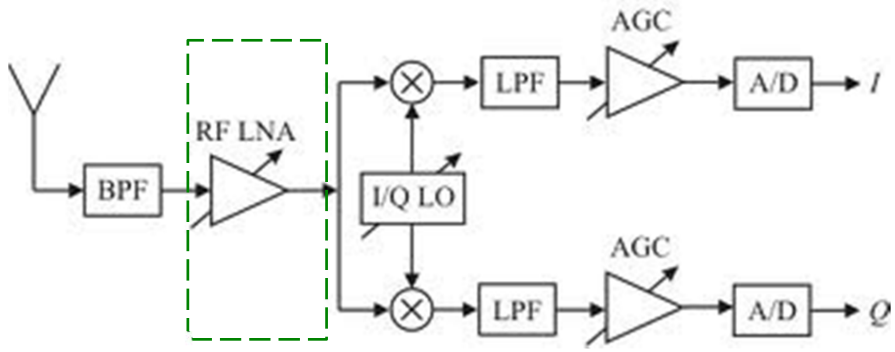
- Frequency of Operation: 402-405 MHz (10 channels MICS)/ 433-434 MHz (2 channels ISM)
- Data Rate: ~20 Kbps
- Modulation Scheme: Non-coherent FSK with index m=0.25
- Adjacent Channel Rejection: 50dB
- Sensitivity: -110 dBm @ 0.1% BER
- Power Consumption: ~1mW
- Range: ~2m
- Minimum Detectable signal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

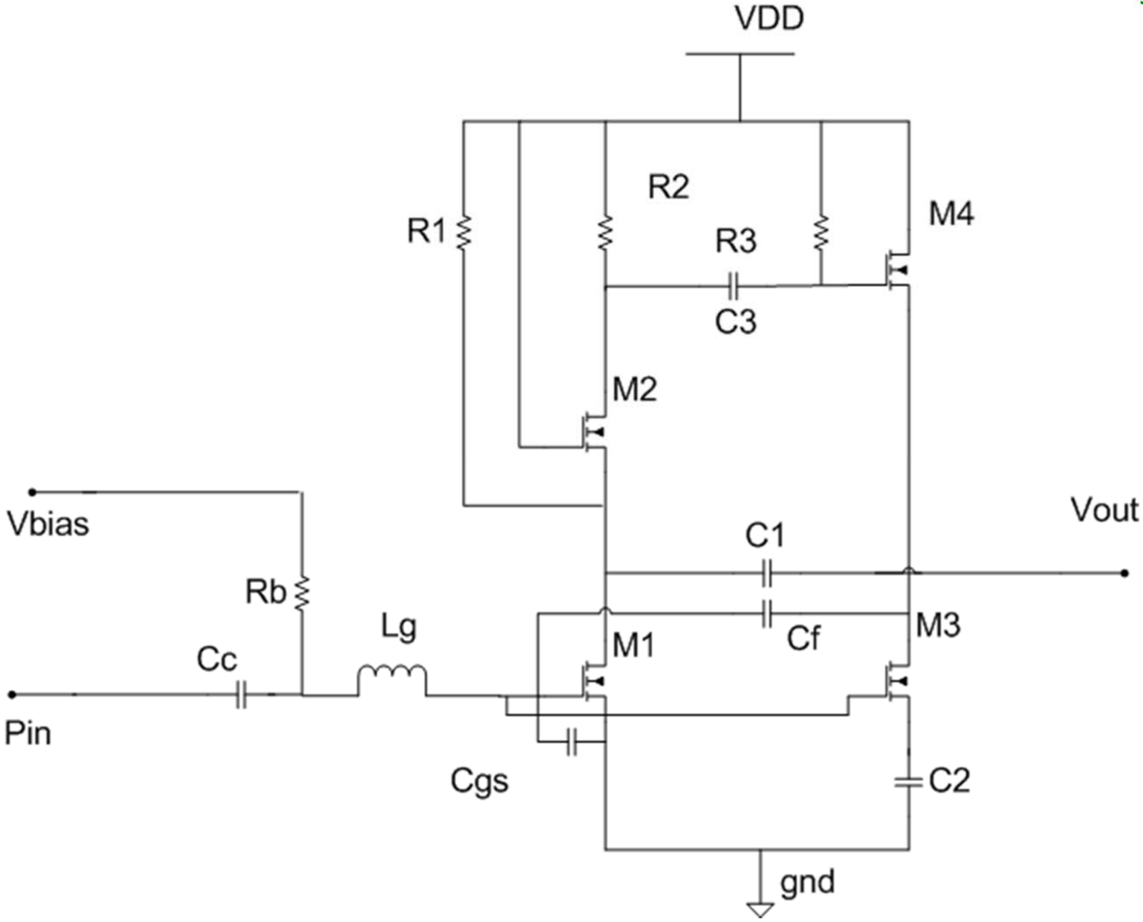
Biological Signal Charactersitic

Parameter	Measurement Range	Signal Frequency (Hz)	Standard Sensor
Electrocardiography (ECG)	0.5 ~ 4 mV	0.01 ~ 250	Skin electrode
Electroencephalography (EEG)	5 ~ 300 uV	dc ~ 150	Scalp electrode
Electromayography (EMG)	0.1 ~ 5 mV	dc ~ 10000	Needle electrode
Electronerography (ENG)	0 ~ 100 uV	250 ~ 5000	Surface or Needle electrode
Electroretinography (ERG)	0 ~ 900 uV	dc ~ 50	Contact electrode

LNA & Single to differential stage

LNA



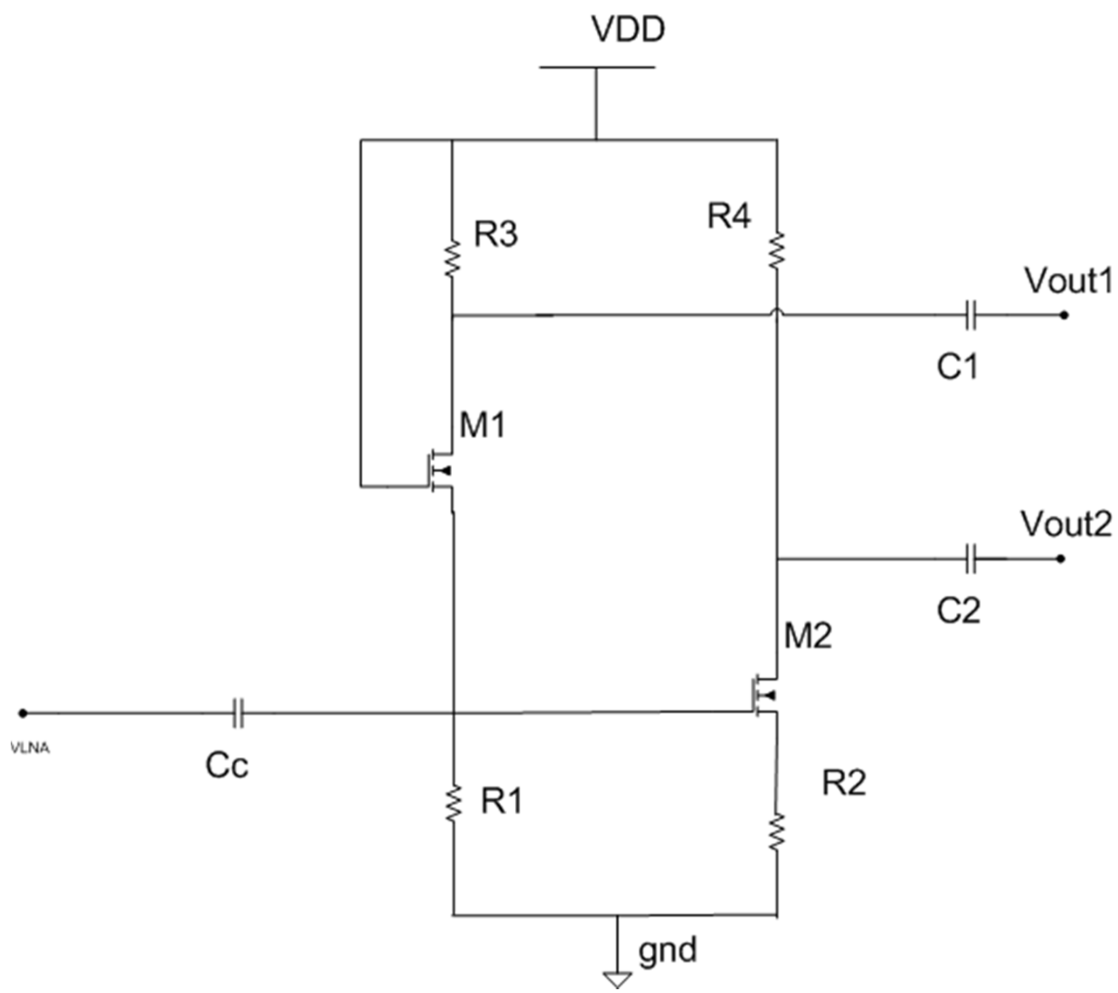


Design Challenge:

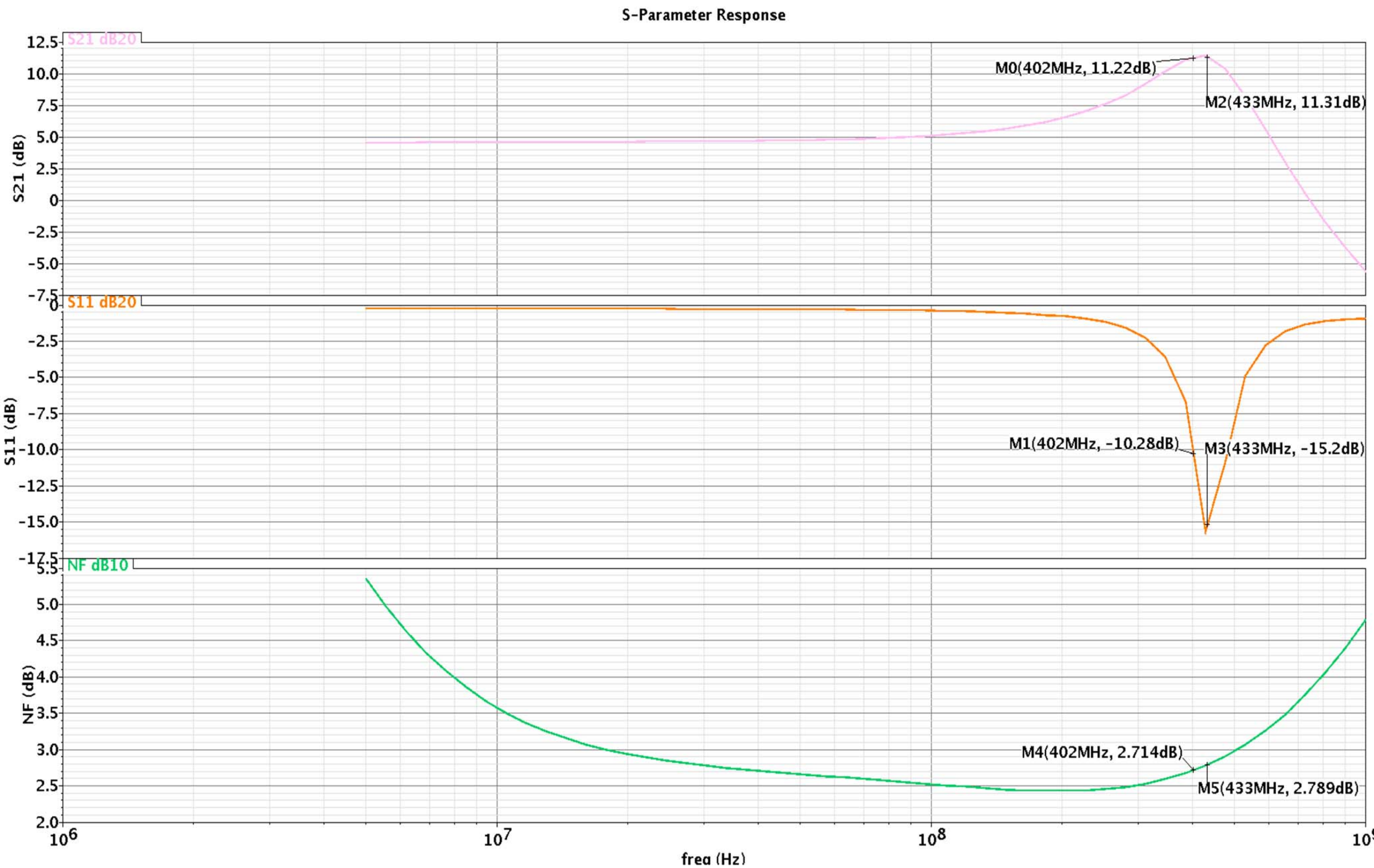
- High Gain
- Return loss
- Noise Figure
- Impedance matching at input

Single to Differential Stage

Cascaded Common Gate Common Source Balun



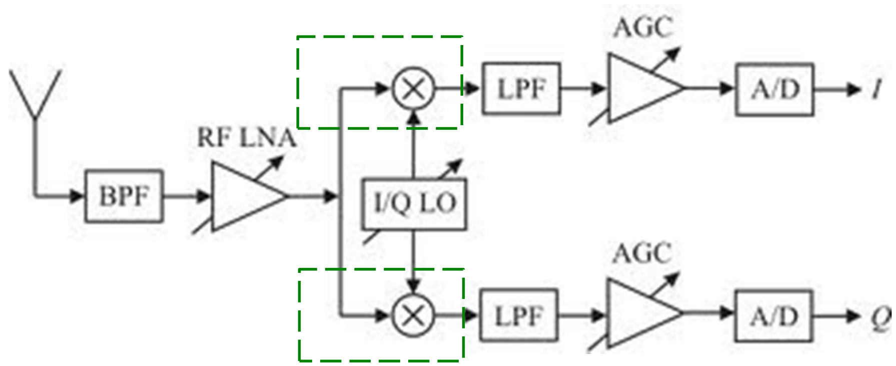
LNA Charactersitics



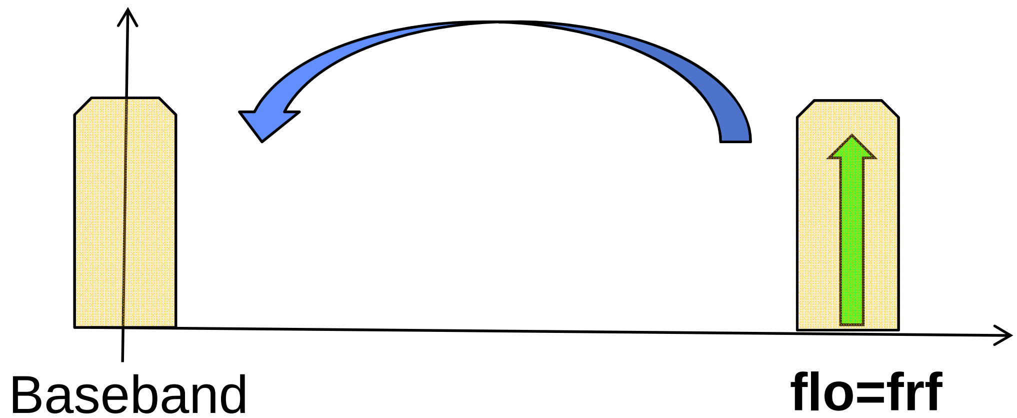
Performance

Parameters	Results
Gain (S21) LNA	11.22 dB
Gain (S21)	16.45 dB
Return Loss (S11) LNA	-10.28 dB
Return Loss (S11)	-9.65dB
Noise Figure (LNA)	2.71 dB
Noise Figure	8.03 dB
Power Consumption (LNA)	9.87 uW
Power Consumption	44.91 uW

Low Power
Low Noise
Self Mixing Free
I-Q down-conversion



Zero-IF Receiver



Merits:

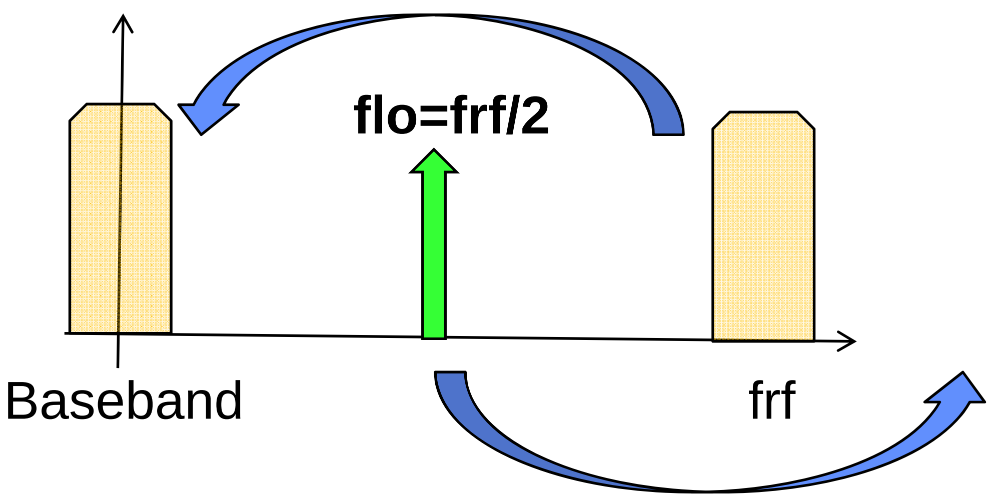
- Low complexity, cost, power

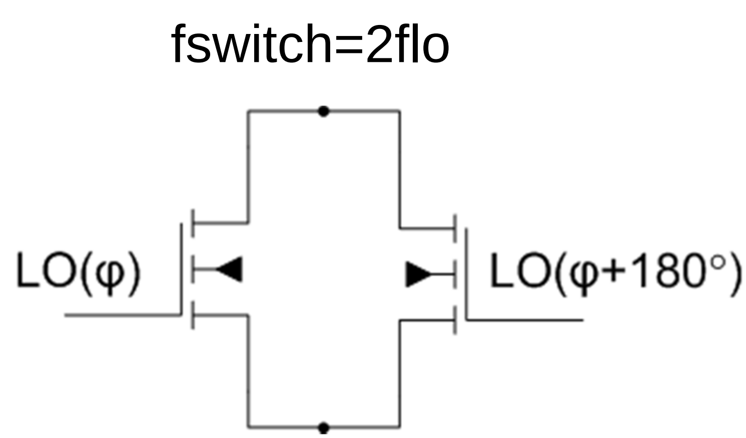
Susceptible to:

- LO Leakage (DC offset)
- 1/f noise
- I/Q Mismatch
- Even order distortion

DC OFFSET at Mixer output

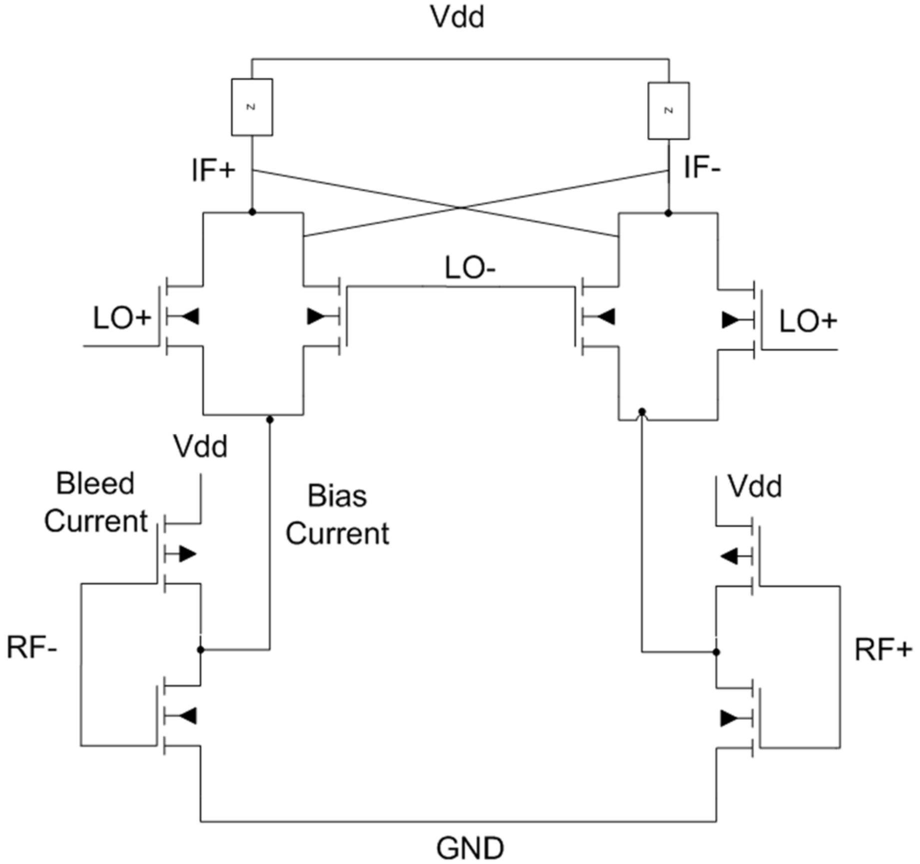
- **LO radiated, reflected and received, mixed with itself**
- **Hard to remove time varying DC offset**
- **Removing by root:**
  - Oscillator running at *half* the signal frequency
  - frequency doubling within the mixer by employing phase shifted LO signals.
  - Oscillator frequency mixed to half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





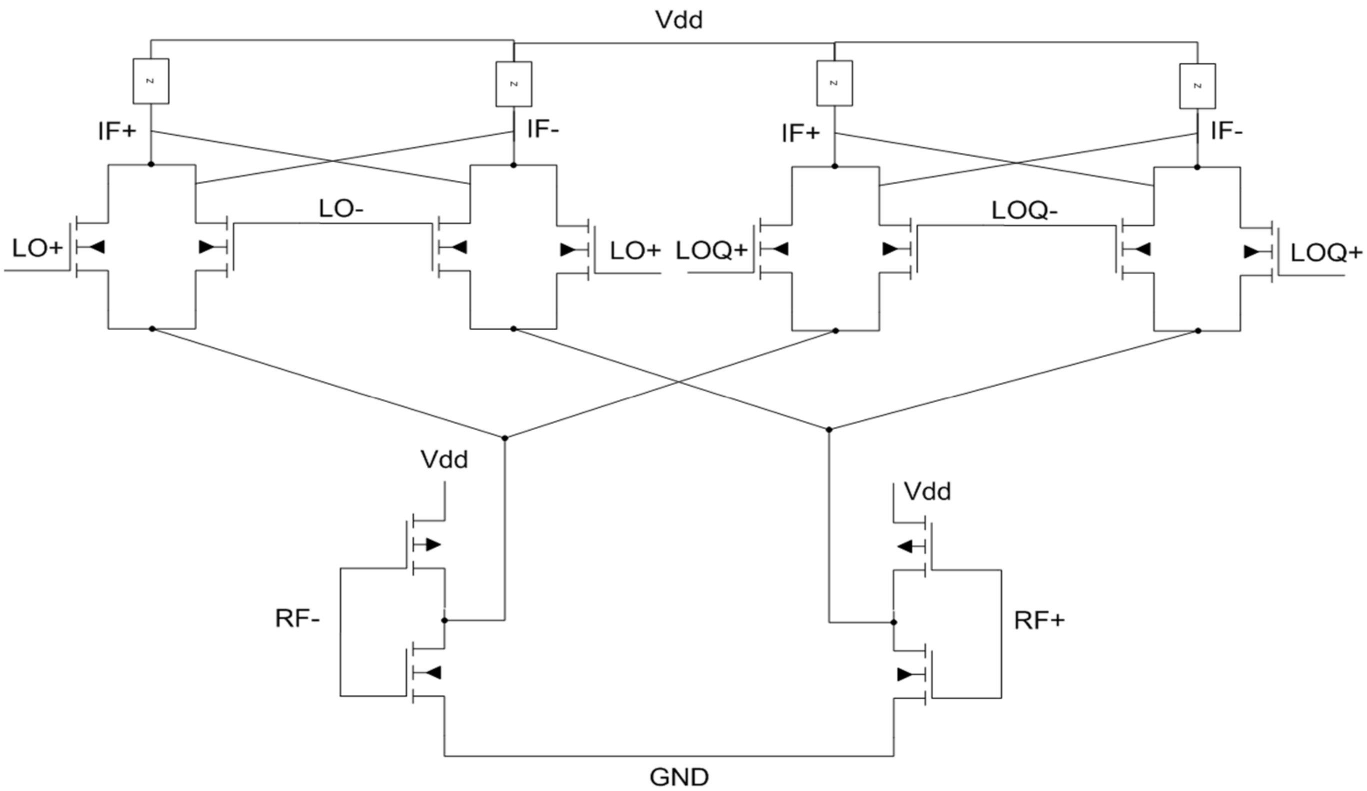
Flicker Noise

- **Main contributor: Switching pairs**
  - In(DC) ~ Ib, 1/Area, 1/frf
- **Bleed current**
  - decrease switch current
  - reused in driver stage for large gm
  - Makes signal more sensitive to parasitic capacitances



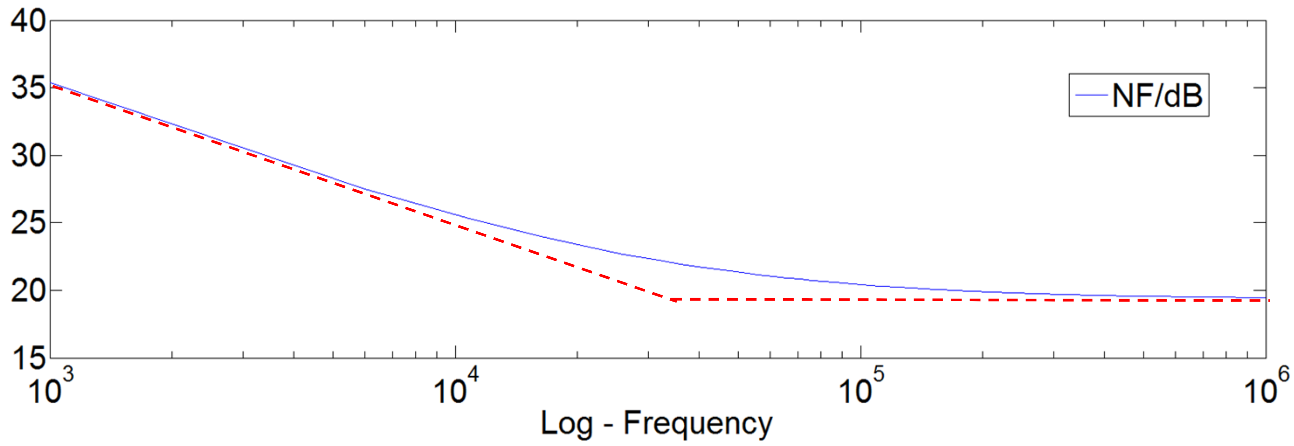
IQ mismatch and low power

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



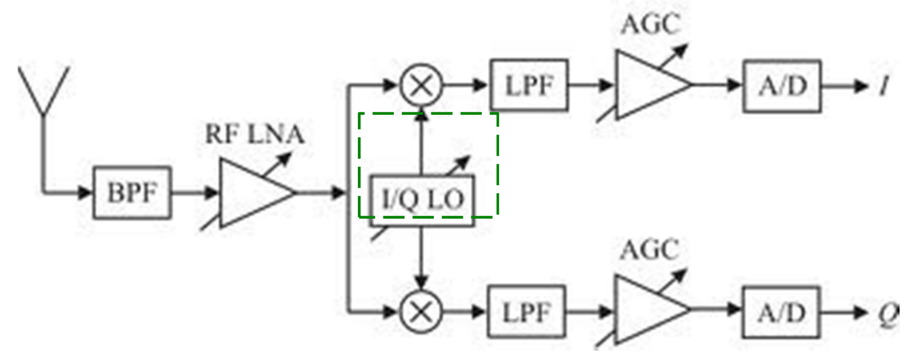
Mixer Summary

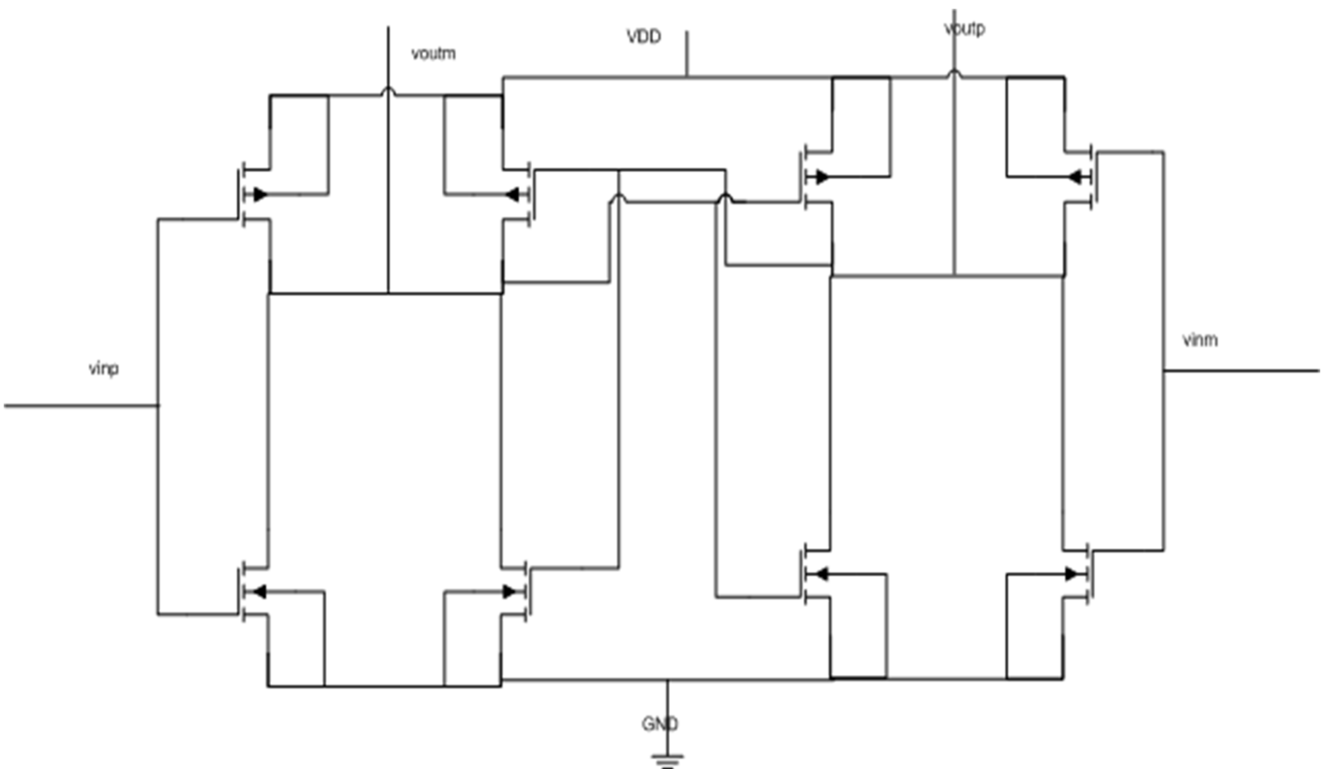
- Power : combined IQ 550μW
- fc=25 kHz
- NF : 17.5dB
- Conversion Gain : 23dB



VCO

Voltage Control Ring Oscillator

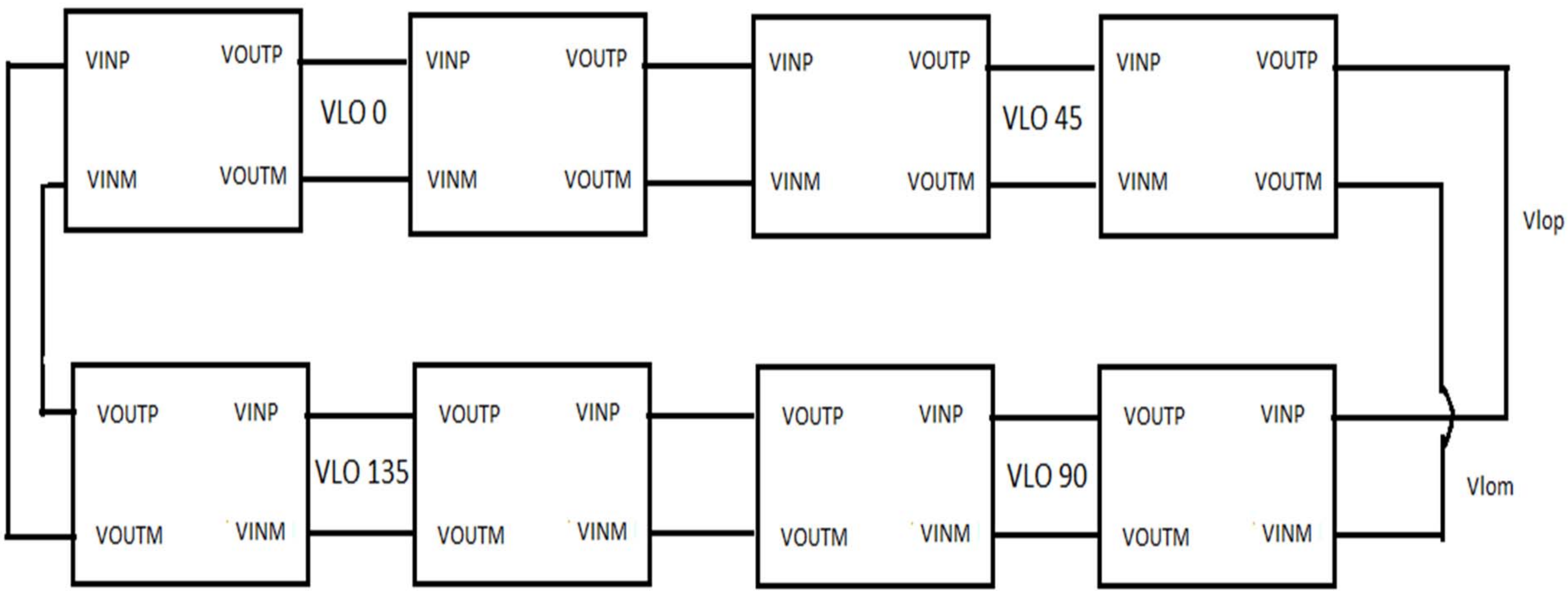




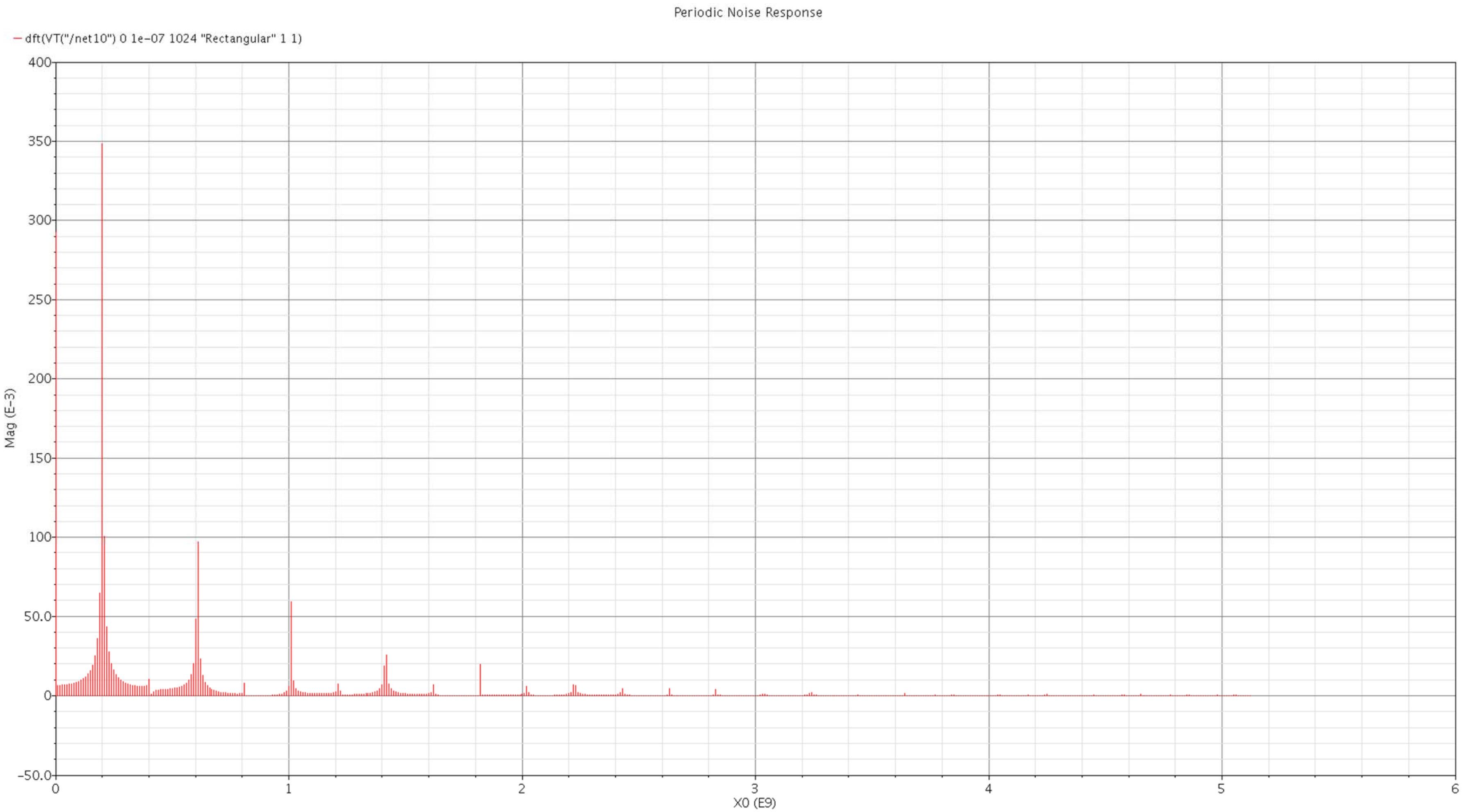
Design Challenge:

- Phase Noise
- Low Power

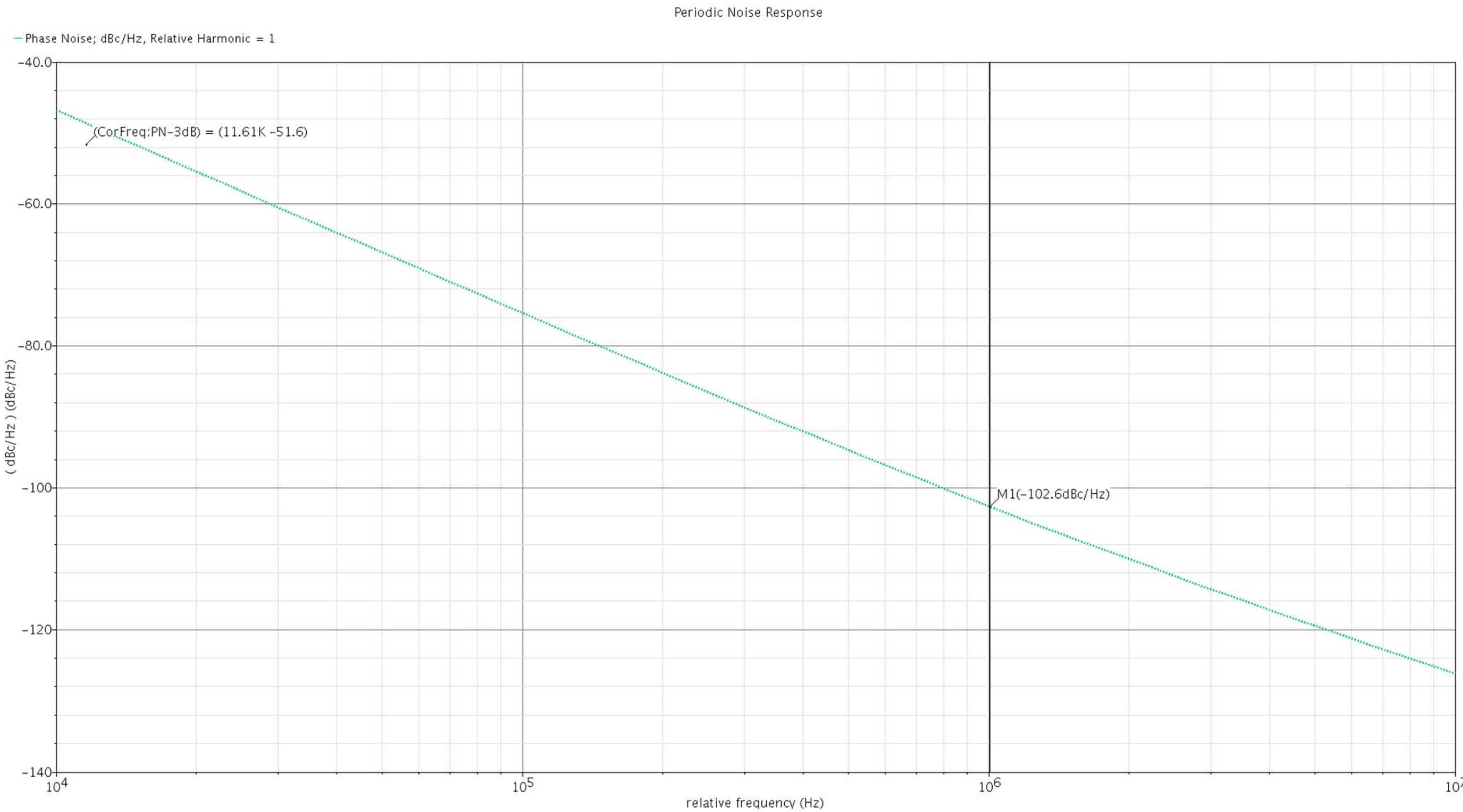
Voltage Control Ring Oscillator



Frequency Spectrum



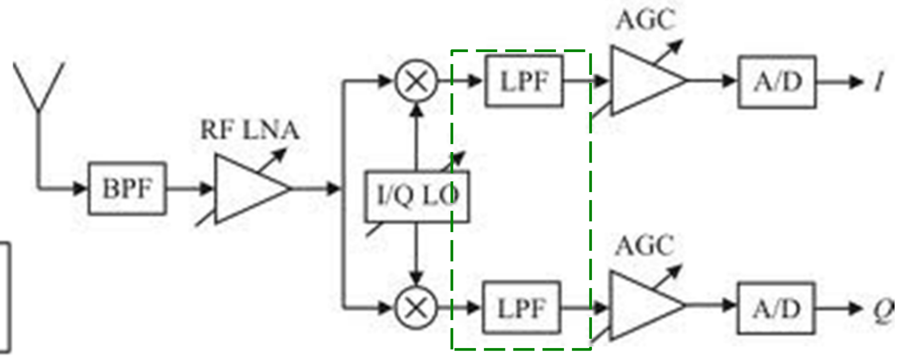
Phase Noise

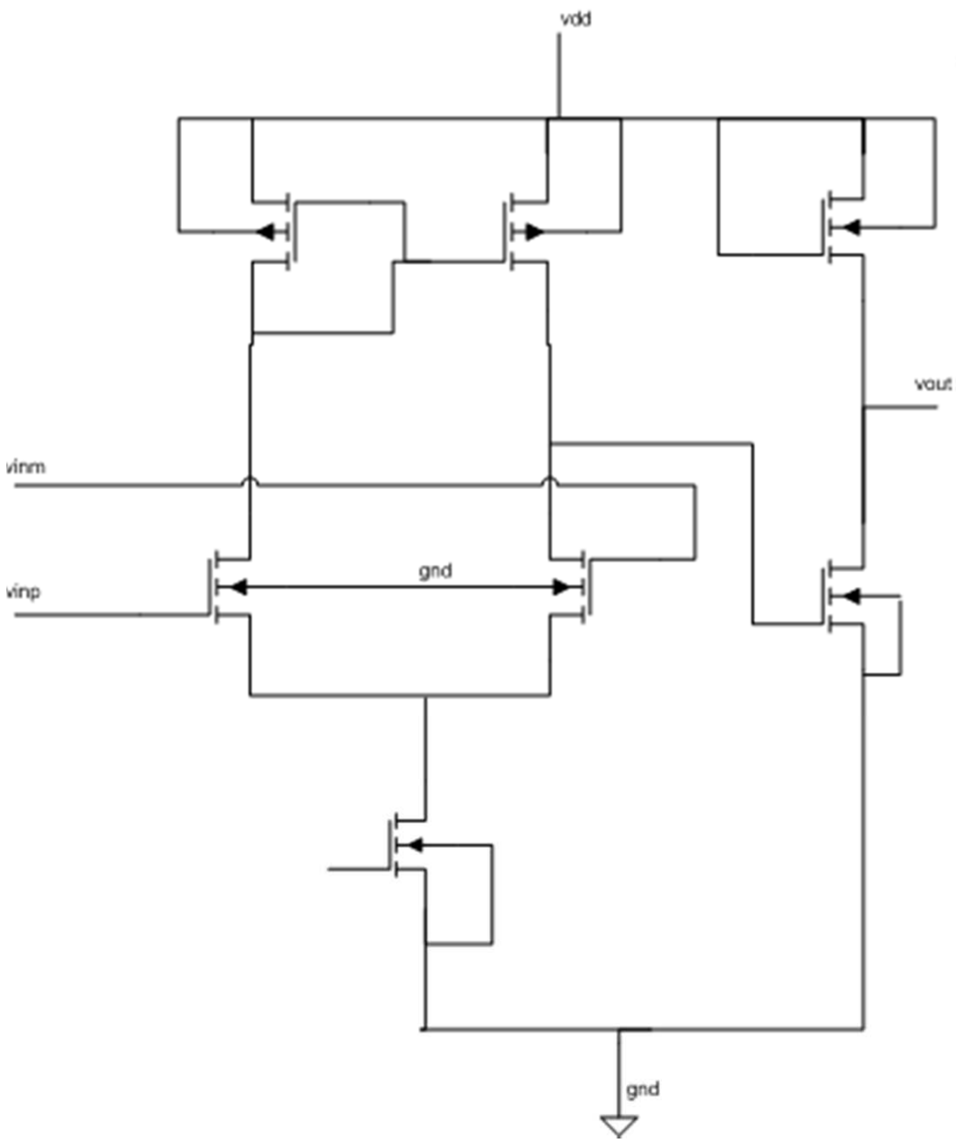


Periodic Noise Response
Phase Noise; dBc/Hz, Relative Harmonic = 1
(CorFreq:PN-3dB) = (11.61K -51.6)
M1(-102.6dBc/Hz)
-40.0
-60.0
-80.0
-100
-120
-140
(dBc/Hz) (dBc/Hz)
10^4
10^5
10^6
10^7
relative frequency (Hz)

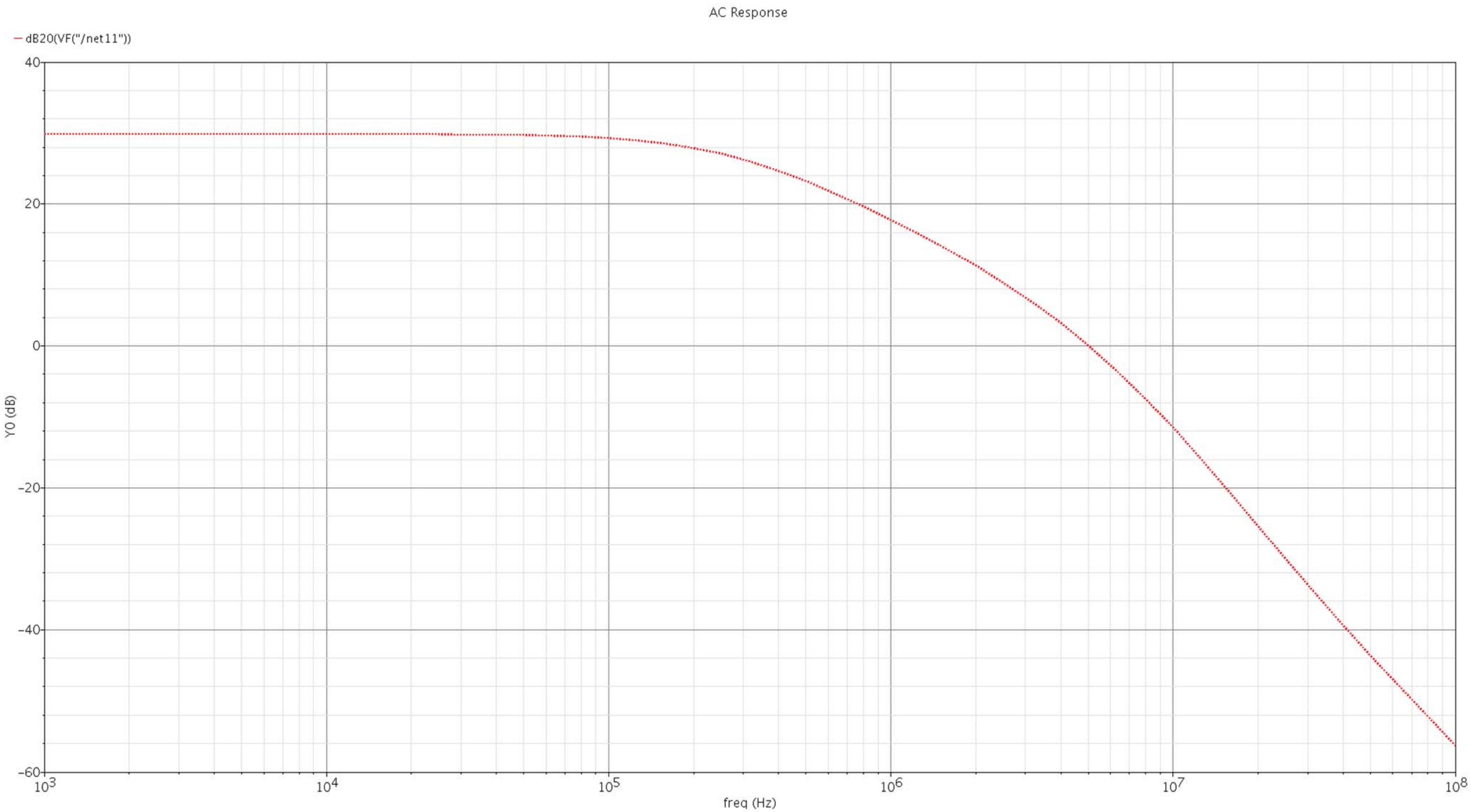
Filter

Low Pass Filter

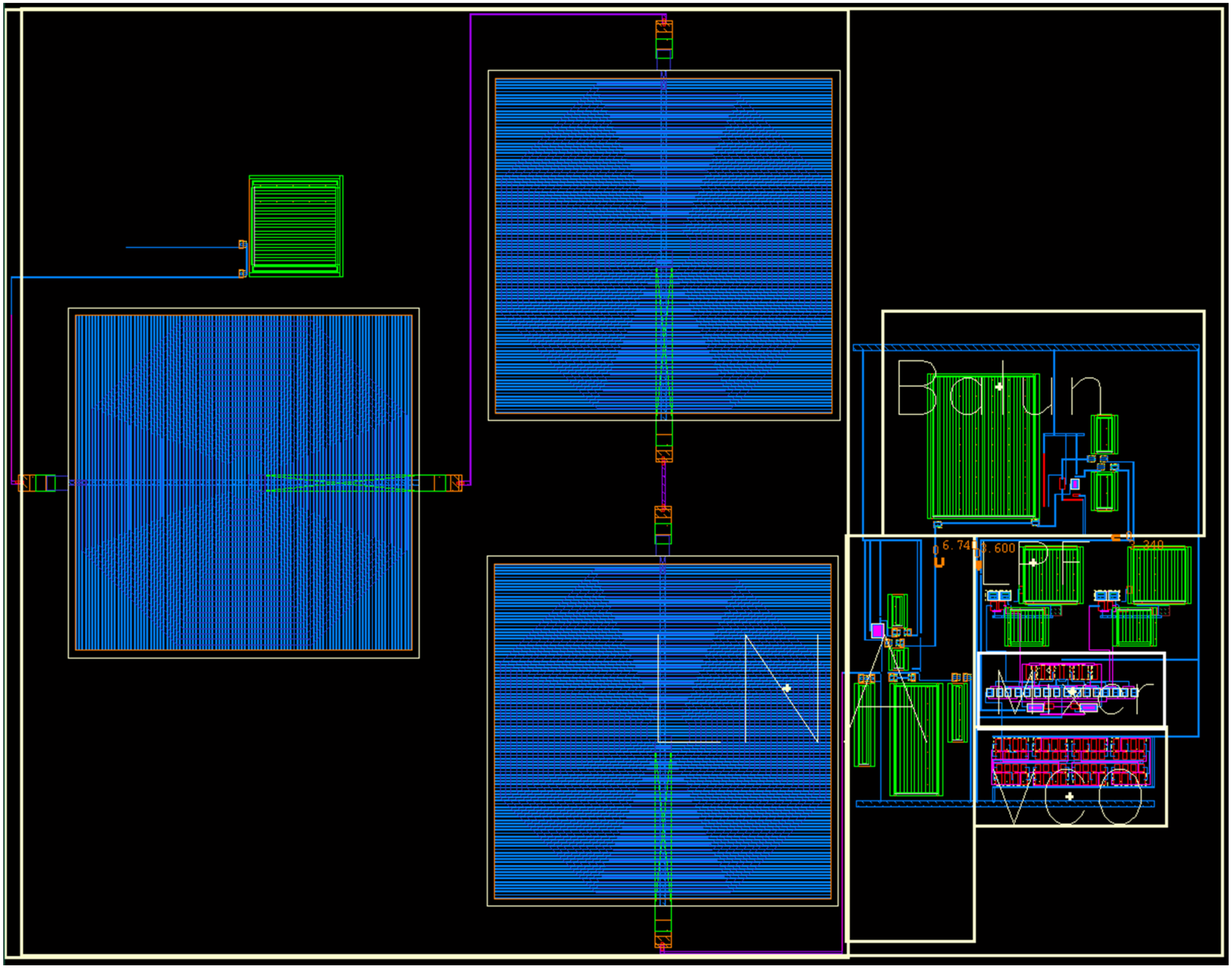




Low Pass Filter Charactersitic



Layout

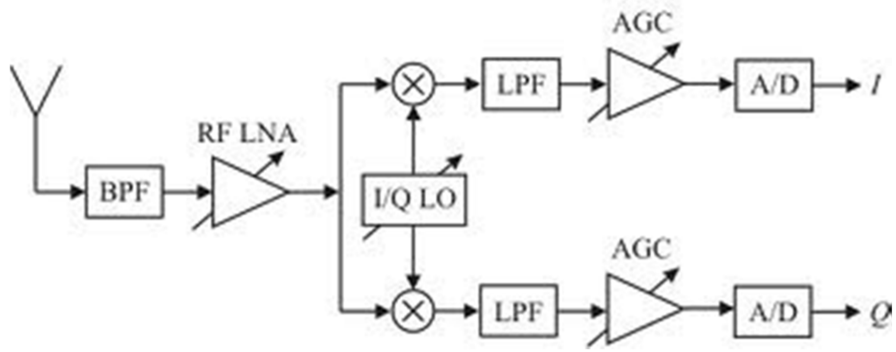


Area:
~ 1124 X 879 um^2

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



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Questions?