20.2: A Dual-band CMOS MIMO Radio SoC for IEEE 802.11n Wireless LAN

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Outline

- Introduction
- SoC architecture
- Circuit implementation
- Measurement results
- Conclusions

802.11n MIMO Wireless LAN

	Legacy 802.11(g/a)	802.11n (Draft)
Spectrum Available	83.5/555MHz	83.5/555MHz
Channel Bandwidth	20MHz	20/40MHz
Non-overlapping channels	3/24	3/24
Max. Data Rate (Mbps)	54	$150 \times N_{streams}$
Modulation	DSSS, CCK, OFDM	DSSS, CCK, OFDM

- **Improved Throughput and range by employing:**
  - Spatial diversity: transmitting multiple streams on multiple radios
  - Higher bandwidth per channel: 40MHz (HT-40)
  - More OFDM subcarriers: 56 vs. 52
  - Shorter guard intervals: 400ns vs. 800ns
  - Higher coding rate: 5/6 vs. 3/4
- **Backwards compatible with legacy 802.11a/g networks**

MIMO Radio Requirements

Compared to legacy 802.11, MIMO 802.11 radios demand:

- **Better error-vector magnitude (EVM)**
- **Tighter spectral mask requirements**

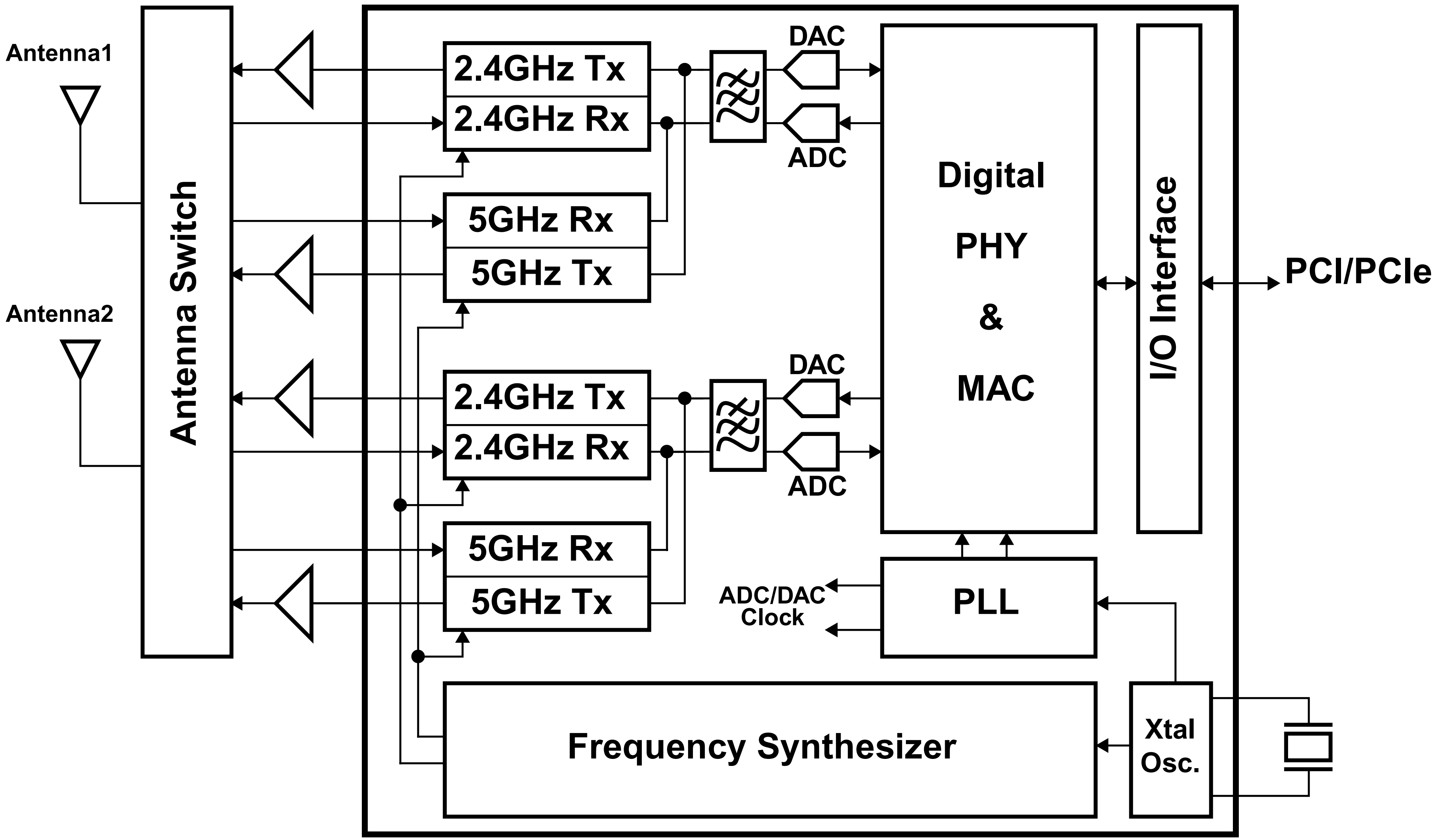
Which translates to:

- **Lower phase-noise**
- **Better I/Q matching**
- **Better Linearity**
- **Less noise**

In Addition, they require

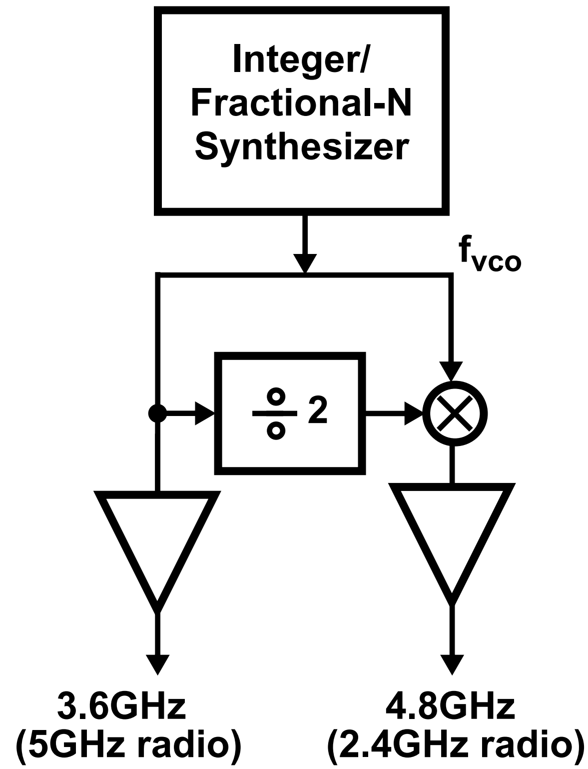
- **Faster ADCs and DACs**
- **Less in-band ripple in the baseband filter**
- **Careful SoC floorplanning to avoid chain-to-chain cross-talk**
- **Lower power, smaller and more modular design**

SoC Block Diagram

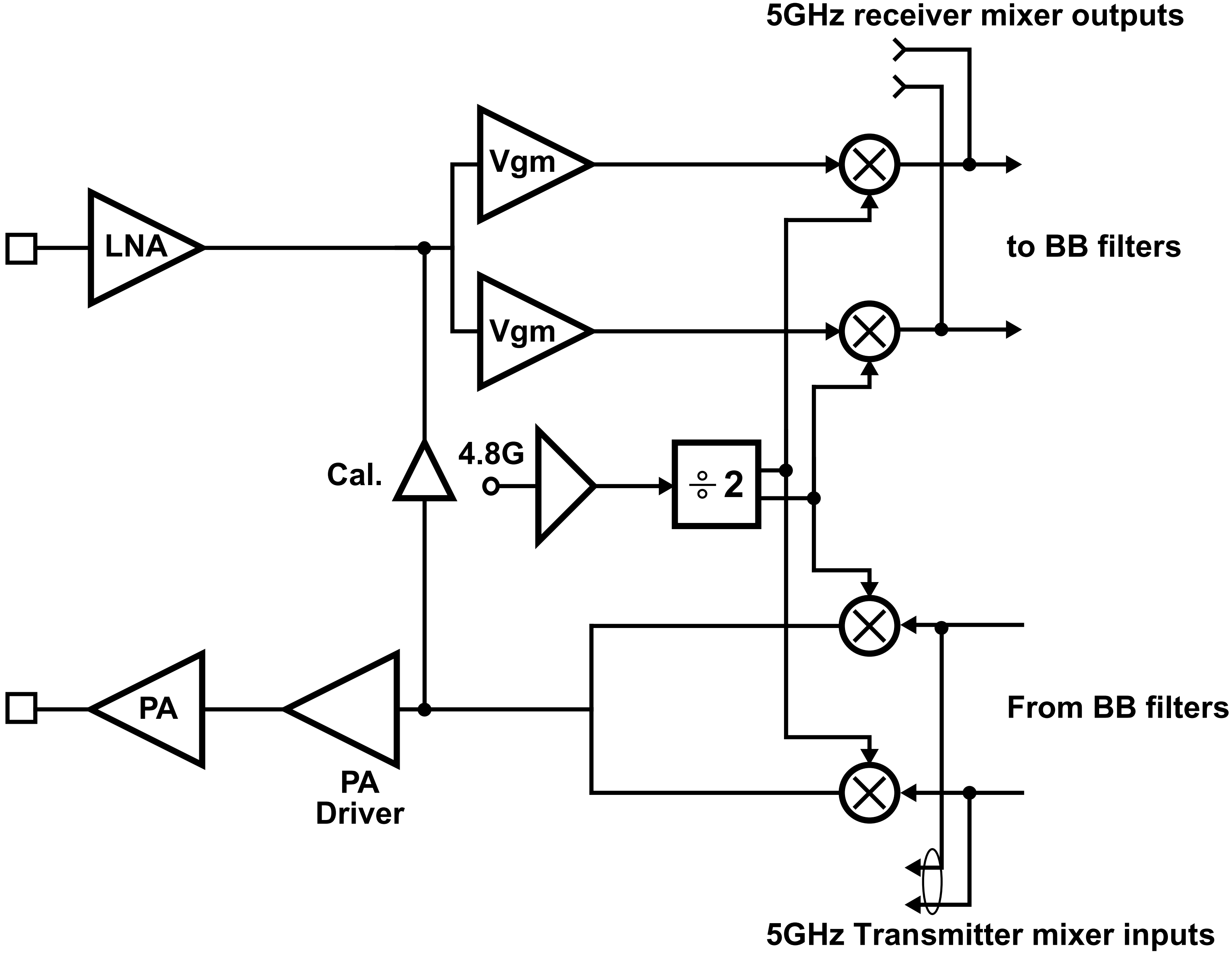


Frequency Plan

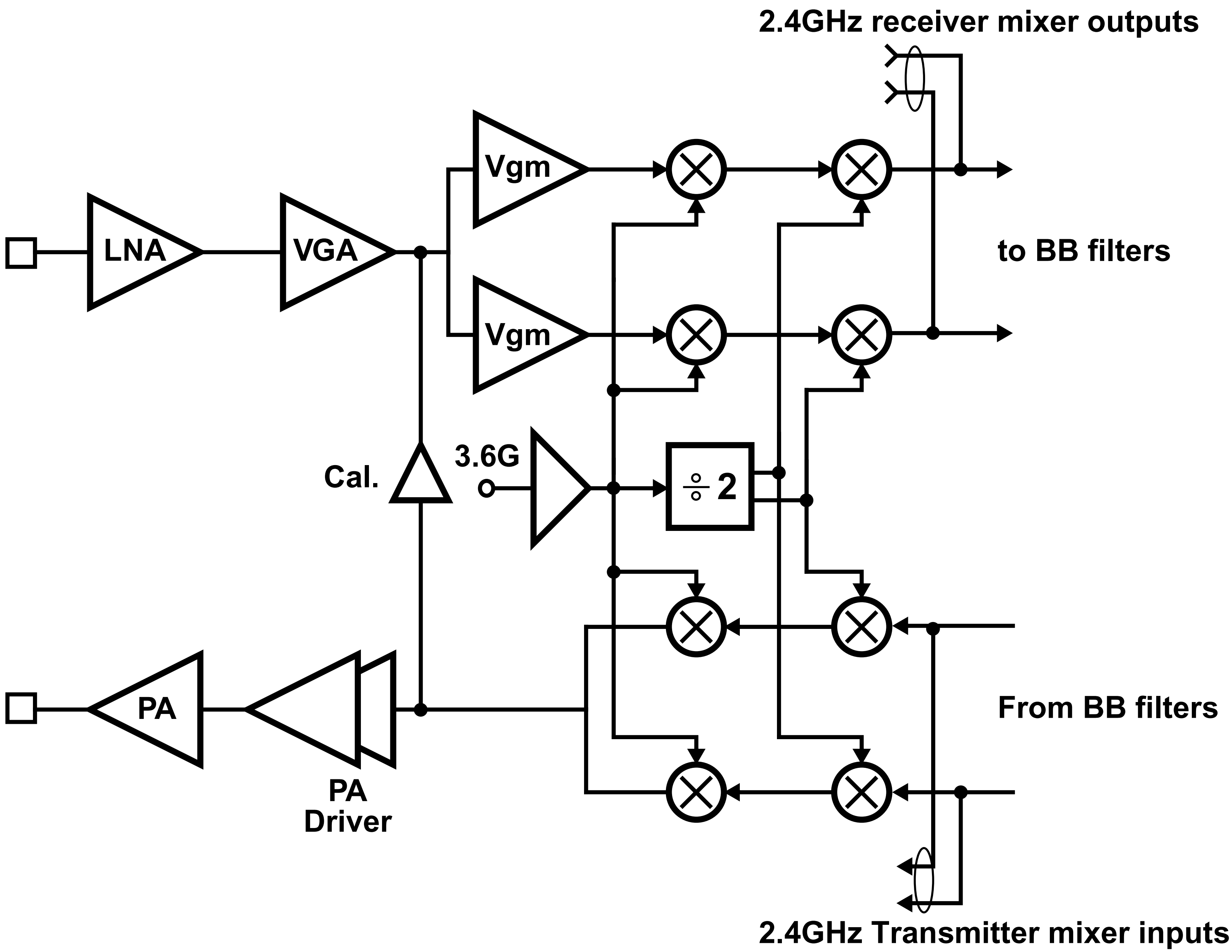
- **Direct Conversion for 2.4GHz**
  - Lower power signal path
  - Smaller area
  - Avoid pulling by running VCO at $4/3 f_{RF}$
- **Dual Conversion for 5GHz**
  - Lower frequency LO circuits
  - Simplified LO generation
  - Better I/Q matching



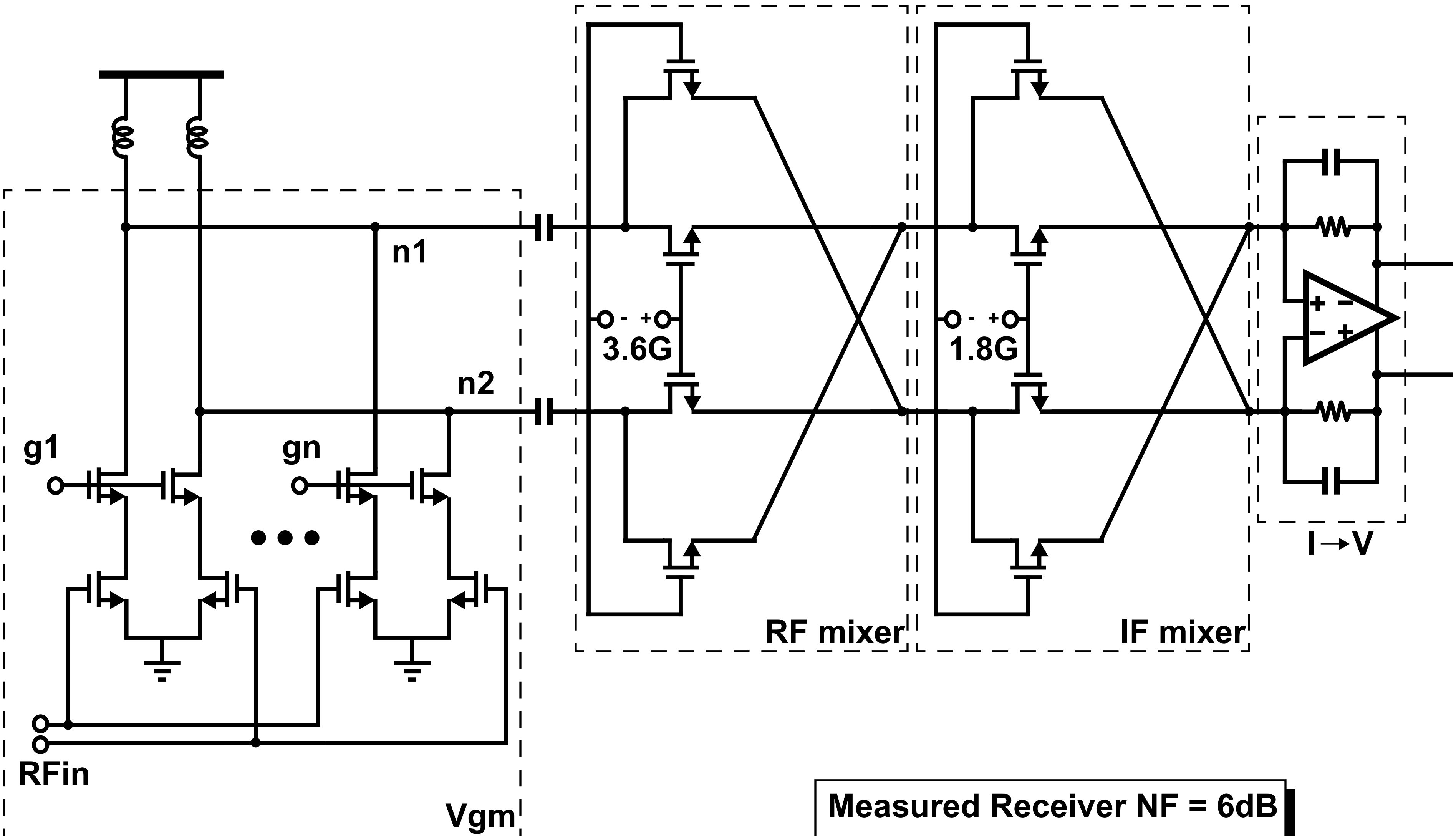
2.4GHz Radio Block Diagram



5GHz Radio Block Diagram

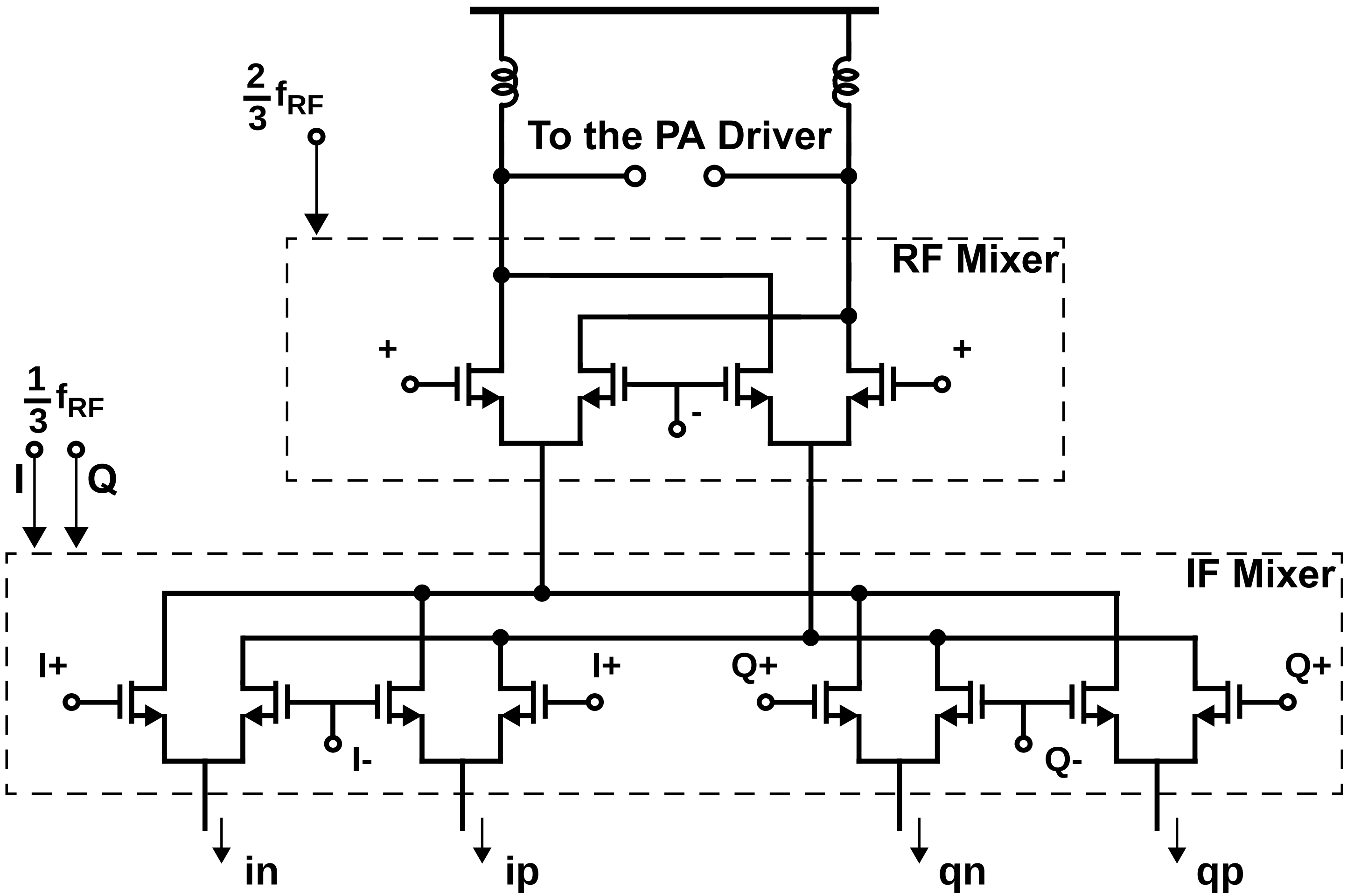


5GHz Receiver Down Conversion

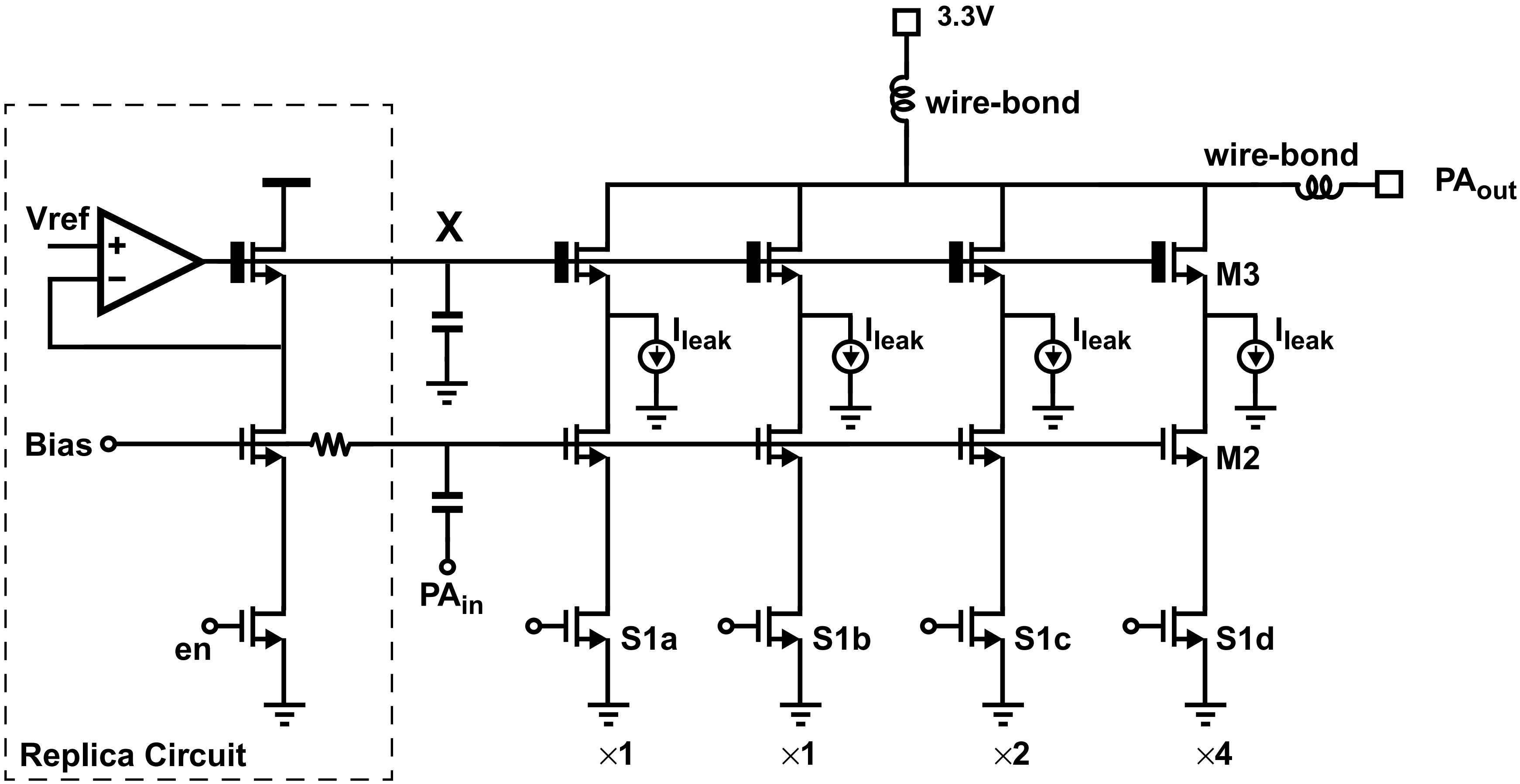


Measured Receiver NF = 6dB

5GHz Dual Upconversion

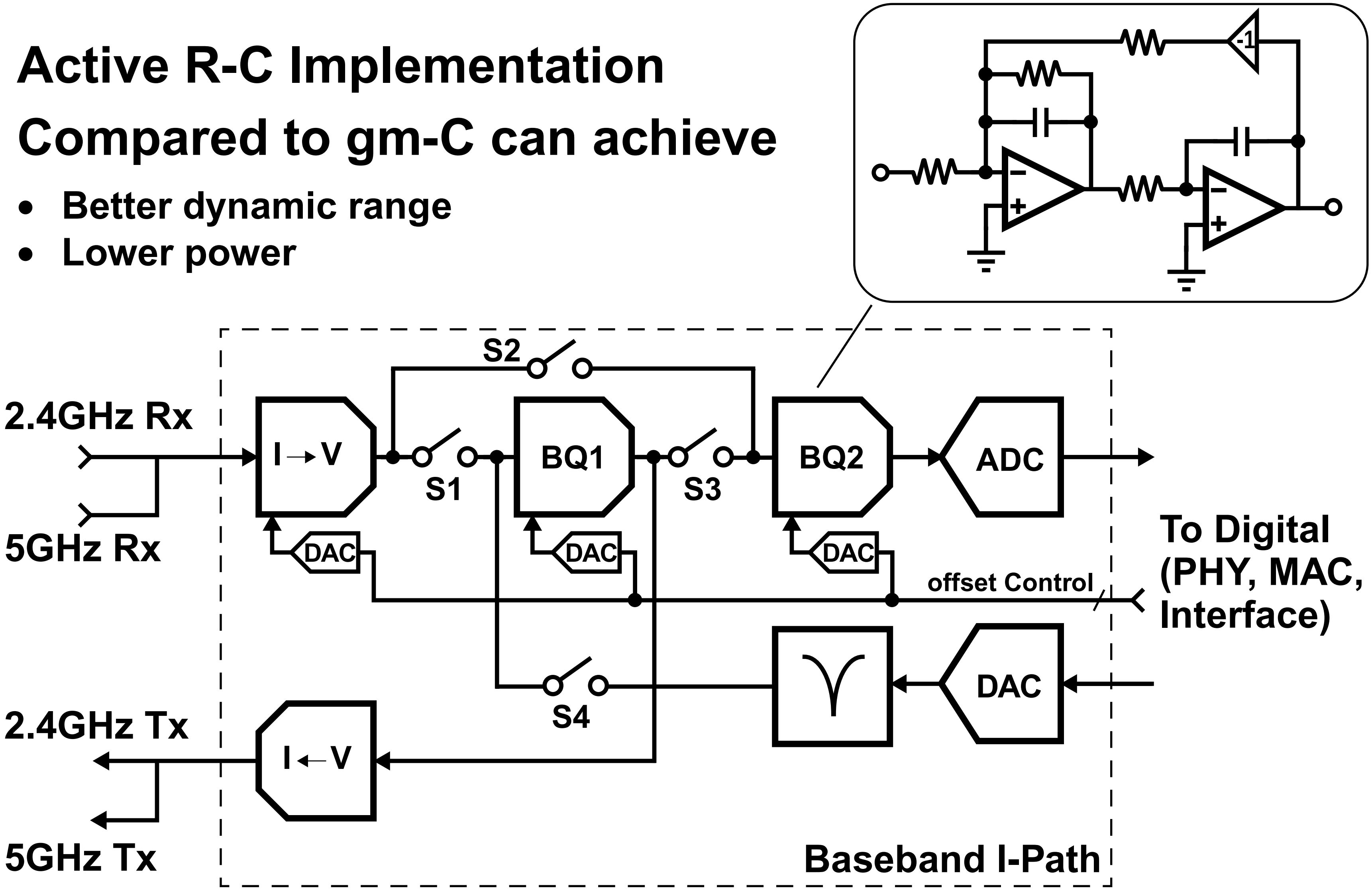


2.4 GHz Power Amplifier

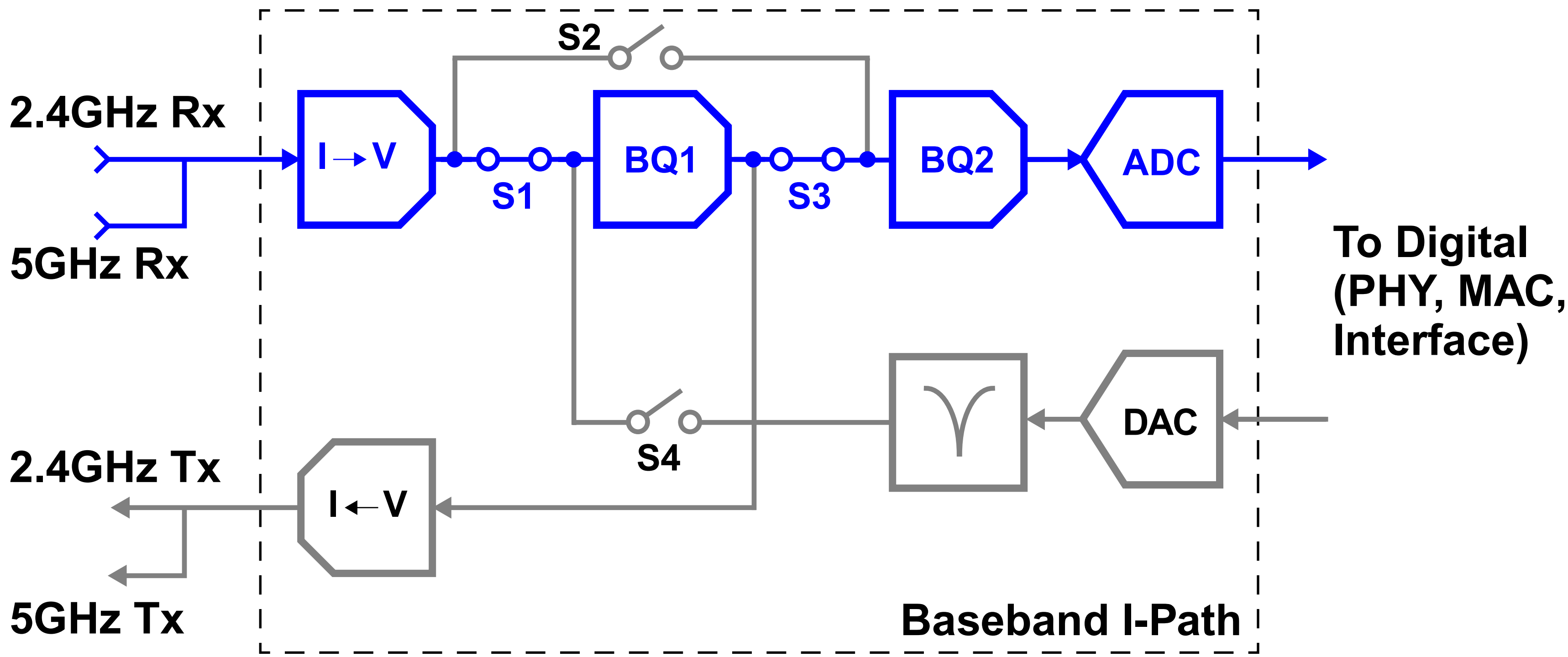


Baseband Filters

- ❑ **Active R-C Implementation**
- ❑ **Compared to gm-C can achieve**
  - **Better dynamic range**
  - **Lower power**

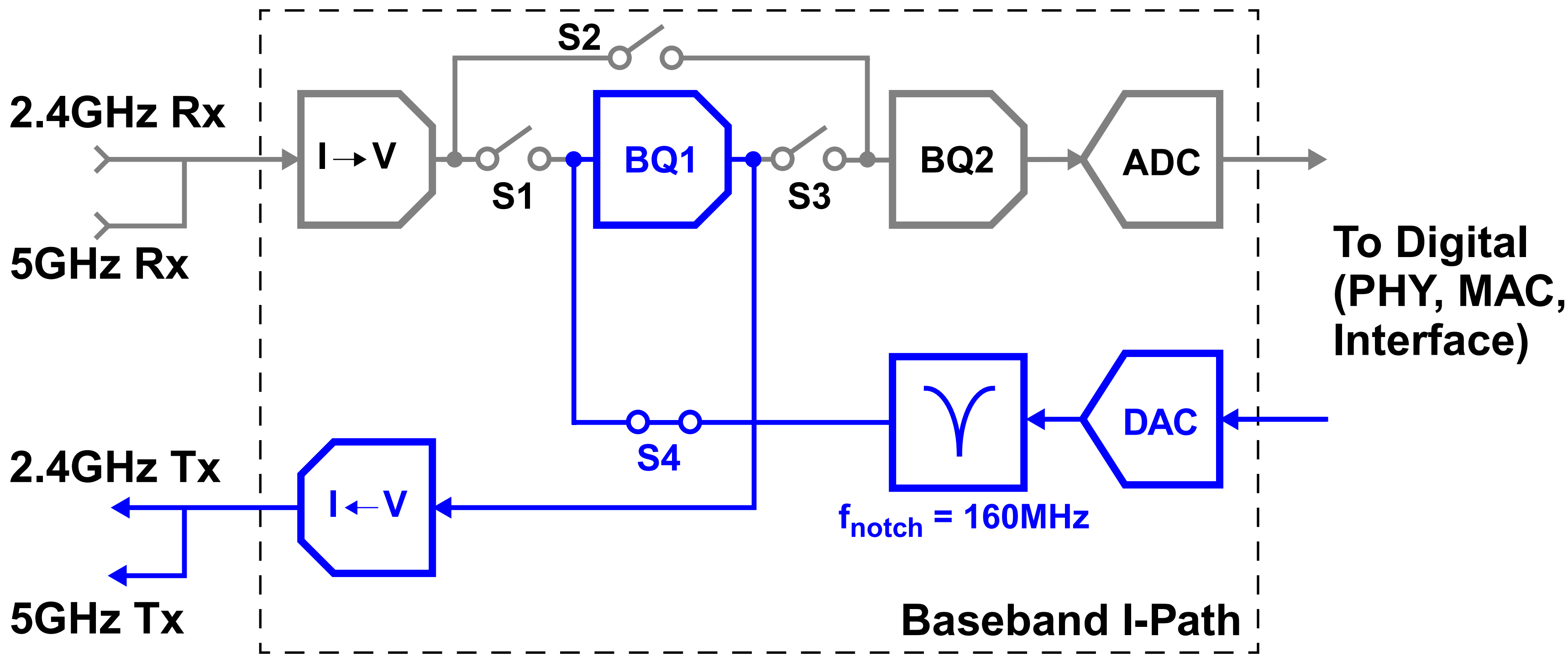


Baseband Filters: Receive mode



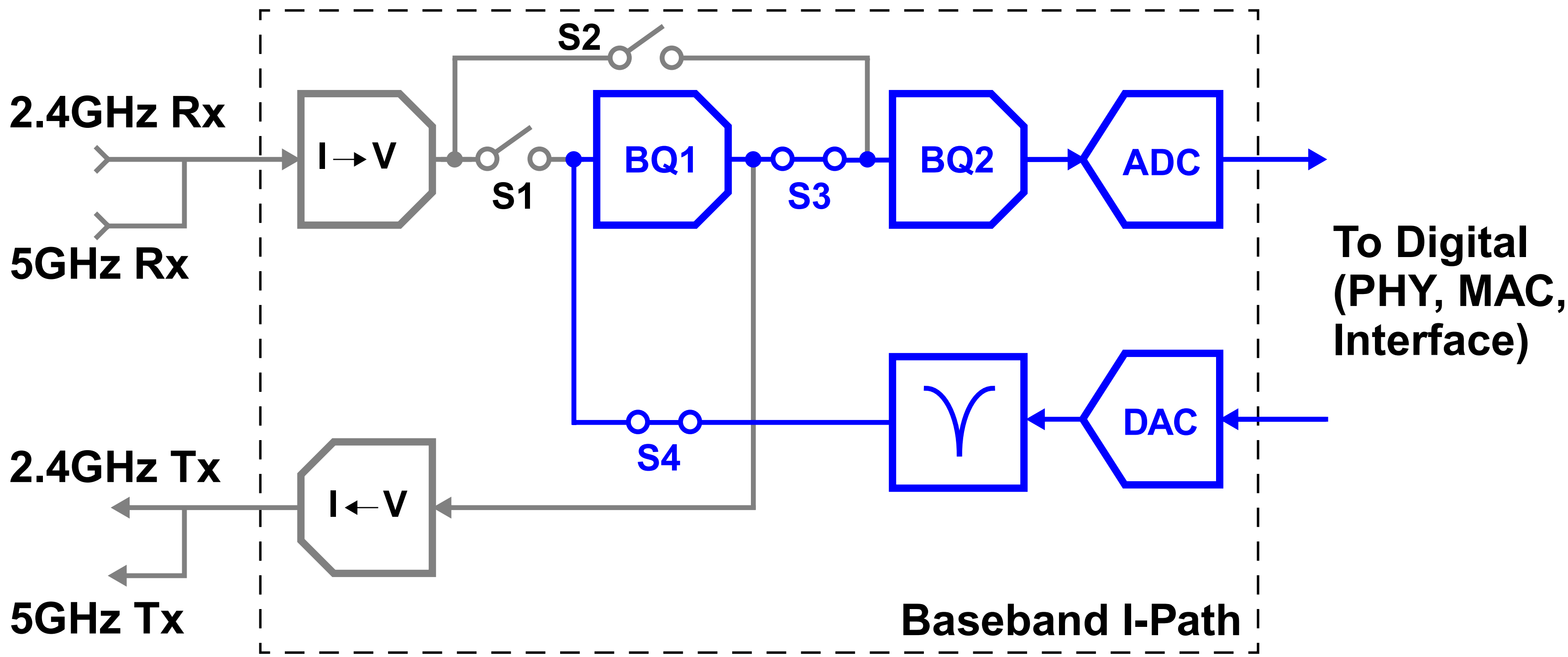
- ❑ **5th order Butterworth**
  - **Single-pole I→V followed by 2 biquads**
  - **Bandwidth adjusted using programmable capacitor arrays**

Baseband Filters: Transmit mode



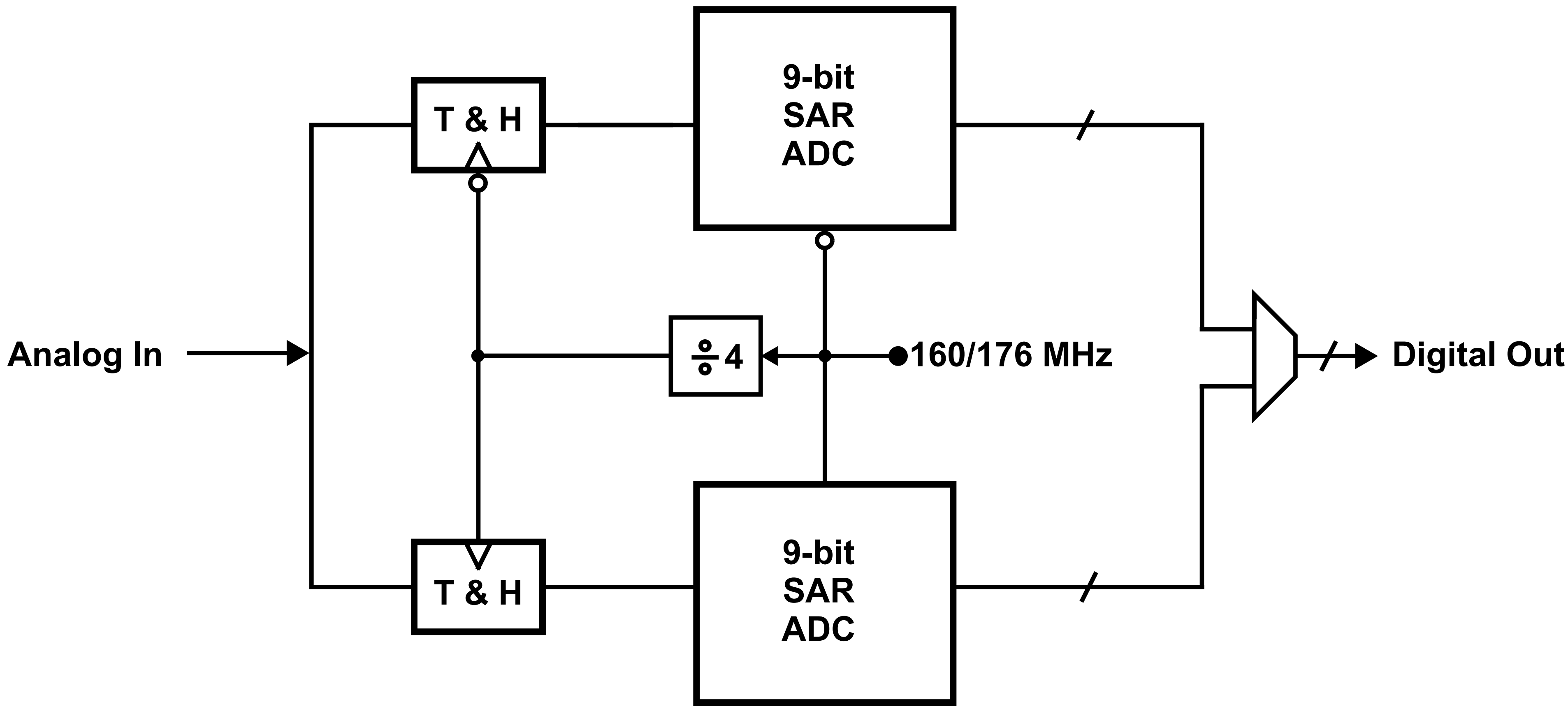
- 2nd order Butterworth with f_{-3dB} = 10/20MHz
  - More than 52dB attenuation at the DAC sampling Frequency of 160MHz

Baseband Filters: Loop-Back



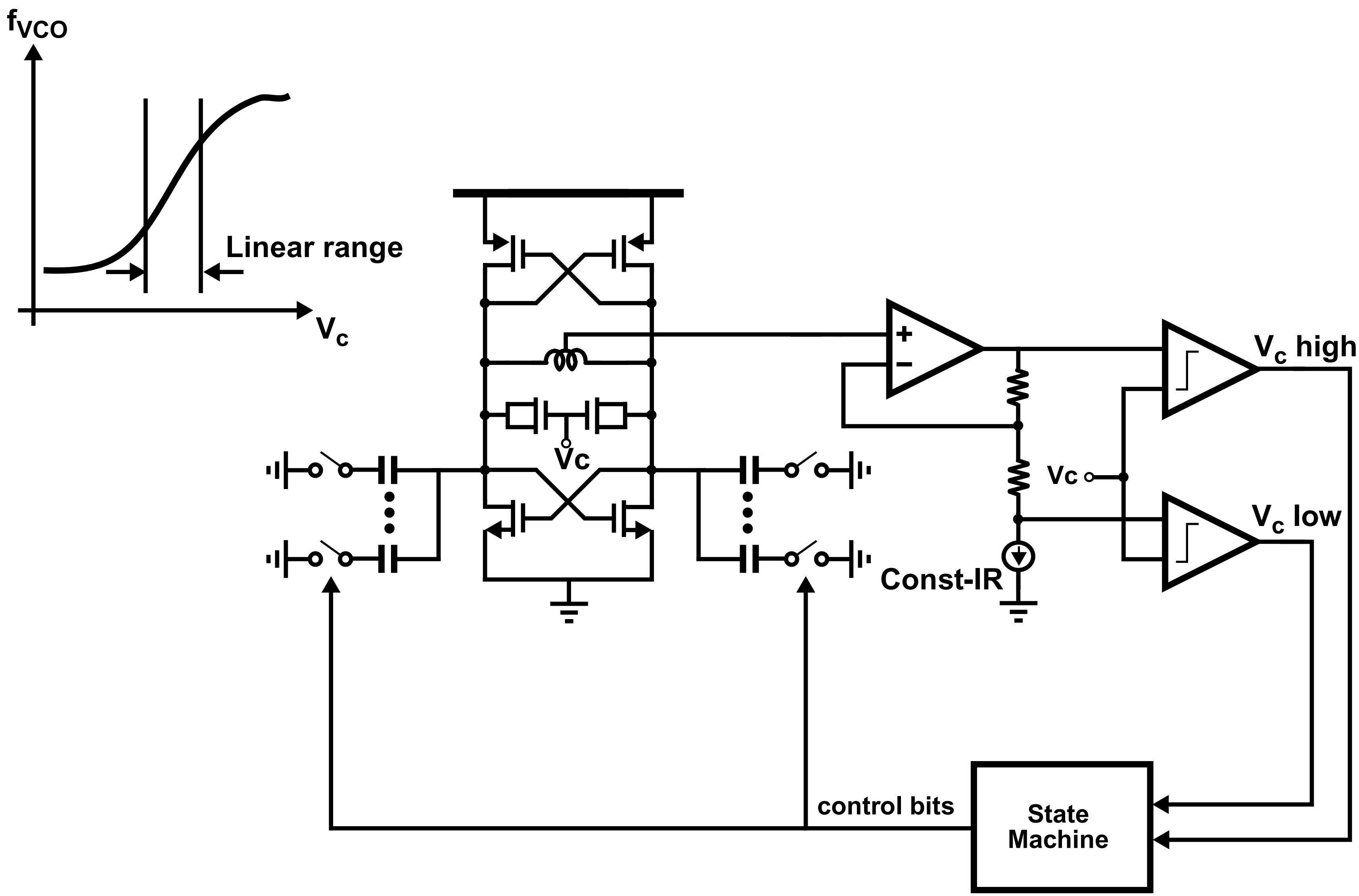
- ❑ Calibrate the cutoff frequency by adjusting the biquad poles
- ❑ Test tone generated by digital baseband

Time-Interleaved SAR ADC



- ❑ **Each 9-bit ADC core including T&H:**
  - **Dissipates 7mA from 1.2V**
  - **Occupies less than 0.1mm^2**

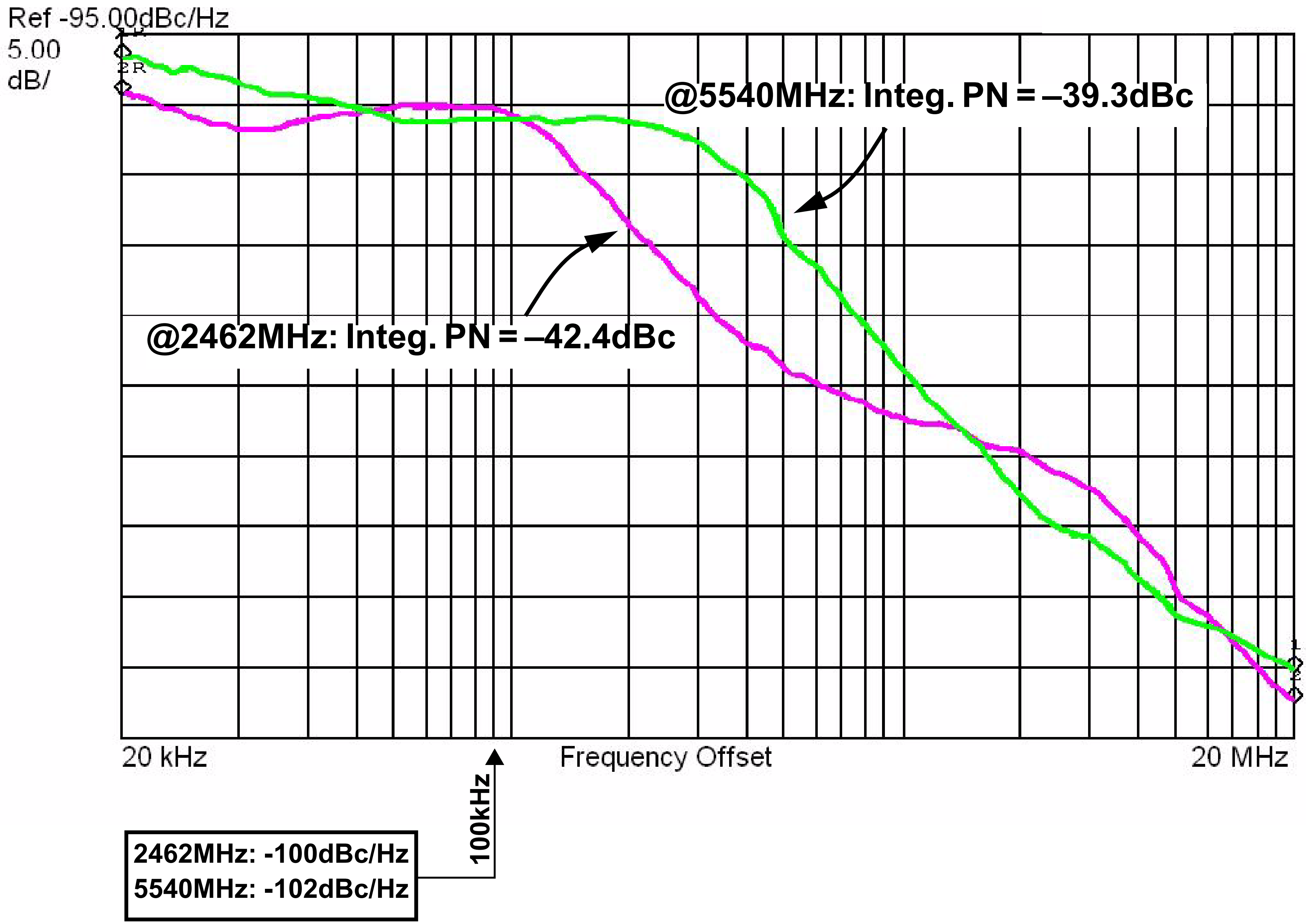
Voltage-Controlled Oscillator



SoC Calibration

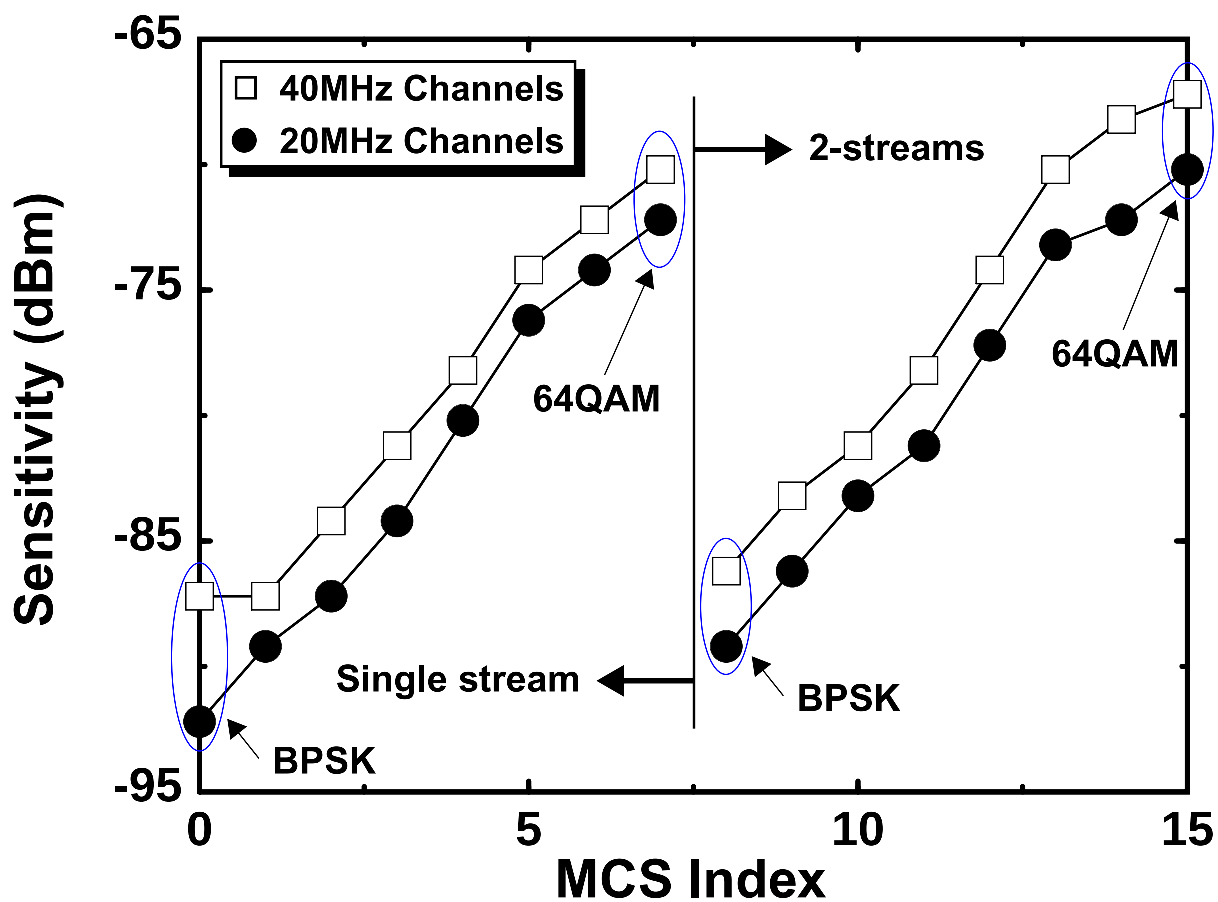
- ❑ Calibration reduces the impact of analog impairments on the radio performance
- ❑ Correction algorithms are generally implemented in the digital domain
  - Lower power
  - Smaller area
  - Better reliability
- ❑ Example:
  - Receiver DC offset
  - Transmit carrier leak
  - Baseband filters bandwidth
  - Receiver I/Q mismatch
  - Receiver noise floor
  - ADC gain & DC offset

Phase Noise



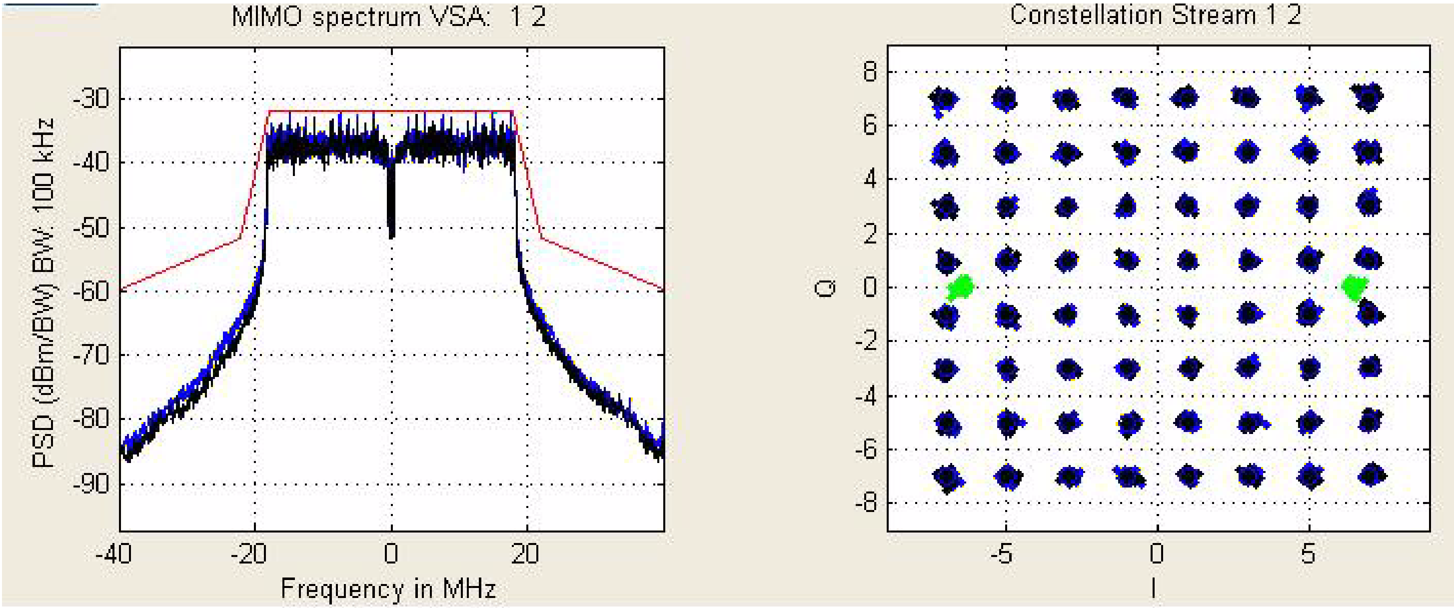
Ref -95.00dBc/Hz
5.00
dB/
@5540MHz: Integ. PN = –39.3dBc
@2462MHz: Integ. PN = –42.4dBc
20 kHz
Frequency Offset
20 MHz
100kHz
2462MHz: -100dBc/Hz
5540MHz: -102dBc/Hz

5GHz Sensitivity

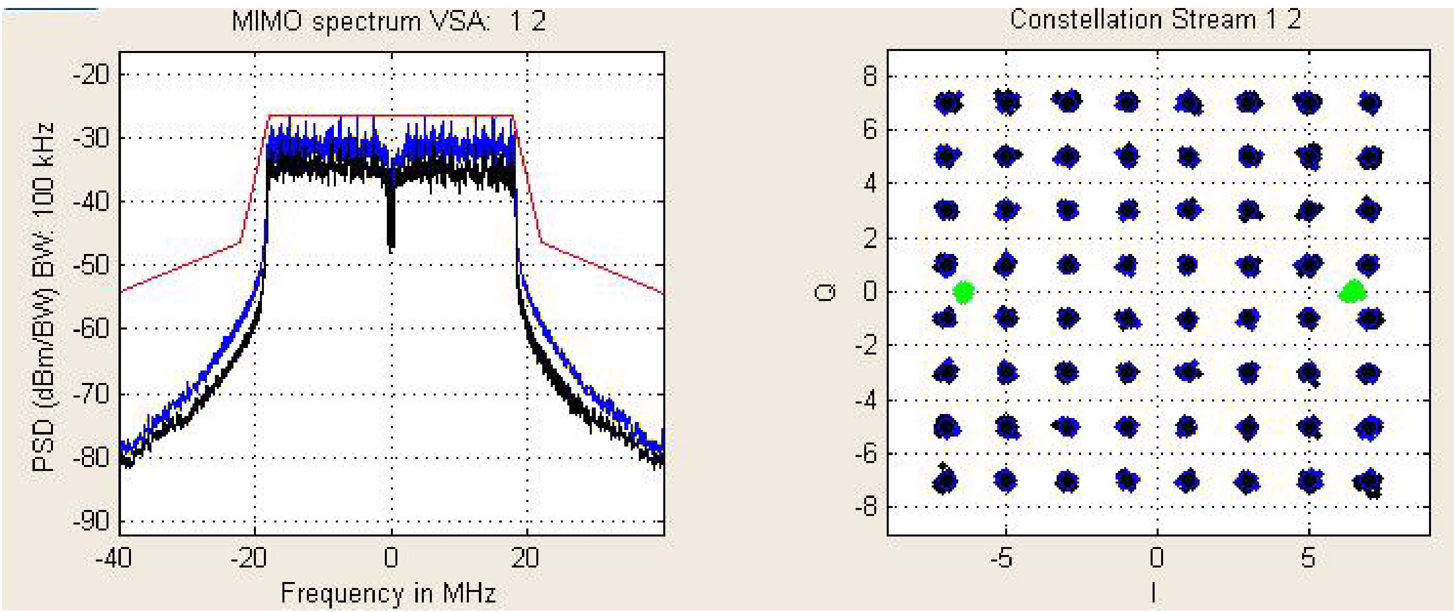


- RF Channel Centered at 5180MHz
- No external LNA

Transmitter Performance

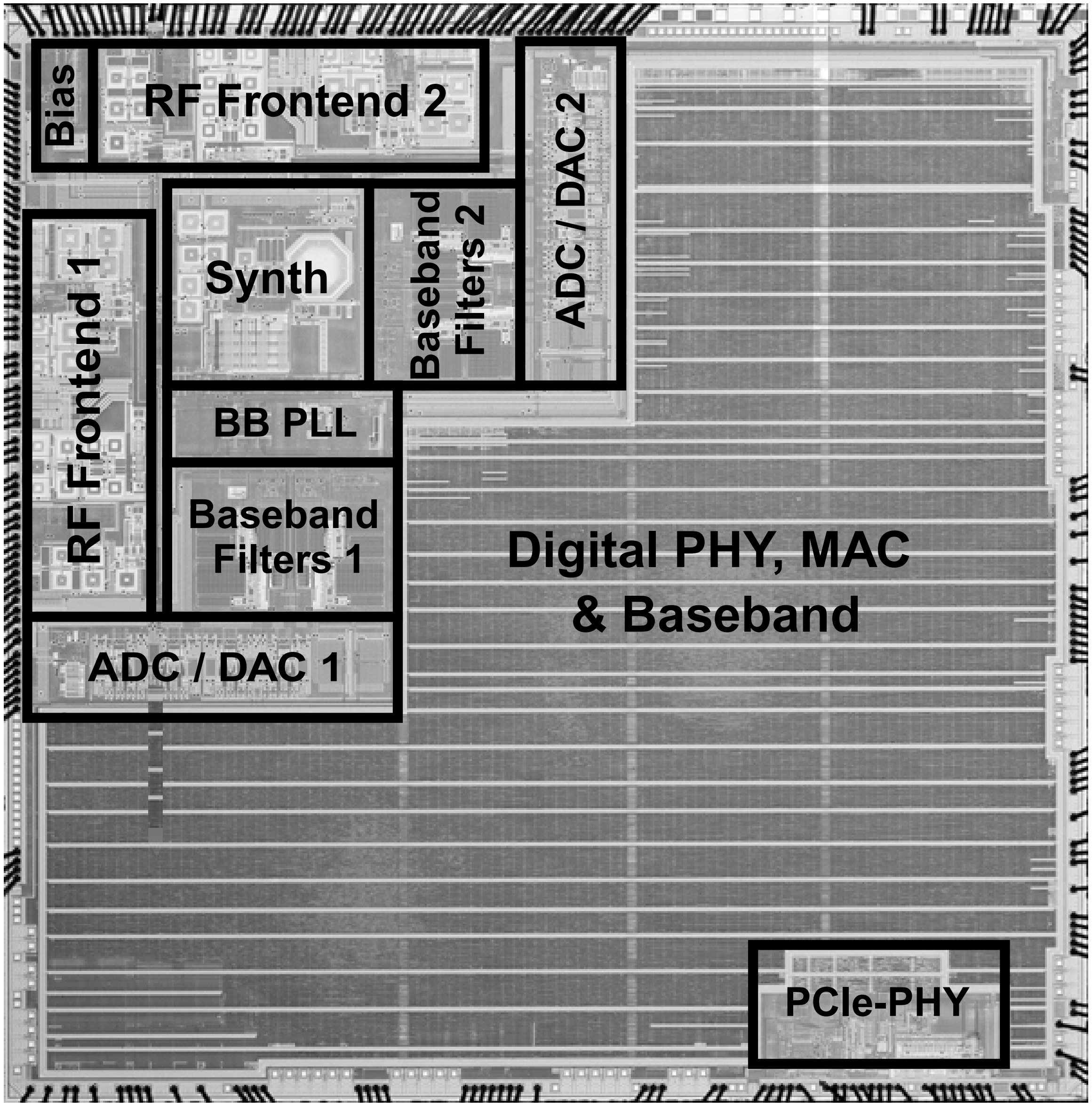


Channel: 2442 MHz
2-Stream HT–40
Pout = –8dBm
EVM = –31dB



Channel: 5220 MHz
2-Stream HT–40
Pout = –4dBm
EVM = –31.5dB

Die Micrograph



- **Process:** 0.13μm CMOS
- **Die Size:** 6×6 mm^2
- **Analog Area:** 11 mm^2
- **Package:** 88-pin QFN

Performance Summary

Parameter	2.4GHz	5GHz
TX EVM (HT-40, MCS 15)	–31dB @ -8dBm	–31.5dB @ –4dBm
Receiver Noise Figure	4dB	6dB
Receiver Sensitivity (HT-40, MCS15)	–70dBm	–68dBm
Integrated Phase Noise	–42dBc	–39dBc
SoC Power Dissipation (HT-40, MCS 15)		
Receive	800mW	830mW
Transmit	630mW	1230mW
Transceiver Power (HT-40, MCS 15)		
Receive (Incl. ADCs)	360mW	400mW
Transmit (Incl. DACs)	285mW	860mW
Over-the-air TCP throughput	205 Mbps	

Conclusions

- Demonstrated a 2×2 MIMO SoC radio that implements the IEEE 802.11n draft
- Receiver sensitivity of –70dBm and –68dBm at MCS15 for 2.4GHz and 5GHz, respectively without any external LNA
- Shared Baseband filters between receiver and transmitter
- Overall analog/RF area of $11mm^2$

Acknowledgements

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