

# A 0.6–3.0 GHz 65 nm CMOS Radio Receiver with $\Delta\Sigma$ -based A/D-Converting Channel-Select Filters

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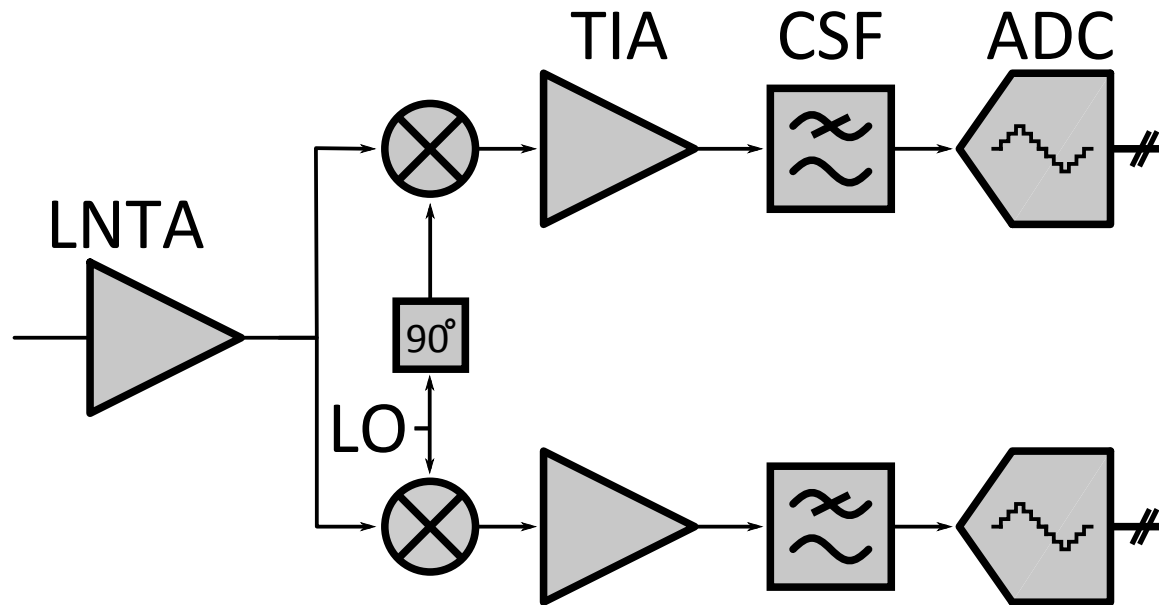


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# Outline

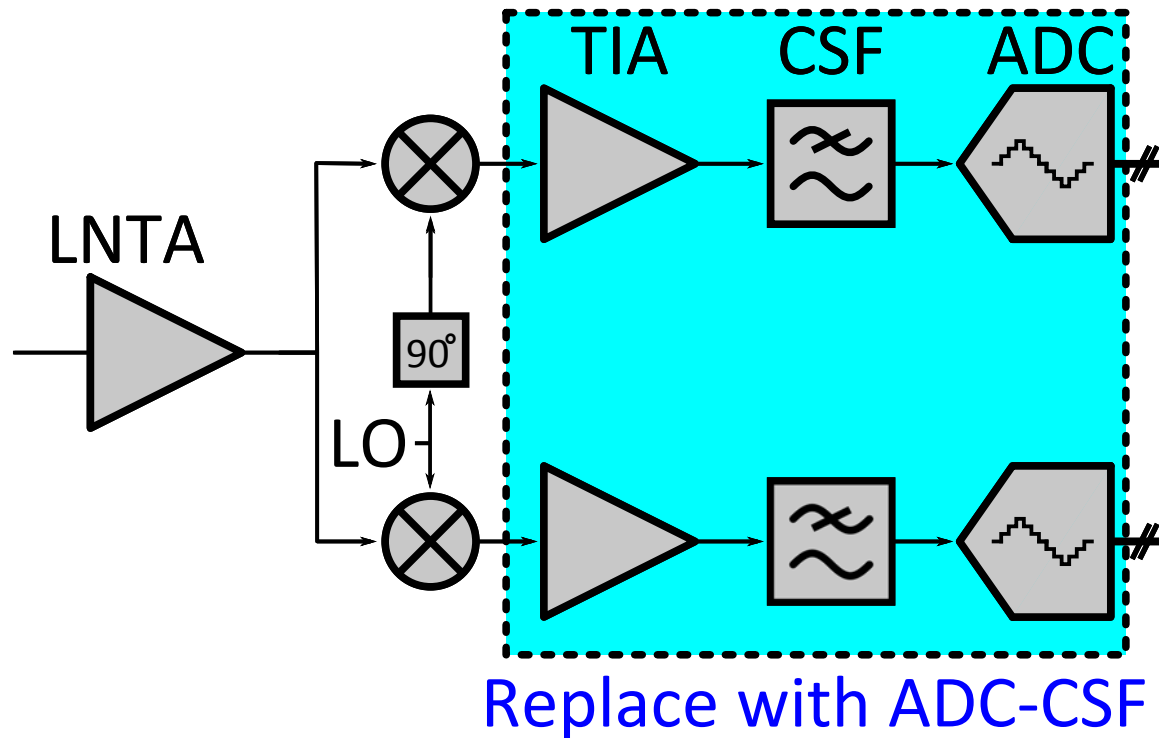
- Motivation
- System Design
- Circuit Implementation
- Measurement Results
- Conclusion

# Traditional RF Receiver



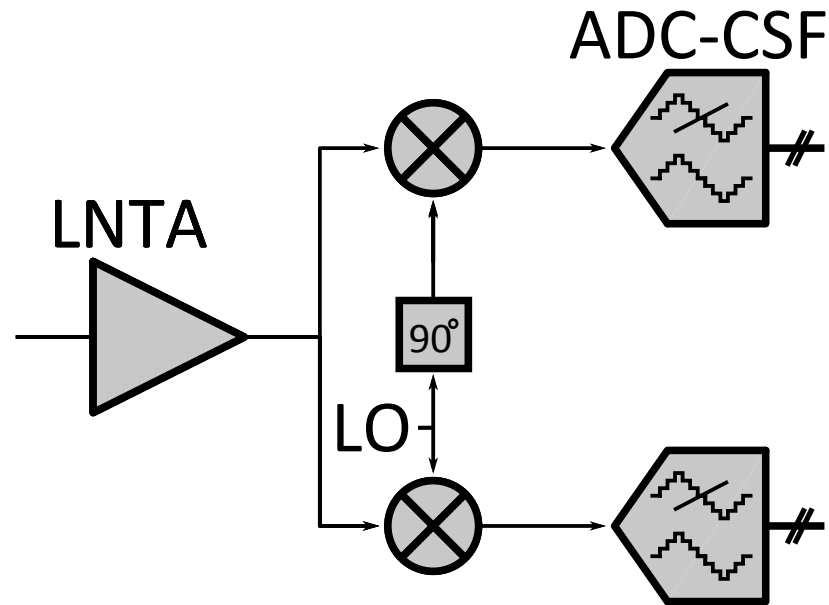
- Direct-conversion receiver
- CSF used to relax DR of ADC

# Traditional RF Receiver



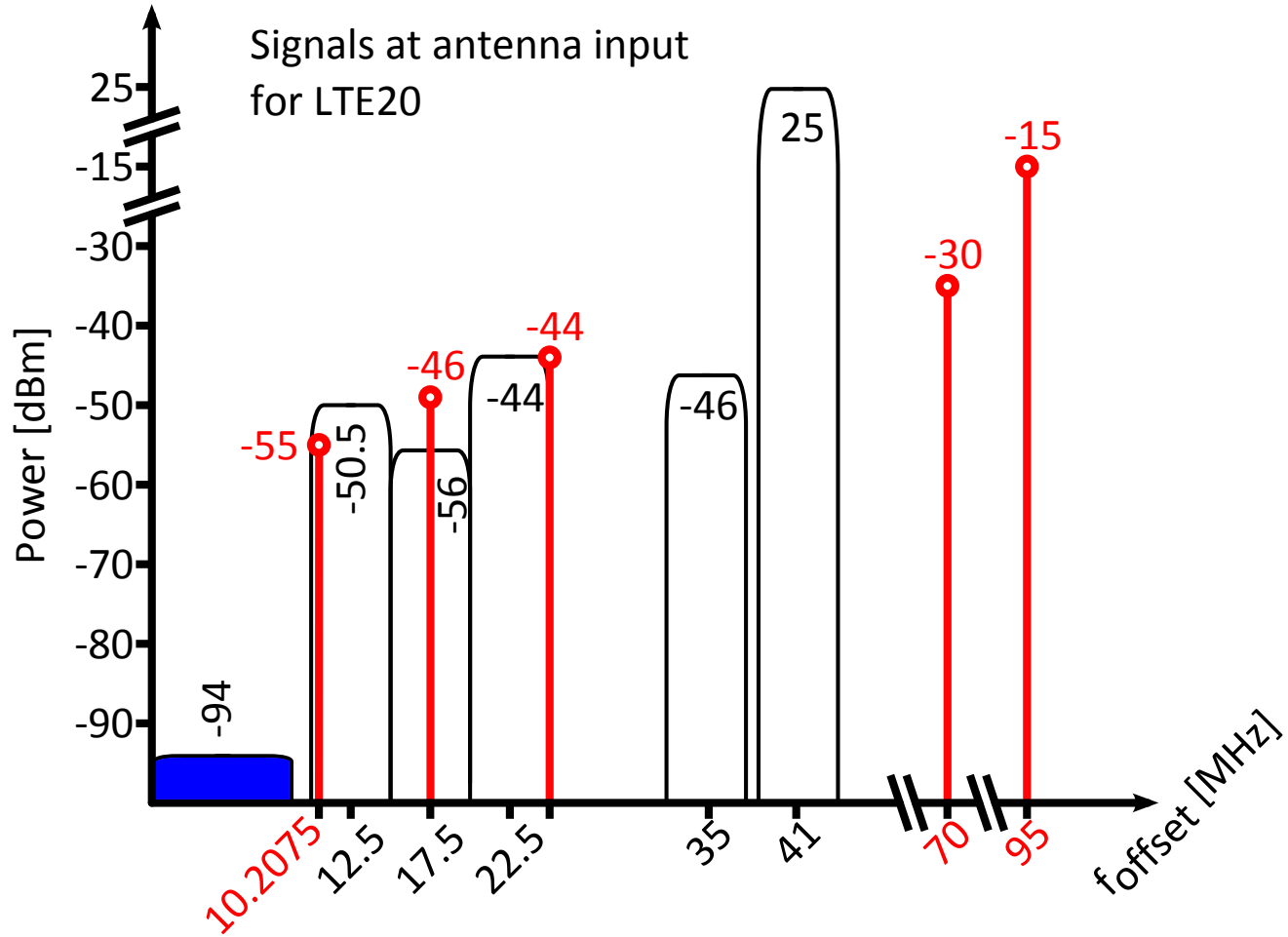
- CSF used to relax DR of ADC

# Proposed Receiver

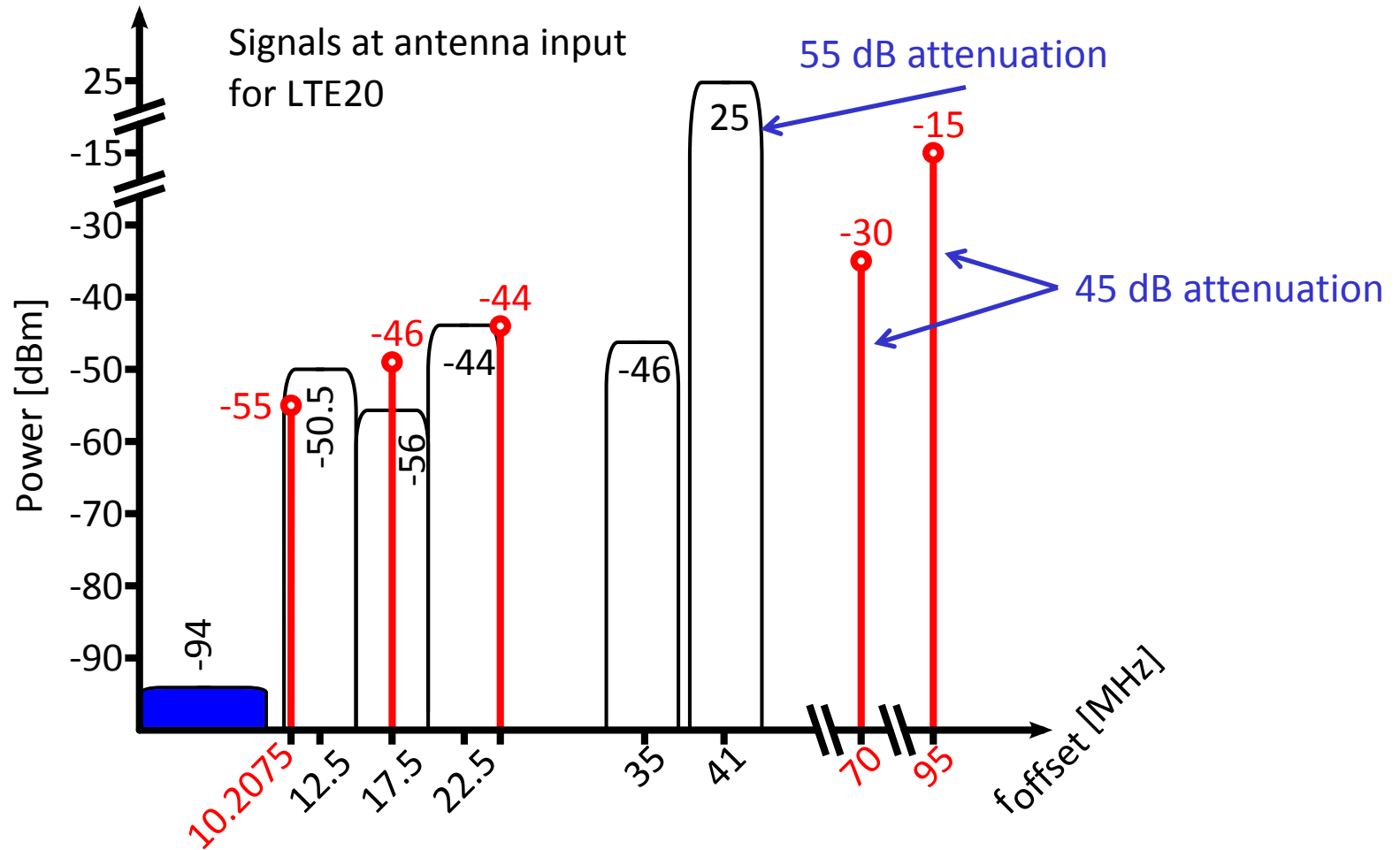


- Reduced power by reduced ADC requirements
- 1<sup>st</sup> order  $\Delta\Sigma$ M

# Blocker Profile LTE20

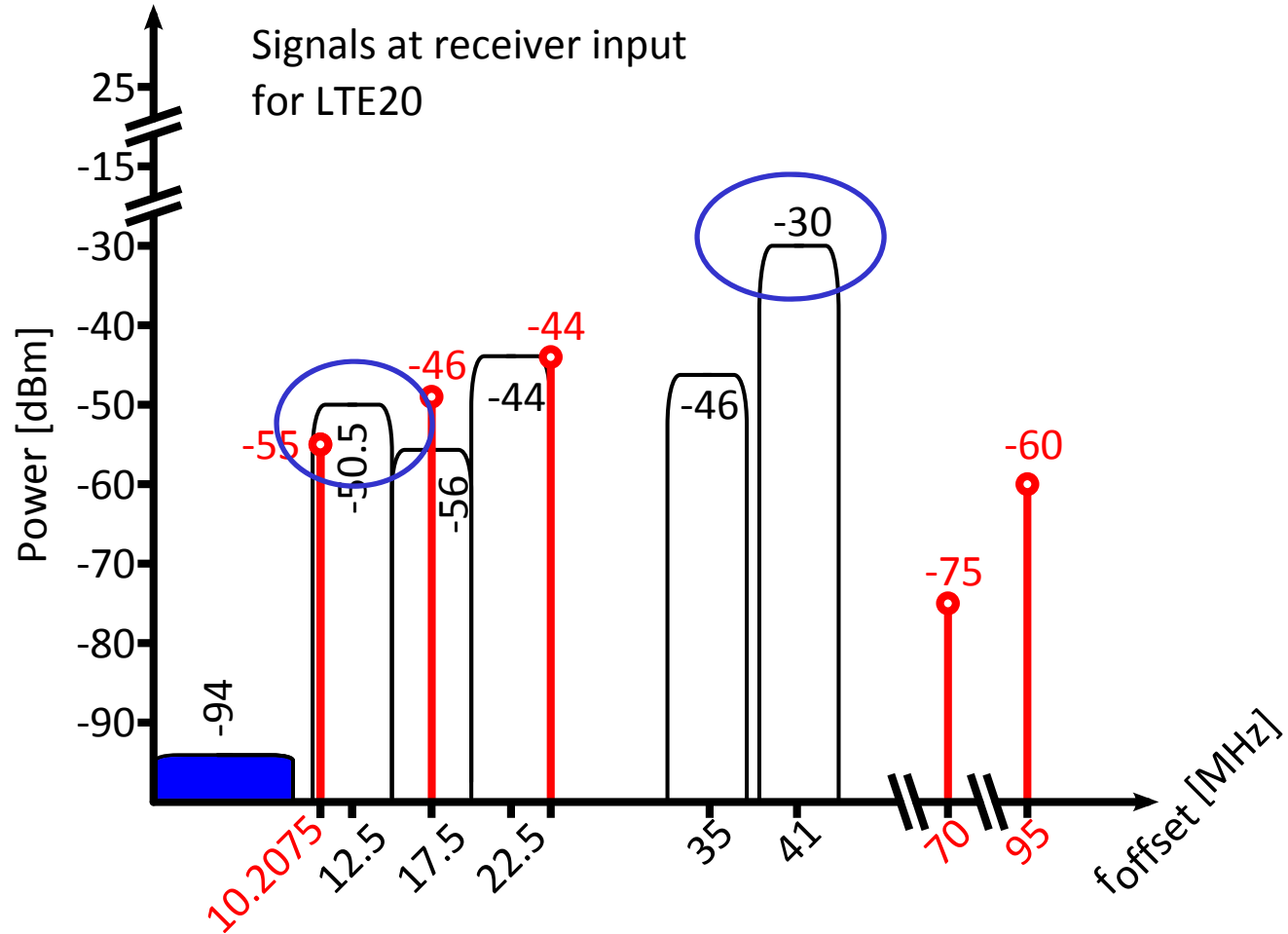


# Blocker Profile LTE20



- Duplexer band 20: **TDK B8633**

# Blocker Profile LTE20

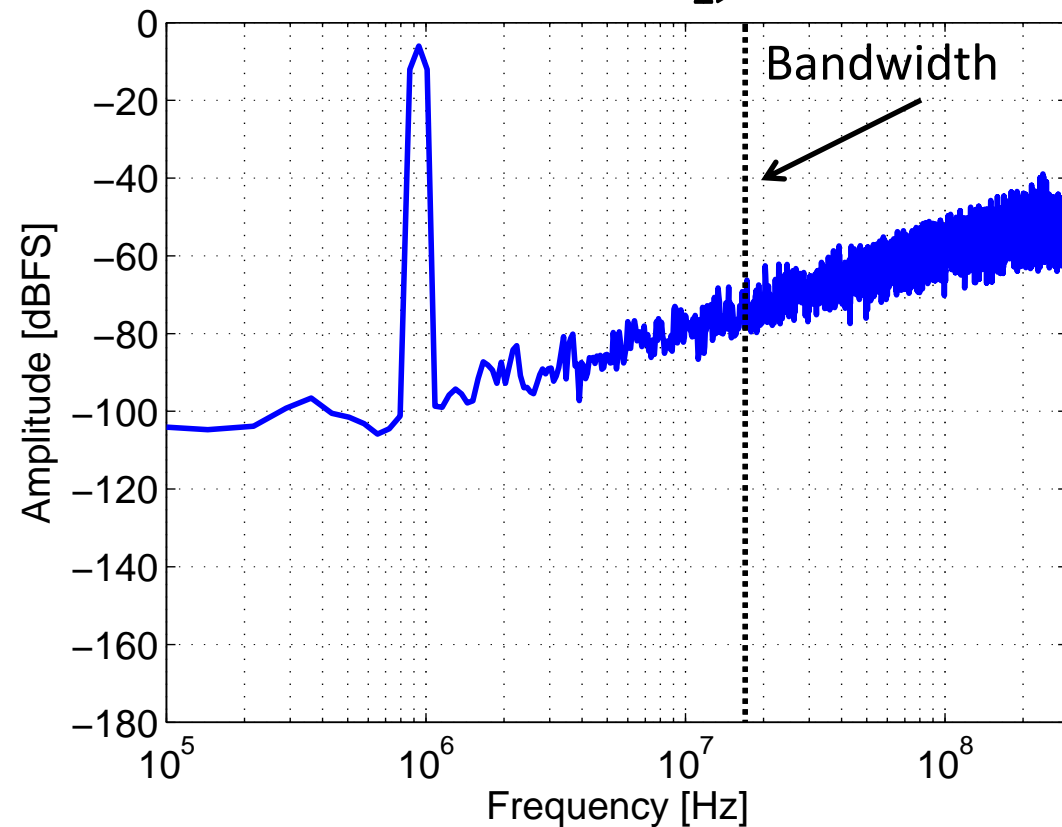
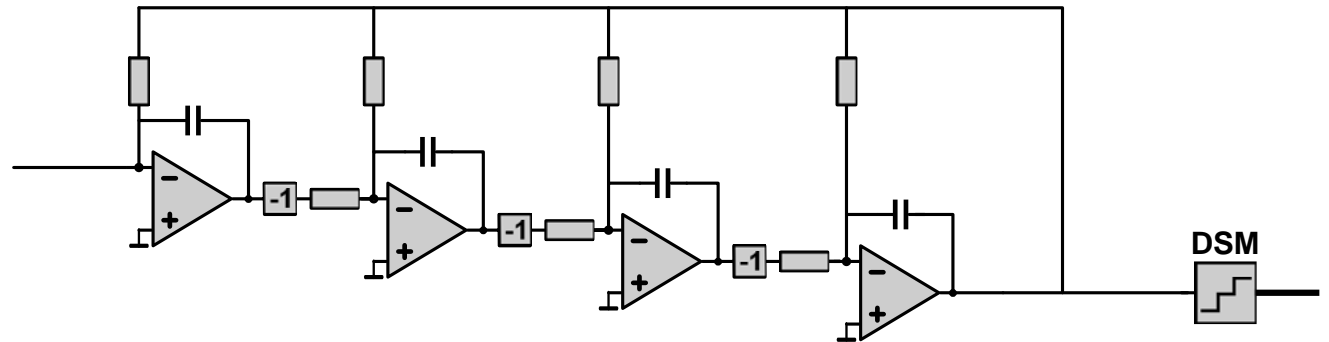


- Adjacent Channel and TX



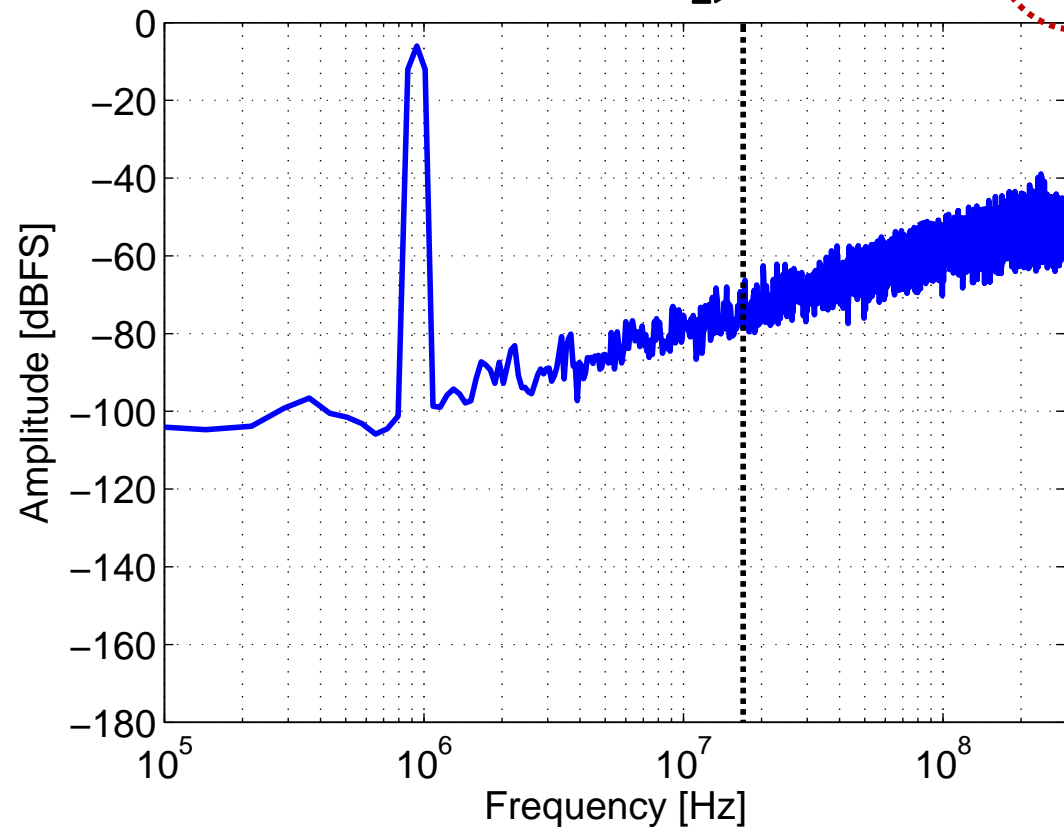
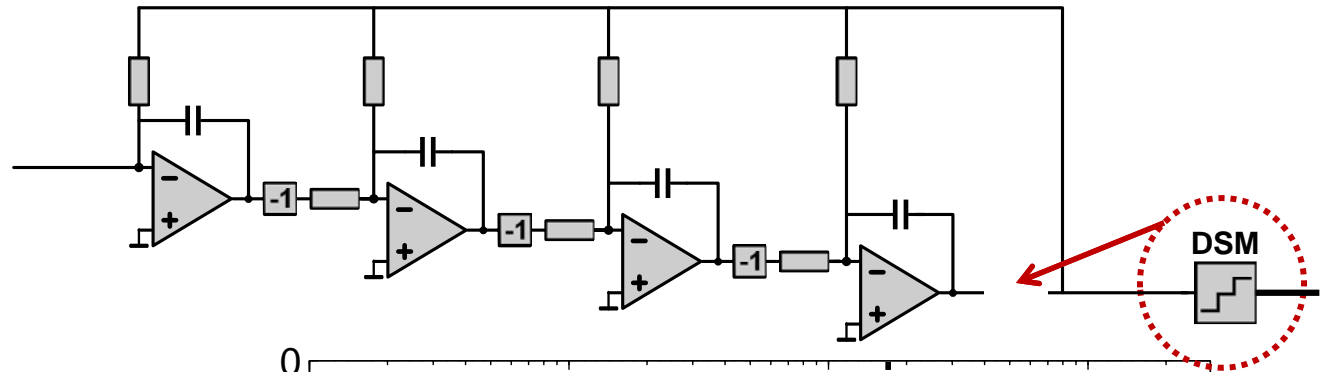
# Why using an ADC-CSF?

- BW: 2xLTE20
- 4<sup>th</sup> Order CSF
- 1<sup>st</sup> Order  $\Delta\Sigma$ M



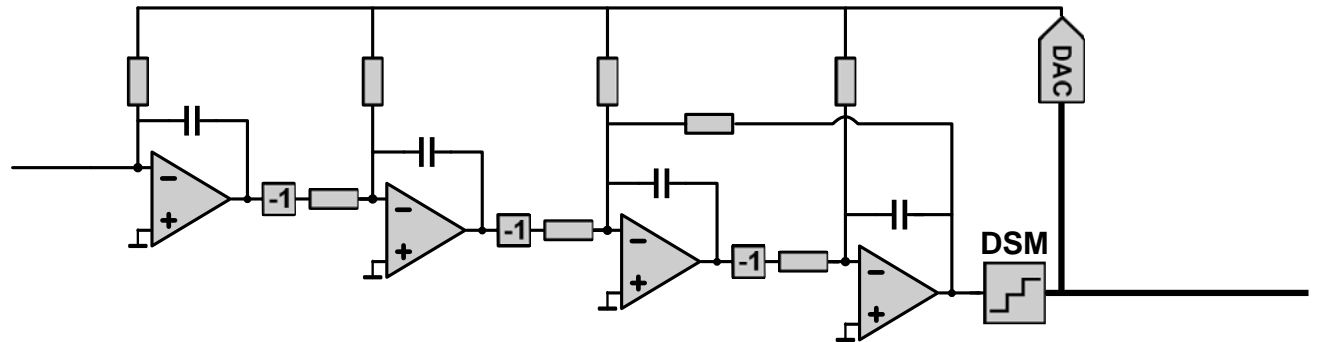
# Why using an ADC-CSF?

- BW: 2xLTE20
- 4<sup>th</sup> Order CSF
- 1<sup>st</sup> Order  $\Delta\Sigma\text{M}$
- Assume  $\text{STF}_{\Delta\Sigma\text{M}}=1$

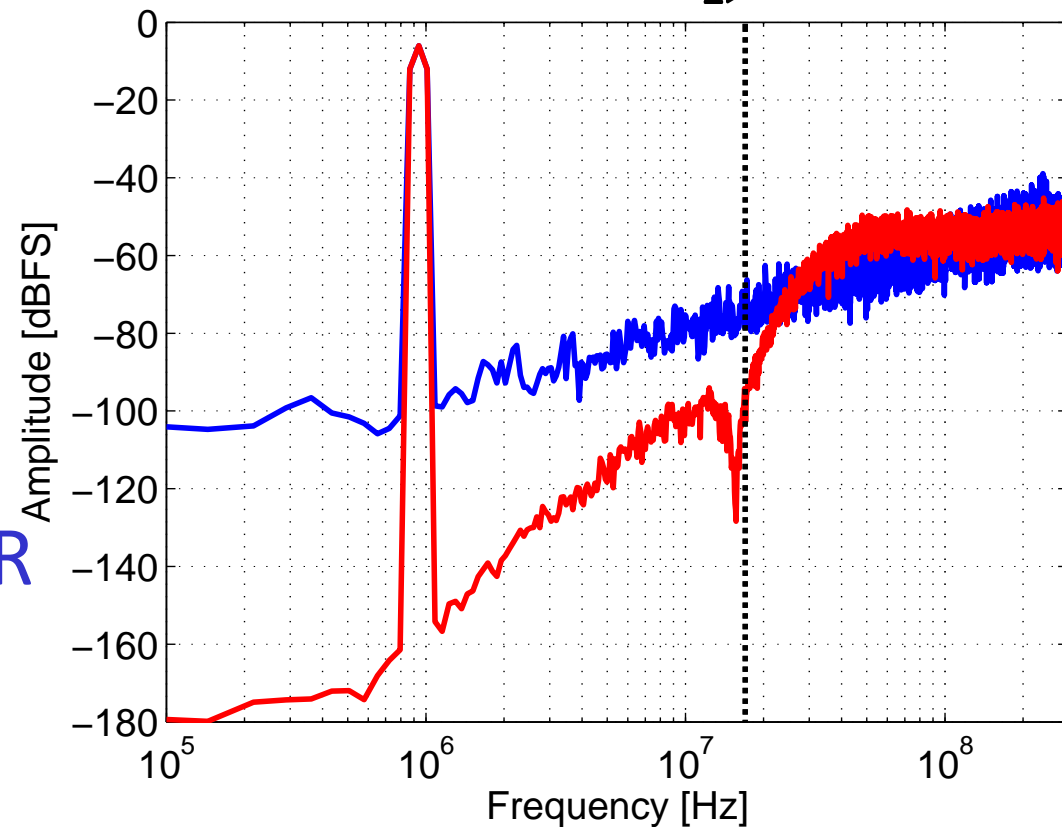


# Why using an ADC-CSF?

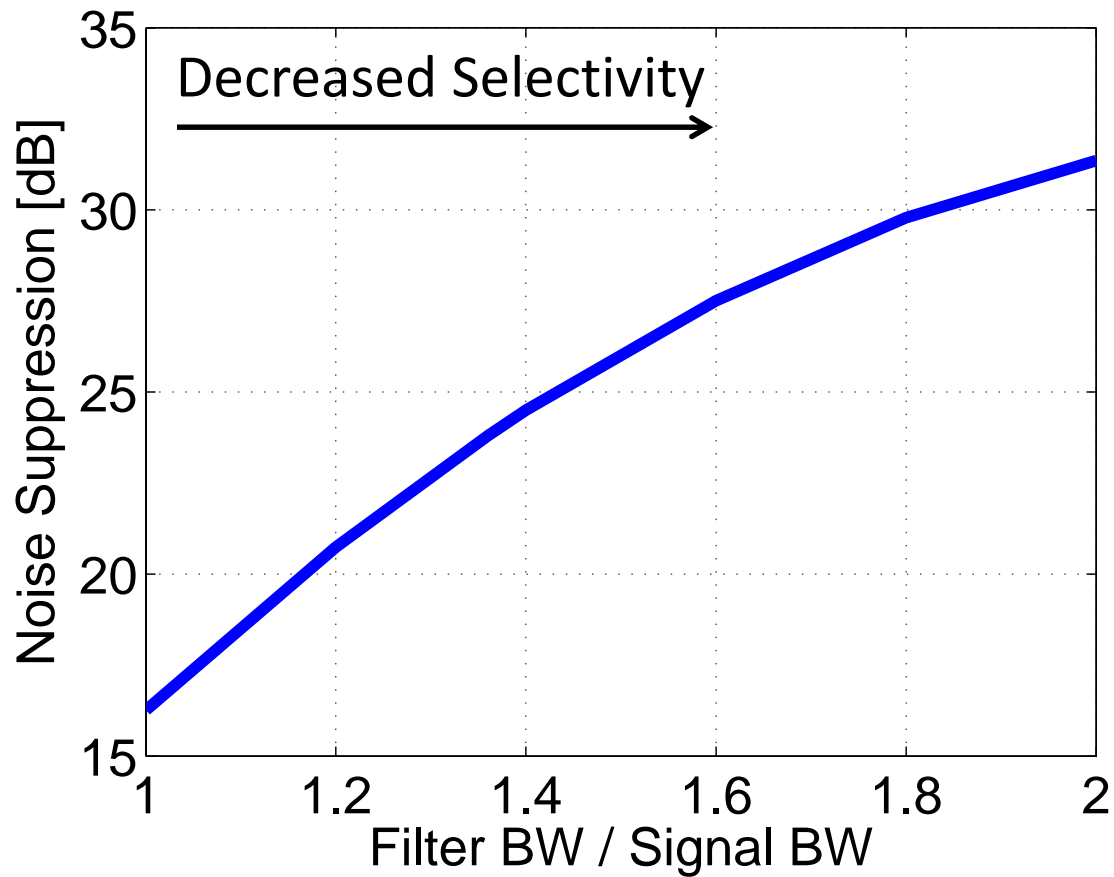
- BW: 2xLTE20



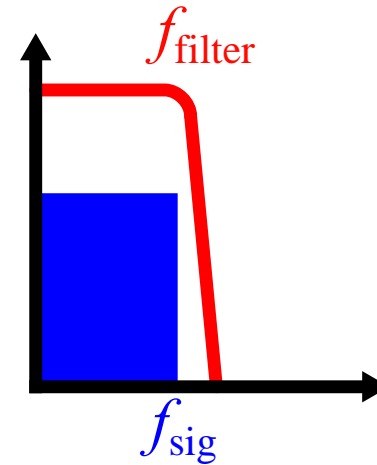
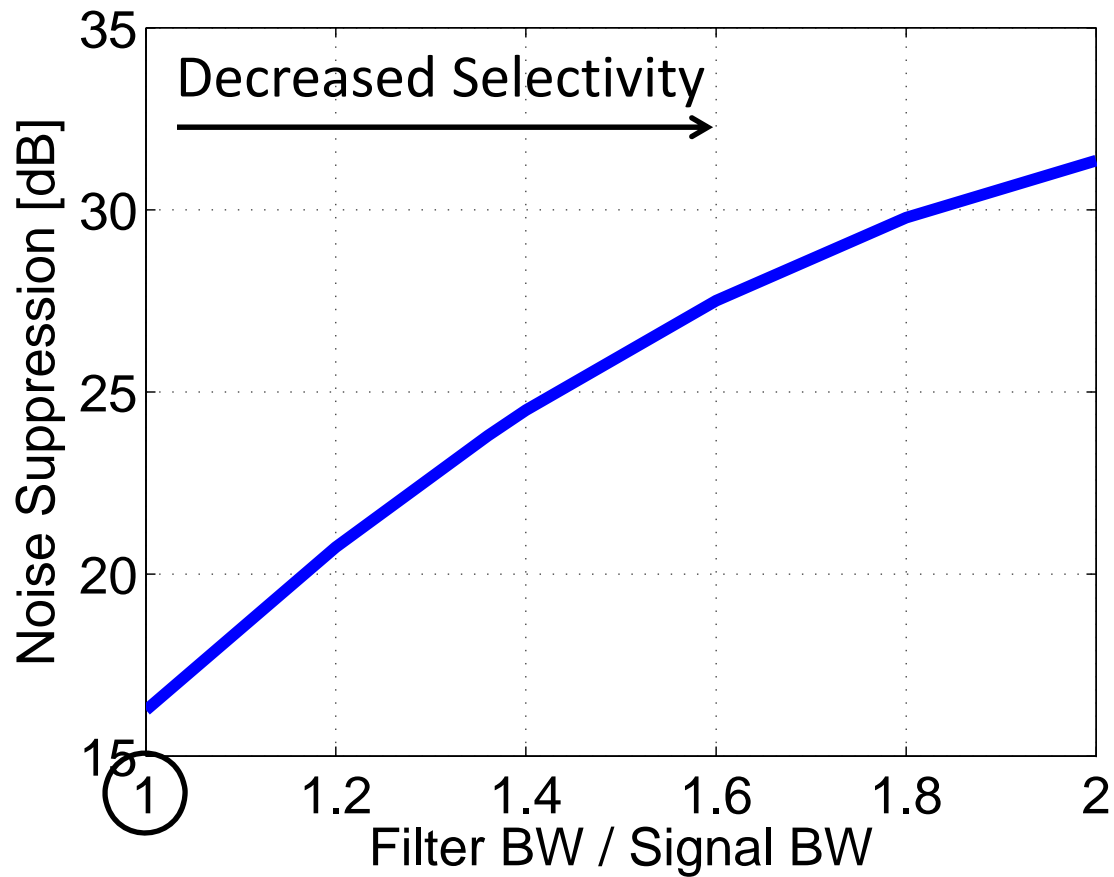
- Power ~ same
- 24 dB better SQNR
- 4+1 Order system



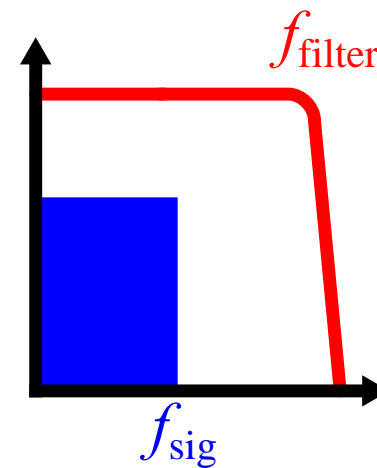
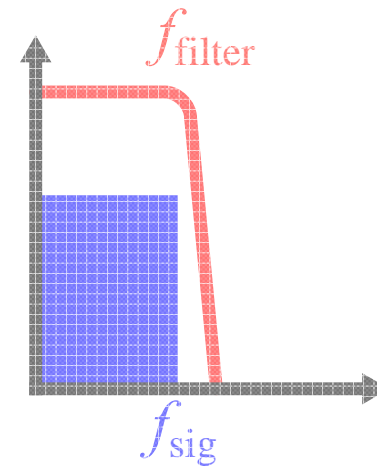
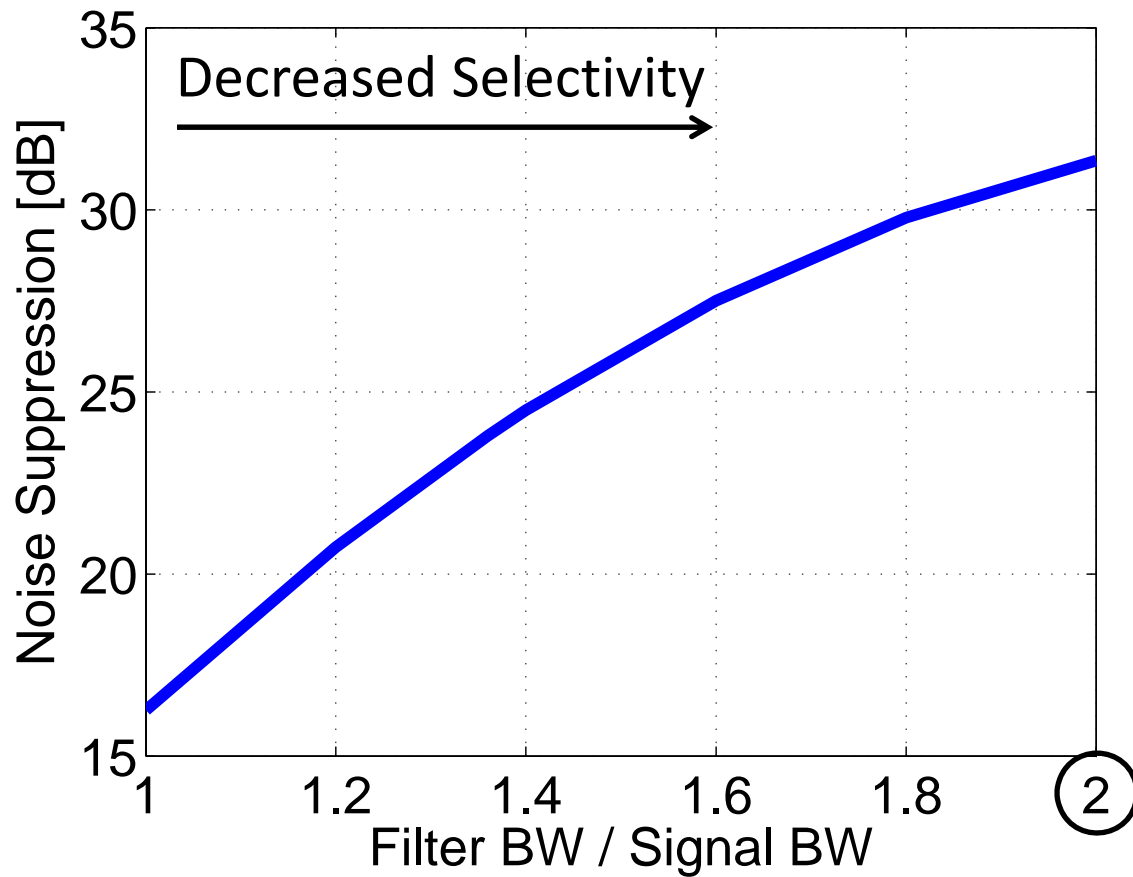
# Noise Suppression vs. Selectivity



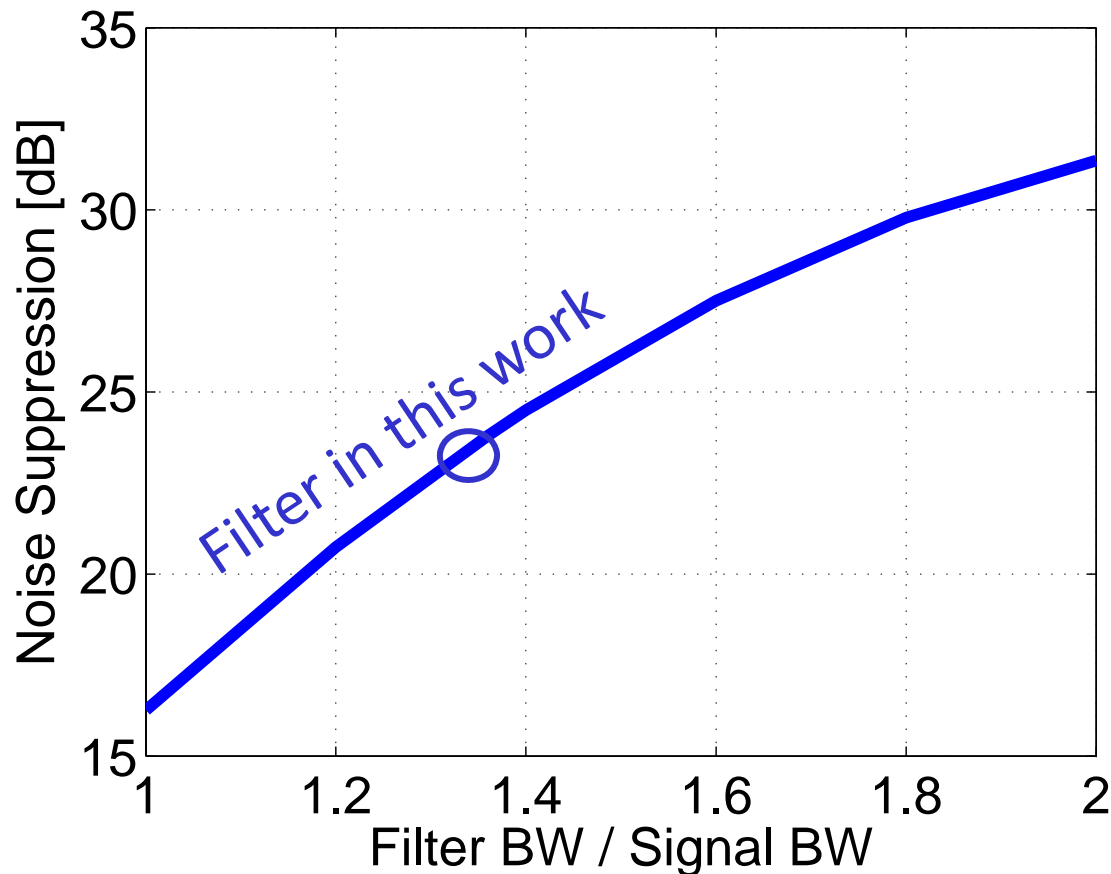
# Noise Suppression vs. Selectivity



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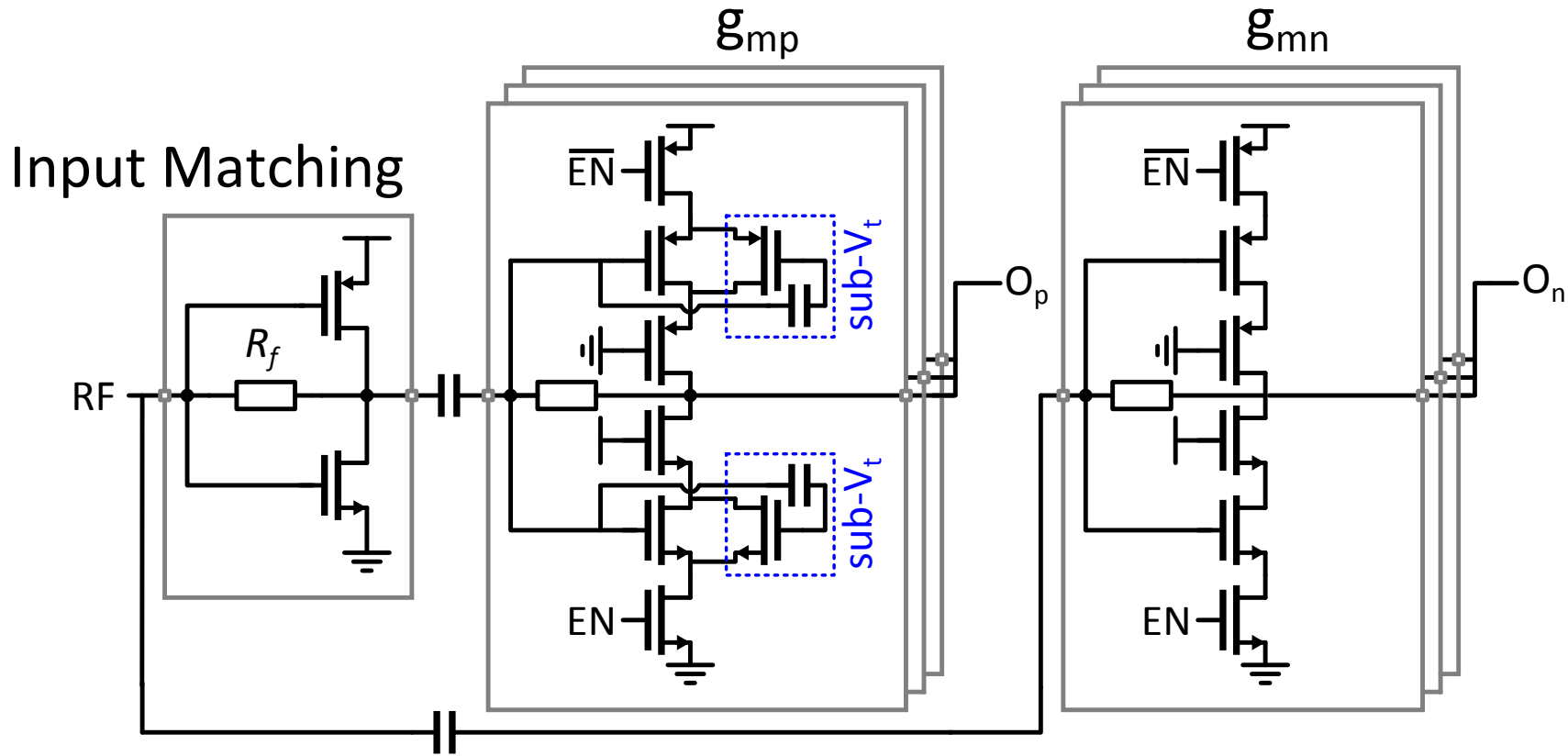


# Noise Suppression vs. Selectivity



- 4<sup>th</sup> Order CSF → 73 dB SQNR
  - 50 dB for 1<sup>st</sup> Order  $\Delta\Sigma$ M and 23 dB suppression

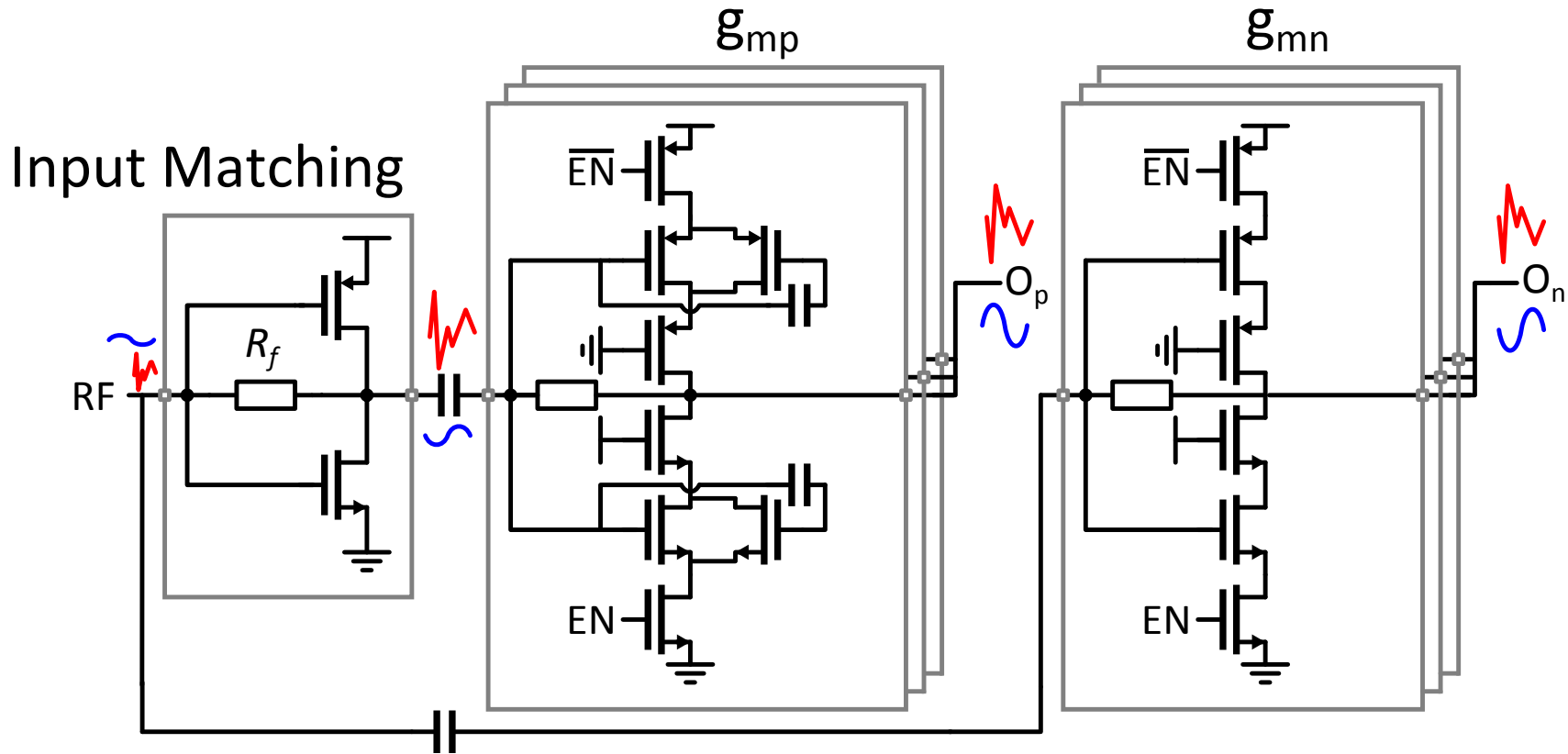
# LNTA



- Single-ended input
- Wideband input match

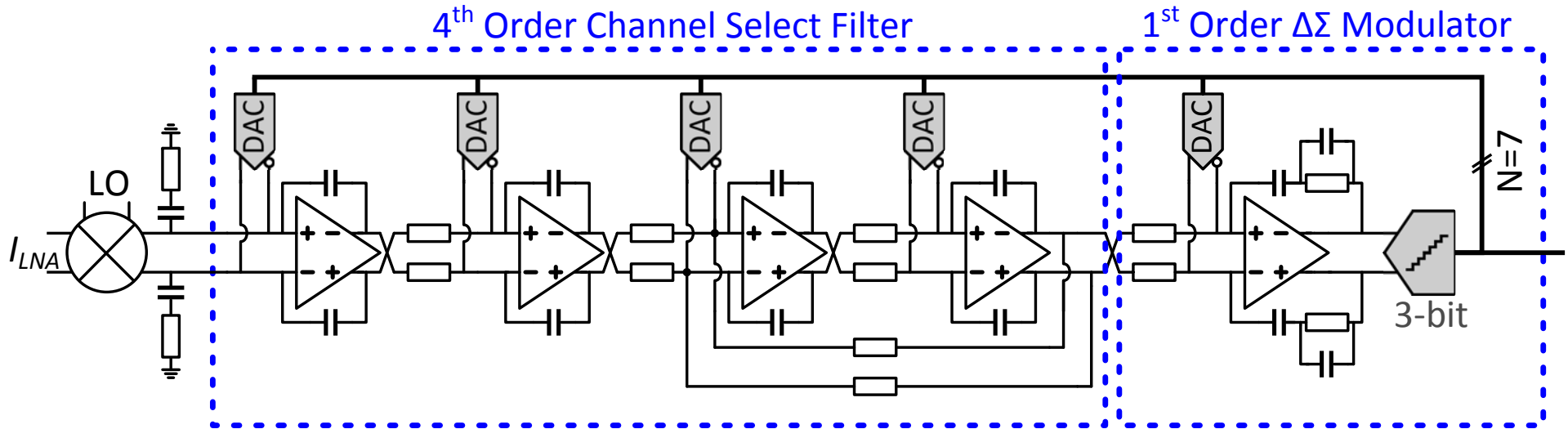


# LNTA



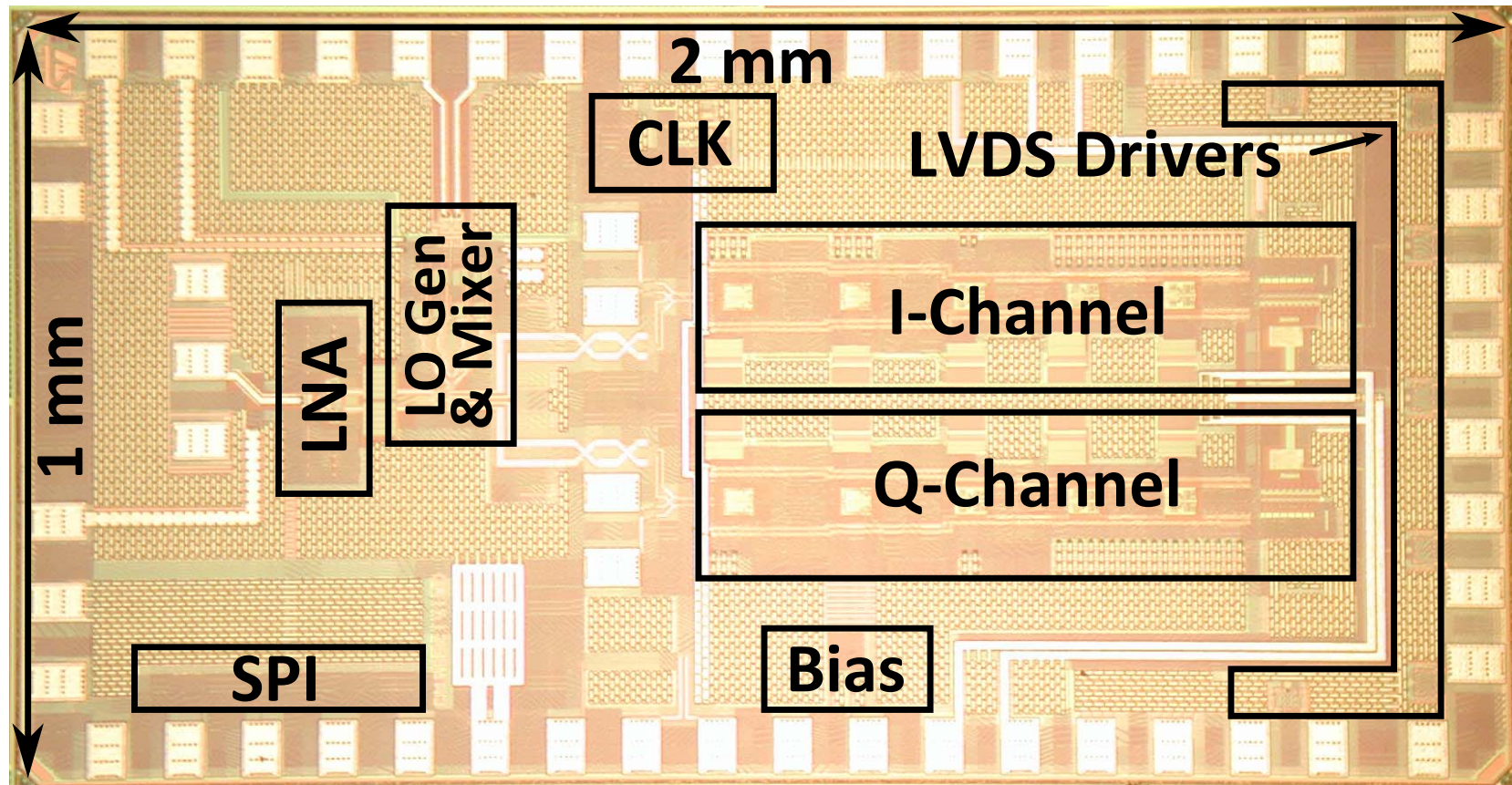
- Single-ended input
- Noise-cancelling,  $NF < 1.6$  dB

# ADC-CSF



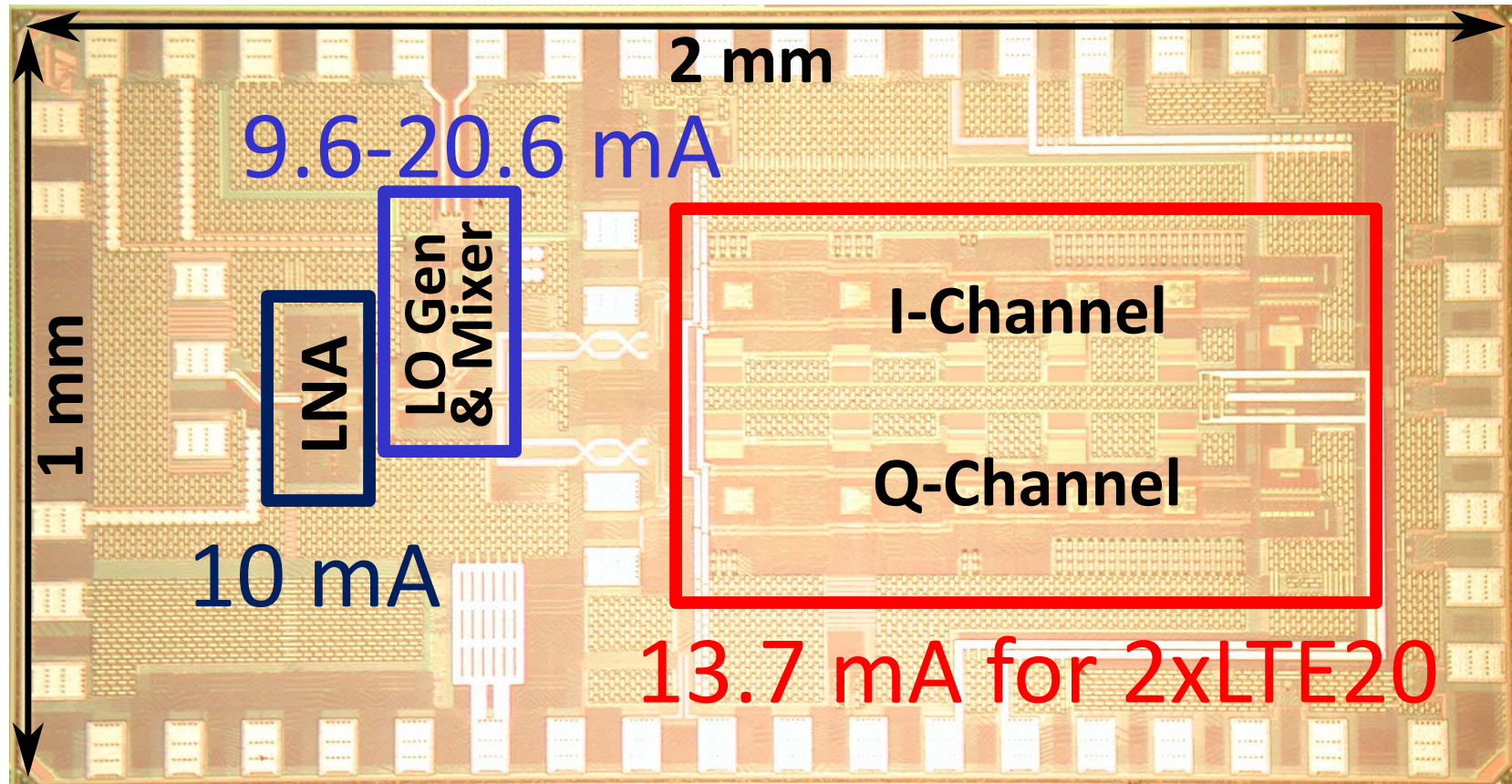
- Bandwidth for LTE10, LTE20 and 2xLTE20
- Max SNDR for stand-alone ADC = 60 dB
- OSR = 16 for all BWs

# Chip Micrograph

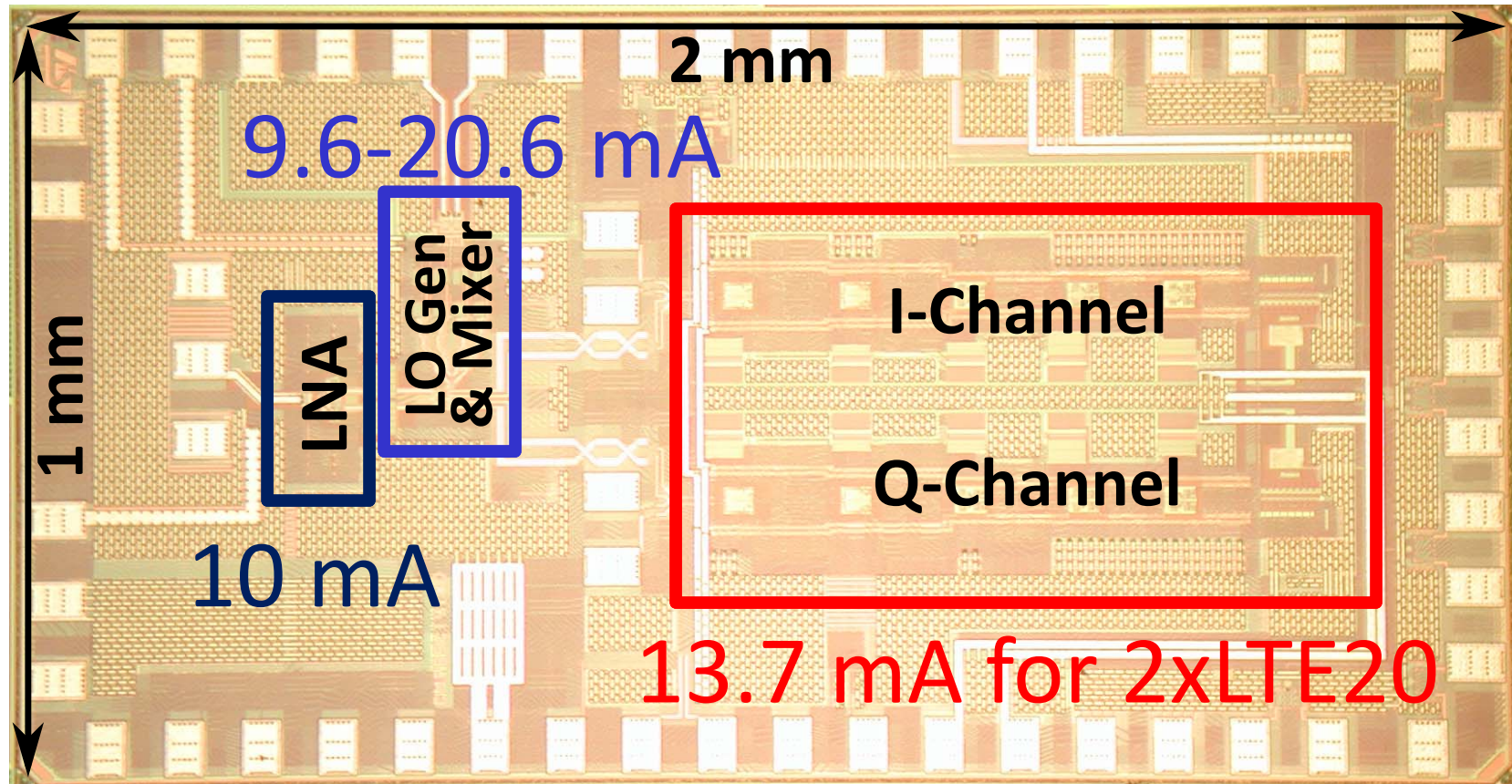


- ST 65 nm CMOS
- Core area: 0.7 mm<sup>2</sup> (excl. LVDS drivers)

# Chip Micrograph

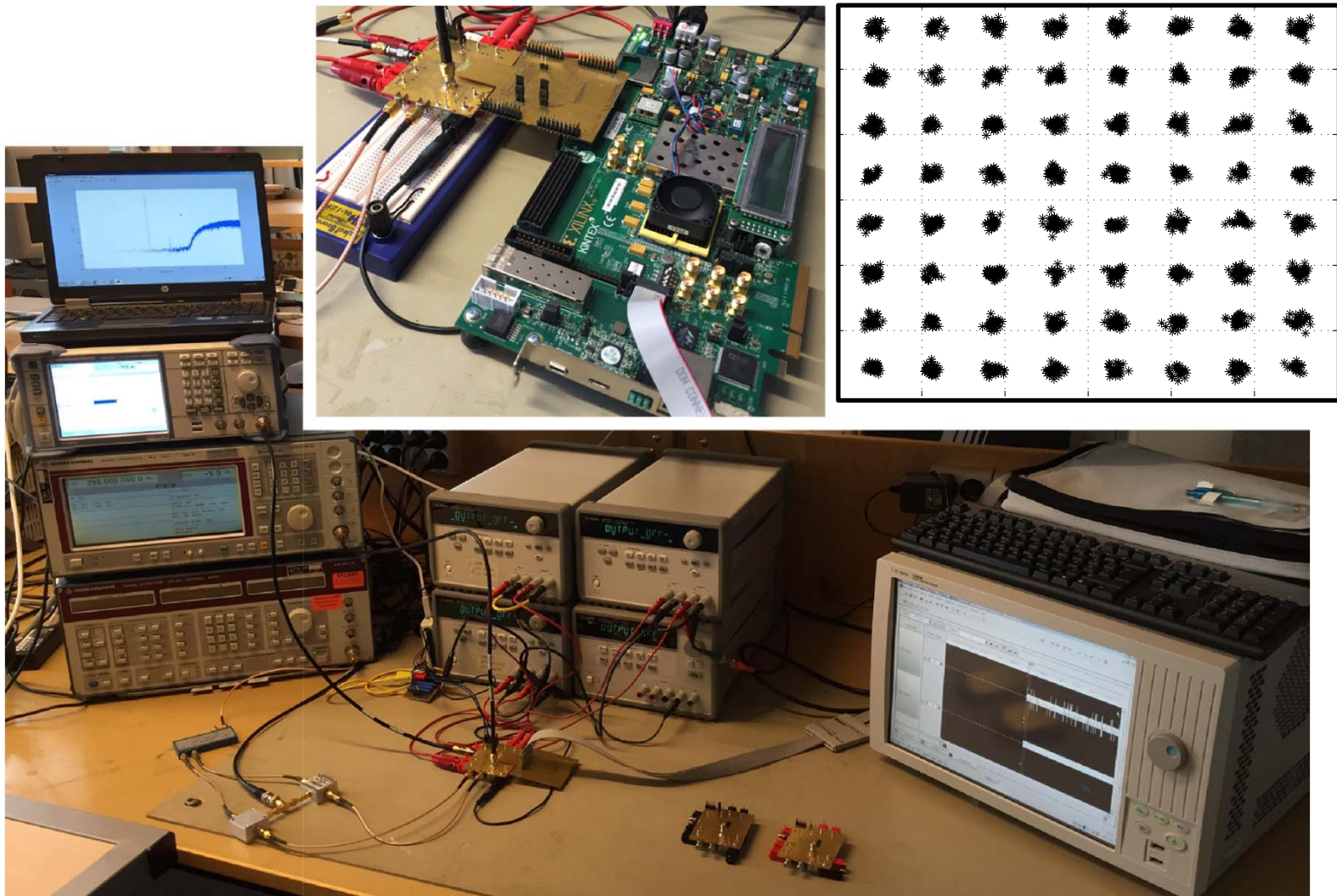


# Chip Micrograph

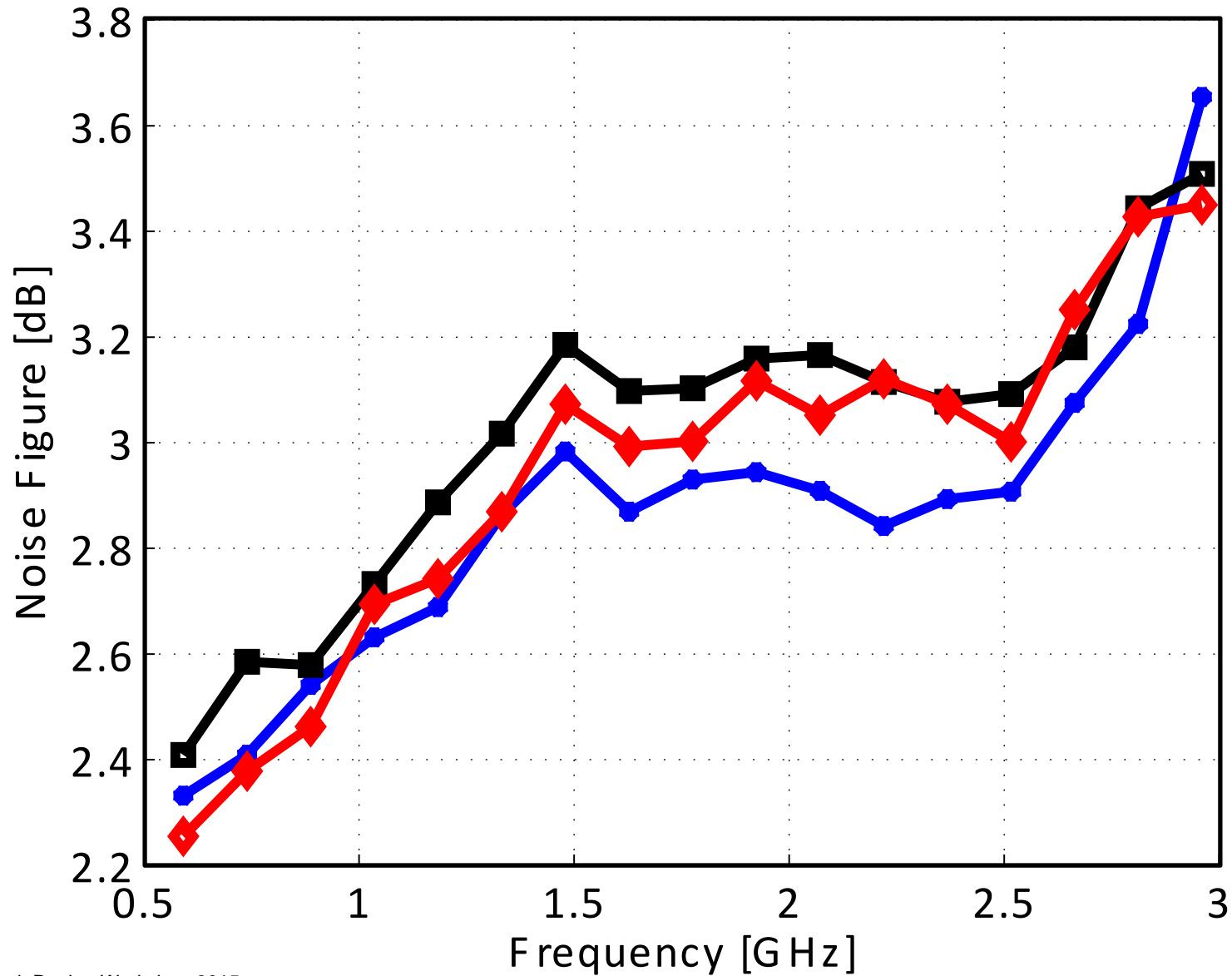


- 36 mW (LTE10 0.6 GHz) – 53 mW (2xLTE20 3 GHz)

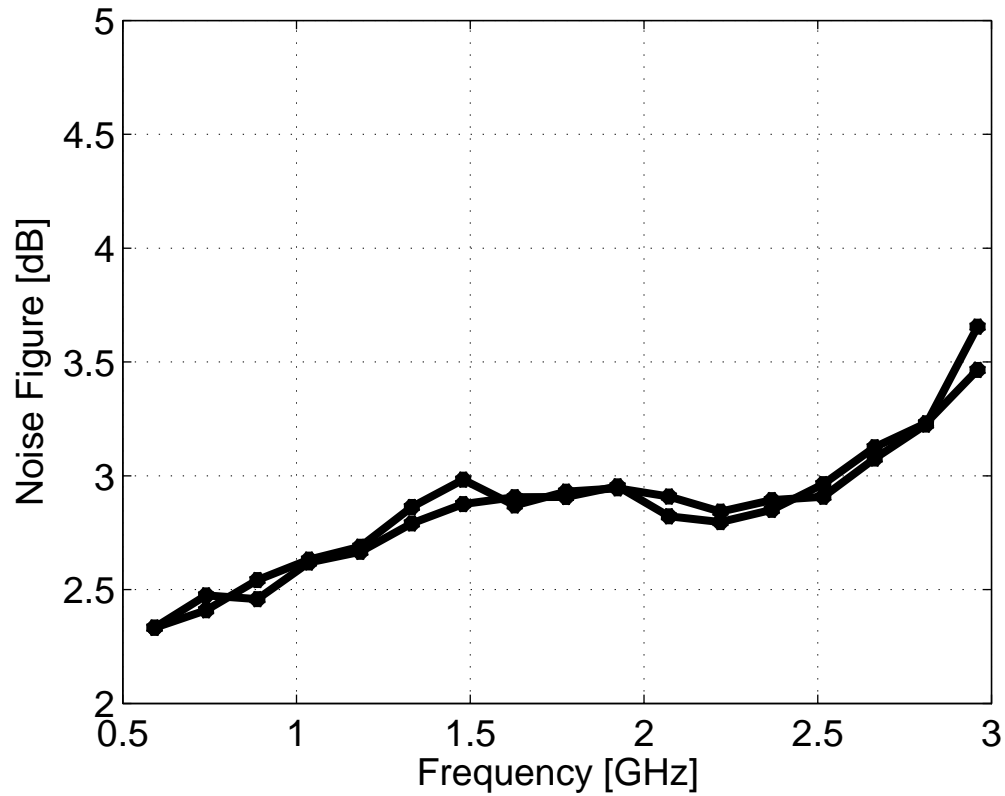
# Measurement Setup



# Noise Figure, 3 Samples, LTE10



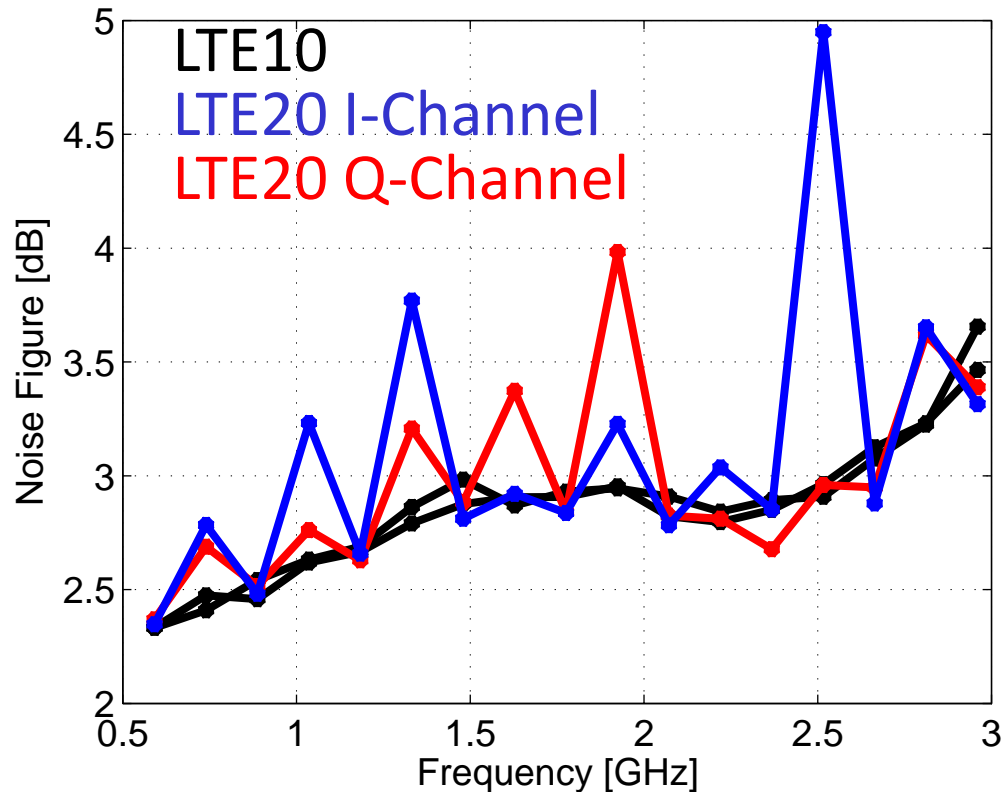
# Noise Figure



- Frequency steps of 148 MHz

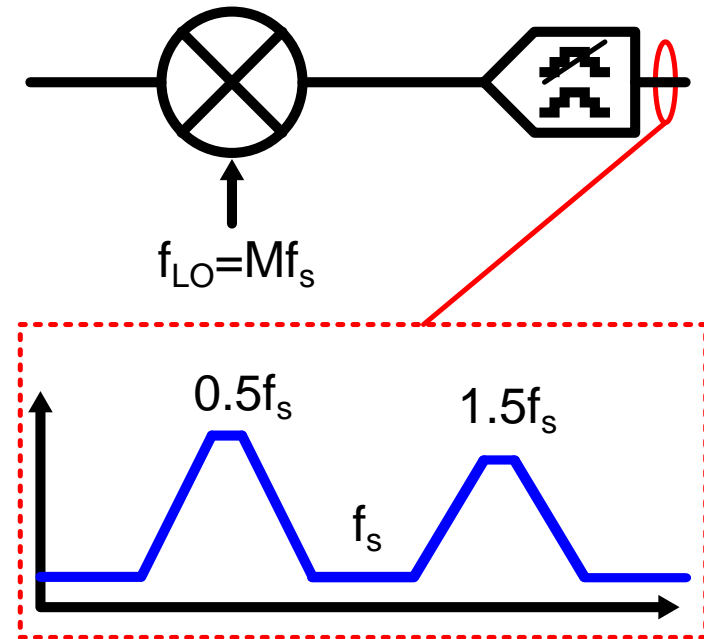
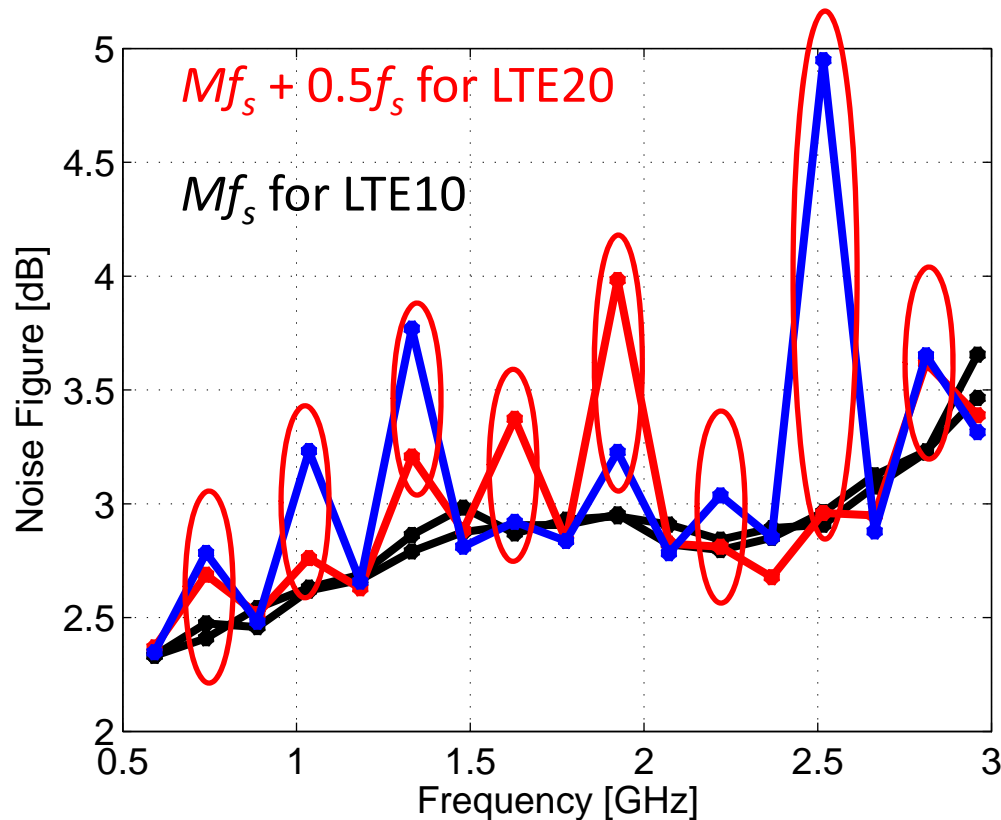


# Noise Figure



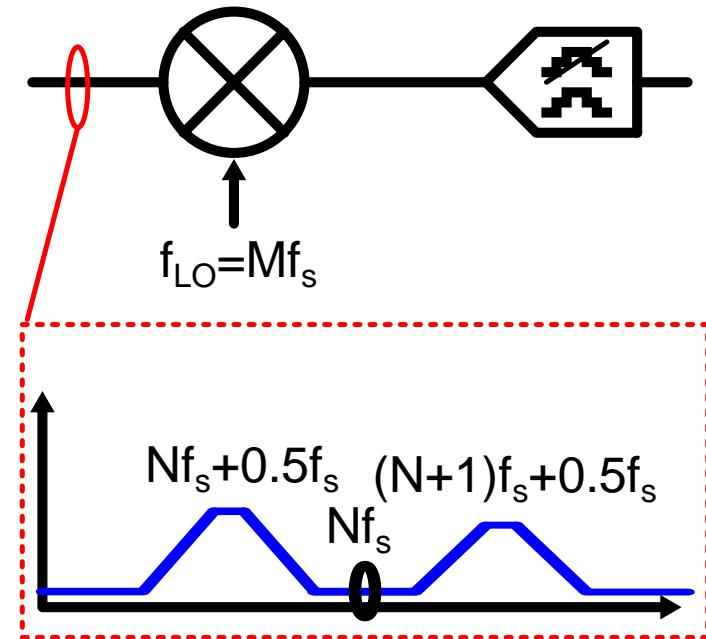
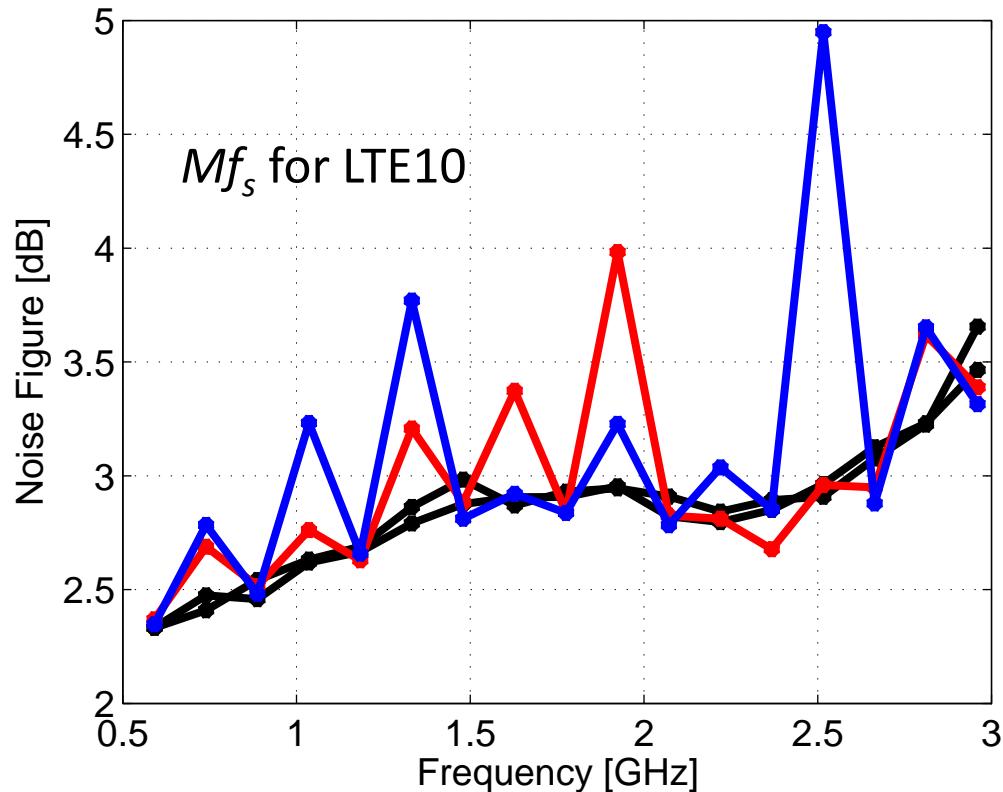
- Frequency steps of 148 MHz
- NF for LTE20 peaks, but NF for LTE10 is flat

# Noise Figure



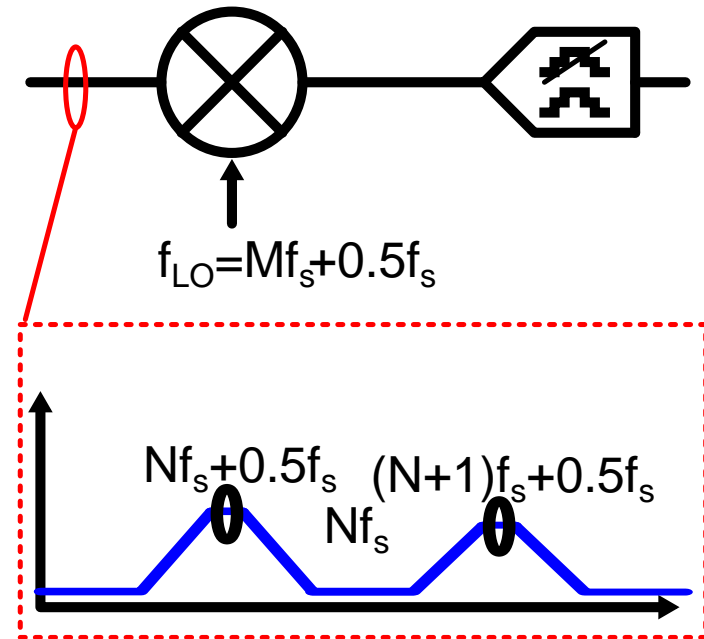
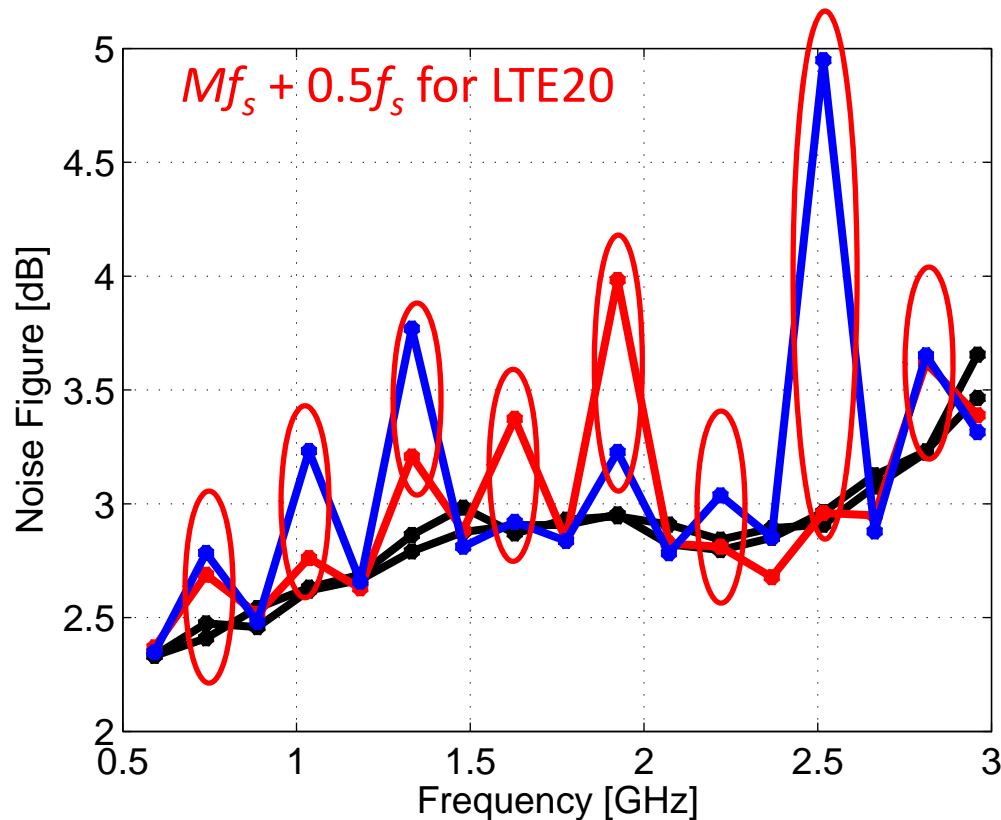
- Noise figure depends on  $f_{LO}/f_s$  ratio
- ADC Noise is shaped, peaks at  $0.5f_s$

# Noise Figure



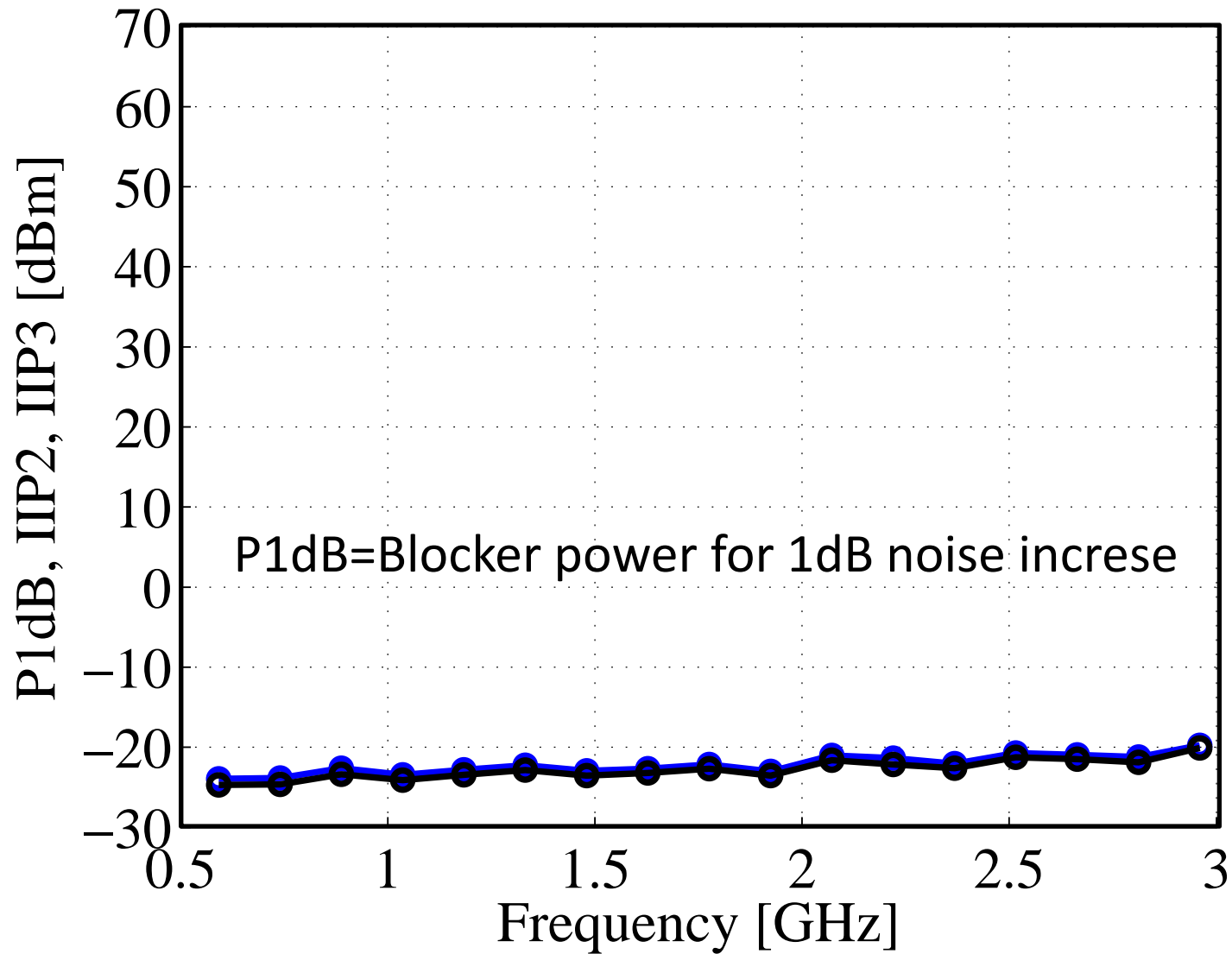
- Assume shaped noise at mixer input
- Low noise down-converted

# Noise Figure

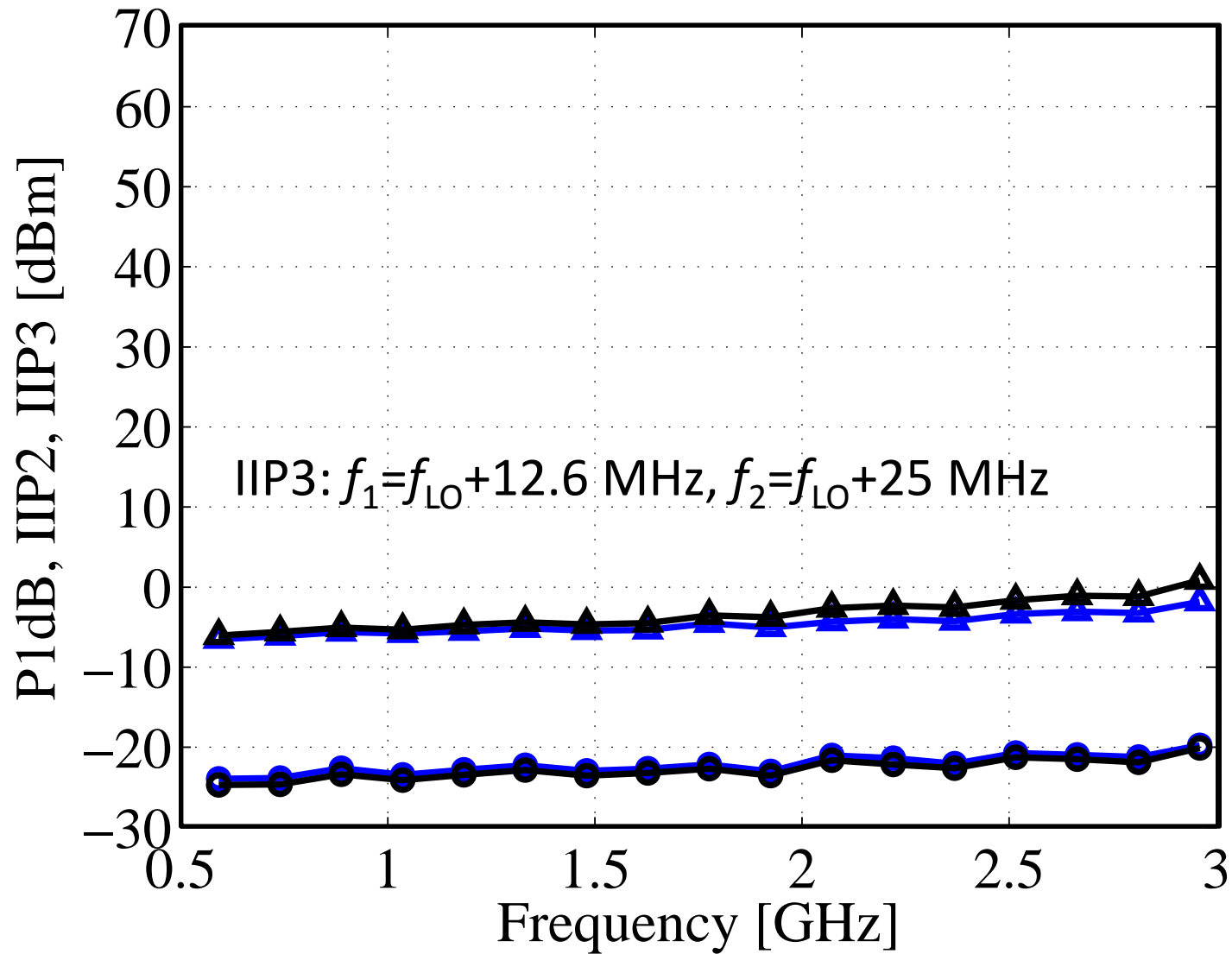


- Assume shaped noise at mixer input
- Noise peaks down-converted if  $f_{LO}/f_s = M.5$

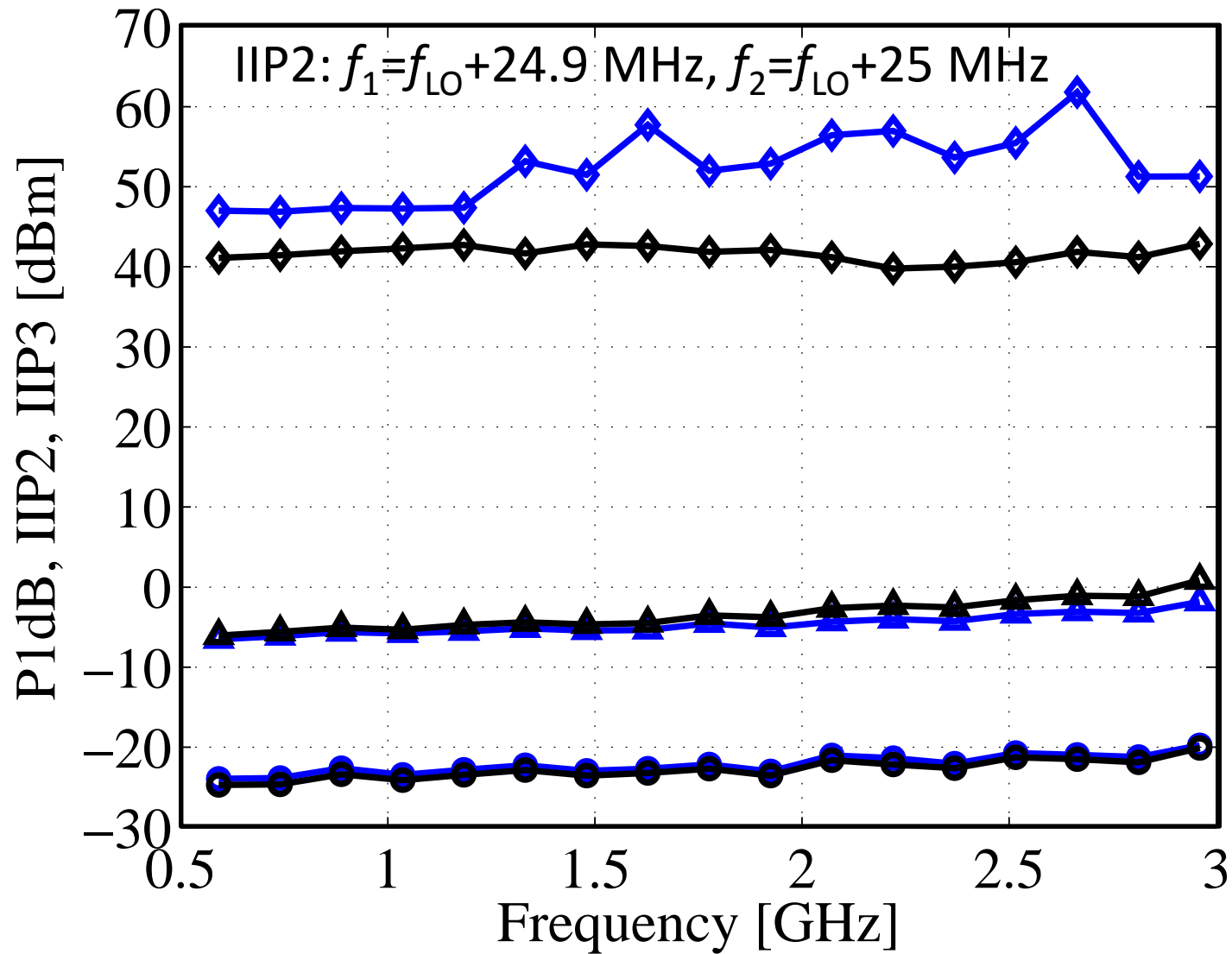
# $P_{1dB}$ , IIP2, IIP3 vs. RF, LTE10



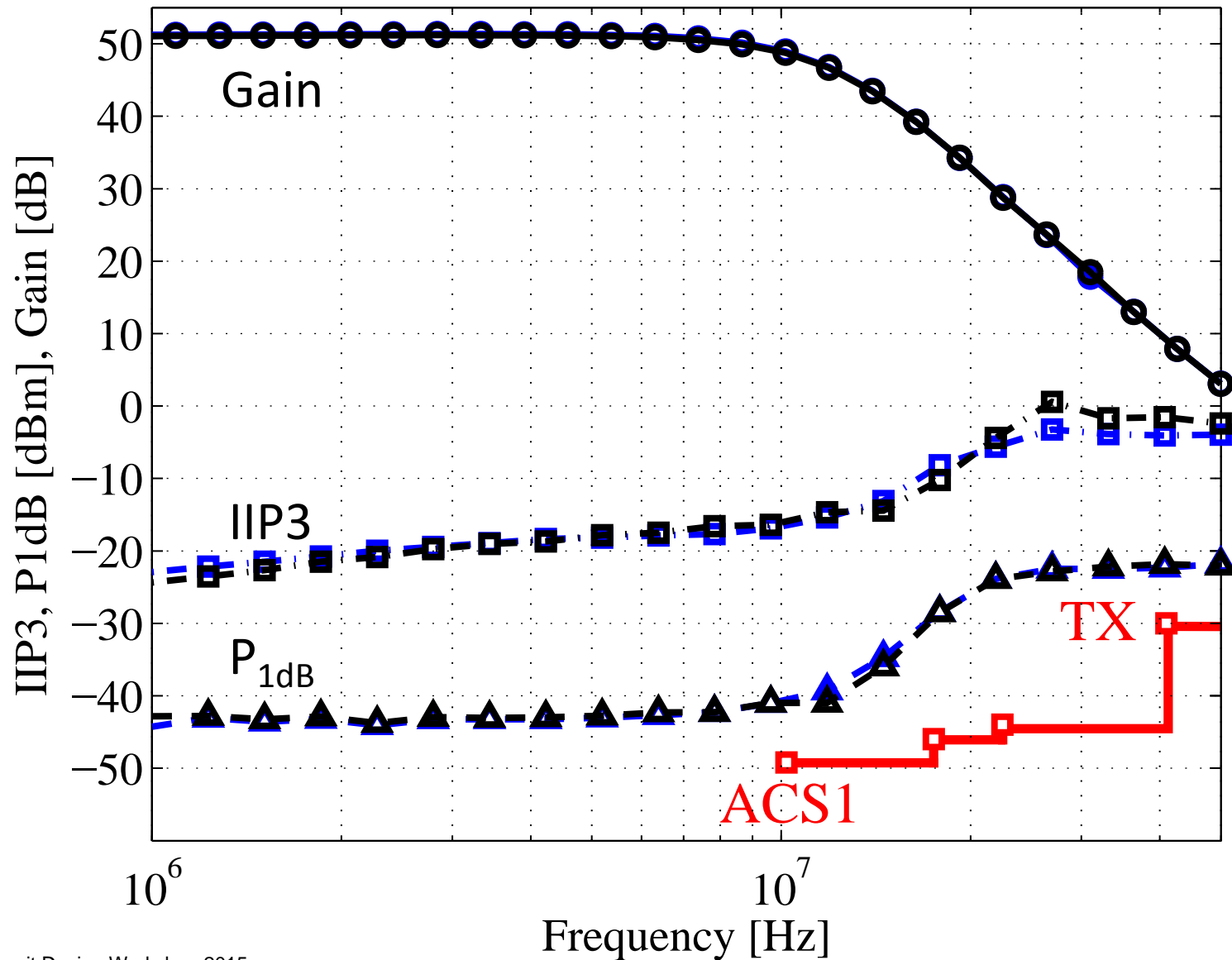
# $P_{1dB}$ , IIP2, IIP3 vs. RF, LTE10



# $P_{1dB}$ , IIP2, IIP3 vs. RF, LTE10

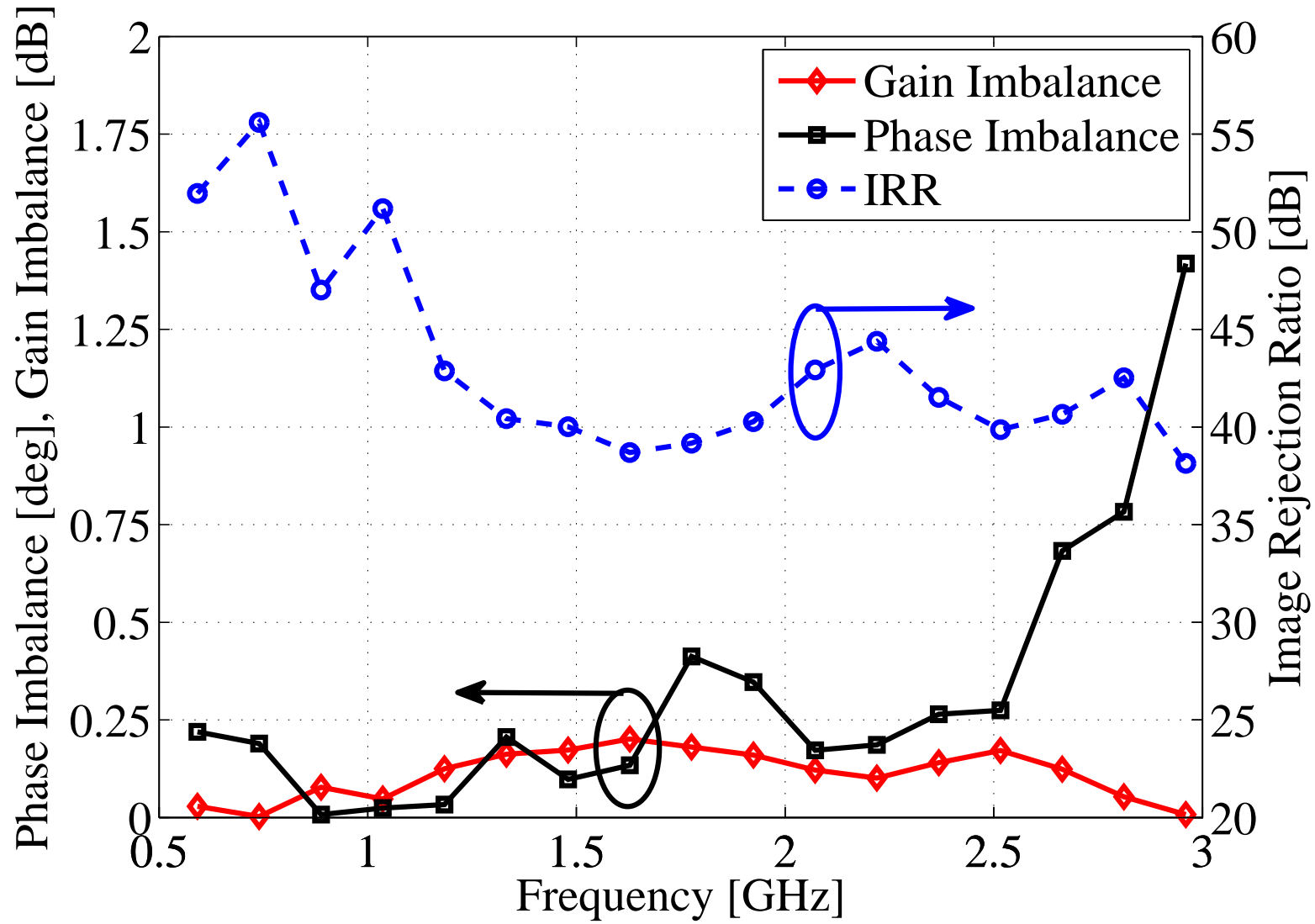


# Gain, IIP3, $P_{1dB}$ at Baseband, LTE20

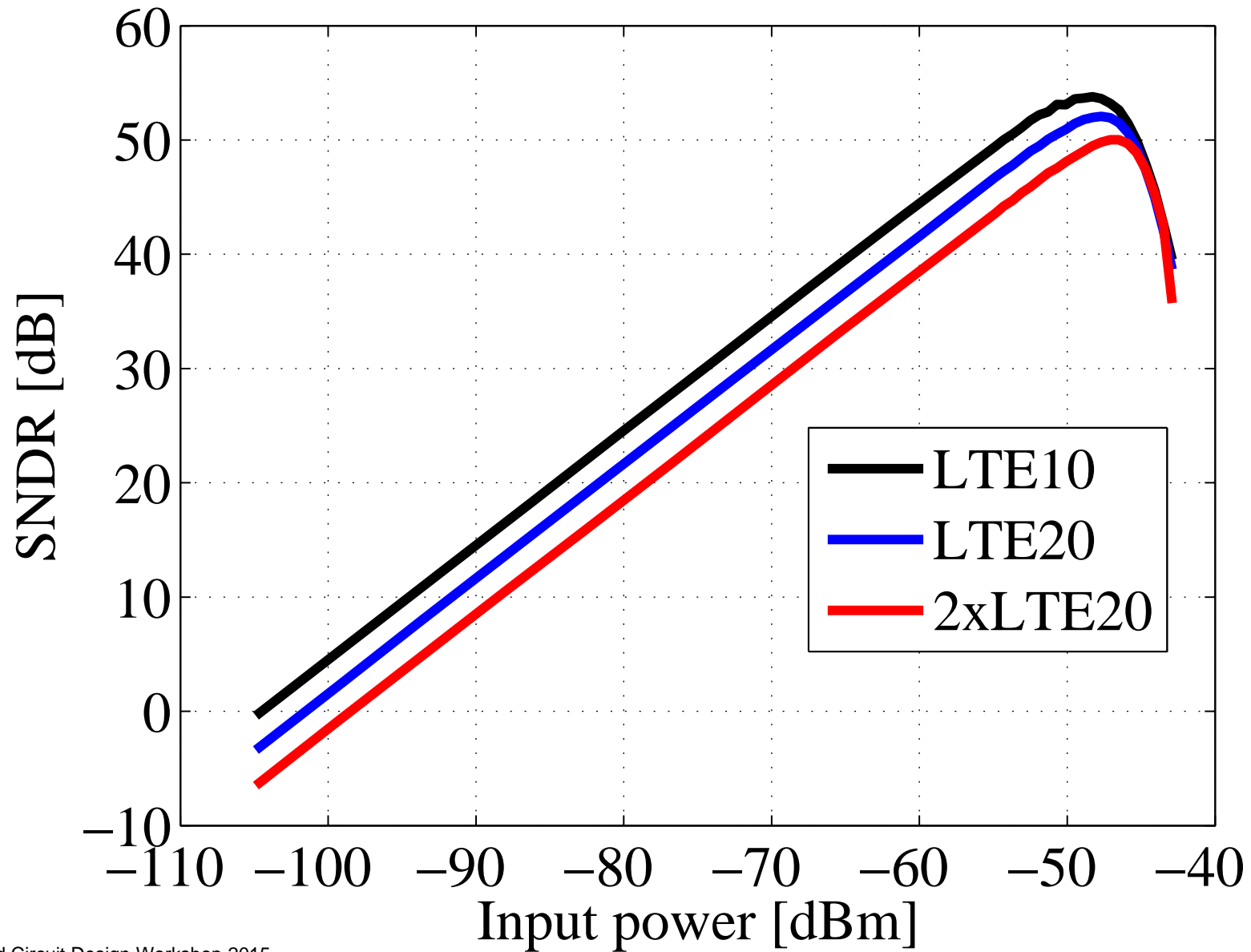




# Image Rejection



# SNDR vs. Power



# Comparison with $\Delta\Sigma$ -based RX

	<b>This Work</b>	<b>JSSC 15</b>	<b>JSSC 14</b>	<b>JSSC 13</b>
Type	<b>RX with ADC-CSF</b>	Direct $\Delta\Sigma$ RX	Direct $\Delta\Sigma$ RX	RX with ADC-CSF
RF Freq. [GHz]	<b>0.6-3</b>	0.7-2.7	0.4-4	0.04-1
NF [dB]	<b>2.4-3.5</b>	5.9-8.8	16	2.7-3.5*
Power [mW]	<b>35.5-53.0</b>	90	17-70.5	221.4
Supply [V]	<b>1.2</b>	1.1	1.5/1.2	1.8/1
IIP3 [dBm]	<b>-6-0</b>	-2	+13.5	-13
SNDR [dB]	<b>48-55</b>	40-43	52-68	-
RF Carrier BW [MHz]	<b>10, 20, 40</b>	1.5, 15	4, 10	5, 6, 7, 8
Area [mm <sup>2</sup> ]	<b>0.7</b>	1	0.56	5.6**
Process [nm]	<b>65</b>	40	65	80

\*Estimated \*\*Incl. PLL and DSP

# Conclusion & Summary

- Wideband Receiver, Digital Output
- Power efficient RX with low NF
- ADC-CSF with aggressive filtering
- 4<sup>th</sup> order Butterworth + 1<sup>st</sup> order  $\Delta\Sigma$ M
- High SNDR for 1<sup>st</sup> order  $\Delta\Sigma$ M

# Acknowledgement

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