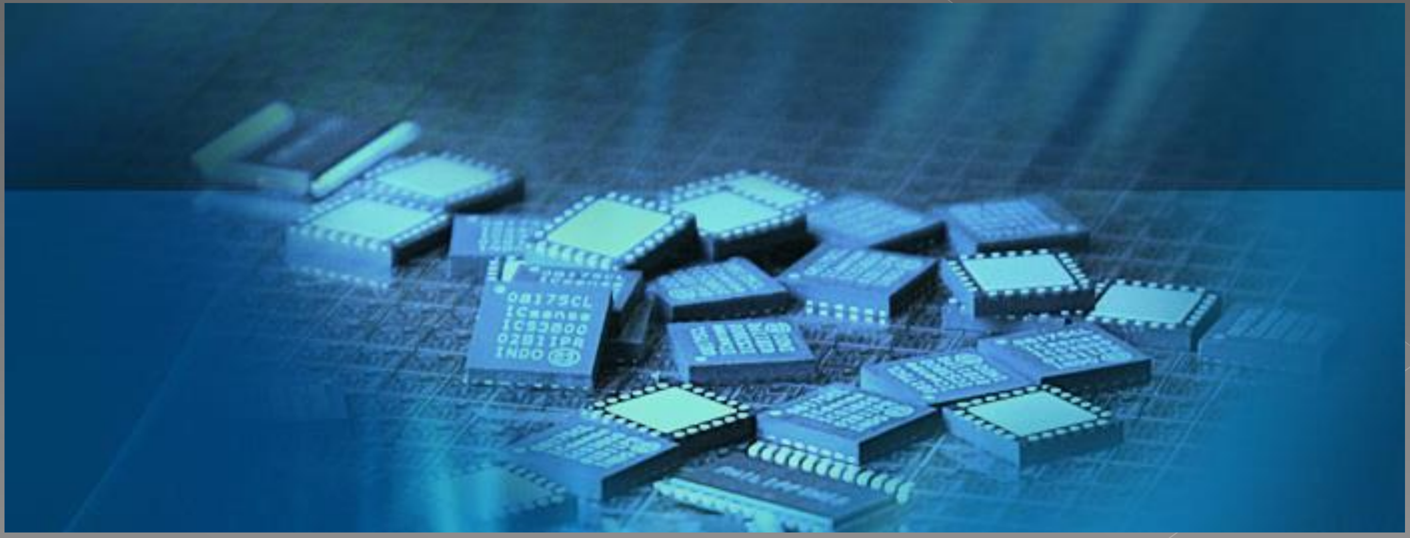
System-On-Chip and Mixed Signal Design For Wireless Communications

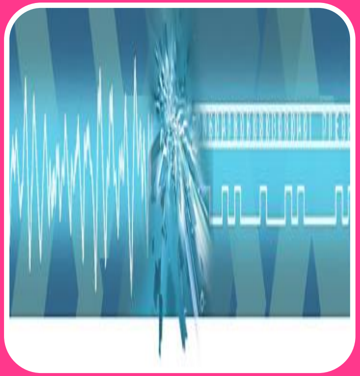


Some Definitions

System-On-Chip (SOC)

- The integration of all circuits required in a system on one chip.
- Example: CPU, Baseband Processor, Analog and RF on one chip.

Mixed-Signal Design



- The combination of analog circuits with DSP to enhance performance and reduce cost.

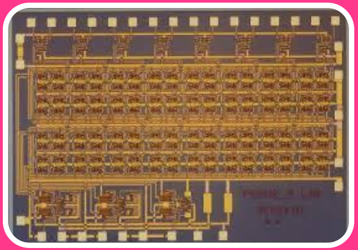
Why System on Chip?

Cost

Size

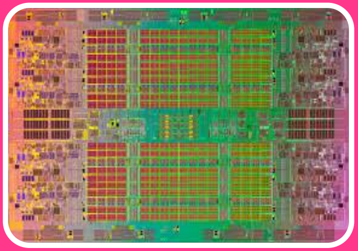
Power

Cost Issues



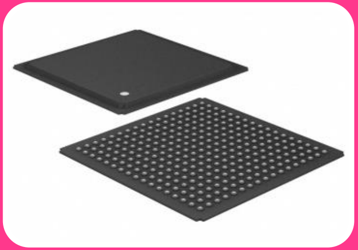
RF Circuits are Expensive

- RF Chips were historically implemented on GaAs processes with low yields and expensive materials.



CMOS is Cheap

- Economies of scale reduce the cost of each chip.
- No exotic materials and high yields.



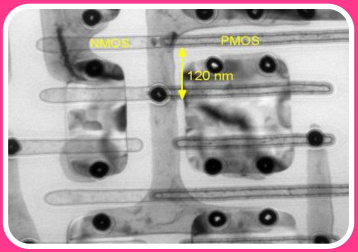
Reduction in Components

- Less chips and passive components on a PCB.
- Packaging a significant part of IC cost.

Size Issues

Consumers Want Smaller Devices

- SOCs allow devices to be smaller.



CMOS Allows For Smaller Chip Area

- Scales Reliably.
- Currently at 28nm for SOCs.

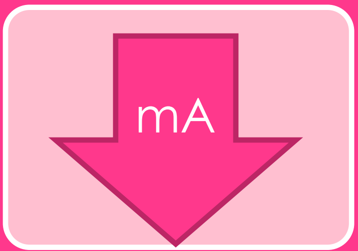
Smaller PCB Area

- Less chips means smaller board area.

Power Issues

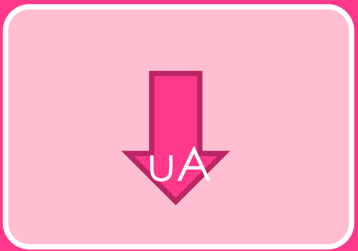
Batteries

- Battery technology doesn't advance as fast as IC technology.
- Small devices prevent the use of larger batteries.



GaAs Circuits Consume High Power

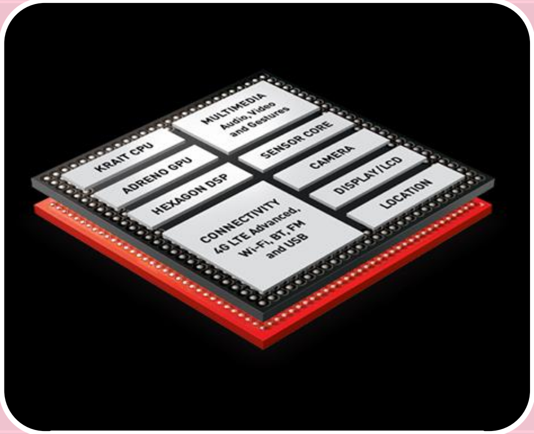
- GaAs ICs require current even when idling.



CMOS Circuits Are Low Power

- Only leakage currents flow in CMOS ICs when idling.

Examples of Communication SoCs

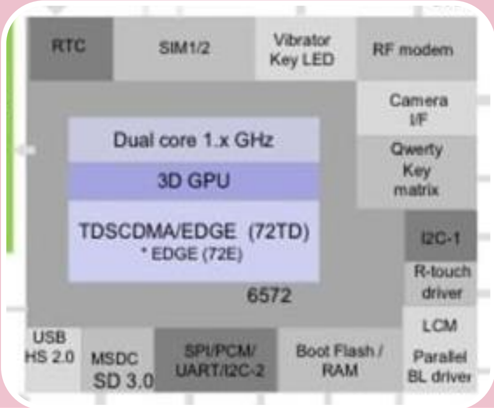


Qualcomm Snapdragon

Integrates CPU, GPU, peripherals and baseband.

Does not integrate RF.

28nm process



MediaTek MT65xx Series

Integrates CPU, GPU, peripherals and baseband.

Does not integrate RF.

28nm process

Broadcom

M320

Integrates CPU, GPU and baseband.

Does not integrate RF.

28nm process

Traditional Transceiver Design

RF portions of the transceiver are made up of an array of RF ICs and passive components.

This interfaces to the baseband processor.

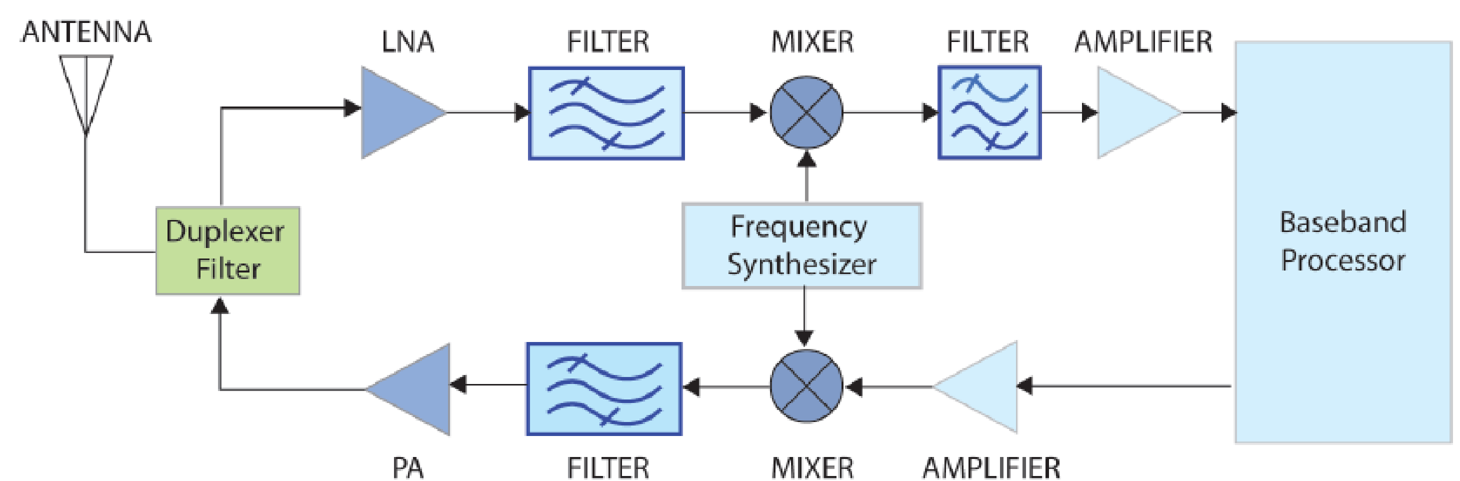
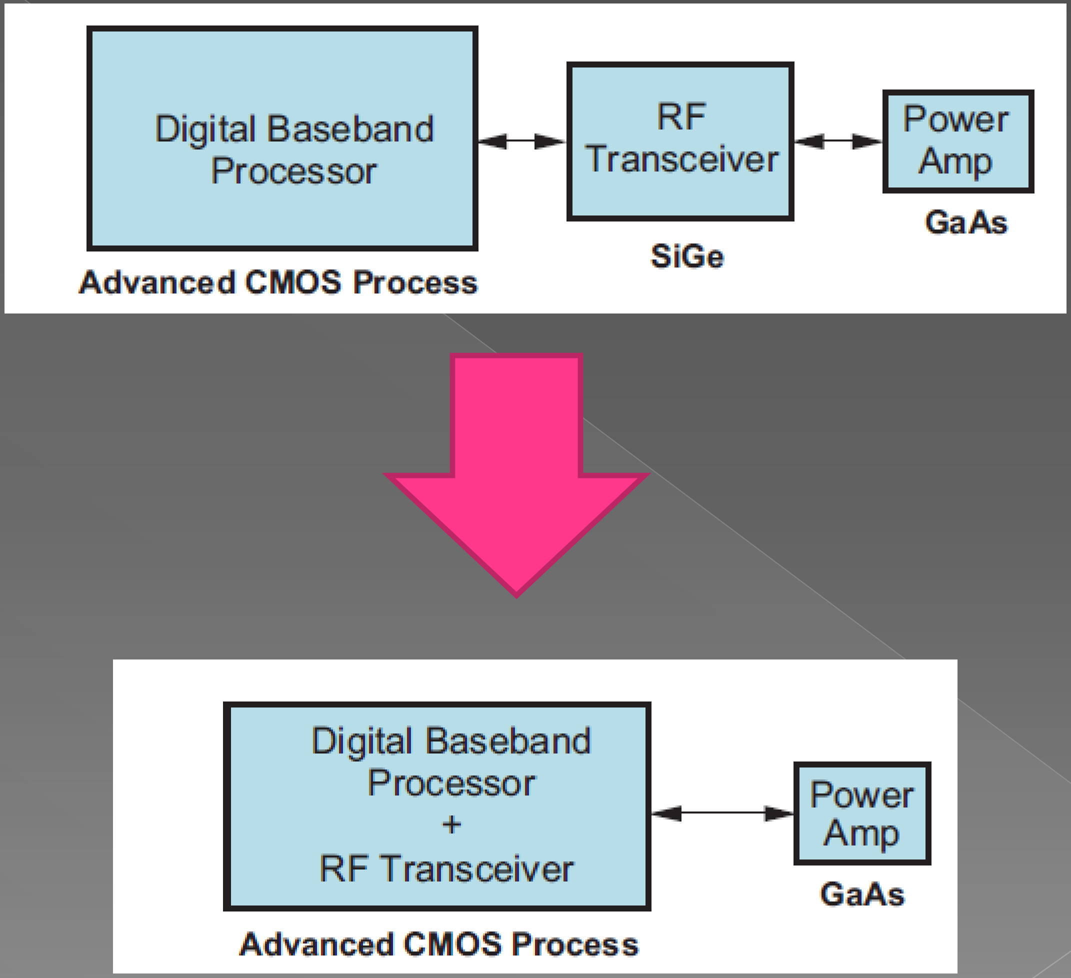


Figure 1 – Simplified RF Transceiver

Integrating Baseband and RF

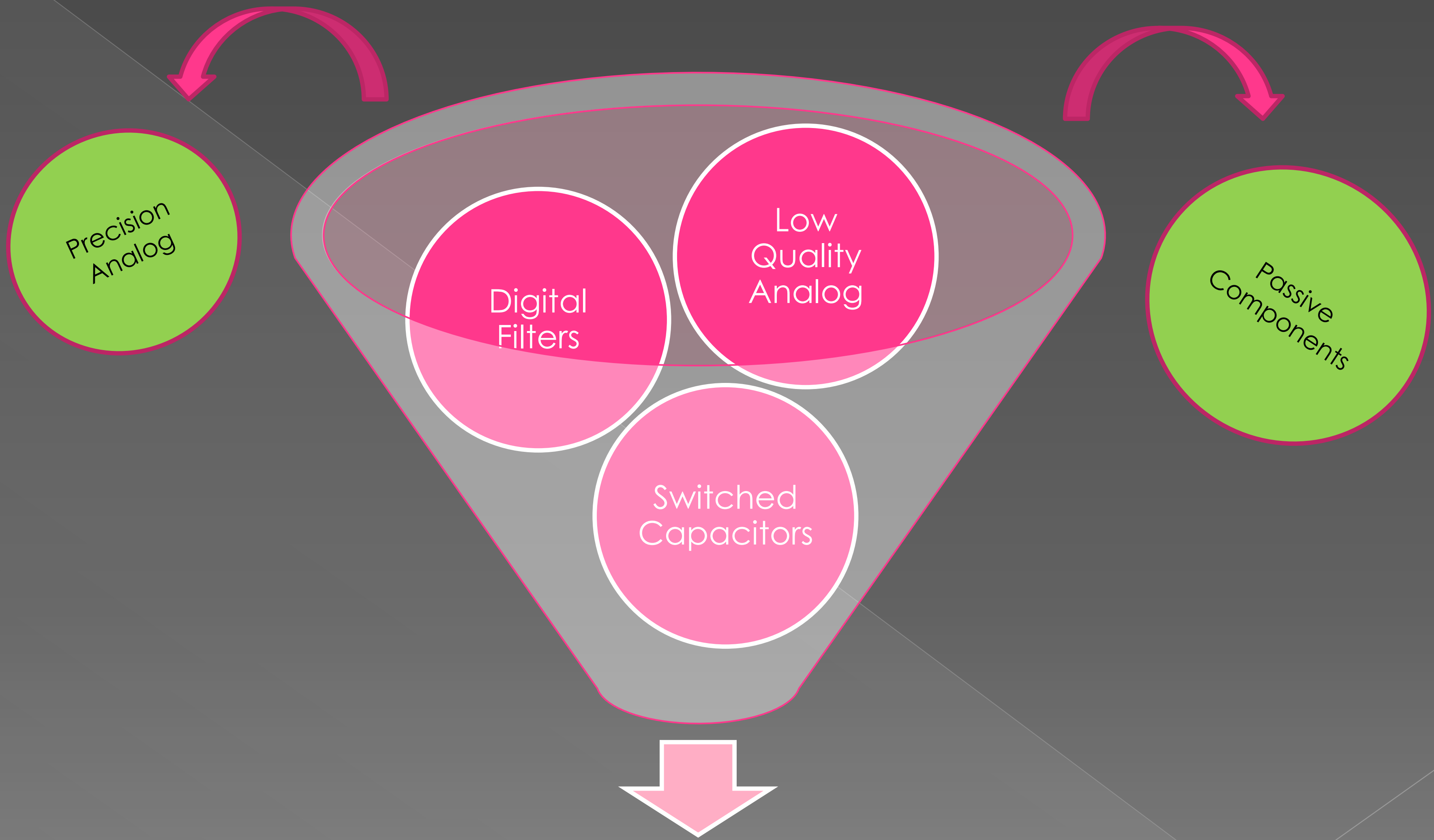


Challenges

- RF circuits prone to interference from digital noise.
- High speed transistors required for RF circuits.
- Analog circuits implemented in nanometer CMOS have poor performance.

Solutions

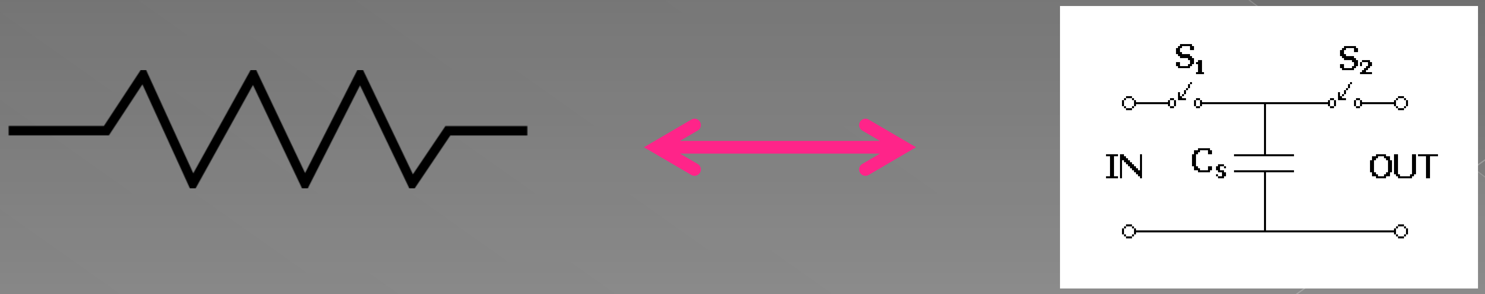
- Careful layout can reduce digital noise.
- CMOS is fast enough for cellular, bluetooth and WiFi communications (below 5GHz).
- Mixed signal design can improve non-ideal analog components.



Mixed Signal Design

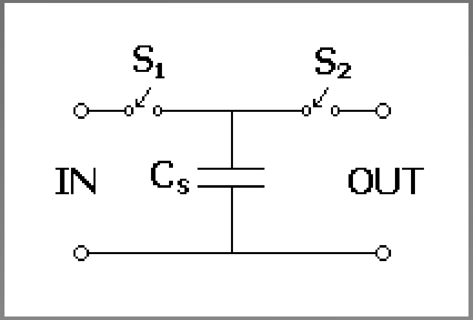
Replacing Passive Components

- Resistors are hard to integrate on ICs.
- Some circuits need resistors.
- Small capacitors can be created on ICs.
- Resistors can be replaced with switched-capacitors.



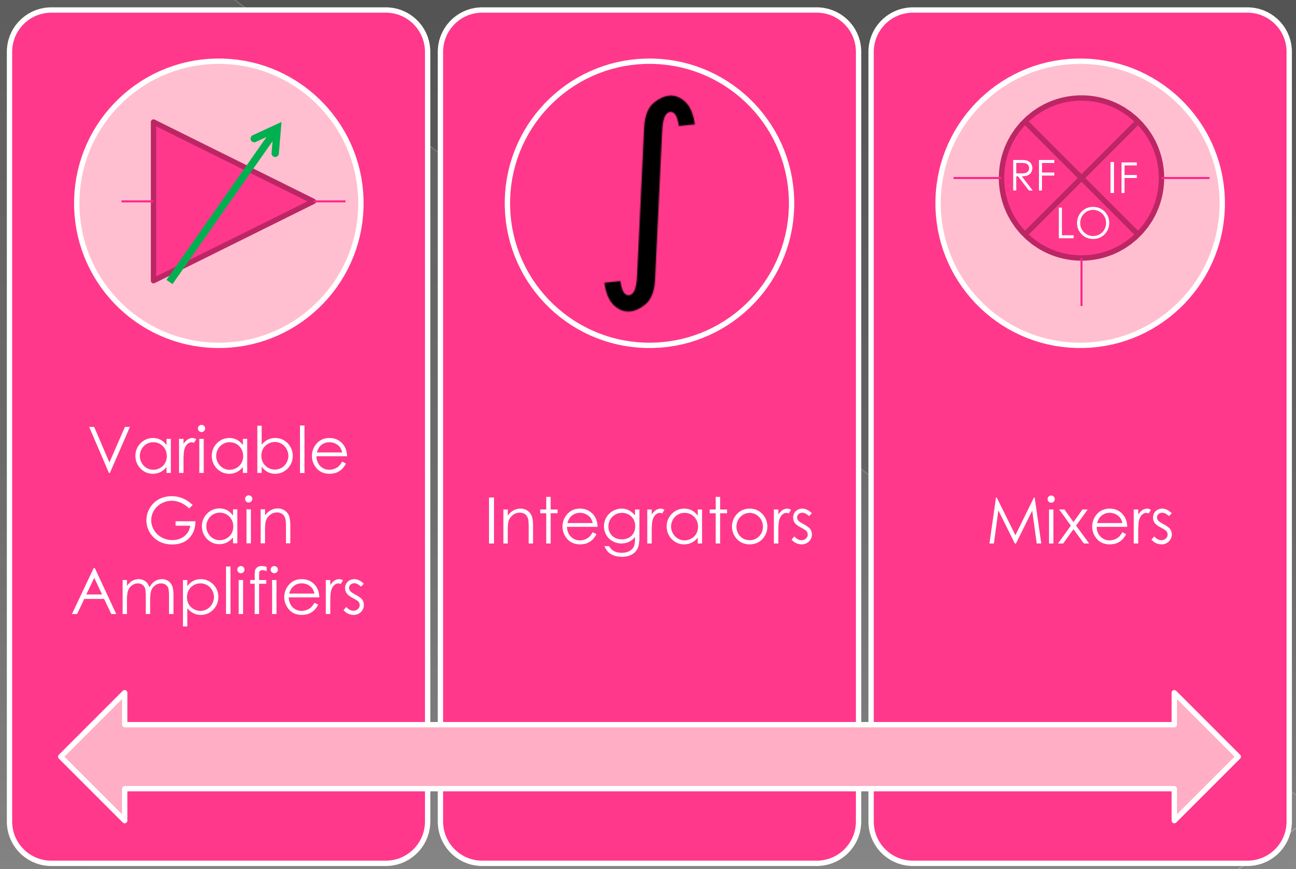
How Switched Capacitors Work

- Value of equivalent resistance is a function of switching frequency and capacitance.
- Resistance can be changed by changing switching frequency.



$$Req = \frac{1}{Cs * Fs}$$

RF Building Blocks Enabled by Switched Capacitors



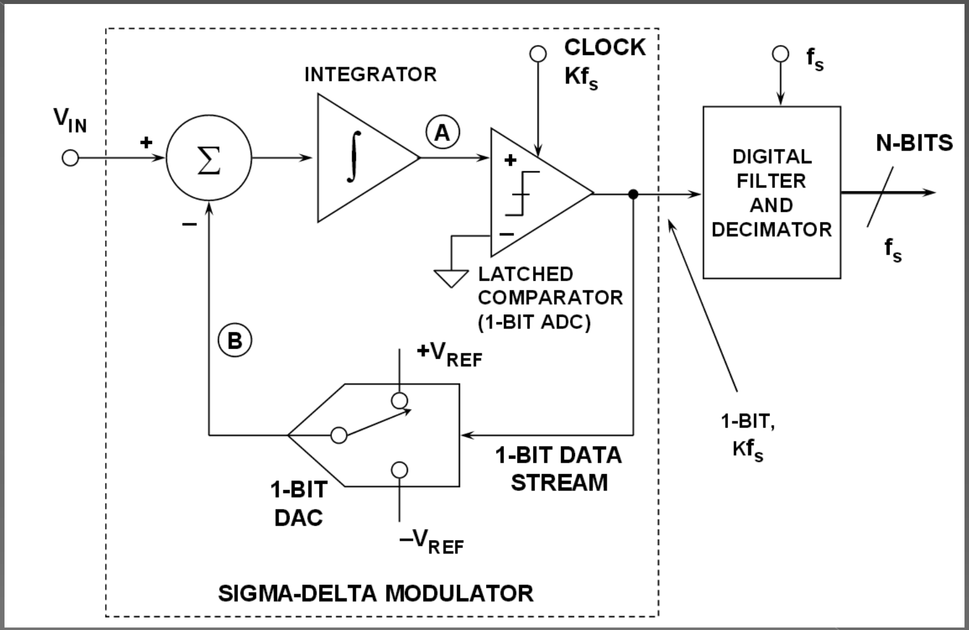
Replacing Precision Analog

- High precision analog is very difficult in nanometer CMOS and voltages below 1V.
- Op-amps are replaced with "operational transconductance amplifiers" (OTA).
- Accumulate and dump filters, FIR filters, decimation filters are used instead of analog filters.
- "Processing gain" used to reduce noise.

Data Converters

- Analog signals need to be converted to digital for baseband processing.
- Flash ADCs can be impractical.
  - 2^n-1comparators required for n bits.
  - Matching of comparators is difficult in nm CMOS.
- Sigma-Delta ADCs are preferred.

Sigma-Delta ADC



Output from the modulator is a one-bit stream. Decimation converts one-bit stream to desired resolution.

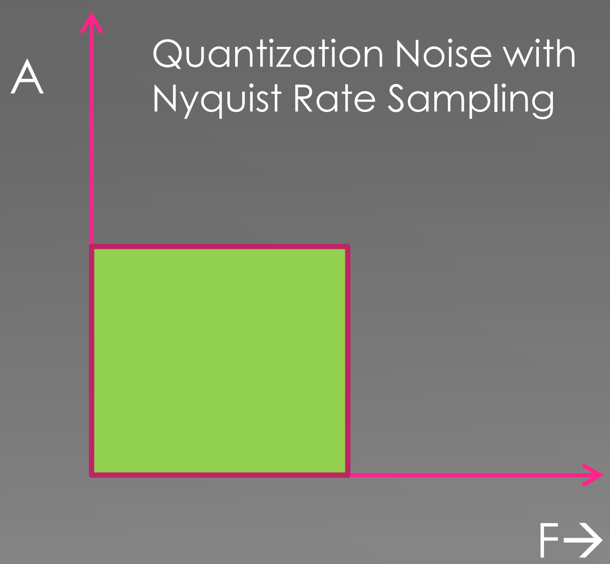
Oversampling and noise shaping are used to obtain high resolution.

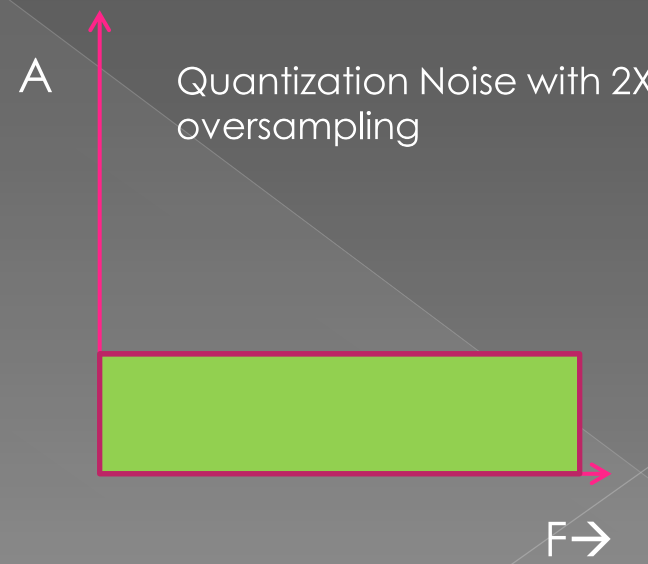
Oversampling

- To get n additional bits of precision, S number of samples are needed.

$$S = 2^{2n}$$

- Quantization noise is spread over a wider bandwidth with a decrease in amplitude at each point.

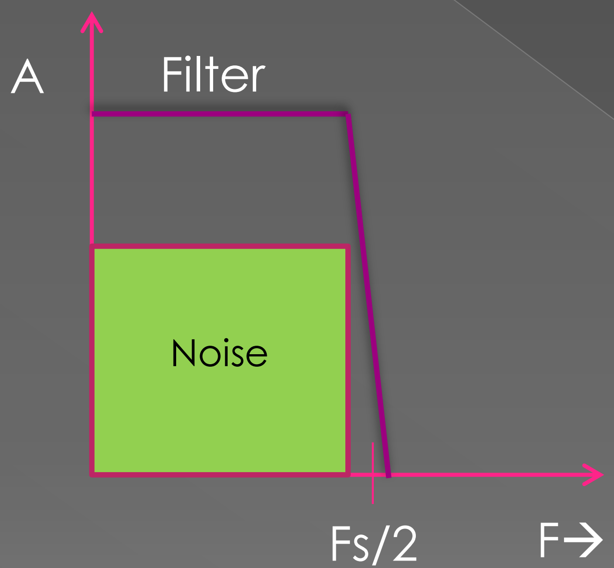




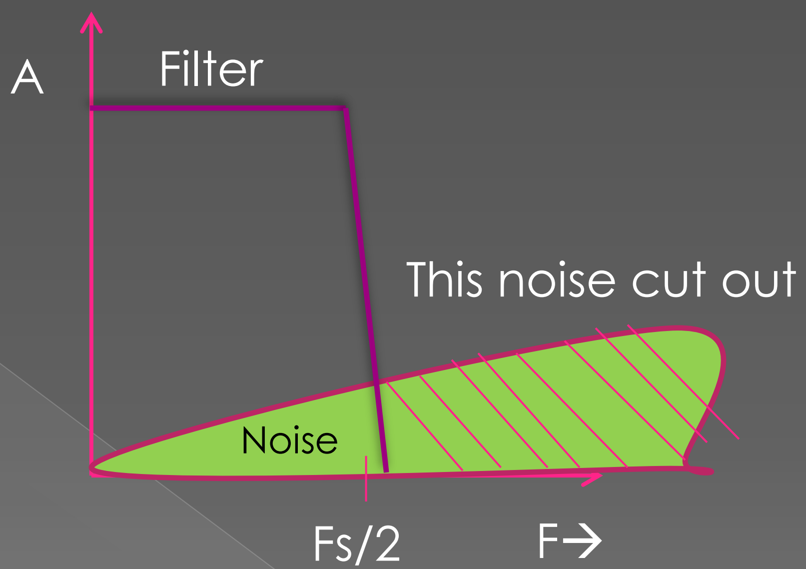
Noise Shaping

- Sigma-delta topology performs noise shaping on the quantization noise.
- Noise shaping is shifting the noise power spectrum towards higher frequencies.

Nyquist Rate Sampling



Oversampling+Noise Shaping



Decimation

- Trading sampling rate for resolution
- Reducing sampling rate by 2^n gives n bits of resolution.
- For example:
- A 128Ms/sec 1bit stream can be converted to a 500Ks/sec 8 bit stream by decimation of $2^8 = 256$.

Sigma-Delta Benefits

- No need for precise anti-aliasing filters
- Low pass filtering inherent in design
- Easy to implement decimation filters, comparators and switched capacitor filters in nanometer CMOS.
- Fast clock-rates over 1GHz has made baseband bandwidth sigma-delta converters possible.

Delta Sigma ADC Applications in Communications

WiMax

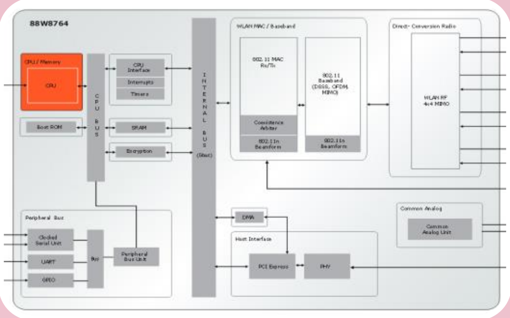
GSM

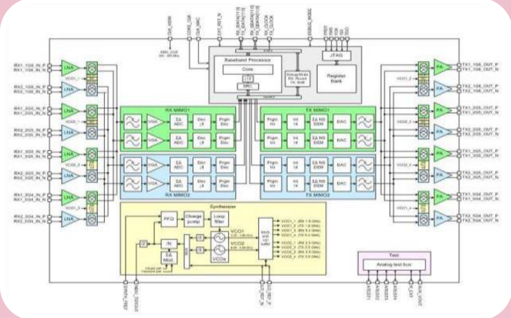
CDMA

LTE

UMTS

Integrated RF+Baseband Examples





Broadcom

BCM61630

Combines RF transceiver and digital baseband for low cost cellular access point applications.

Marvell

Avastar 88W8764

Combines RF and Baseband for 802.11n

Catena

WiMAX SOC Transceiver

Combines RF and Baseband for WiMAX.

Choices

Currently, a choice must be made as to what to integrate on a single chip.

Computing (CPU, GPU etc)+Baseband	or	Baseband+RF

It is not yet possible to integrate RF, baseband and high performance computing as demanded by mobile applications on a single chip.

Conclusion

- The market demand for increased SoC integration in wireless communications will grow.
- Mixed-signal design techniques facilitate these SoCs.
- In a few years we may see RF, Baseband and CPU integration become the norm.