A 2.5nJ/b 0.65V 3-to-5GHz Subbanded UWB Receiver in 90nm CMOS

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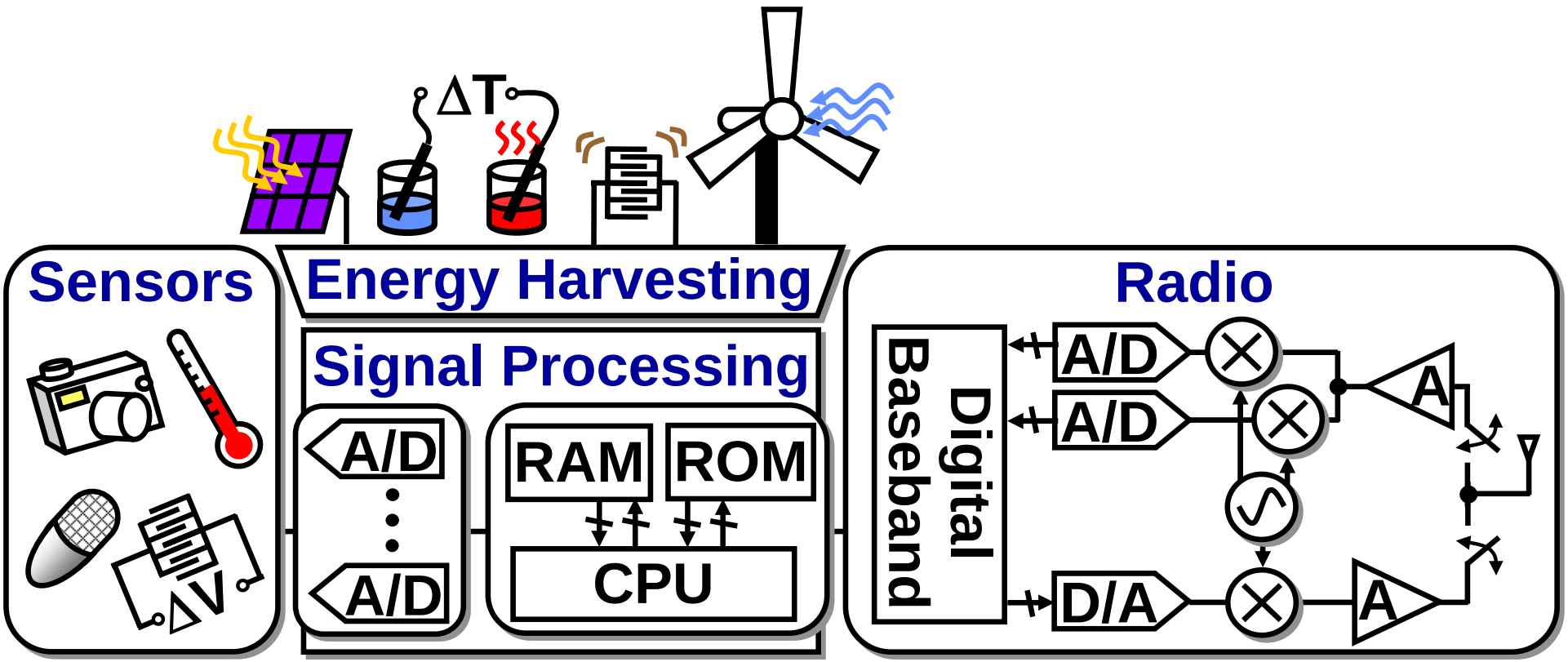
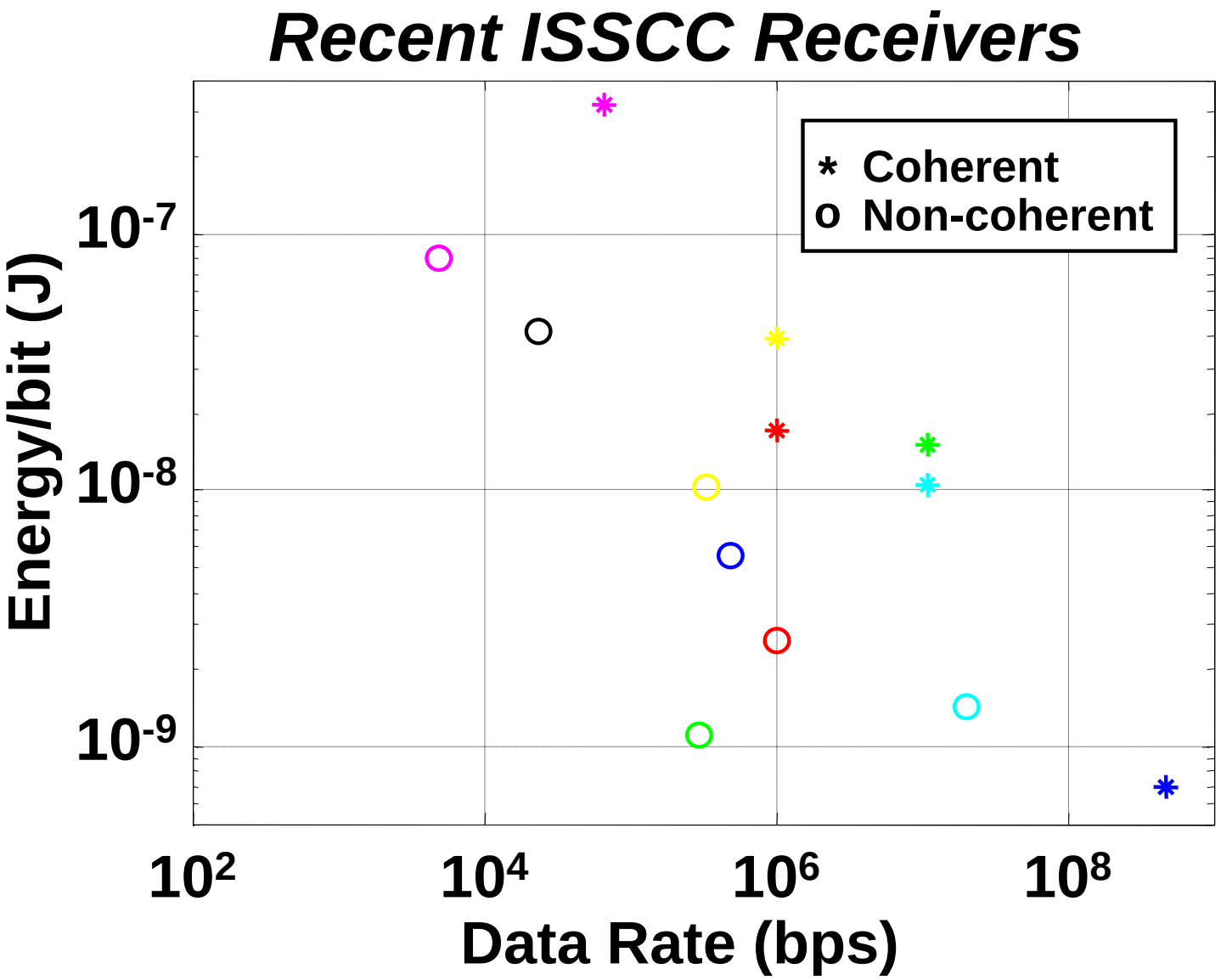
Wireless Sensor Networks



Simple Architecture
Low Data Rate
Low Power Radio

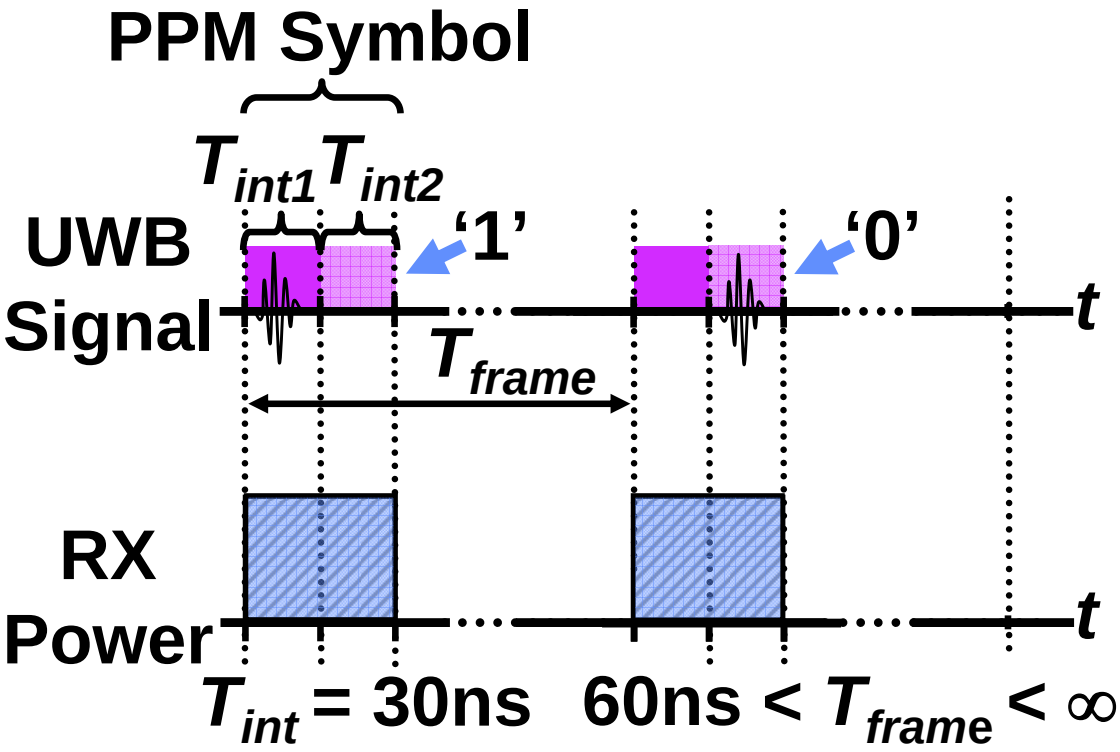
Radio Challenges



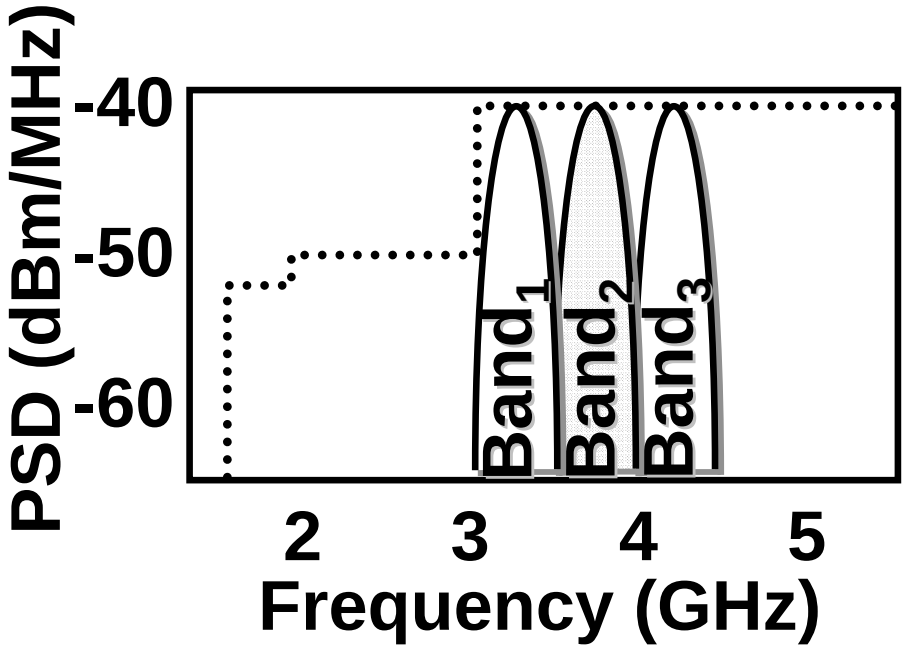
Data Rate Independent, Low Energy/bit Radio

Signaling and Frequency Plan

Signaling Method: 2-PPM

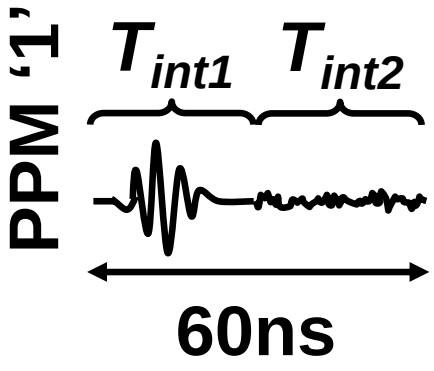


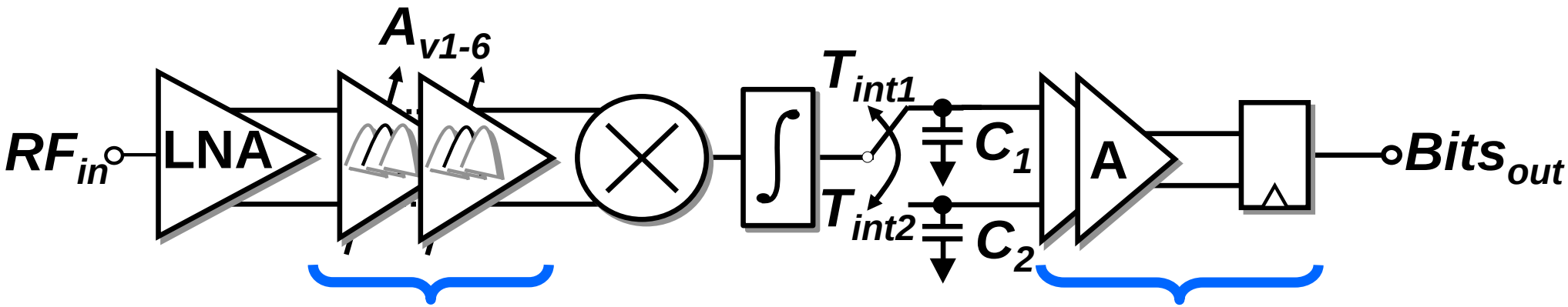
3 Band Frequency Plan



- T_{int} set for worst channel
- Allows for duty-cycled RX
- Increased diversity
- Interference robustness

Receiver Architecture





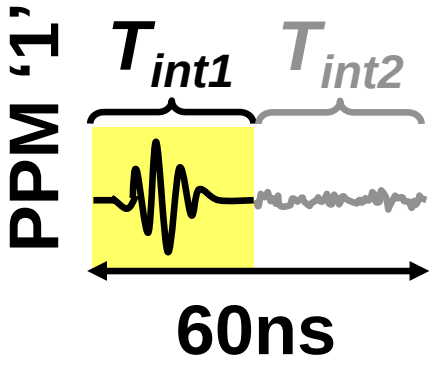
6-Stage Adjustable BPFs and Gain

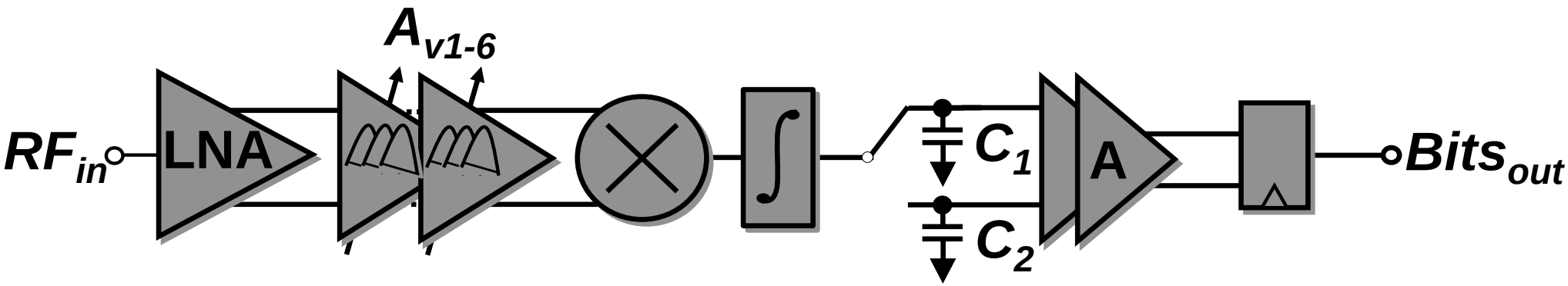
Offset Compensated Preamplifiers and Latch

- **Energy detection receiver**
- **All circuits on/off time ~2ns**
- **No RF PLL; only 30MHz clock**

Low Complexity Receiver

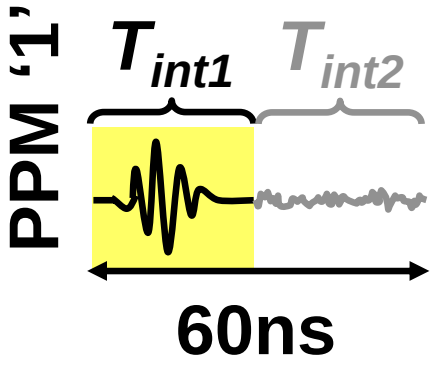
System Functionality

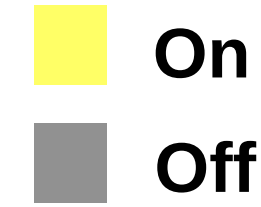


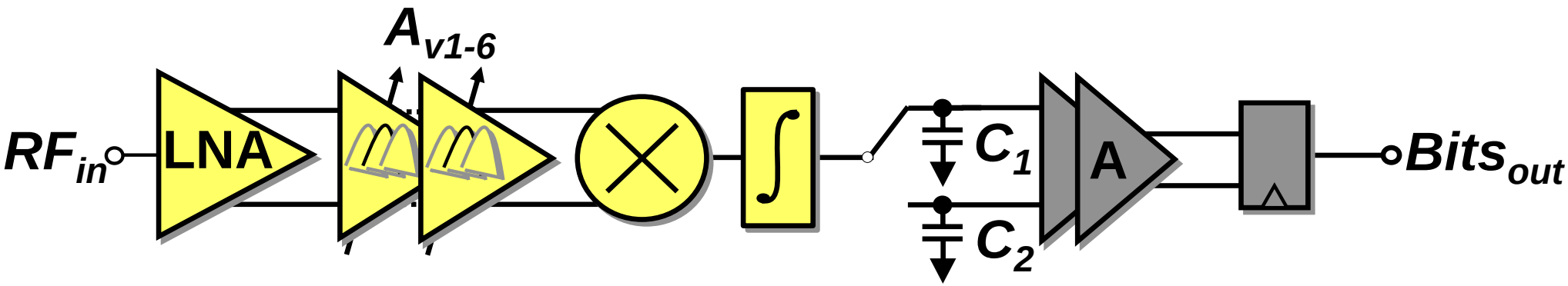


Receiving a '1'

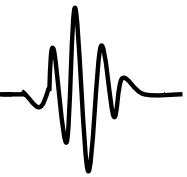
System Functionality



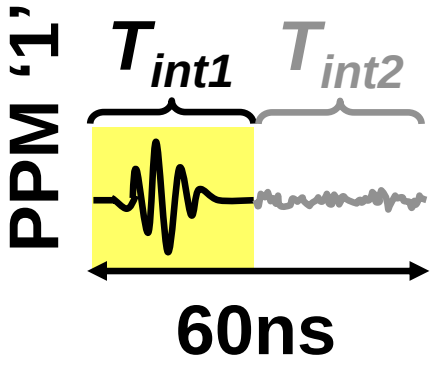


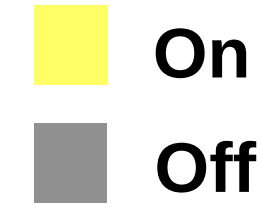


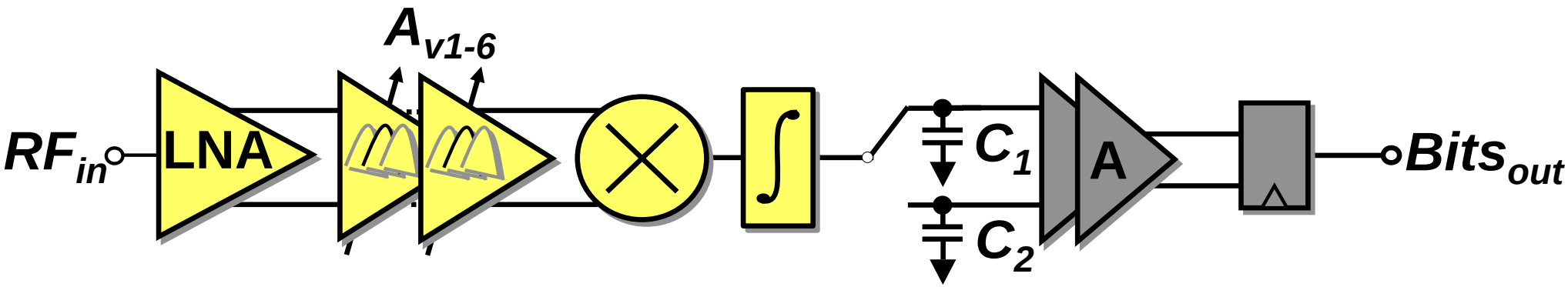
Pulse Reception



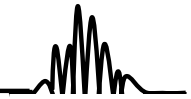
System Functionality



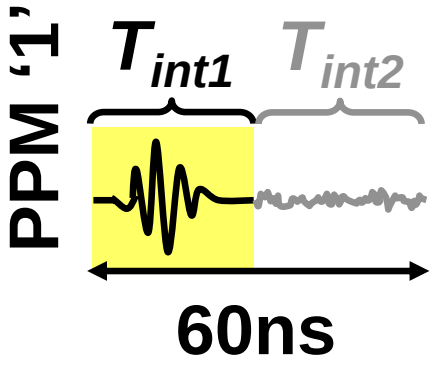




Pulse Reception

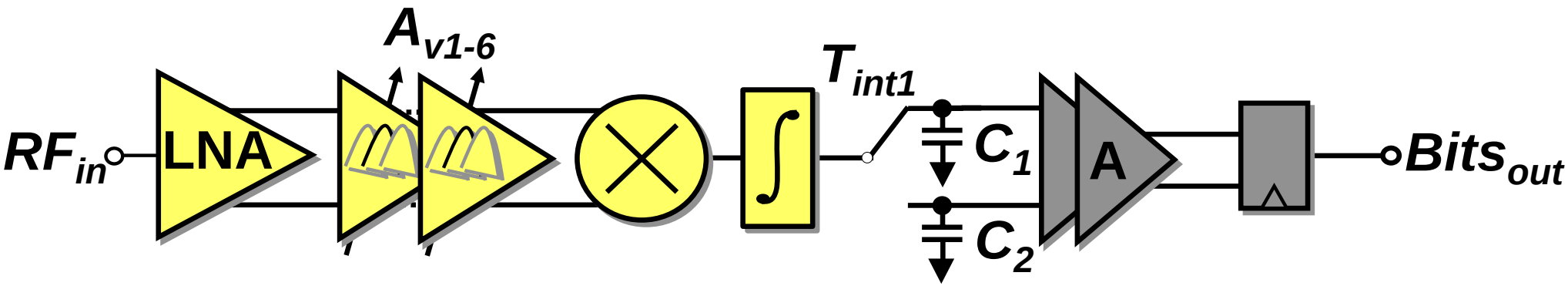


System Functionality



On

Off



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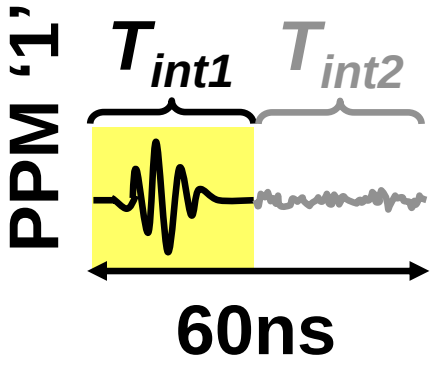
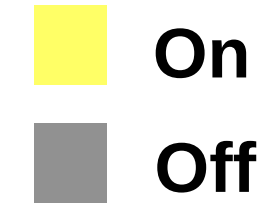
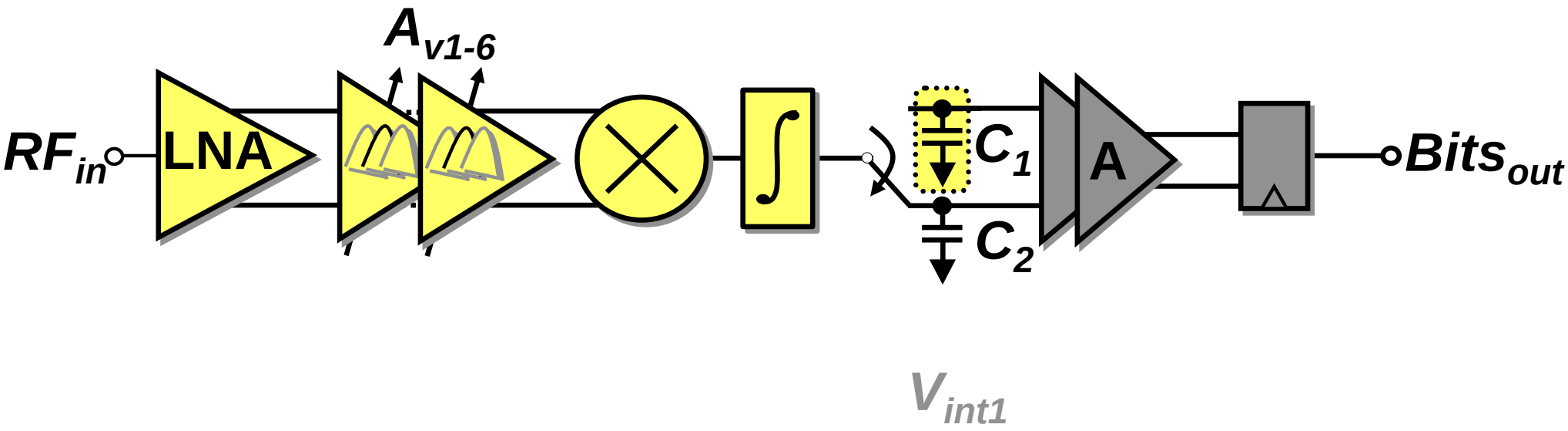
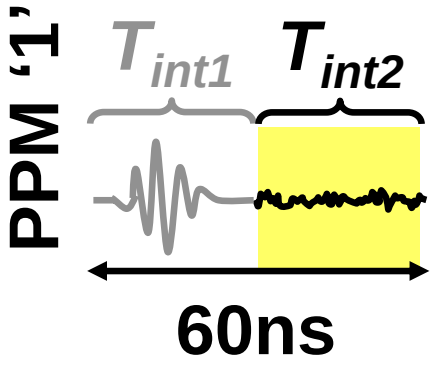


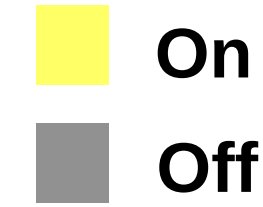


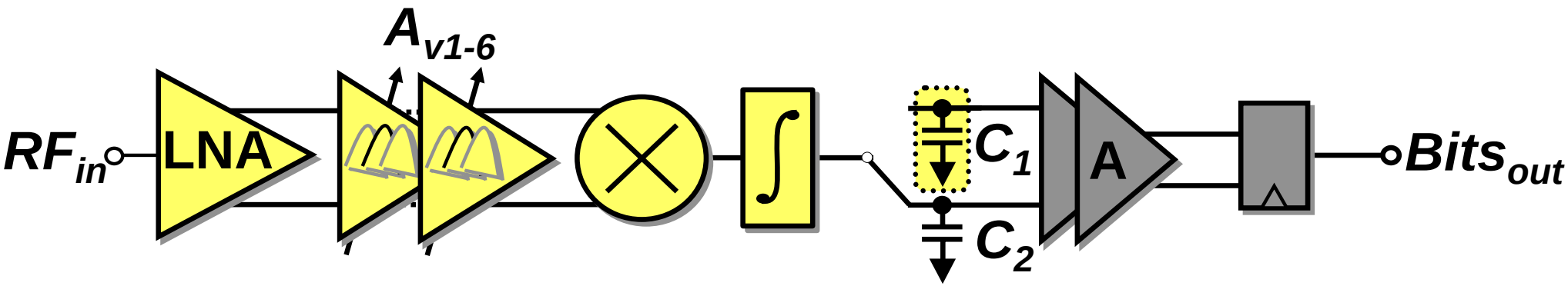


Pulse Storage

System Functionality



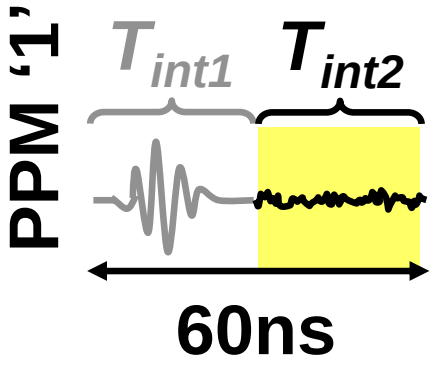




V_{int1}

Noise Reception

System Functionality



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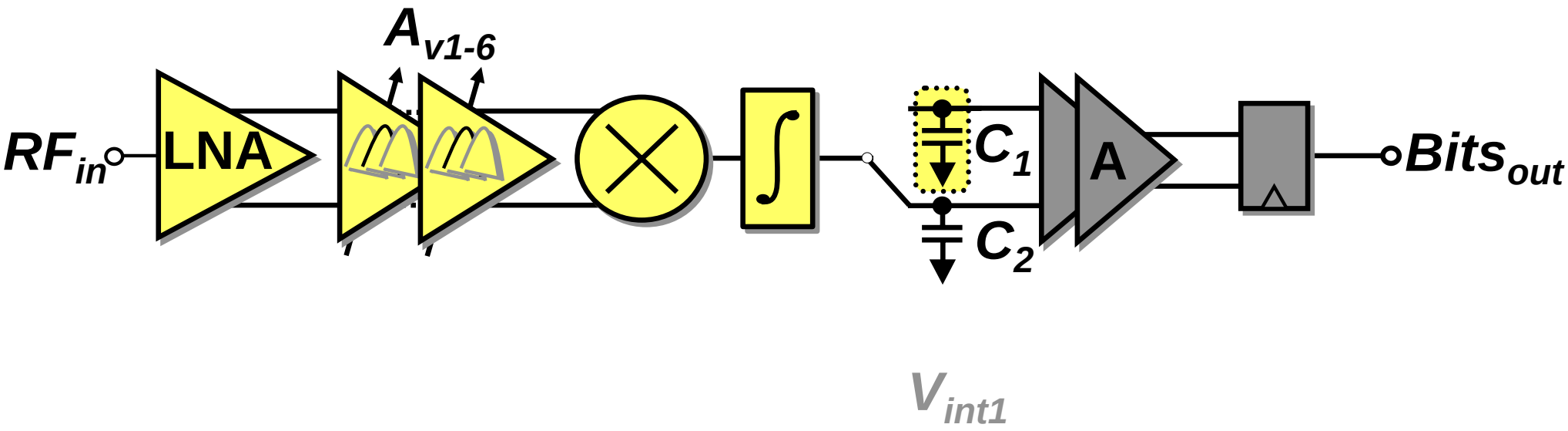
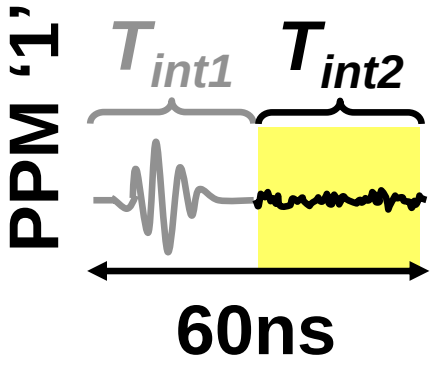


V_{int1}

Noise Reception

System Functionality



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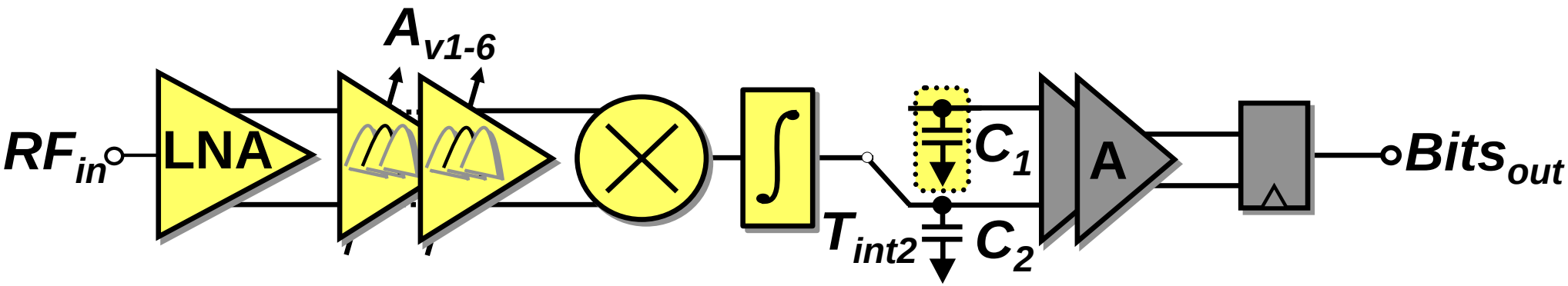
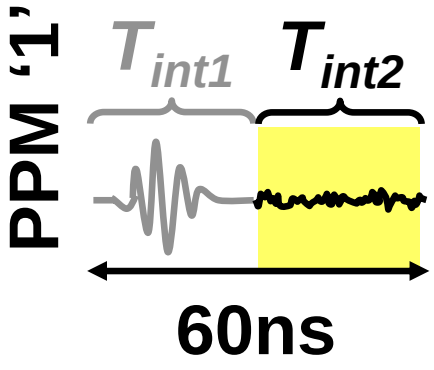


System Functionality



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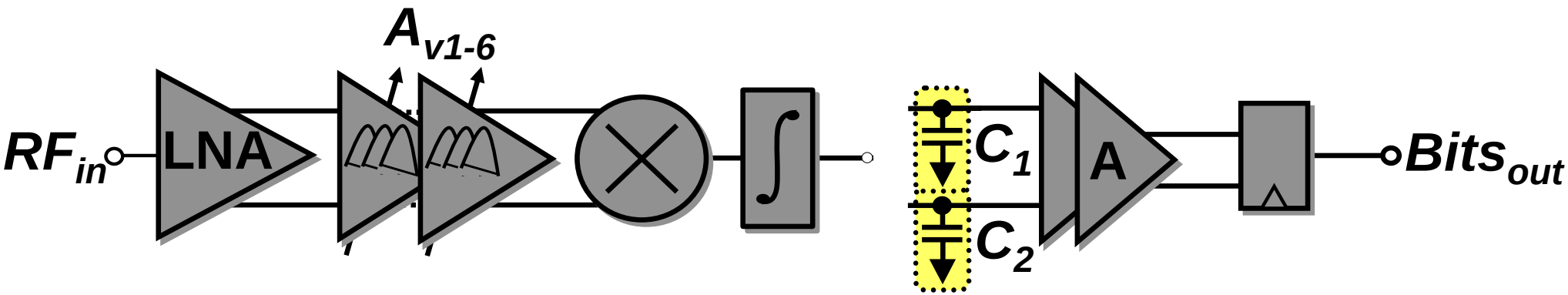
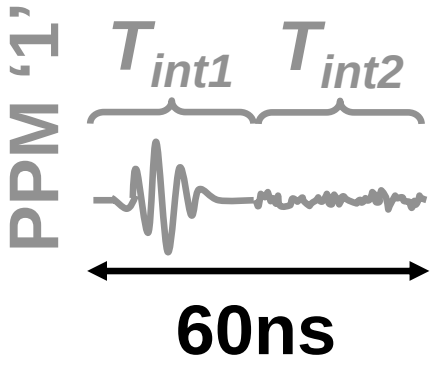


V_{int1}

V_{int2}

Noise Storage

System Functionality



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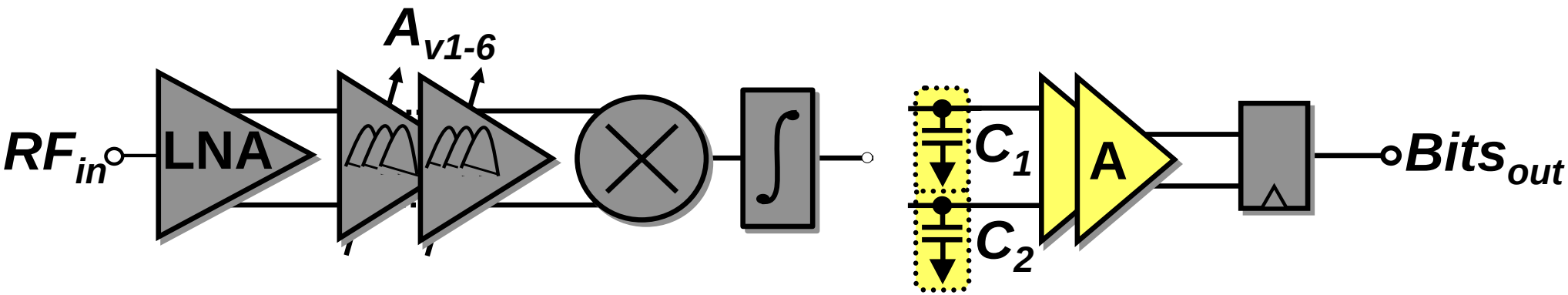
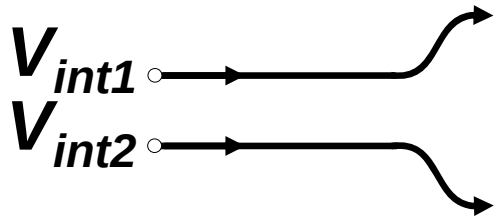
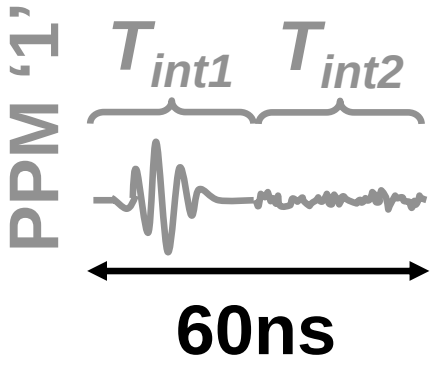




Relative Compare

(DC offsets and path non-idealities automatically normalized)

System Functionality



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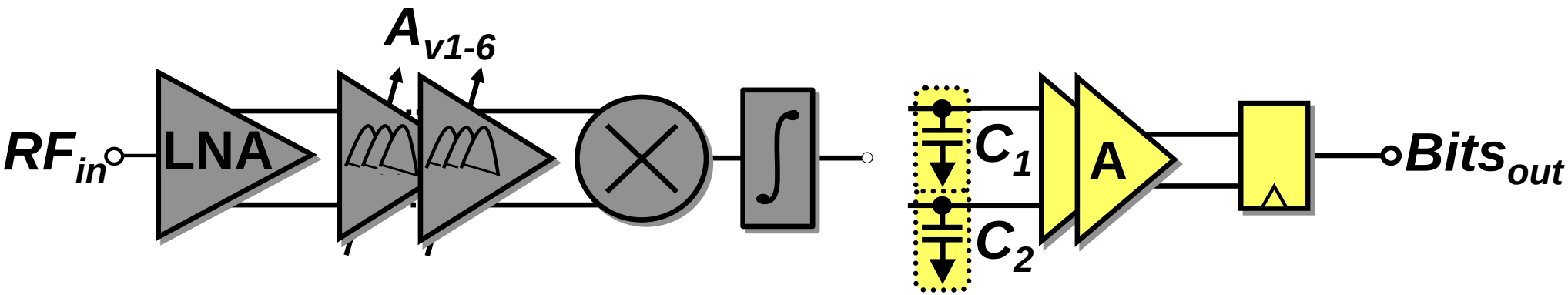
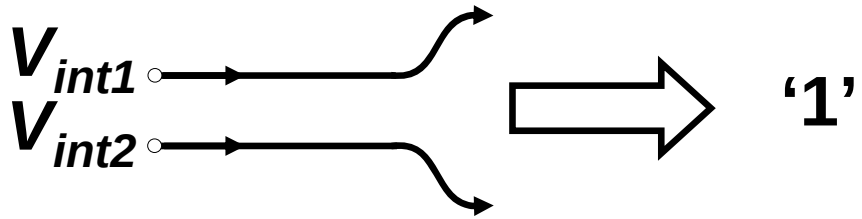
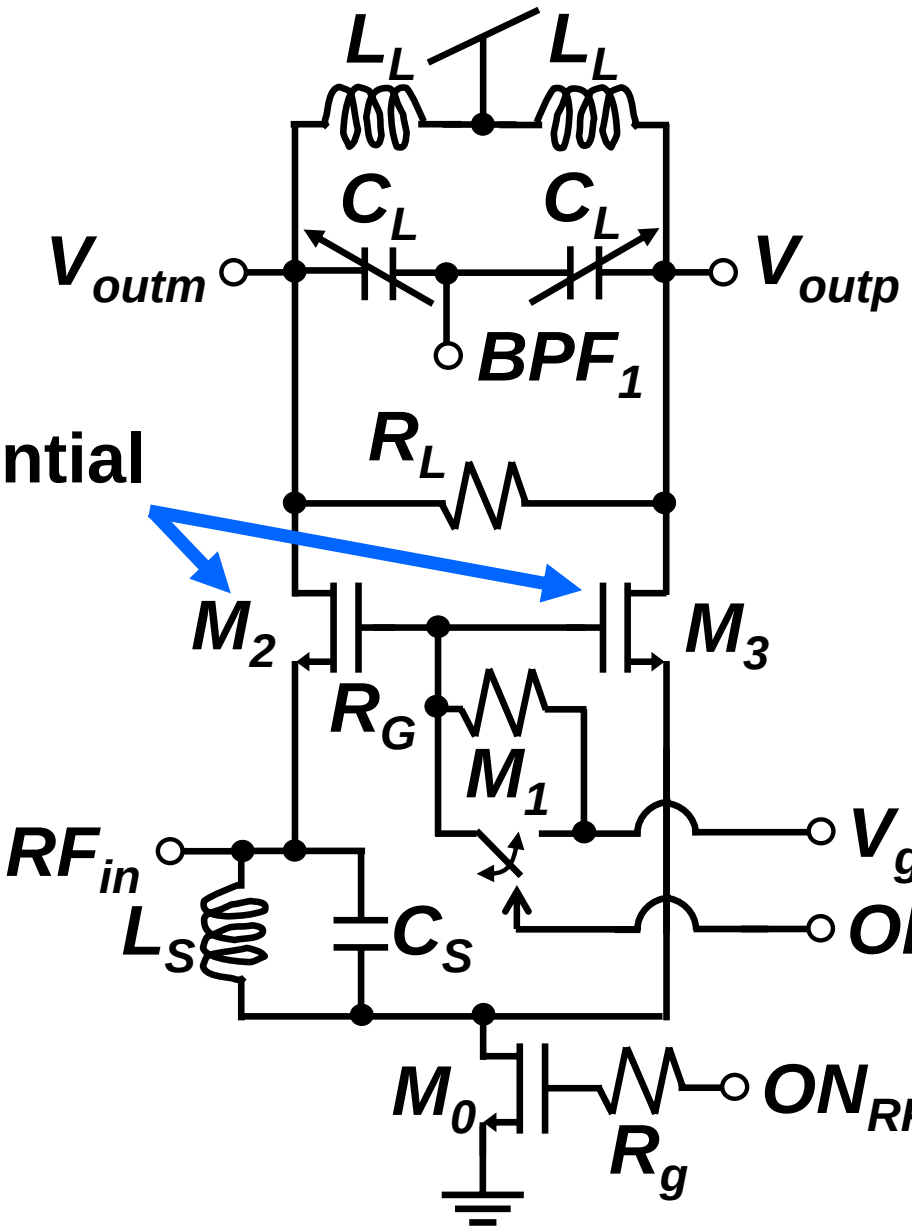


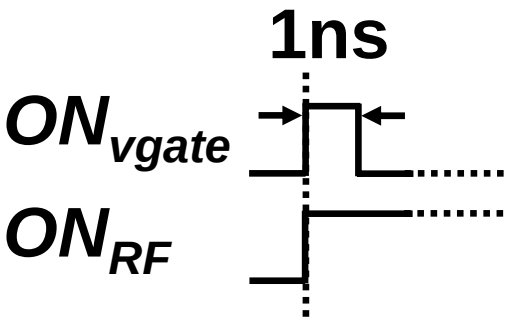


Bit Evaluation

0.5V-0.65V *LNA*

Common-gate single-to-differential conversion

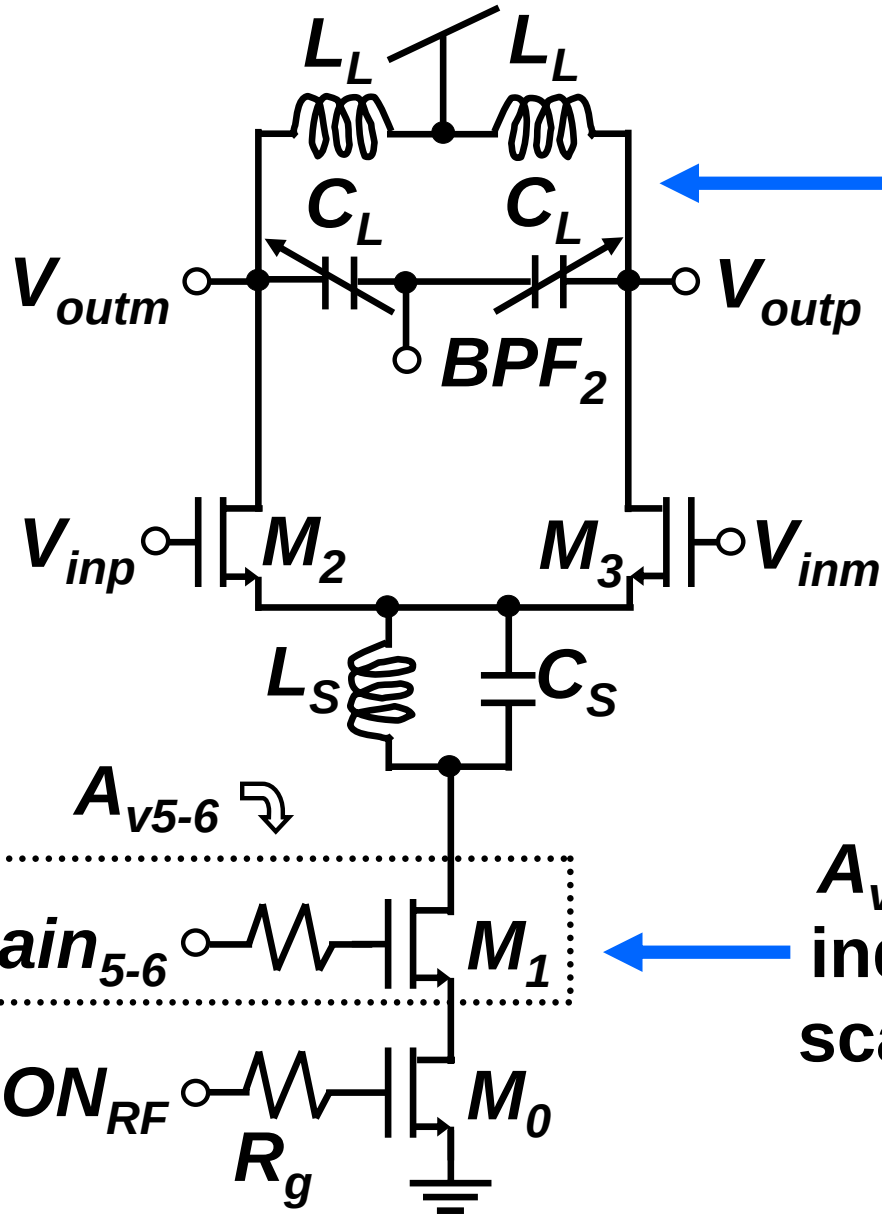




Dynamically biased in ~2ns

0.5V-0.65V A_{v1-6}

1 of the 6 cascaded gain stages



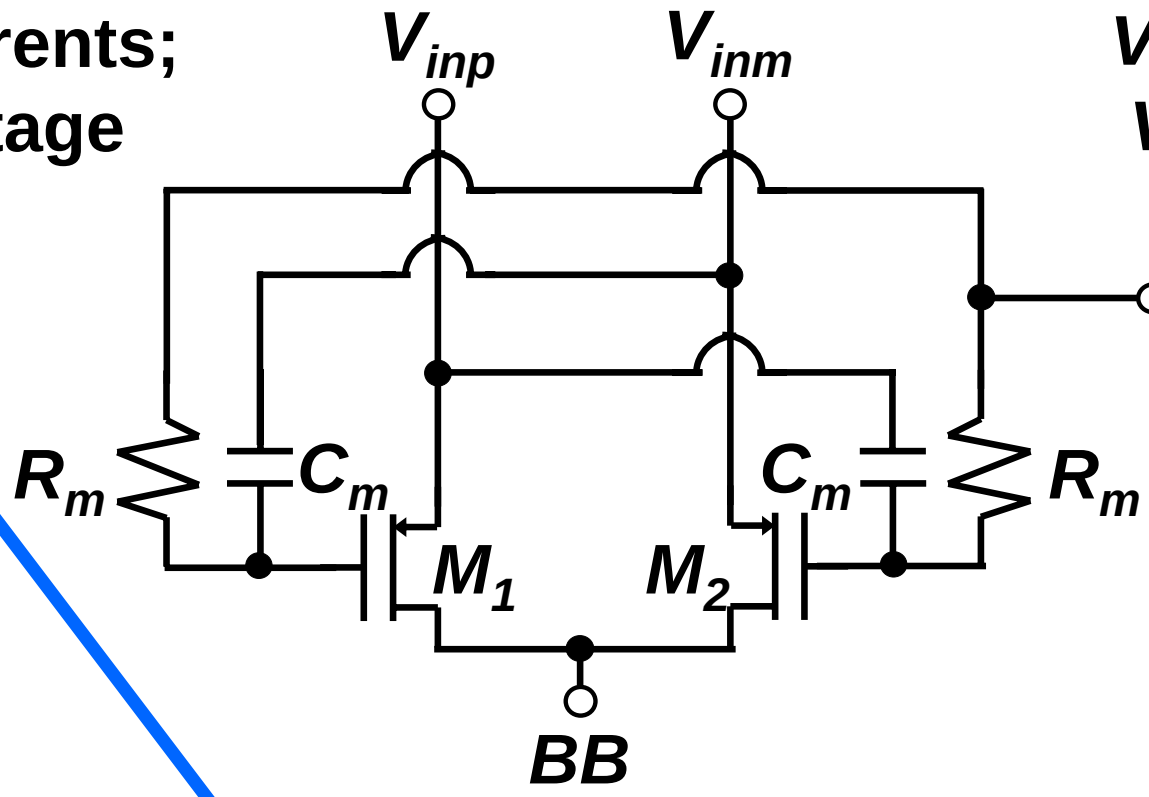
Tunable *BPF* over 1GHz

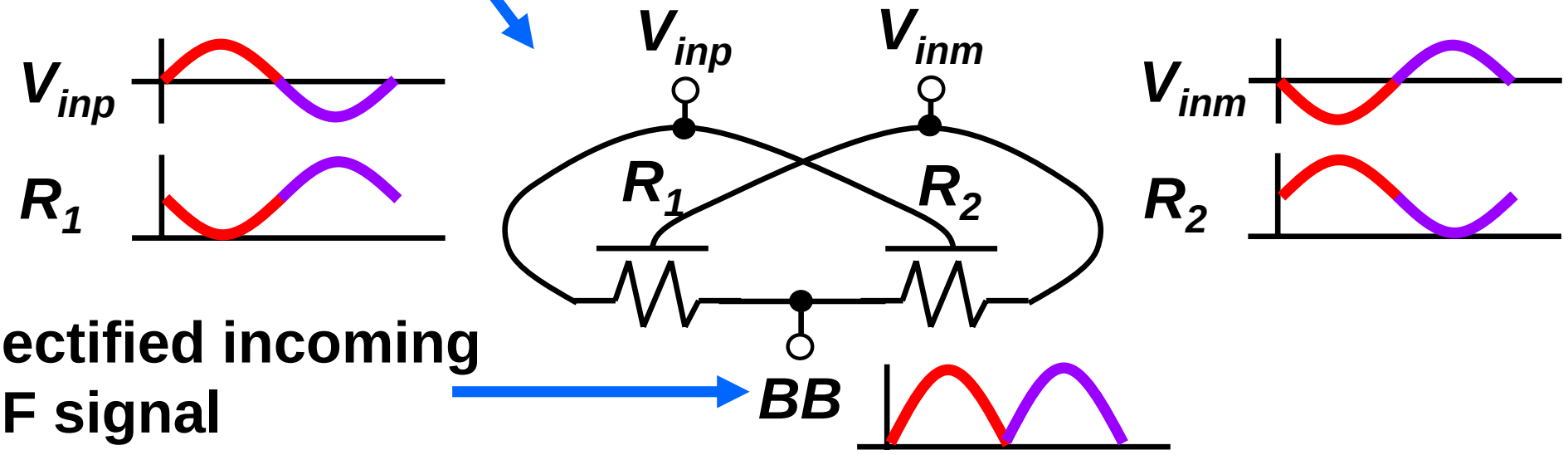
A_{v5-6} has bandwidth-independent, power-scalable gain control

Passive Self-Mixer

No static currents; works as voltage divider

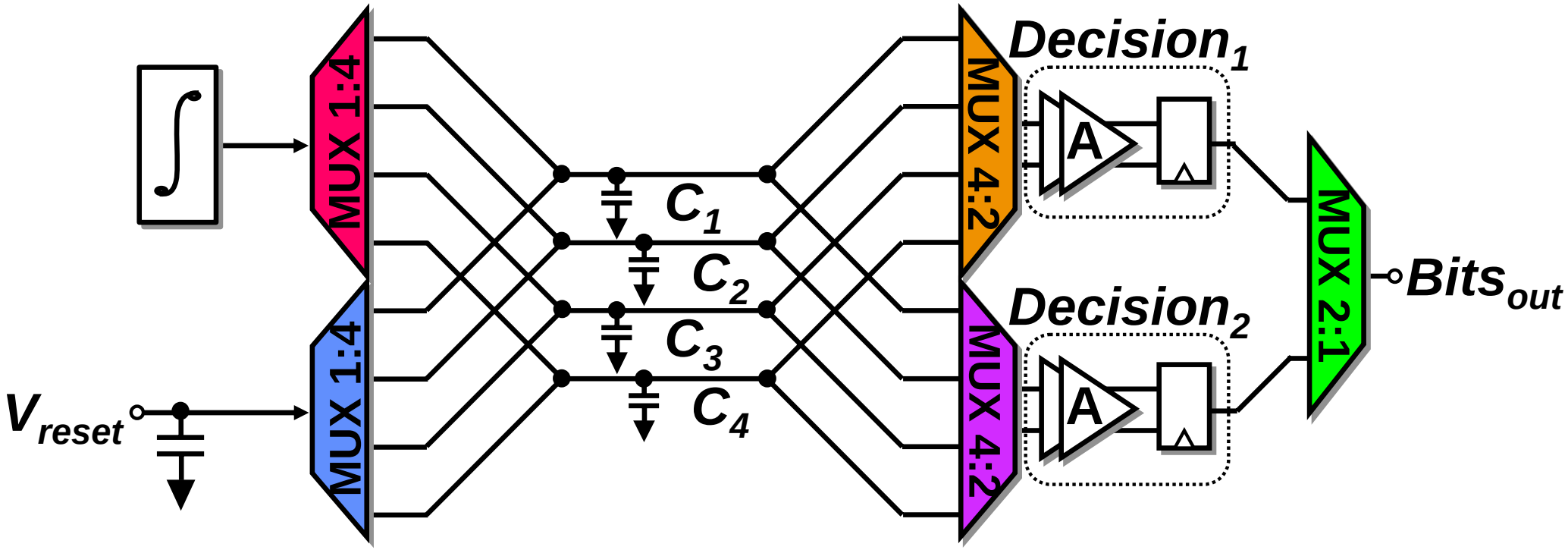
V_g set close to V_T for max ΔR





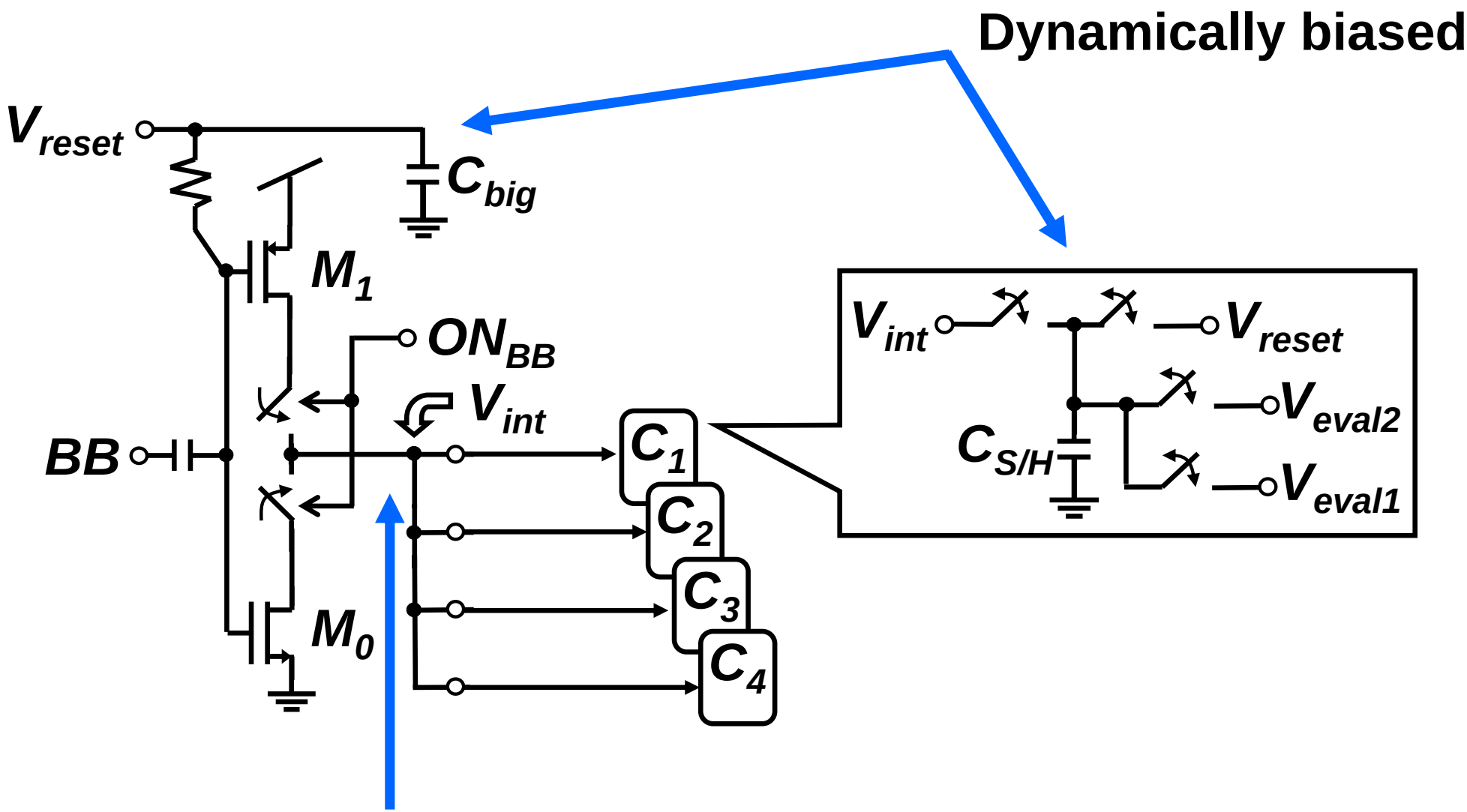
Rectified incoming RF signal

High Speed Baseband Demodulator

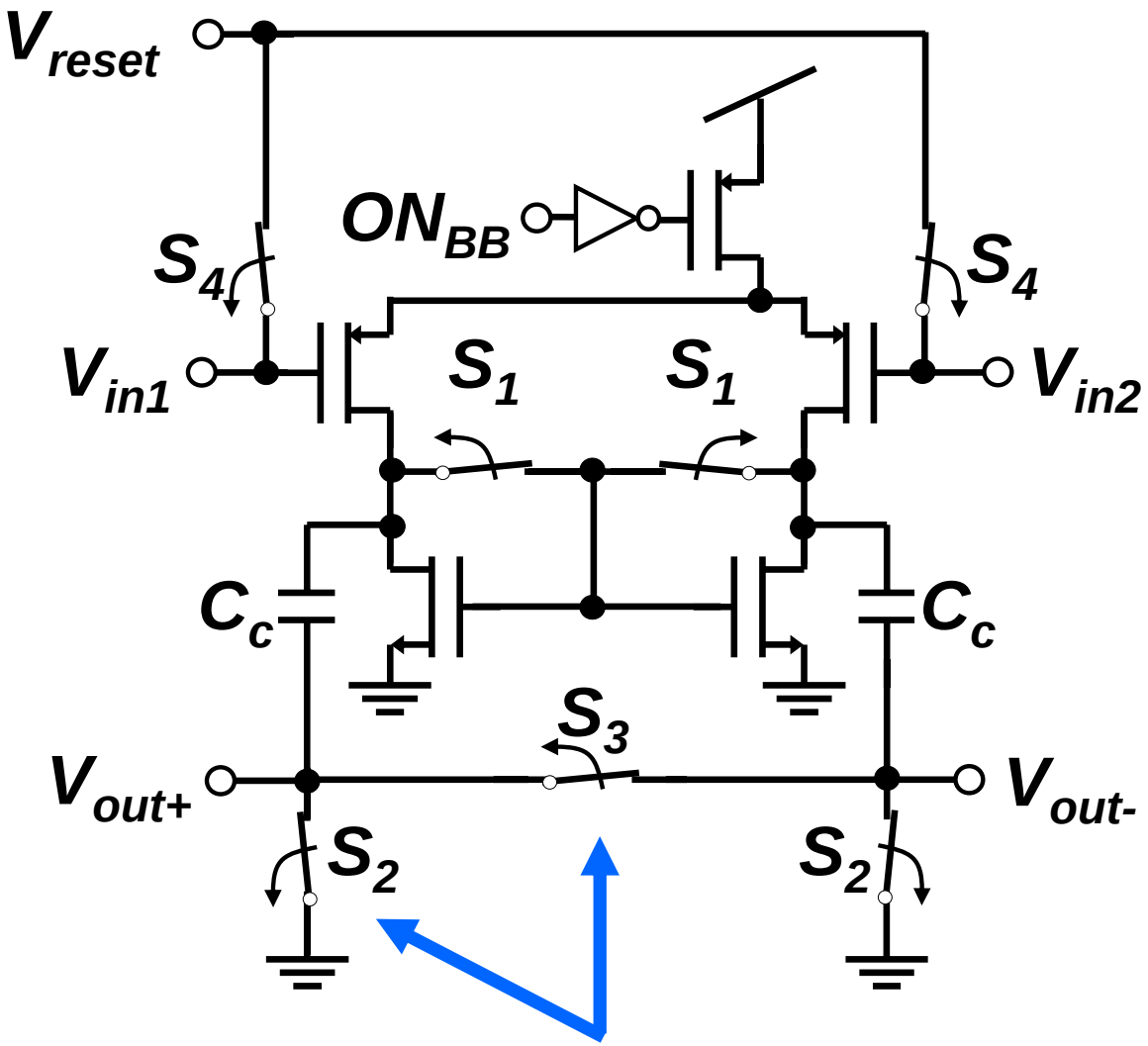


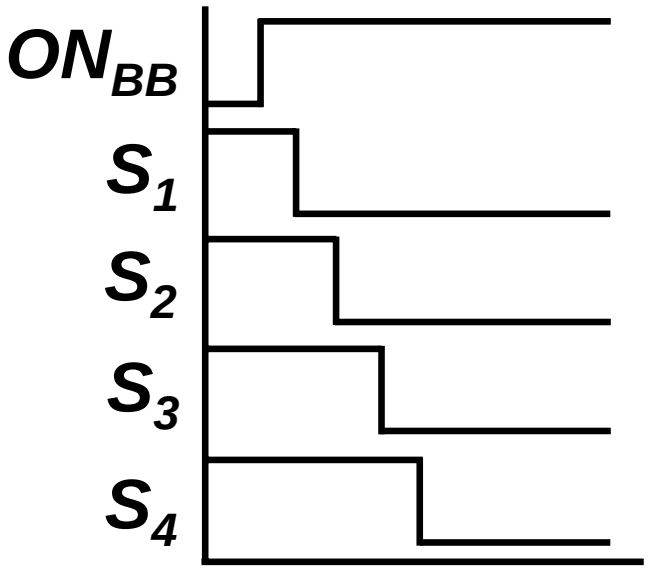
Integrate to…	C_1	C_2	C_3	C_4	C_1	…
Reset to…	C_2	C_3	C_4	C_1	C_2	
$Decision_1$ State	V_{reset}	V_{reset}	Eval Bit C_1 & C_2	V_{reset}	Eval Bit C_3 & C_4	
$Decision_2$ State	V_{reset}	V_{reset}	V_{reset}	Eval Bit C_2 & C_3	V_{reset}	
Time ($\Delta T = T_{int}$) →	30ns	60ns	90ns	120ns	150ns	

0.5V Integrator



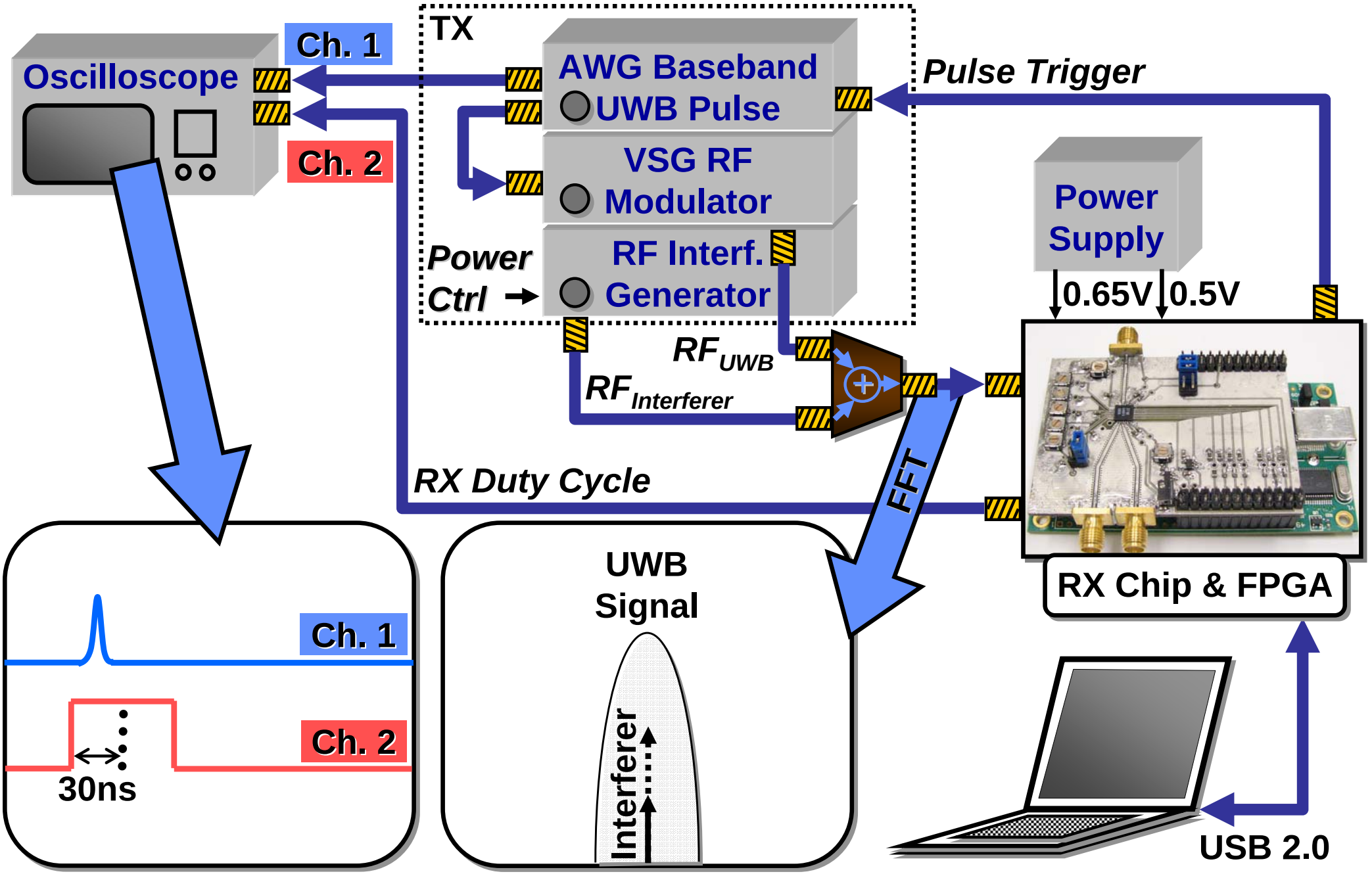
0.5V Offset Compensated Preamp



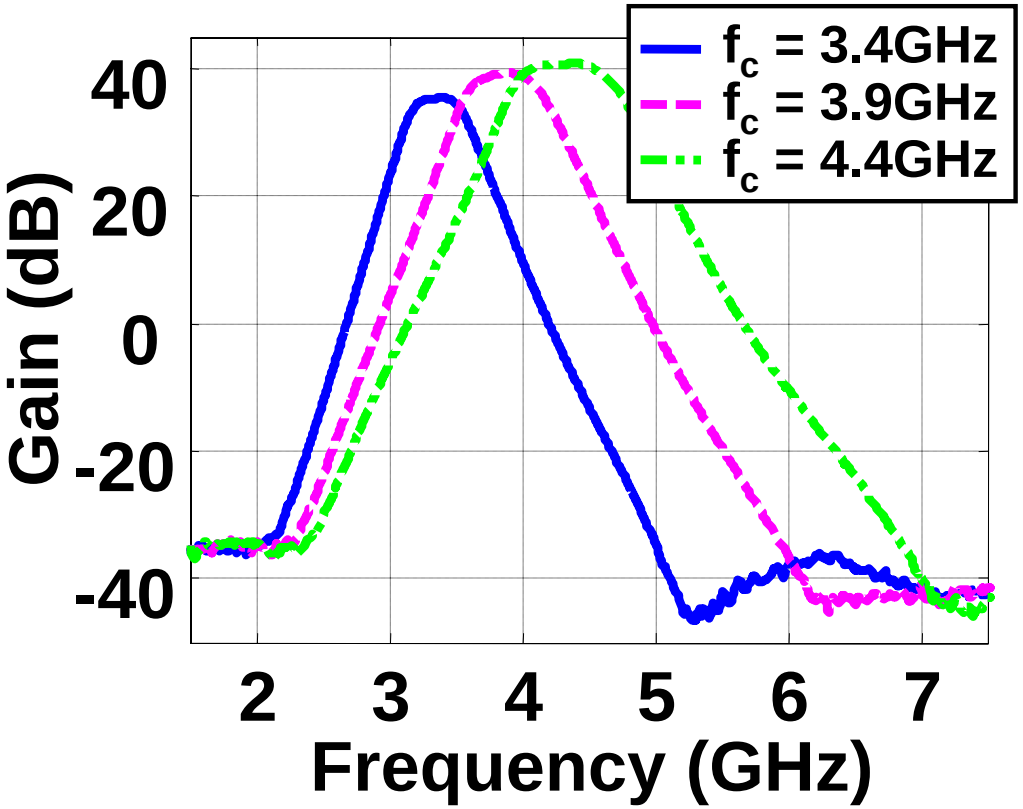


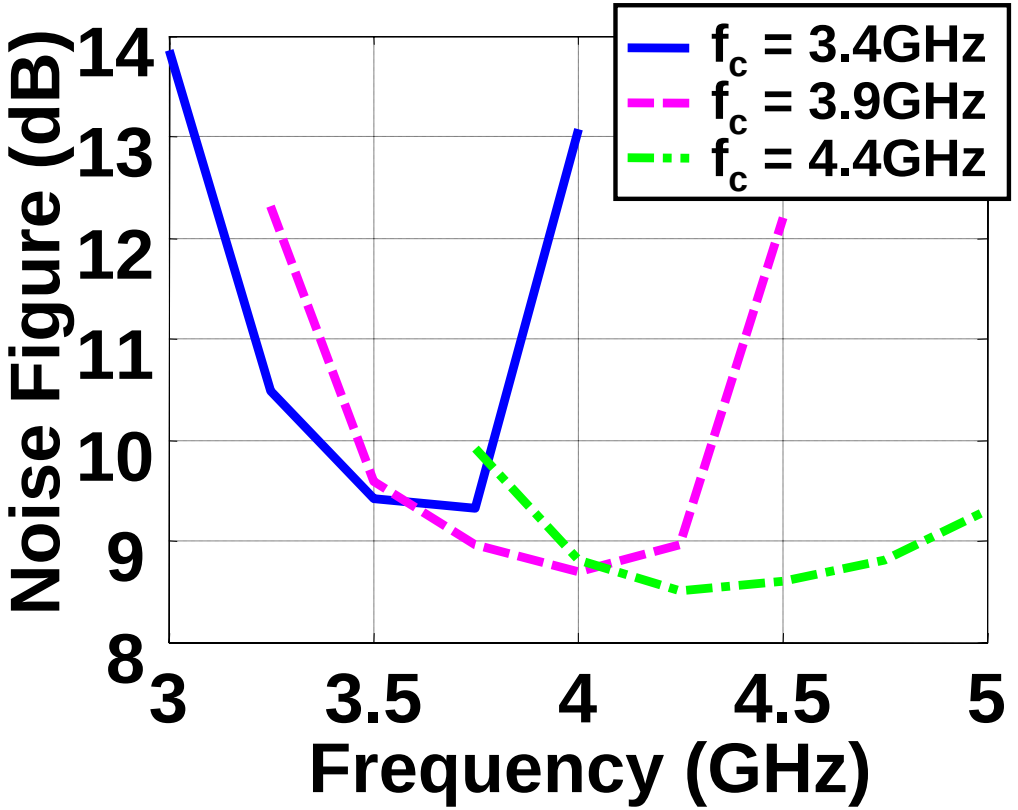
Offset stored on C_c when switches open

Measurement Setup



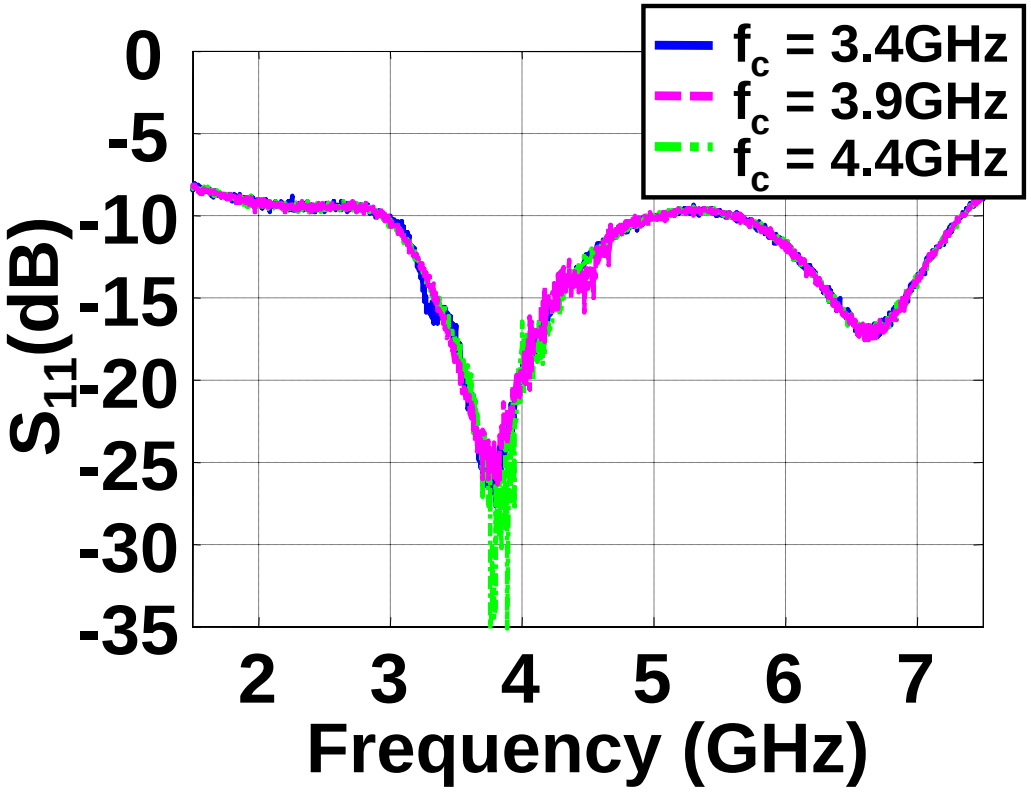
RF Front-end Measurements

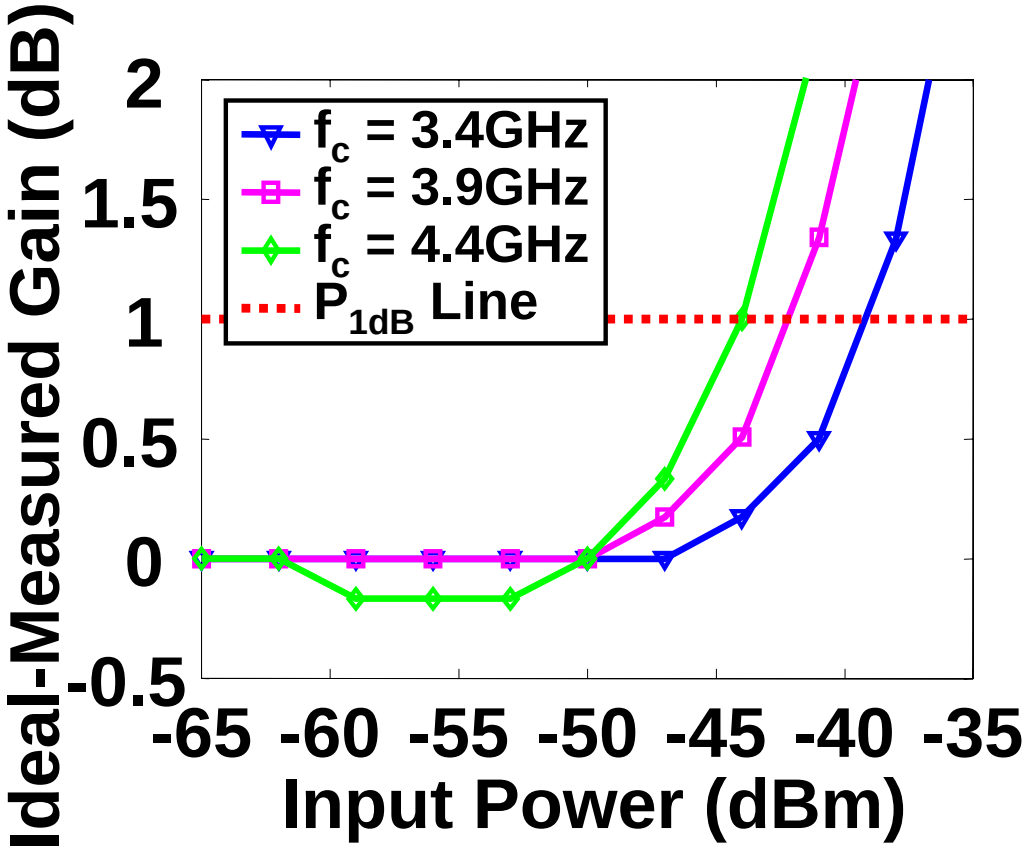




40dB Gain, 8.6dB NF at 4.4GHz Band

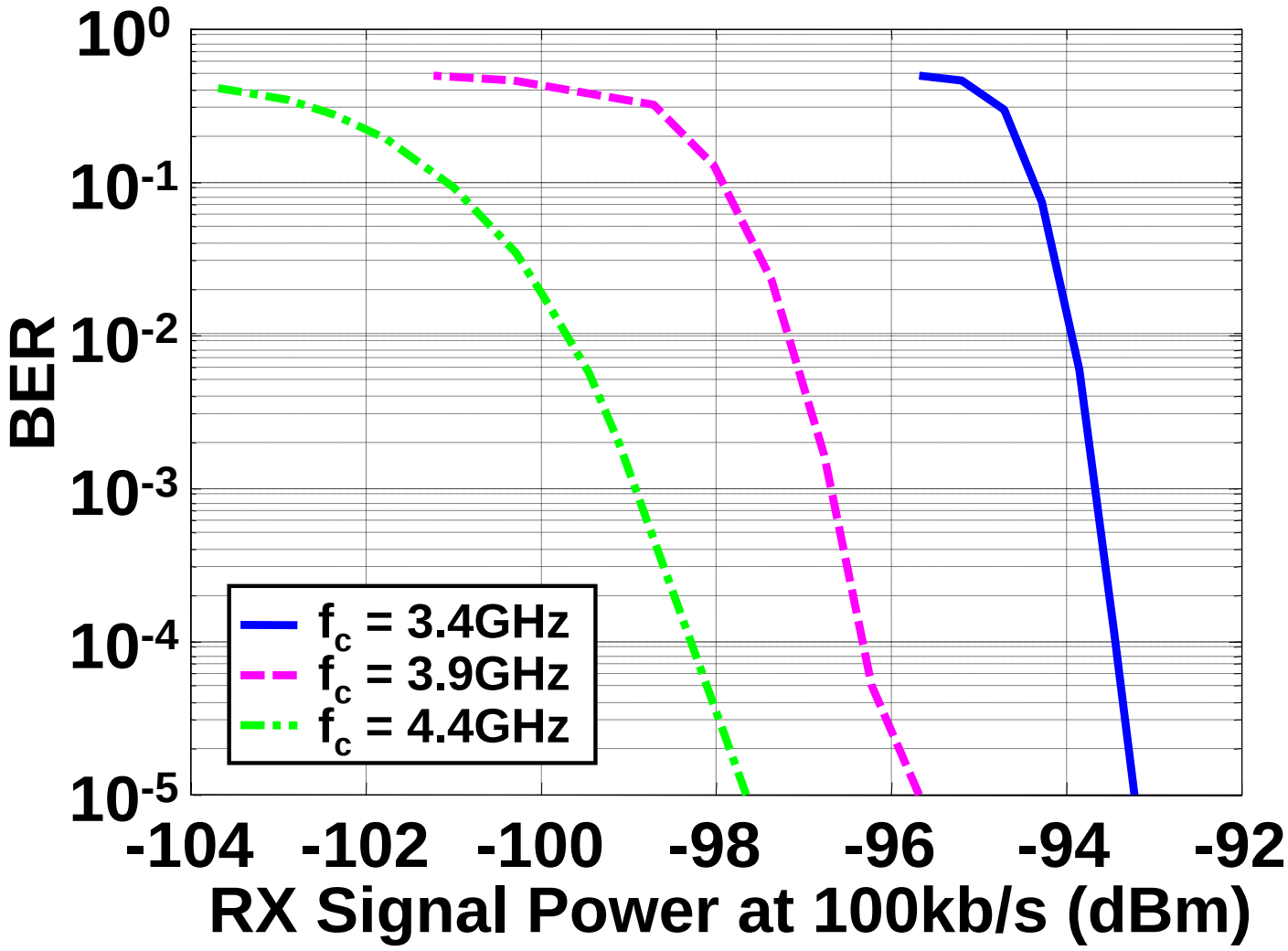
RF Front-end Measurements





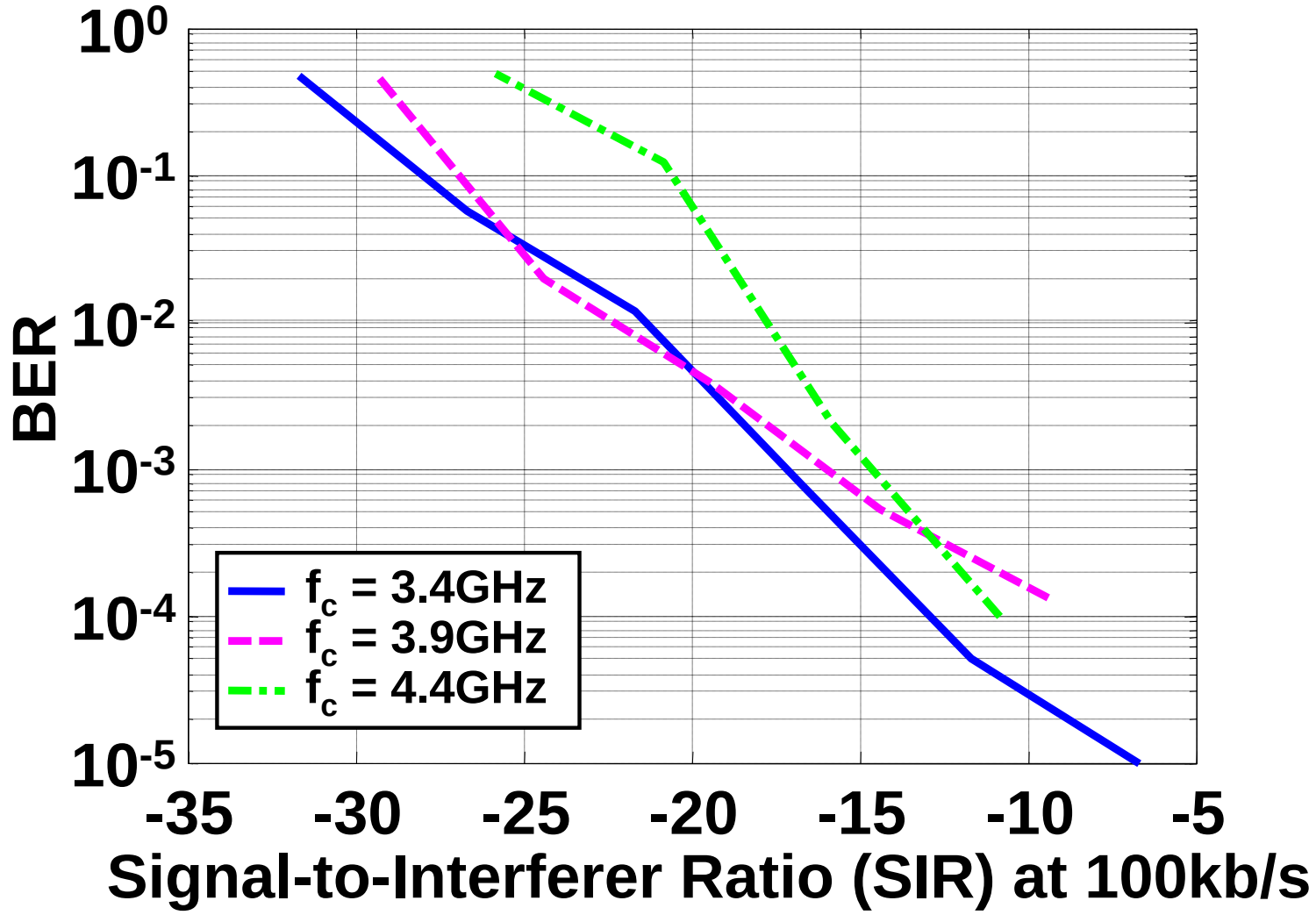
-10dB S_{11} in All Bands, -45dBm P_{1dB} at Highest Gain

Bit Error Rate



-99dBm Sensitivity for 10^{-3} BER in 4.4GHz Band

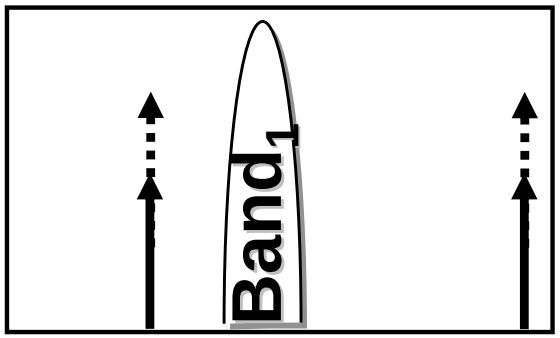
In-band Interference

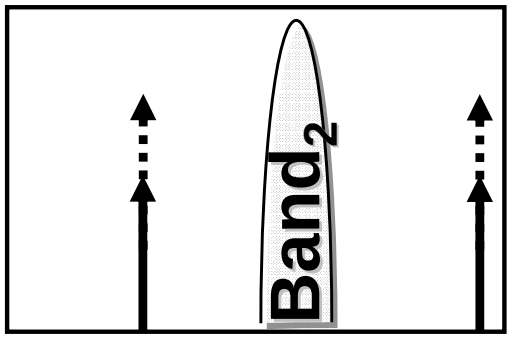


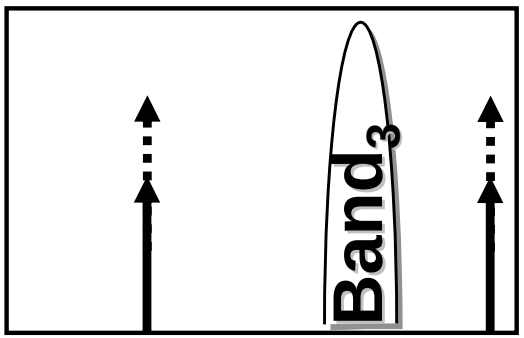
-15dB SIR for 10^{-3} BER in 4.4GHz Band

Out-of-band Interference

P_{UWB} at 10^{-5} BER Sensitivity







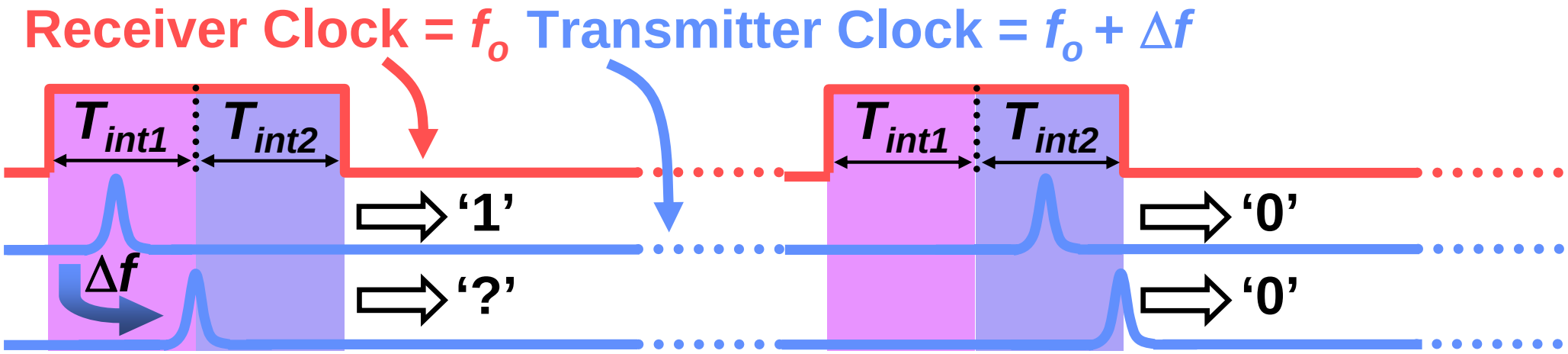
f_{interf}	P_{interf} 10^{-3} BER
2.45GHz	-20dBm
5.25GHz	-15dBm

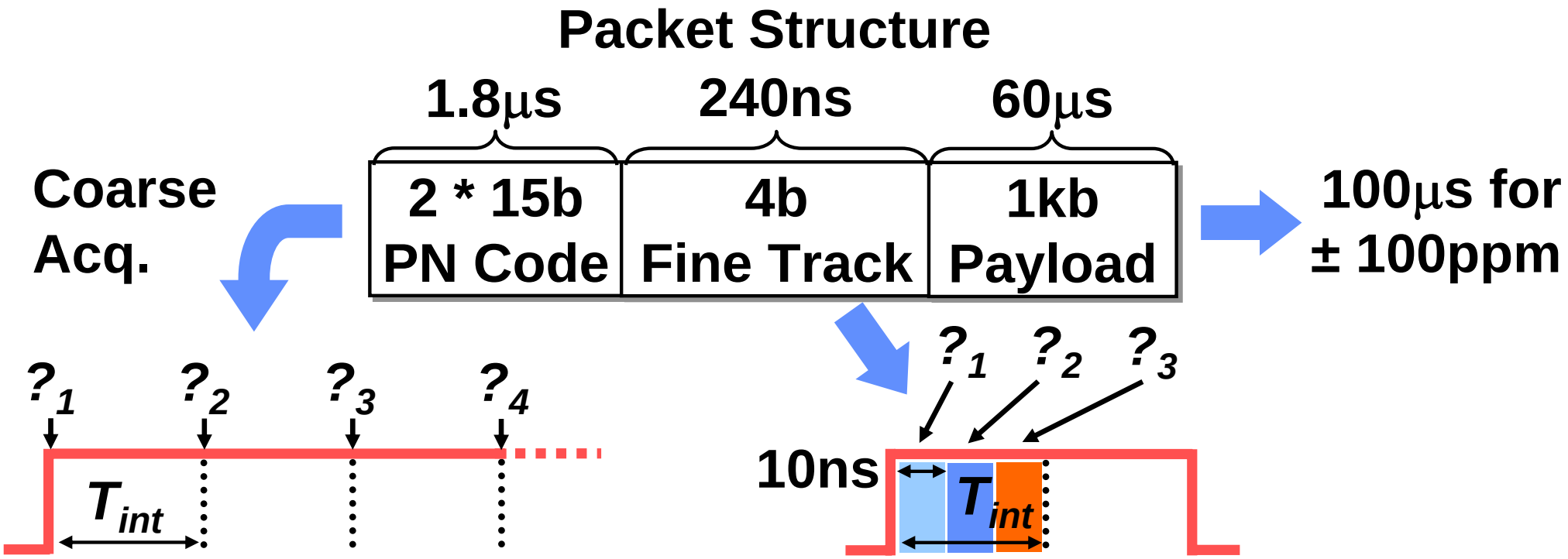
f_{interf}	P_{interf} 10^{-3} BER
2.45GHz	-20dBm
5.25GHz	-15dBm

f_{interf}	P_{interf} 10^{-3} BER
2.45GHz	-20dBm
5.25GHz	-47dBm

Due to slow BPF roll-off

Acquisition Algorithm (FPGA)





w/ TX in paper 6.4, we achieved 10m wireless demo

Chip Measurements

UWBRX Chip Info

Technology	90nm CMOS
Supply	0.65V
Die size	1mm x 2.2mm
Modulation	PPM
Data Rate	0-16.7Mb/s
Pulse BW	500MHz
f_c subbands	3.4, 3.9, 4.4GHz

Measured Results (f_c=4.4GHz, T_{int}=30ns, 100kb/s)

Front-end gain	40dB
Front-end NF	8.6dB
Sensitivity (10^{-3} BER)	-99dBm
In-band SIR for 10^{-3} BER	-15dBm
On power (99% in front-end)	35.8mW
Off power (leakage)	3.5μW
Turn-on time	~2ns
Energy/bit	2.5nJ/b
P_{interf} at 2.4GHz for 10^{-3} BER	-20dBm

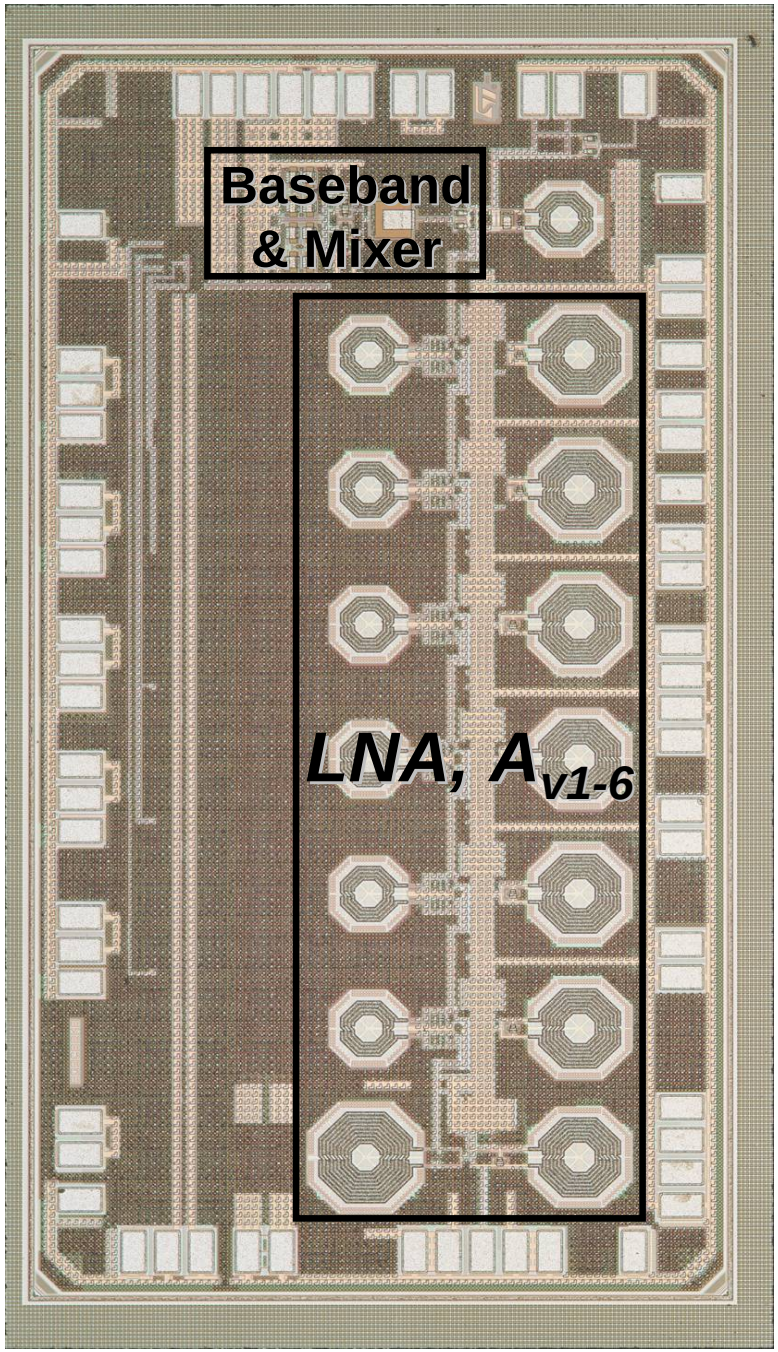
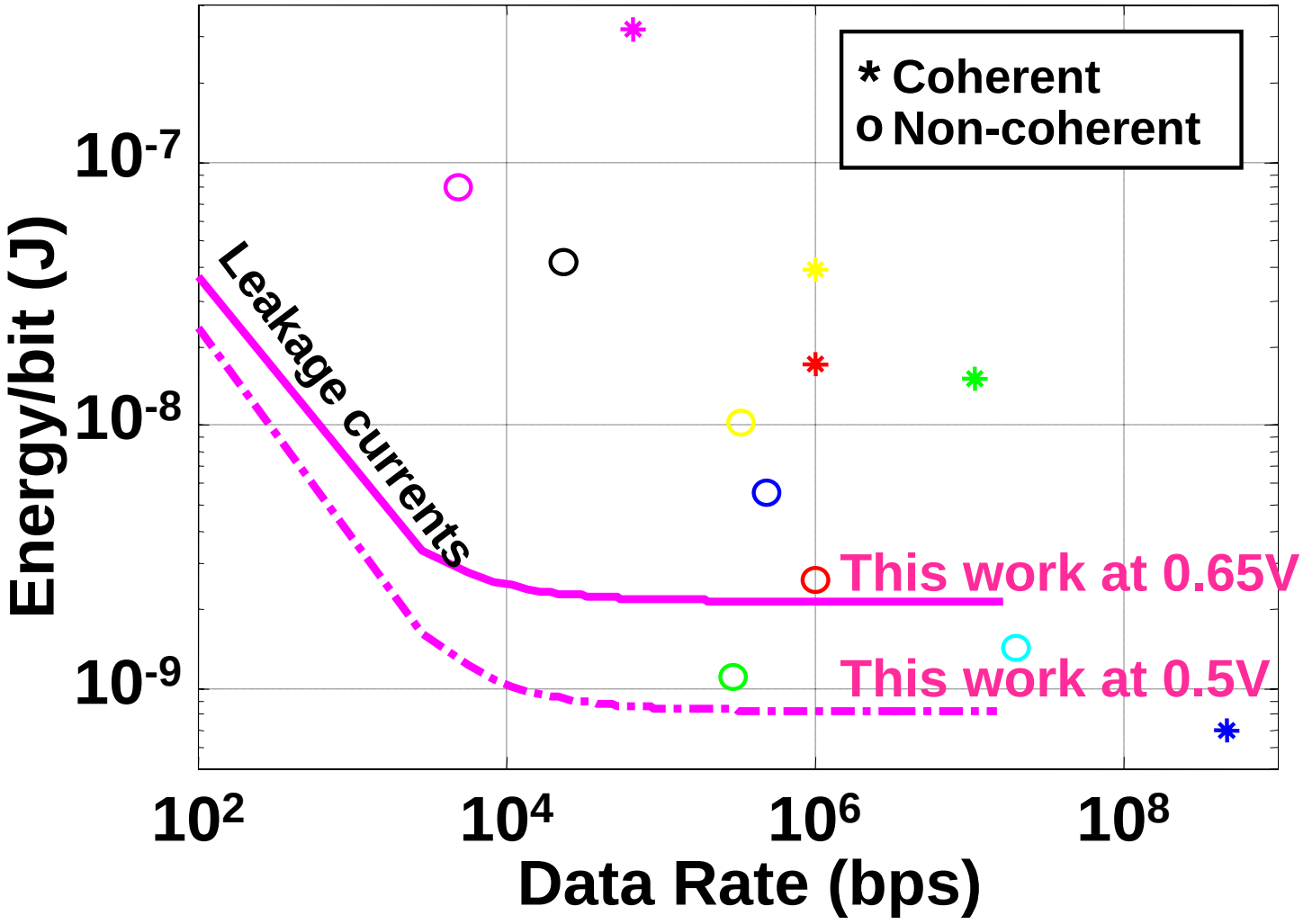


Figure of Merit



Data Rate Independent Low Energy/b Radio

Conclusions

- **Realized a data rate independent 2.5nJ/bit radio. (over 3 orders of magnitude in data rate)**
- **At low data rates, leakage power dominates energy efficiency.**
- **Relative compare backend is a simple demodulator and also normalizes DC offsets and pre-integrator path non-idealities.**
- **-99dBm of sensitivity for 10^{-3} BER at 100kb/s is achieved with this receiver.**

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