Low-Noise, High-Linearity, SAW/BAW-less Receivers and ADCs Using LPTV Circuits

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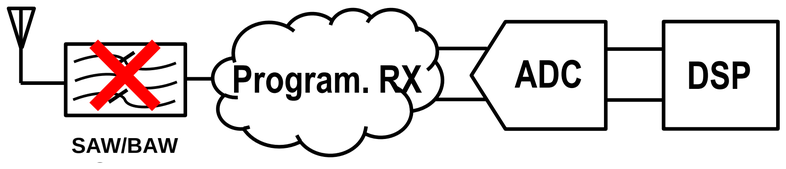
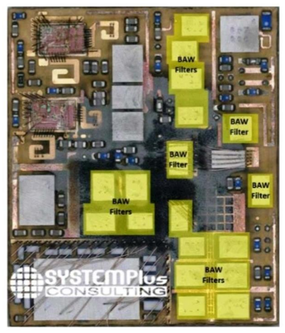
Motivation

- Conventional receivers require a large number of SAW/BAW filters for supporting multiple bands & standards
  - High cost, large area, etc.
- Ideal solution: one high-programmability receiver as a true software-defined radio
- Stringent requirements due to the absence of SAW/BAW filters
  - Sharp filtering (~100 dB at mere a few tens of MHz offset)
  - Low noise figure (sub-6, -3 or even -1 dB)
  - High linearity (>50 dBm)
  - Carrier aggregation
  - etc.
- State of the art has not reached such rigorous specifications

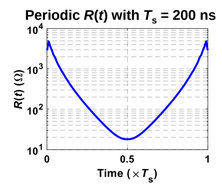


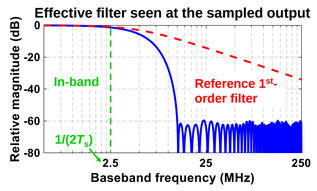


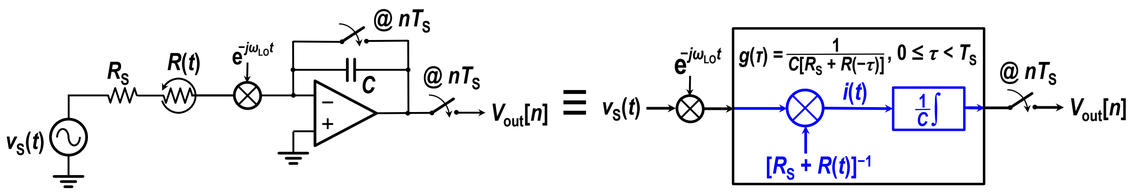
Broadcom AFE module for iPhone X (System Plus Consulting)

Prior Art

- We have demonstrated very sharp filtering that conventional LTI circuits are incapable of by using intentionally periodically time-varying circuits
  - ✓ Very sharp analog FIR filters can be achieved by varying $R(t)$ intelligently
  - × Noise higher than conventional LTI circuits due to time-varying $R(t)$
    - NF > 6 dB
  - × Still not linear enough for some applications, e.g., FDD
    - IIP_3 ~ +20 dBm only
  - × Single channel operation



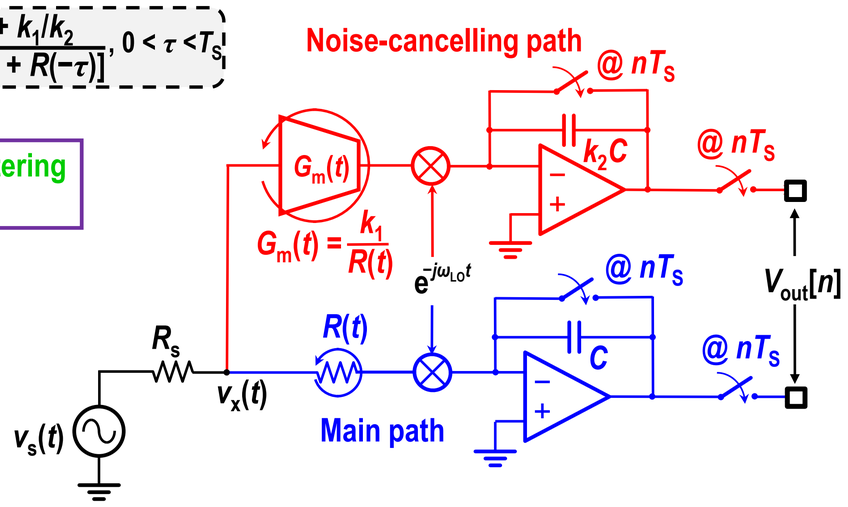


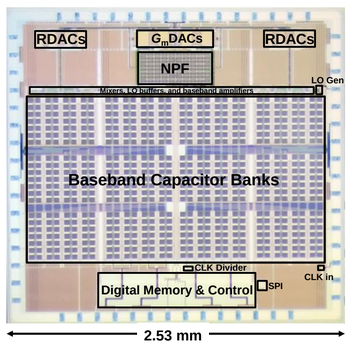


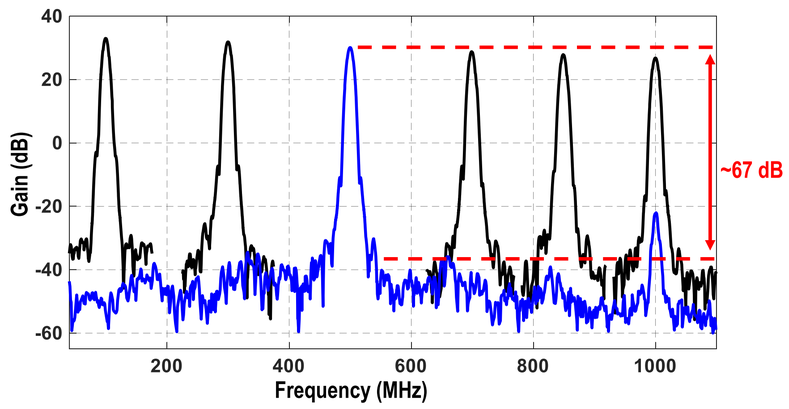
Periodically Time-Varying Noise Cancellation

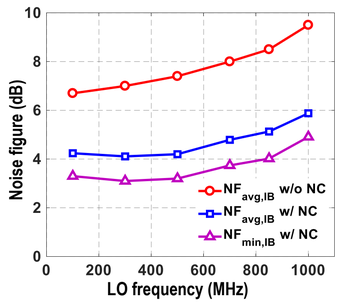
$$g(\tau) = \frac{1 + k_1/k_2}{C[R_s + R(-\tau)]},\ 0 < \tau < T_S$$

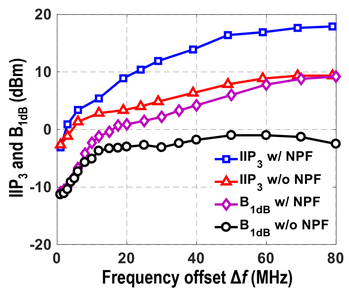
- ✓ Sharp filtering
- ✓ Low NF

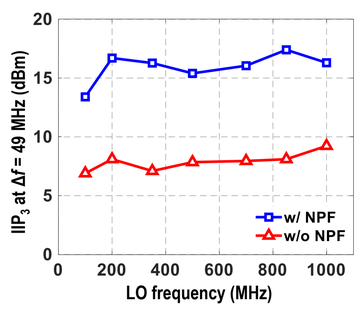












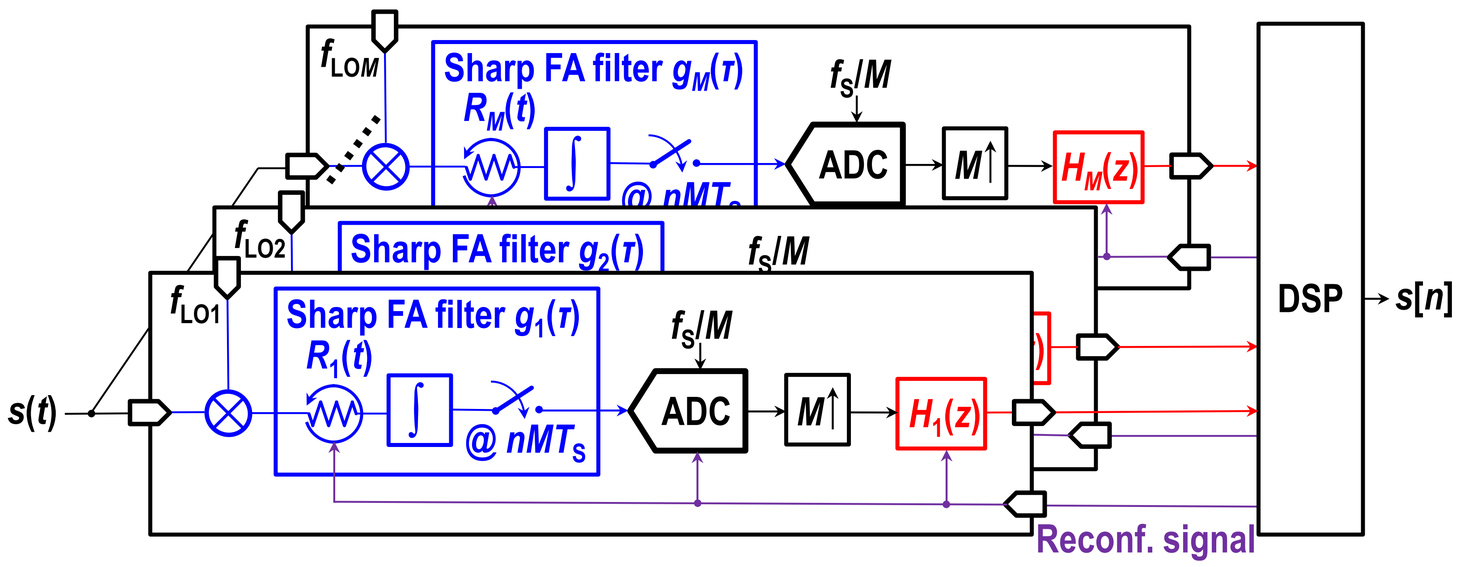
- LTI noise cancellation applied to such LPTV system nulls sharp filtering
- Intentionally time-varying $G_m(t)$ cancels most noise from $R(t)$ while maintain sharp filtering
  - Sharp filtering preserved: >67-dB rejection with a transition BW of 4× RF BW
  - NF improved by ~3 dB
  - Moderate linearity: IIP3 <20 dBm even with an up-front N-path filter
  - Single-channel operation

Performance Summary

	Murphy JSSC'12	Lien ISSCC'17	Hameed JSSC'18	Xu JSSC'16	Song ISSCC'18	This work CICC'19
Architecture	FTNC	N-path	TI-FA	N-path + DT filt.	N-path	TI-FA + LPTV-NC
Technology	40 nm	28 nm	65 nm	65 nm	65 nm	28 nm
RF freq. (GHz)	0.08–2.7	0.1–2	0.1–1	0.1–0.7	0.8–1.1	0.1–1
RF input	SE	Diff.	Diff.	Diff.	Diff.	Diff.
BW (MHz)	4	13	2.5–40	6.4–9.6	30–50	2.5–40
Gain (dB)	72	16	23	40	−5*	30
A_{stop} (transition BW)	N/A	>47* (6×BW)	>45 (1.7×BW) >70 (4×BW)	>70 (8.5× BW)	>15* (0.5×BW)	>46 (1.7×BW) >67 (4×BW)
$NF_{min,IB}$* (dB)	1.6 @ 0.5 GHz	4.9 @ 0.5 GHz	6 @ 0.5 GHz	8.6 @ 0.5 GHz	5 @ 0.87 GHz	3.2 @ 0.5 GHz
$NF_{avg,IB}$** (dB)	N/A	N/A	7 @ 0.5 GHz	N/A	~7.6# @ 0.87 GHz	4.2 @ 0.5 GHz
OOB IIP_3 (dBm)	+13.5	+44	+24	+24	+24	+18
OOB IIP_2 (dBm)	+55	+90	+64	N/A	N/A	+65
OOB B_{1dB} (dBm)	−2	+13	+13	+14.7	+9	+9
Supply (V)	1.3	1.2/1.0	1.2/1	1.2/1.6	1	0.9
Power (mW)	35–78	38–96	75–99	59–105	80–97	48–74
Area (mm^2)	1.2	0.49	2.3	1.2	1.9	3.75

* Minimum in-band noise figure over $[0, f_s/2]$ ** Average in-band noise figure over $[0, f_s/2]$
\# Estimated from reported figures

Current Work in Progress



- Currently, we are exploring extending the LPTV operation to multi-channel networks to support techniques such as carrier aggregation
- Techniques to improve linearity in order to extend the system dynamic range is under investigation
- Our final goal is to implement a frequency-channelized ADC for wideband high-resolution applications with extremely high programmability