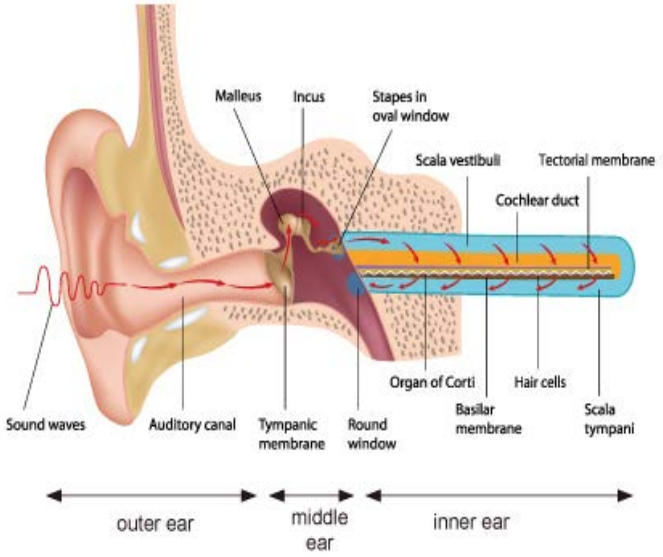
Cochlear signal analysis for broadband spectrum sensing in cognitive radio networks

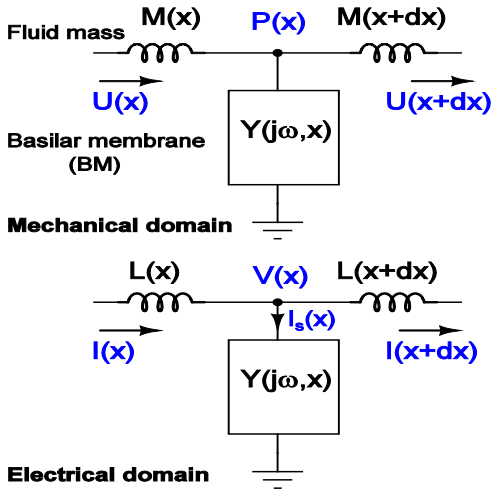
Yingying Wang, Soumyajit Mandal
Electrical Engineering and Computer Science Department, Case Western Reserve University, Cleveland, Ohio 44106

Cochlea – Introduction

Anatomy of human ear (source: Wikipedia)



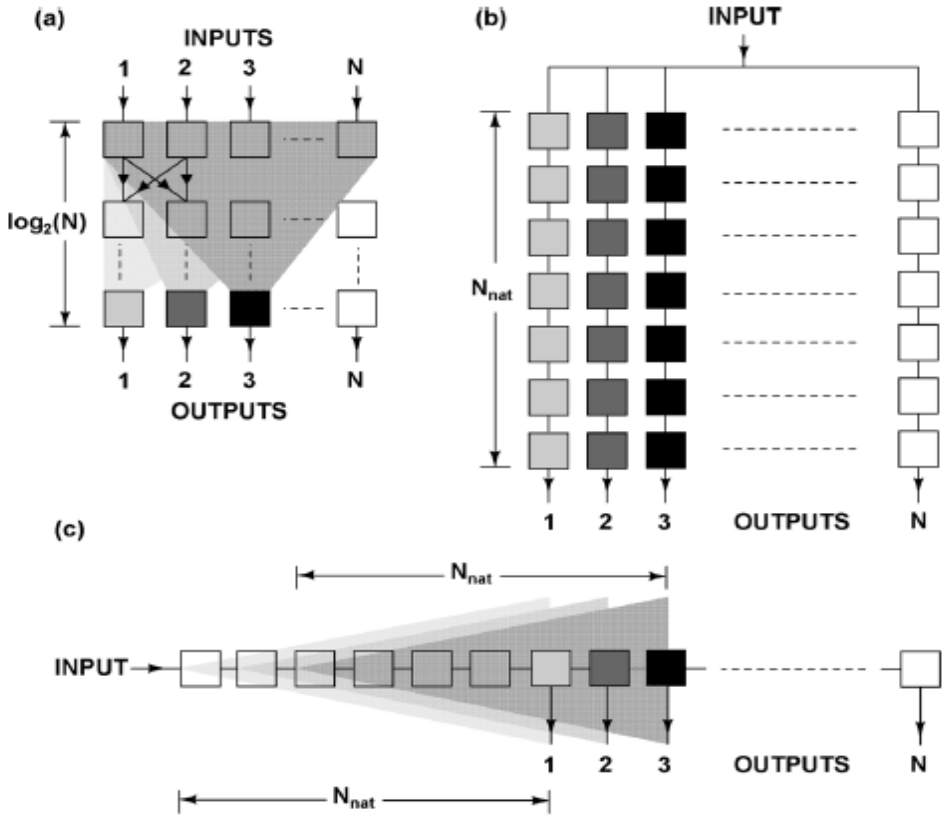
A generic spatially-varying one-dimensional transmission line



Parameter	Value
Dynamic range (at input)	120 dB
Power consumption	Around 14 µW
Power supply voltage	150 mV
Volume	Around 35 mm x 1 cm x 1 cm
Detection threshold at ear drum	0.05 Å at 3 KHz
Frequency range	20 Hz ~ 20 KHz
Output fibers	Around 25,000
Filter bandwidth	Around 1/3 octave
Phase locking threshold	Around 5 KHz

(S. Mandal, "Collective Analog Bioelectronic Computation," Ph.D. Thesis, MIT, 2009)

Cochlea – Introduction



Algorithm	Analysis time	Hardware cost
FFT	$O(N\log_2 N)$	$O(N\log_2 N)$
Filter bank	$O(N)$	$O(N^2)$
Cochlea	$O(N)$	$O(N)$

Comparison of the spectral analysis algorithms of (a) the FFT, (b) a parallel bank of independent filters and (c) the cochlea.

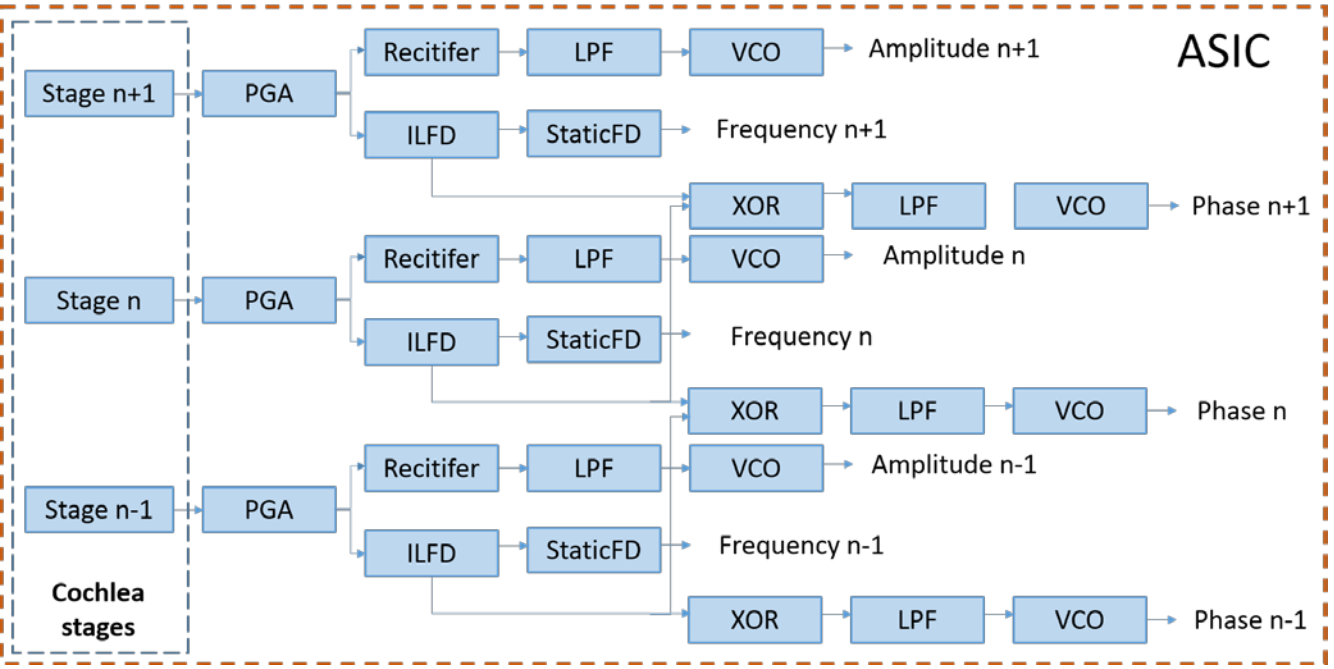
(S. Mandal, "Collective Analog Bioelectronic Computation," Ph.D. Thesis, MIT, 2009)

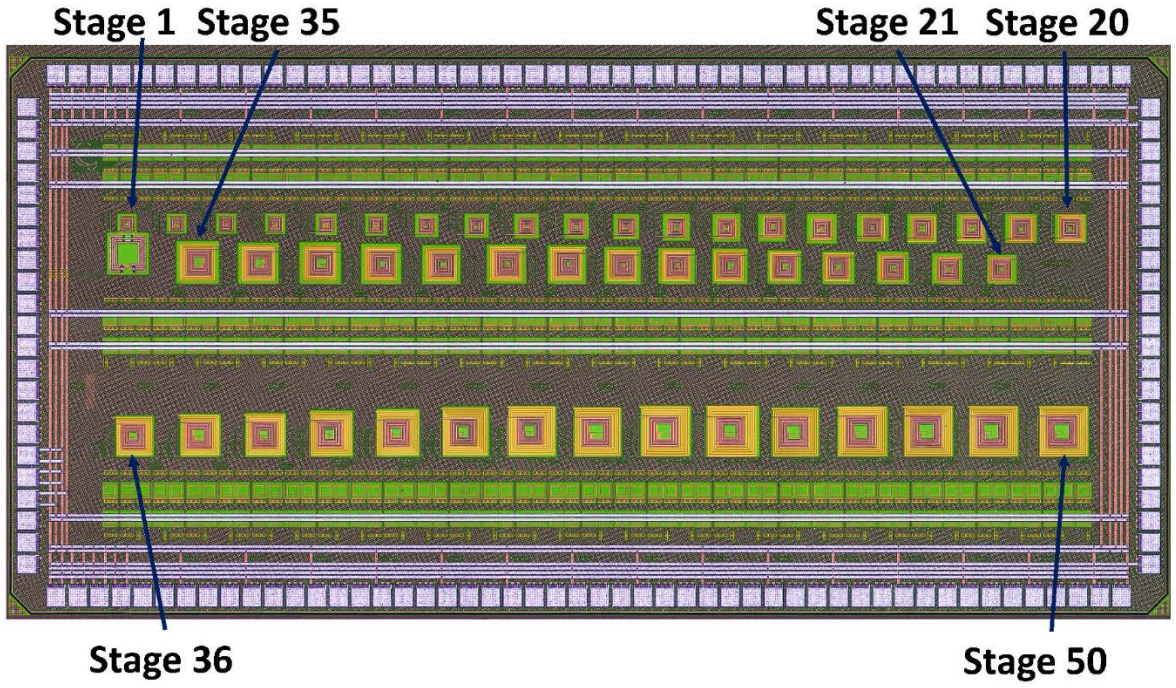
Cochlea – Specifications

Goal: To detect and analynize the output from RF Cochlea circuit, using oscillator based frequency divider for frequency information, and phase detector to get both amplitude and phase information to improve frequency resolution. The overall goals of this project are to extend our prior work by understanding the fundamental principles of cochlea-like signal analysis and applying them to the problem of analyzing “RF scenes”.

Parameter	Value
Technology	UMC 65 nm 1P8M1T0F1U LL
Dimensions	3.95 mm(H) x 1.875 mm(V)
Power supply voltage	2.5v +/- 5%, 1.2v +/- 5%
Power Consumption	2.6 mW/stage for signal analysis circuits 8.0 mW/stage for Cochlea
Analog Gain	x1 to x8
Frequency range	0.6 GHz ~ 8.4 GHz
# of stages	50
# of programmable bits/stage	20
# of pads	144

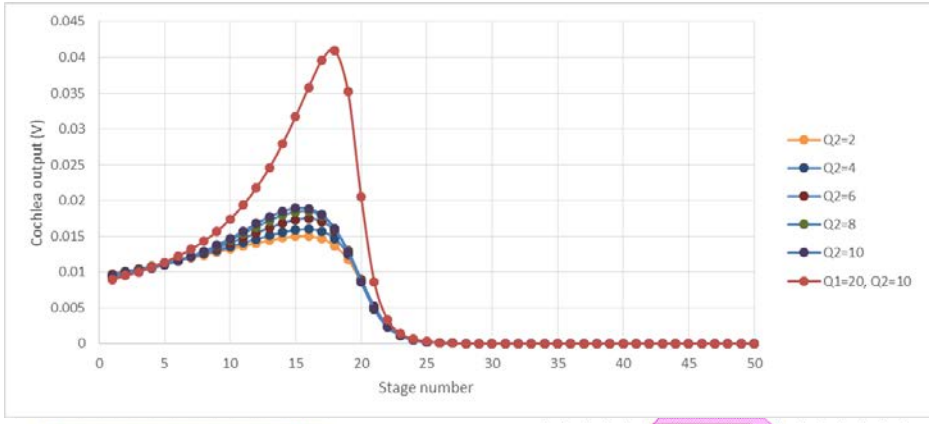
Cochlea – chip block diagram

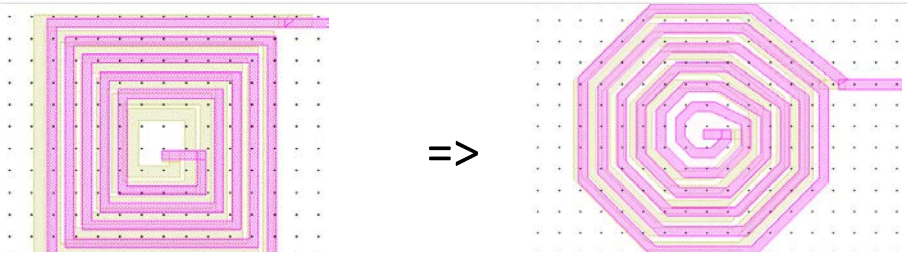


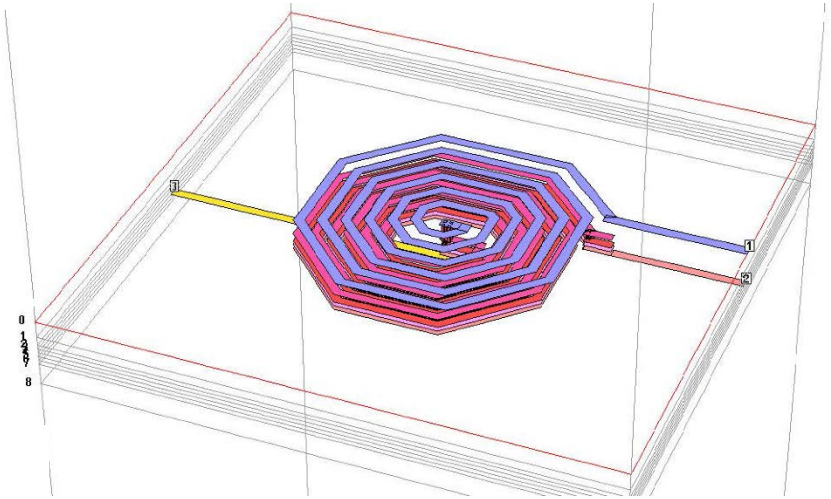


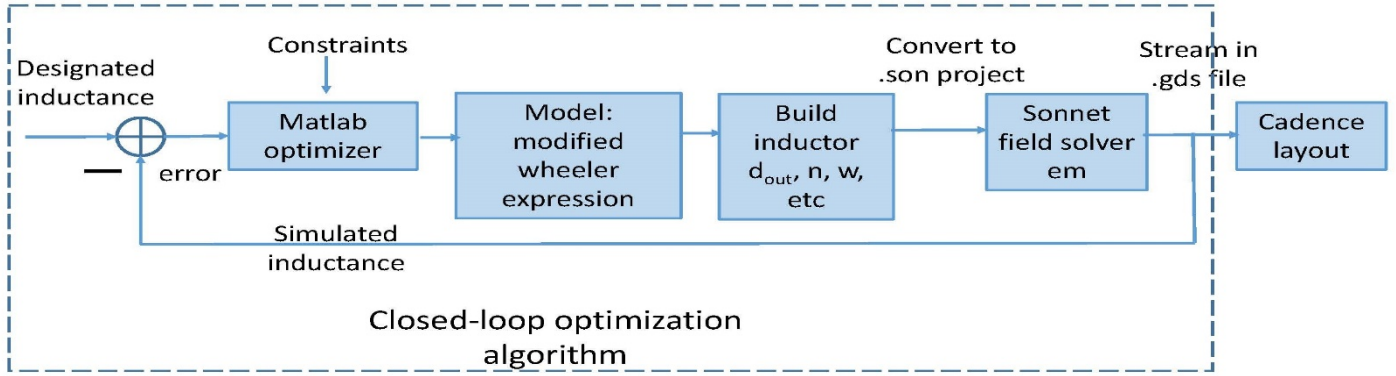
Cochlea – Cochlea Stages

➢ ***Block diagram of the proposed closed-loop optimization algorithm.***

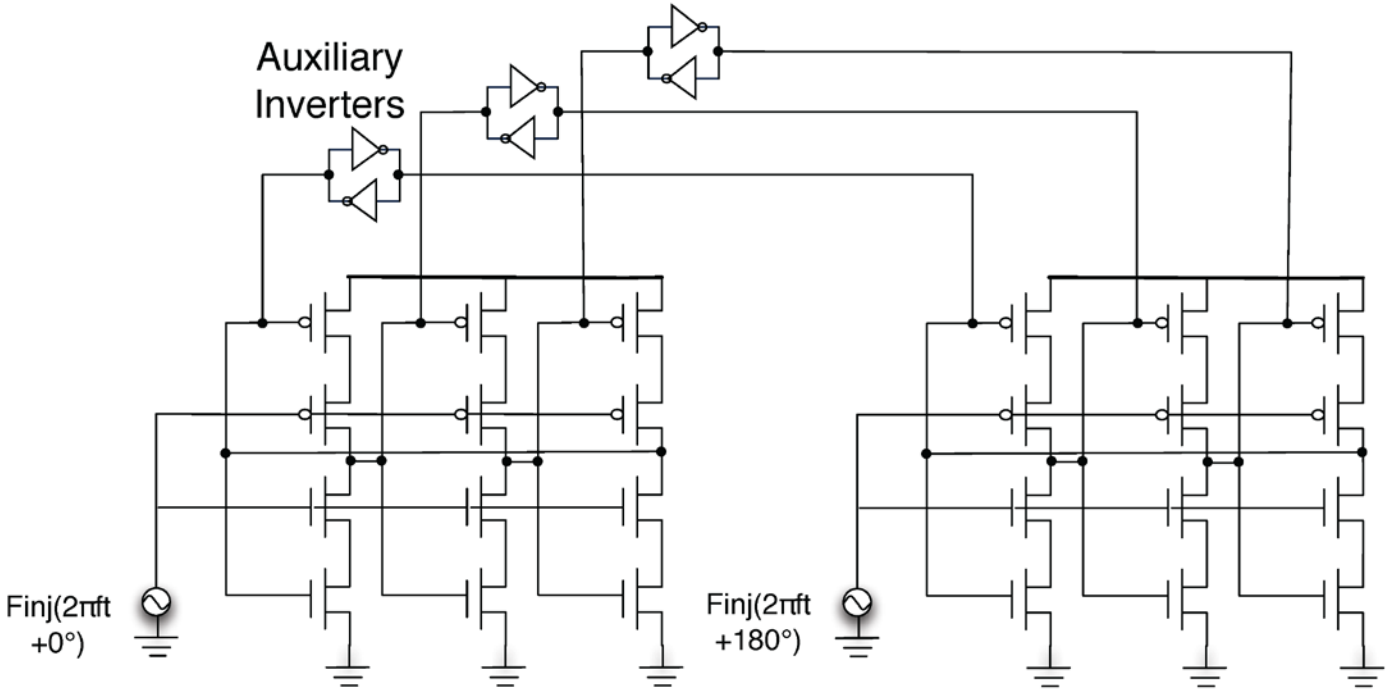


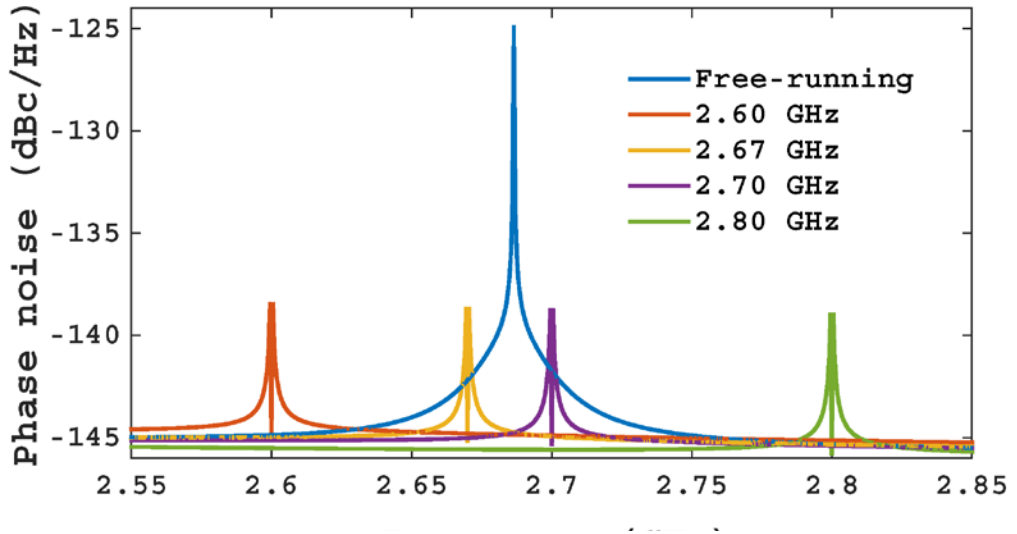


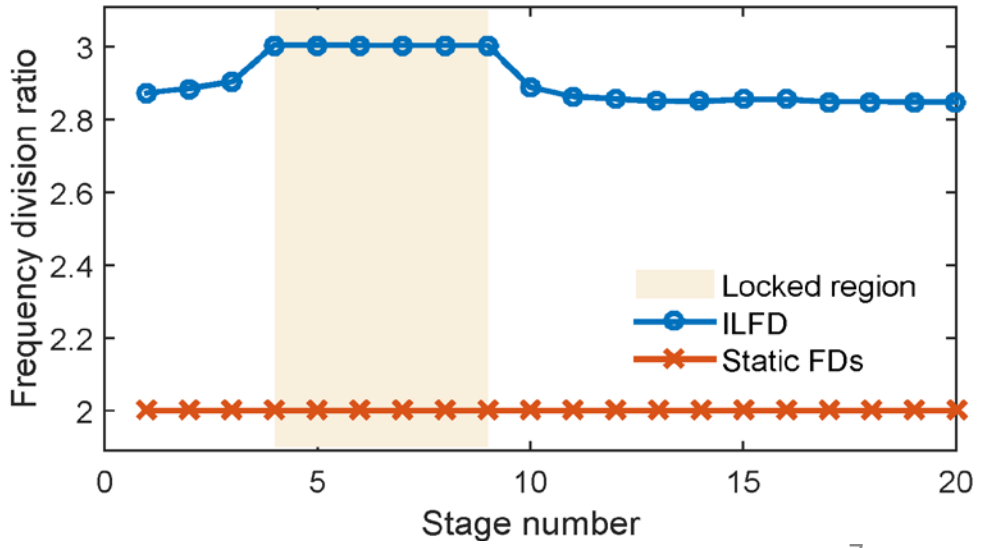




Cochlea – Readout block I

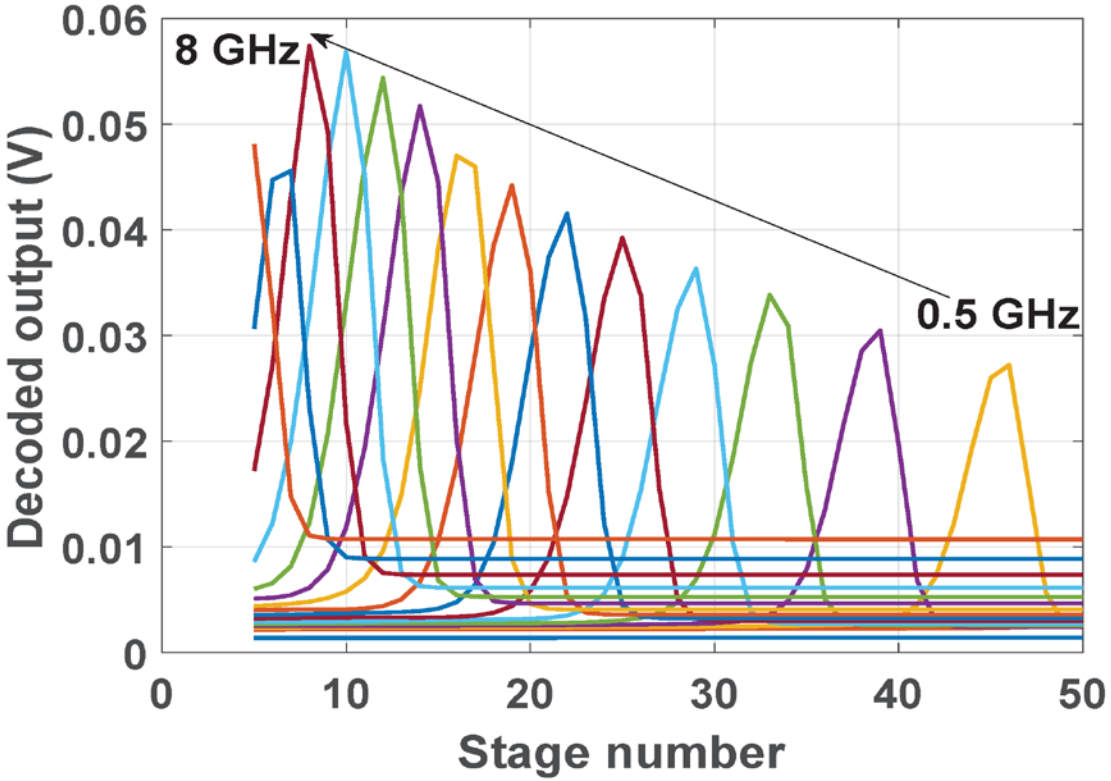


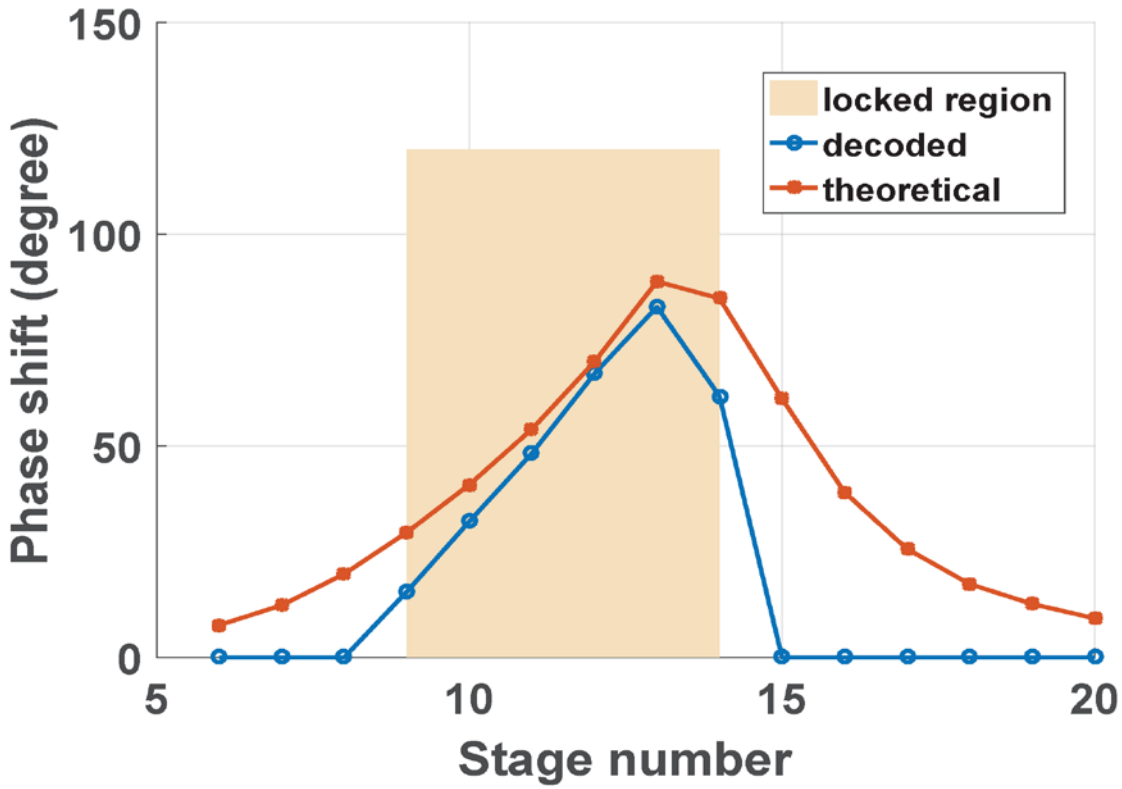




- ***Simplified schematic of the divide-by-3 differential complemetary-injection-locked frequency divider (ILFD) circuit;***
- ***The phase of the oscillator and the injected signals track each other in the locks state, thus phase noise at locked frequencies is reduced.***

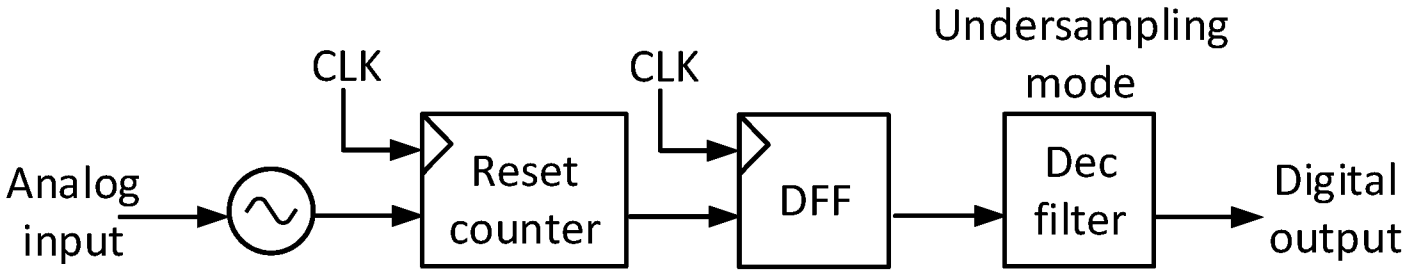
Cochlea – Readout block II





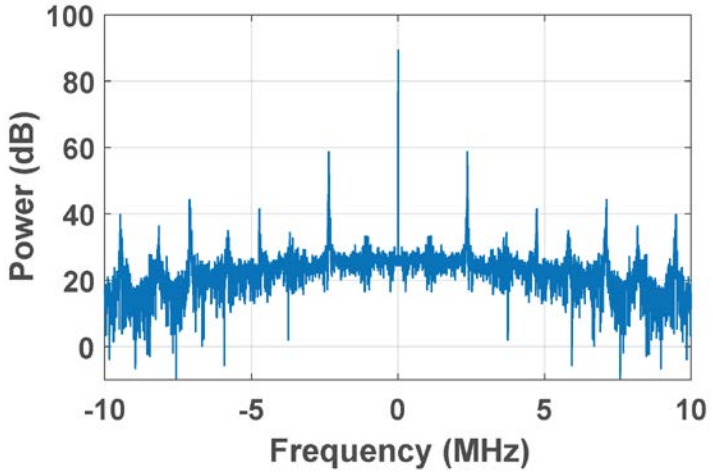
- ***Decoed cochlear output amplitude from single-tone inputs. The input frequency was varied linearly from 0.5 GHz to 8 GHz in steps of 0.5 GHz.***
- ***Simulated frequency encoding of a single-tone input at 7 GHz using a divide-by-3 ILFD followed by 2 statis divide-by-2 stages.***

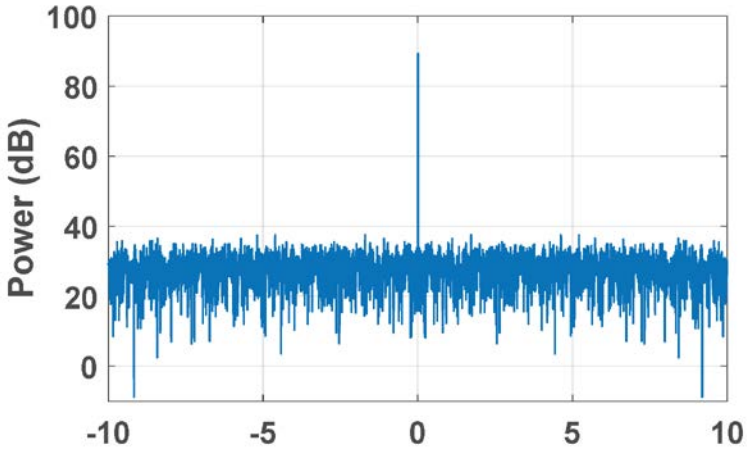
Cochlea – VCO-based Quantizer I



- ***Frequency proportional to the analog input;***
- ***Quantizing by counting the edges of VCO output;***
- ***Inherent 1st-order quantization noise shaping;***
- ***Digital calibration methods could be implemented;***

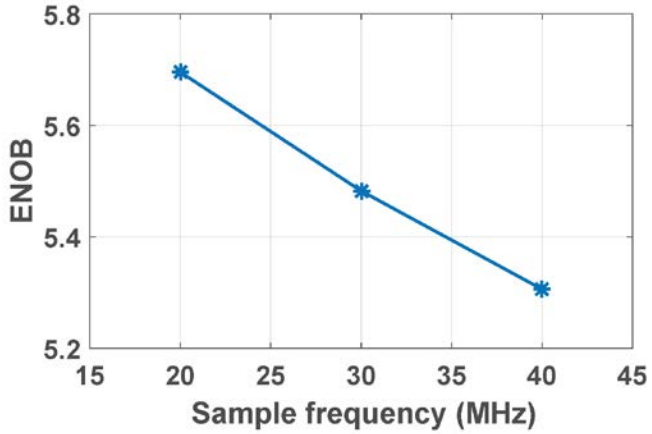
Simulated output power spectrum for f_{clk} = 20 MHz

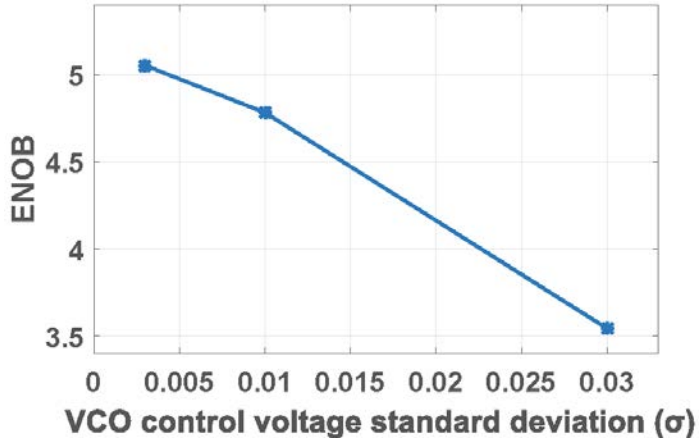




with noise added to the VCO control voltage (σ = 0.01 V).

Estimated ENOB versus sampling frequency f_{clk}

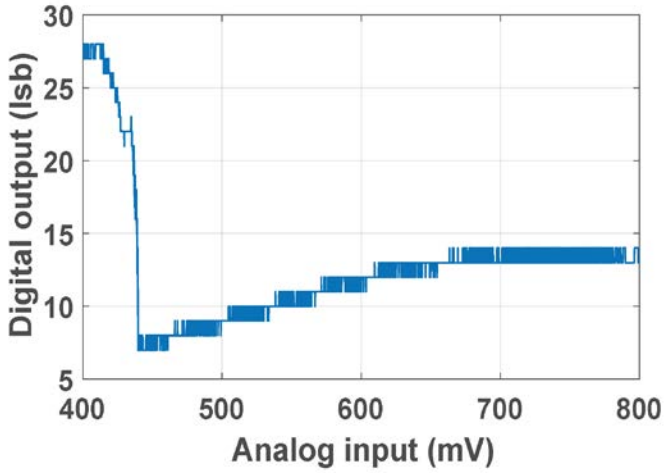


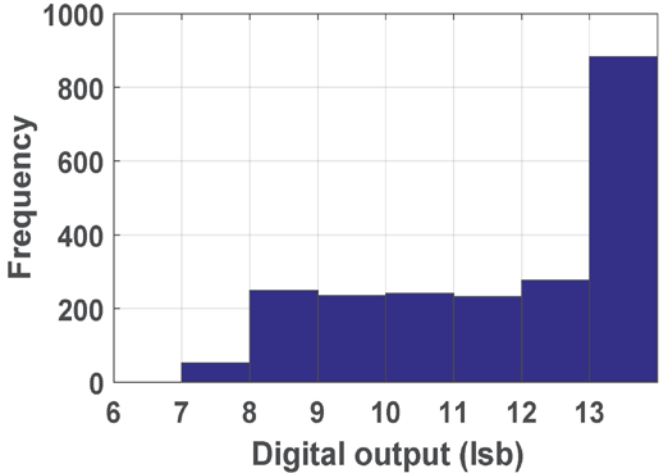


Cochlea – VCO-based Quantizer II

- ***VCO-based quantizer;***

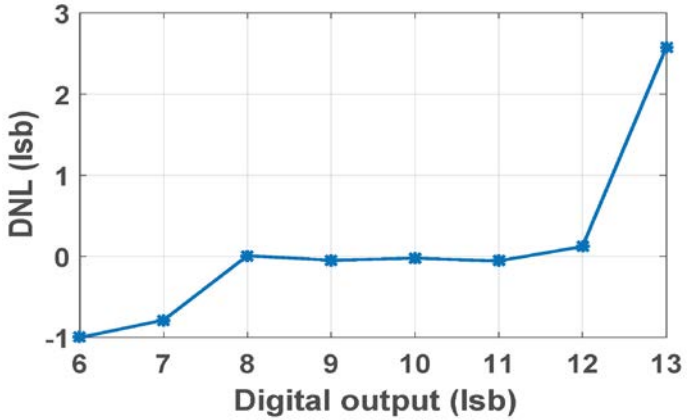
VCO-based quantizer transfer function

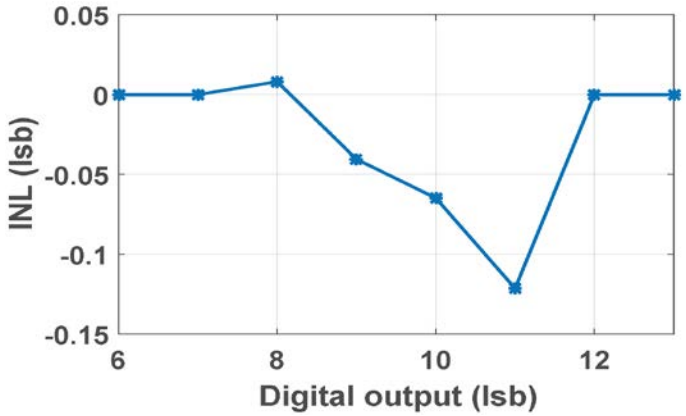




Histogram of simulated digital counts

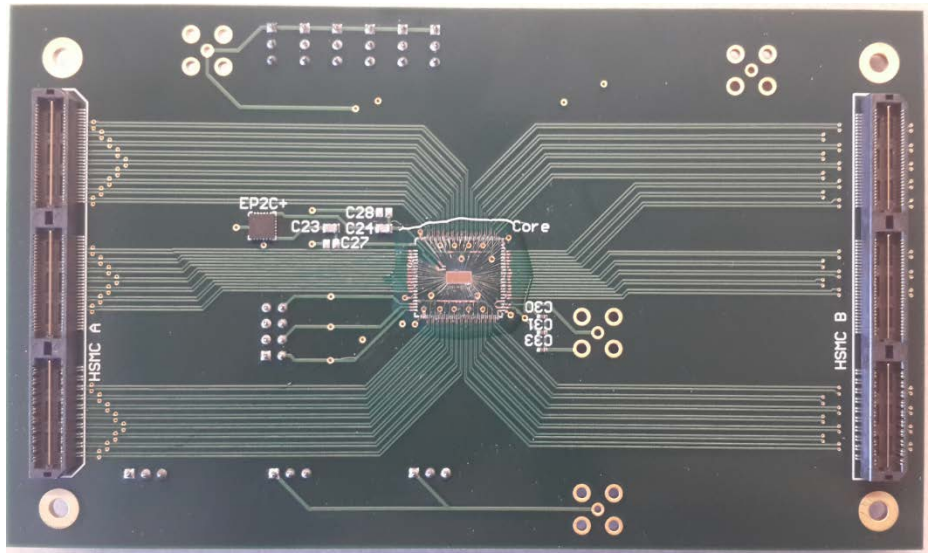
DNL

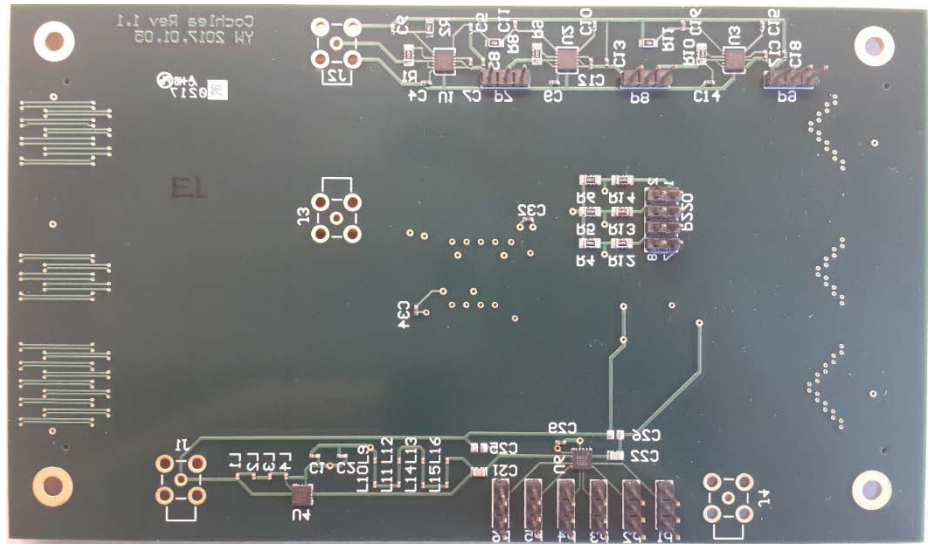


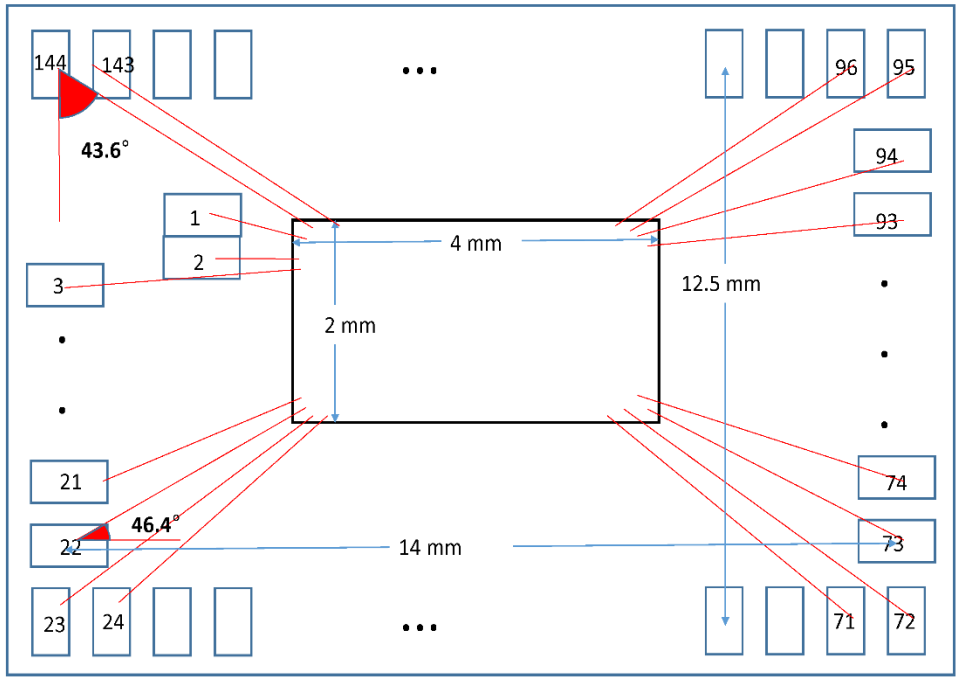


INL

Cochlea – PCB

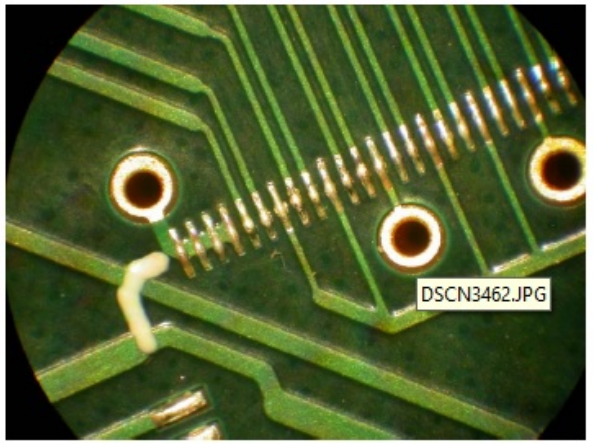


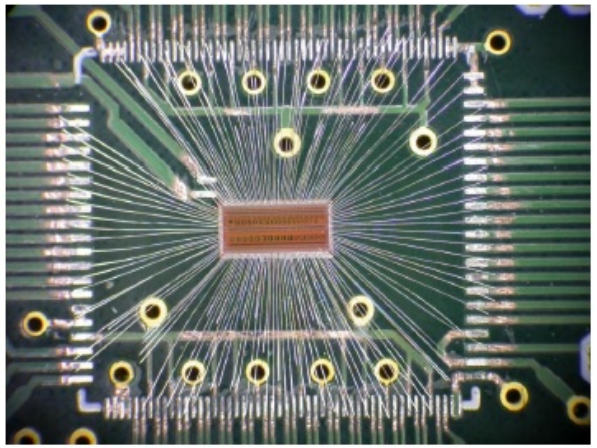




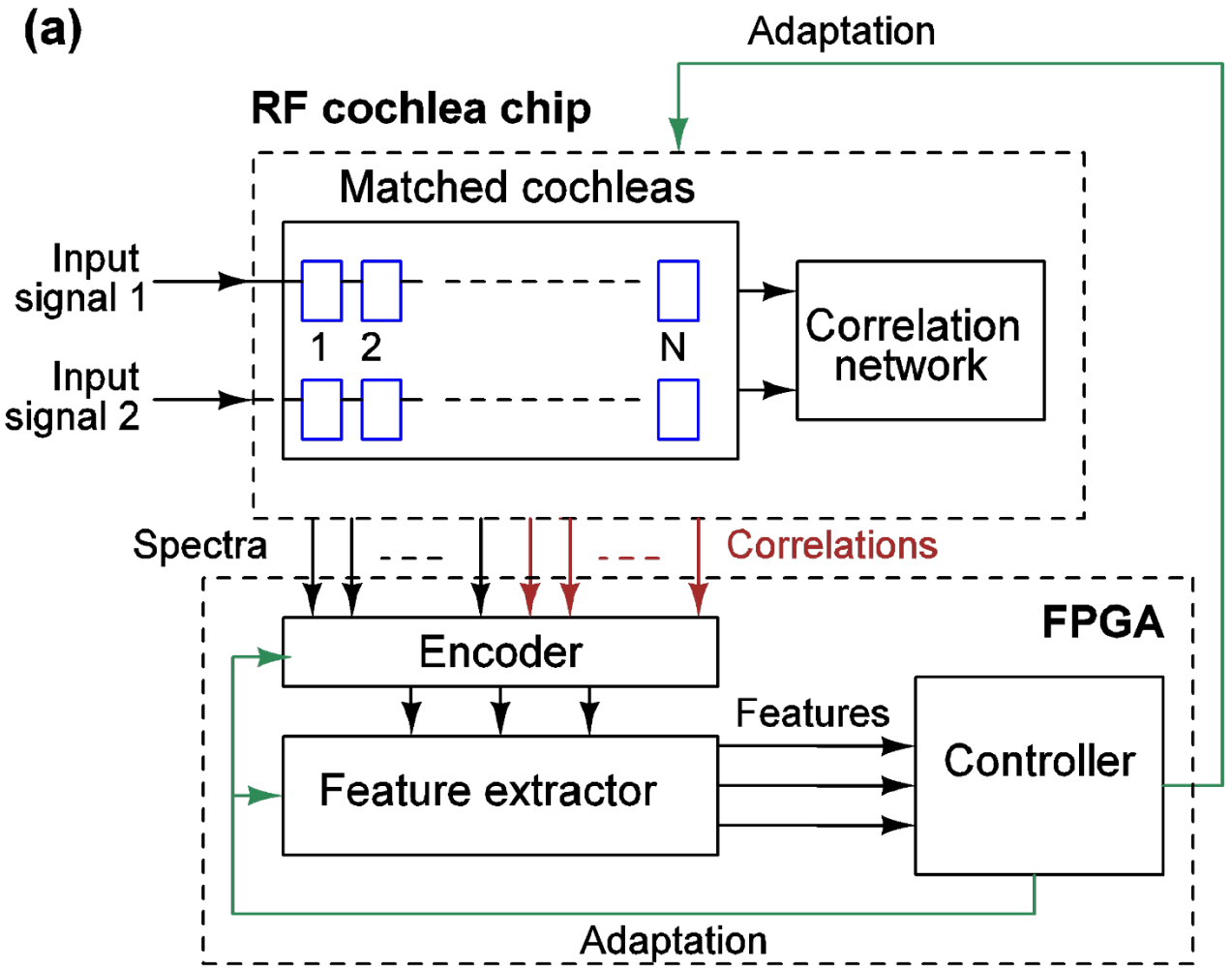
Vertical pads:
10 mil x 30 mil pad
Pitch = 20 mil
solder mask
expansion = 4 mil

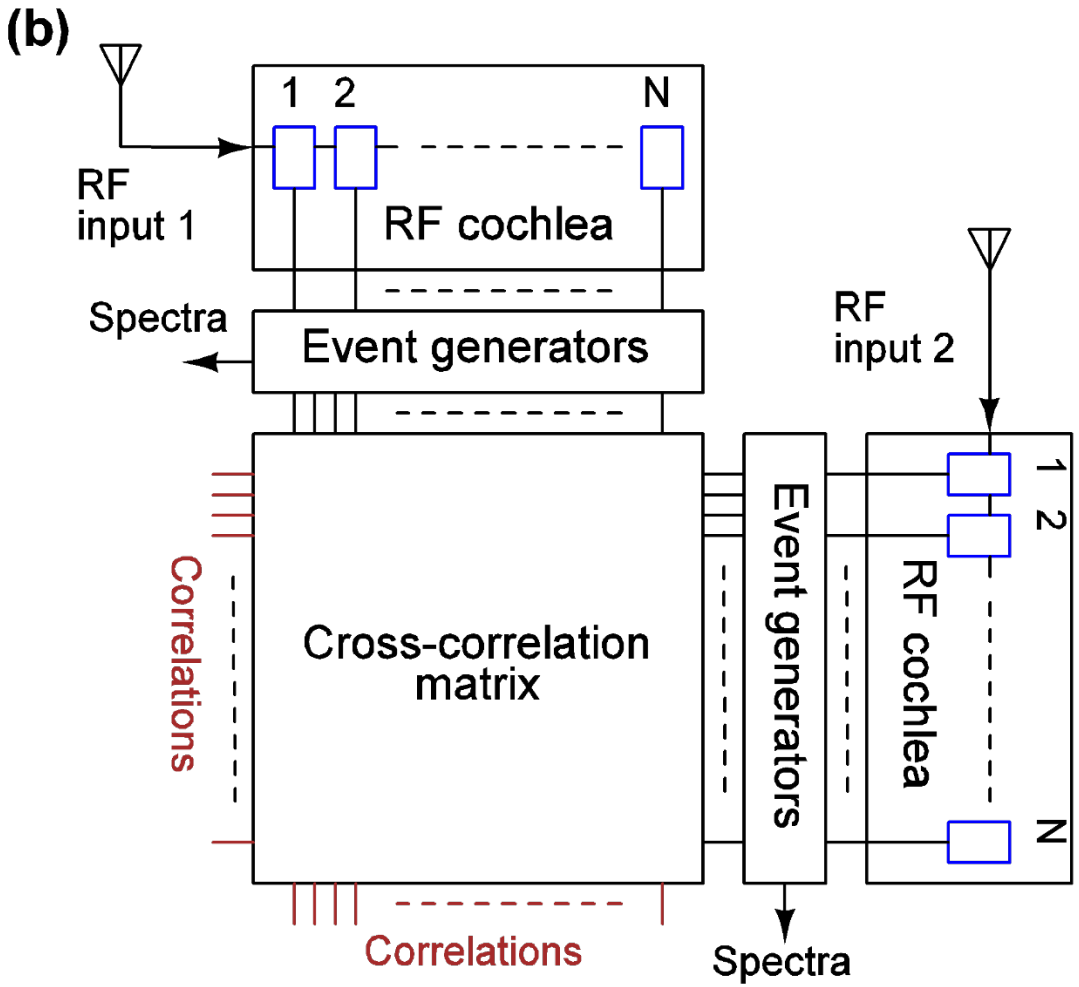
Horizontal pads:
5 mil x 30 mil pad
Pitch = 10 mil
solder mask
expansion = 0 mil





Cochlea – RF scene analyzer





➢ ***Block diagram of the adaptive RF scene analysis system.***

➢ ***Detailed block diamgram of the RF cochlea used within the scene analyzer.***


thank you for your attention