Approximate Delay-and-Sum Beamforming Mobile Ultrasound Applications

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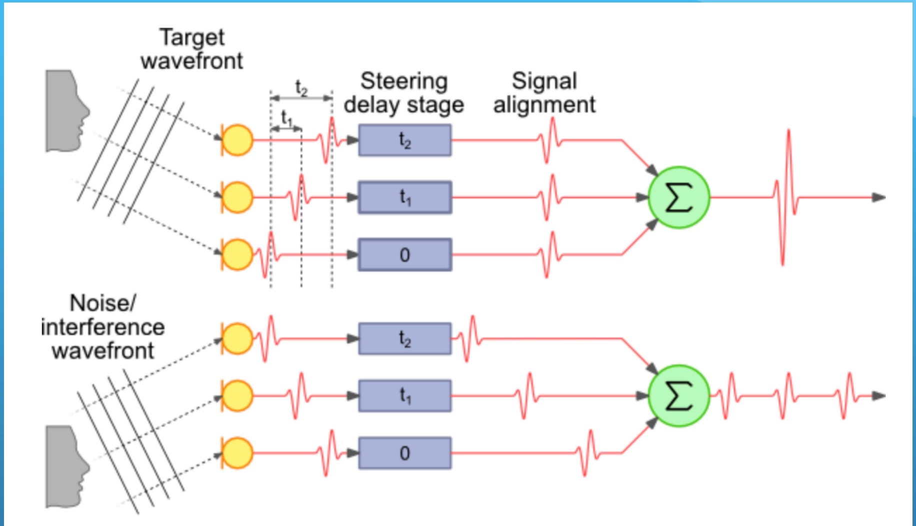
Trends in Ultrasonic Imaging Devices

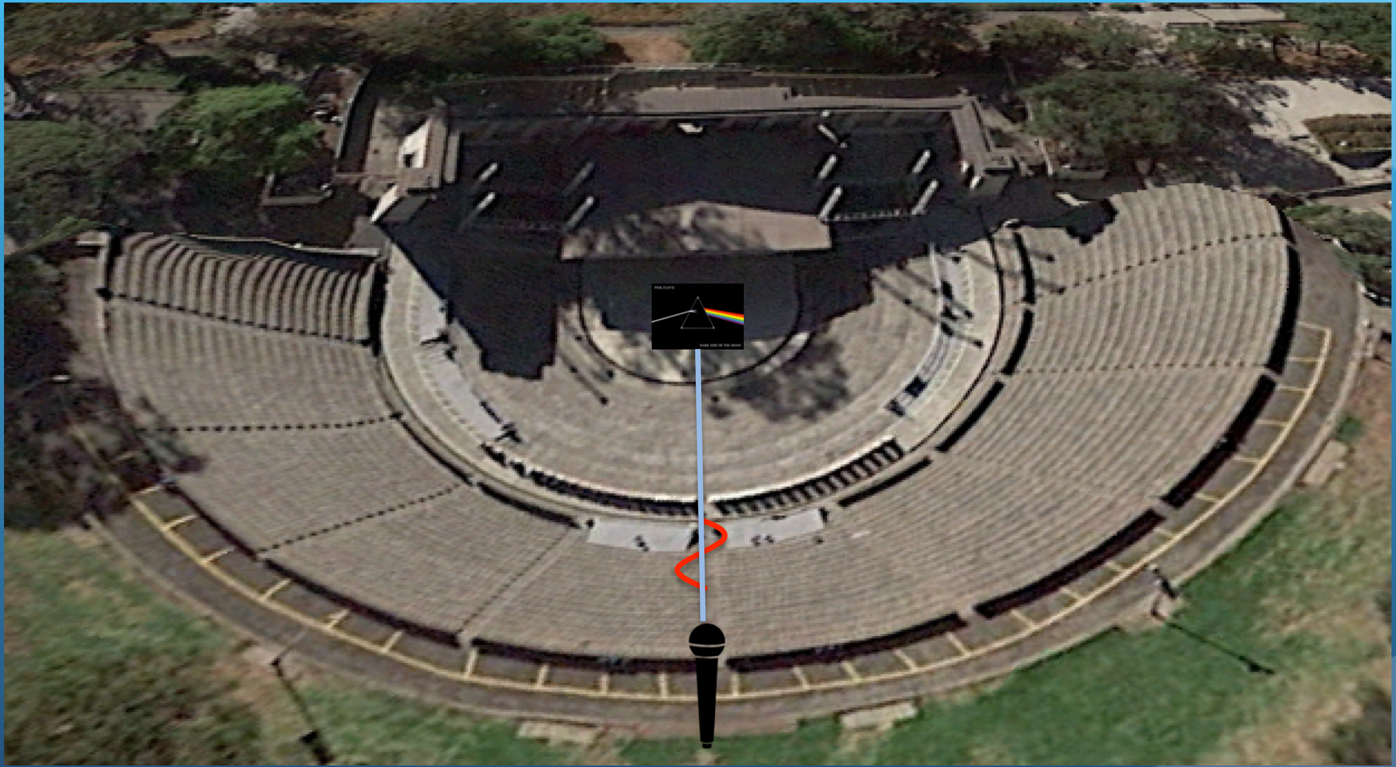
- Growing Number of Elements in Sensor Array
- Portable Systems
- Challenge: Low power ultrasound solution for mobile applications without compromising image resolution provided by larger sensor array
- Proposed Solution: Delay-and-Sum beamforming with Approximate Compute

Delay-and-Sum Beamforming

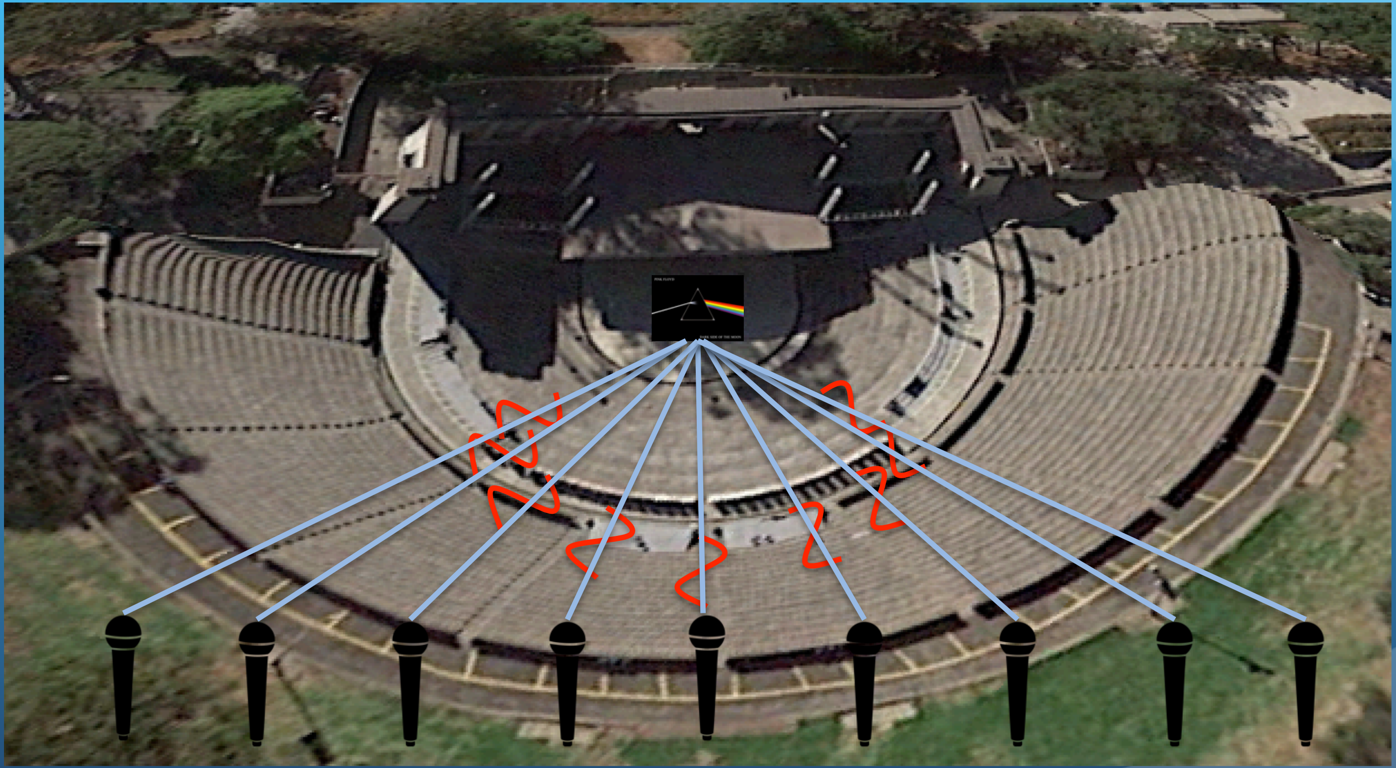


- Compensate signal delay to each transducer appropriately before summing the signals
- Improves signal to noise ratio (SNR)
- Relatively simple

Delay and Sum Example - 1 Microphone



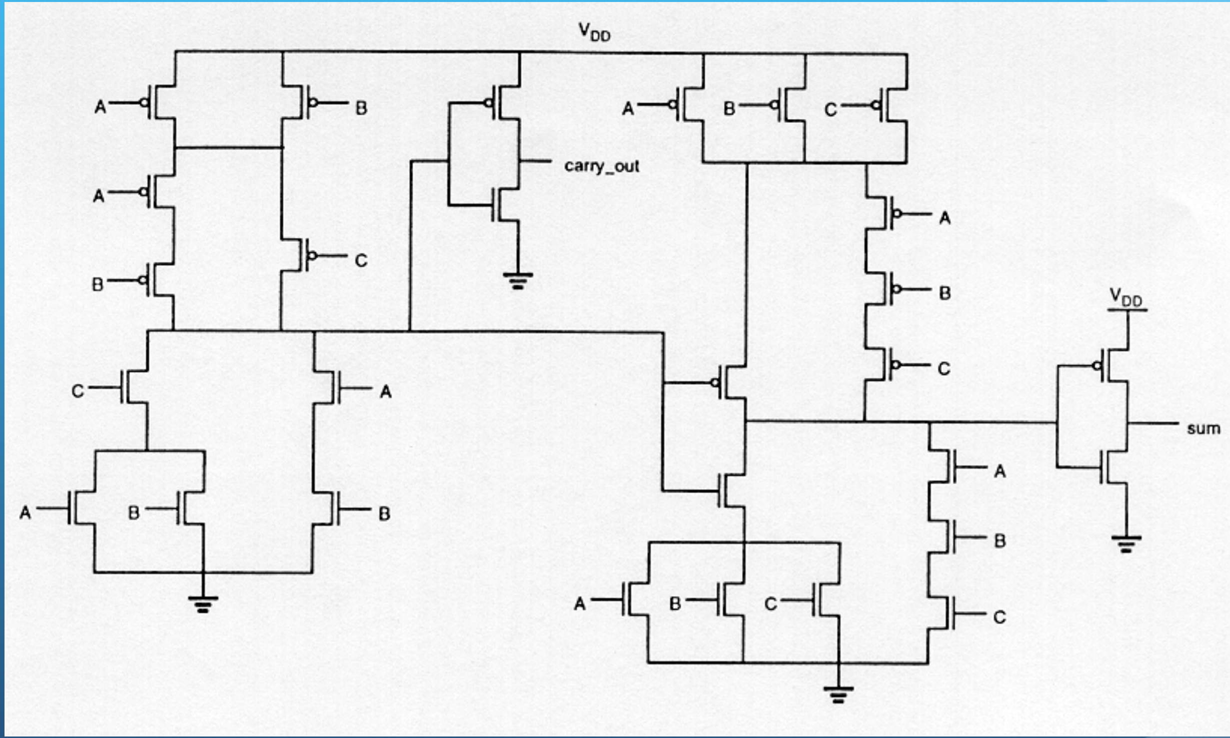
Delay and Sum Example - Microphone Array with Beamforming



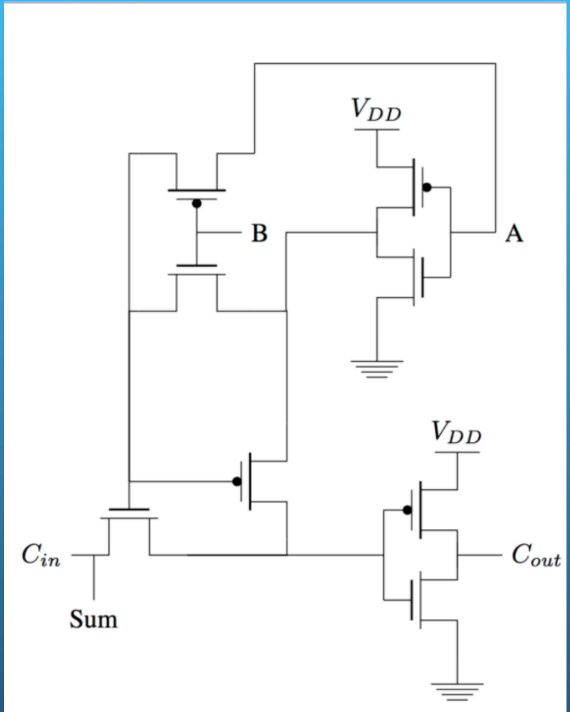
Approximate Computing

- Deterministic hardware produces low order errors but uses much fewer resources
- Save power and area at the expense of accuracy
- Possible solution for low power beamforming
  - Improved resolution must justify increased area and power dissipation

28T Full Adder Cell



8T Approximate XOR Adder (AXA1)

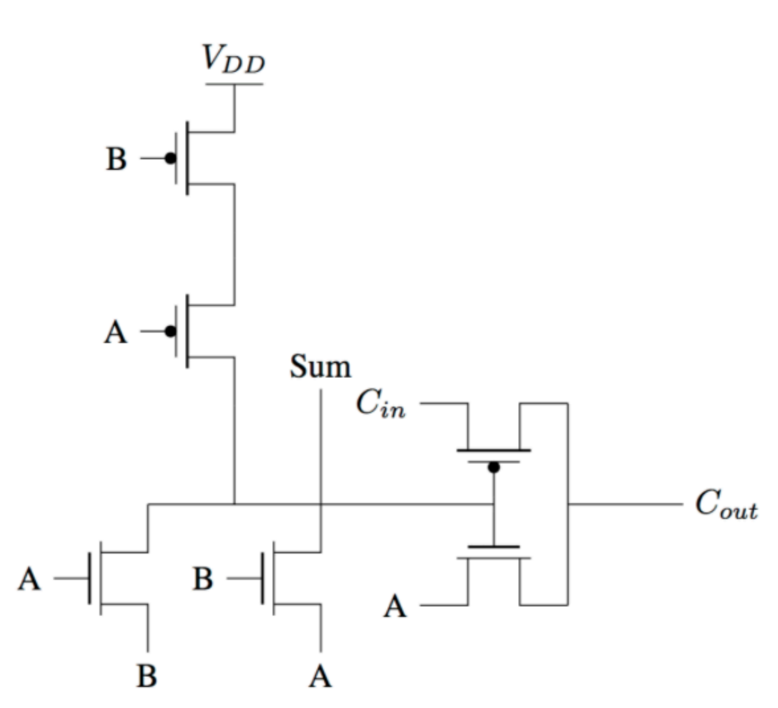


$$Sum = C_{in},$$
$$C_{out} = \overline{(X \oplus Y)C_{in} + \bar{X}\bar{Y}}.$$

A	B	C_{in}	C_{out}	Sum
0	0	0	0	0
0	0	1	0	1
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	1	0
1	1	1	1	1

TABLE I
TRUTH TABLE FOR AXA1

6T Approximate XNOR Adder (AXA2) with Pass Transistor Logic

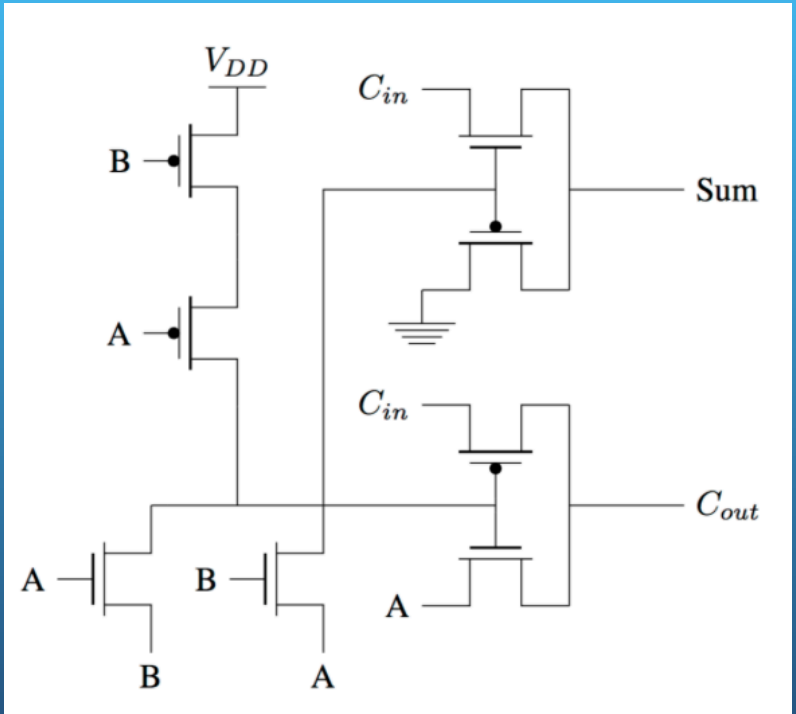


$$Sum = \overline{(X \oplus Y)},$$
$$C_{out} = (X \oplus Y)C_{in} + XY.$$

A	B	C_{in}	C_{out}	Sum
0	0	0	0	1
0	0	1	0	1
0	1	0	0	0
0	1	1	1	0
1	0	0	0	0
1	0	1	1	0
1	1	0	1	1
1	1	1	1	1

TABLE II
TRUTH TABLE FOR AXA2

8T Approximate XNOR Adder (AXA3) with Pass Transistor Logic

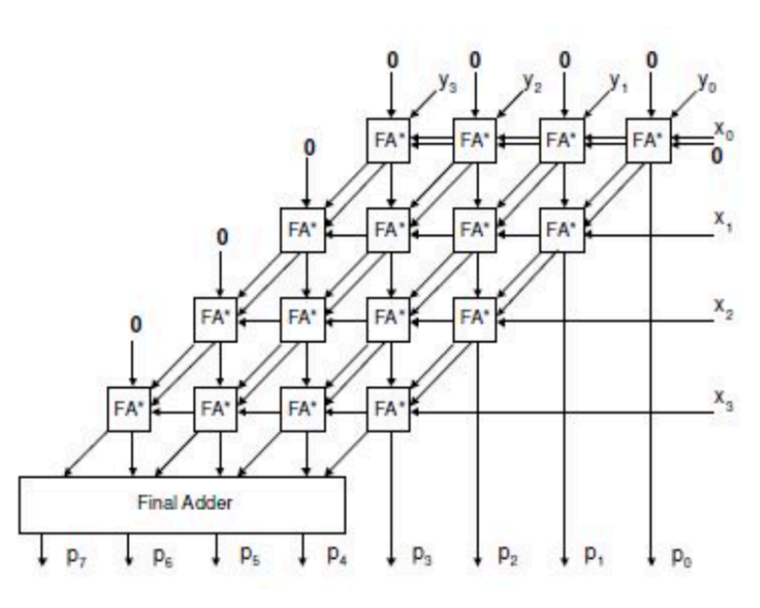


$$Sum = \overline{(X \oplus Y)}C_{in},$$
$$C_{out} = (X \oplus Y)C_{in} + XY.$$

A	B	C_{in}	C_{out}	Sum
0	0	0	0	0
0	0	1	0	1
0	1	0	0	0
0	1	1	1	0
1	0	0	0	0
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

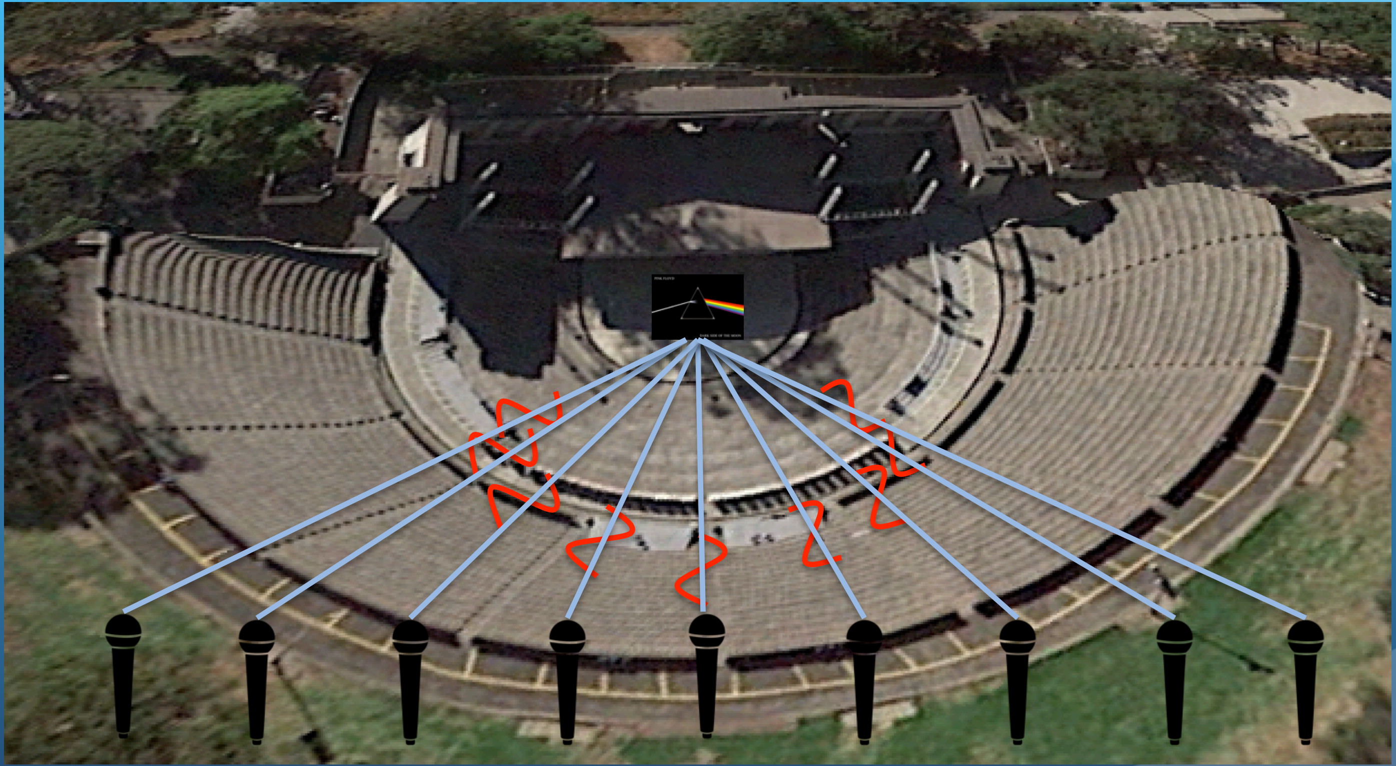
TABLE III
TRUTH TABLE FOR AXA3

Approximating Multiplications with Carry Save Multipliers

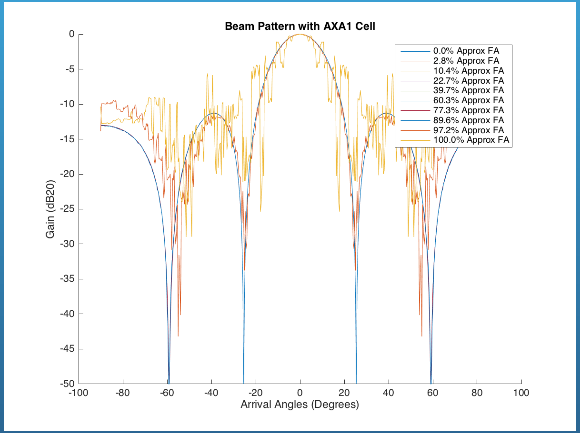


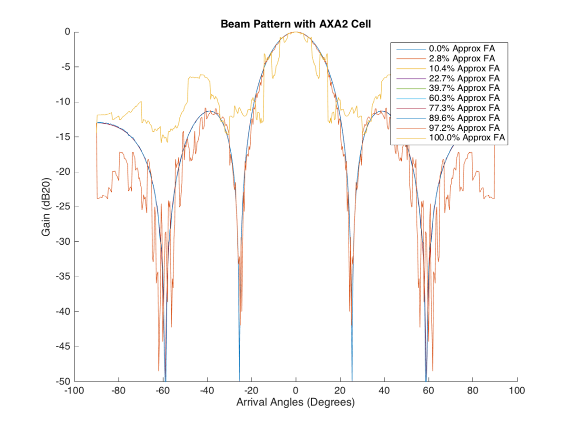
- Multiplications performed with 24 bit carry save multiplier with a ripple carry output stage
- Used for mantissa operations in a floating point multiplication unit
- Various percentages of full adder cells replaced with approximate computing adders

Approximate Computing Gone Wrong

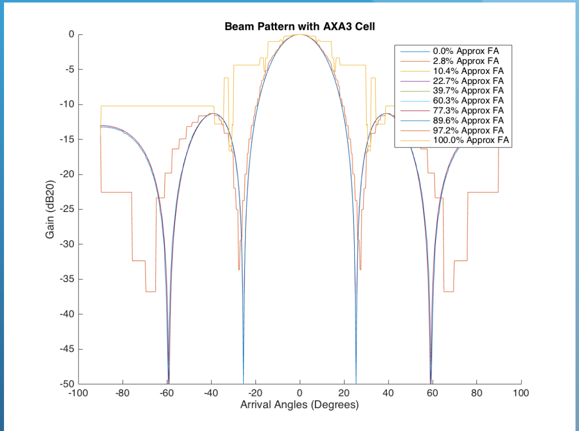


Steered Responses for n bits of Approximation





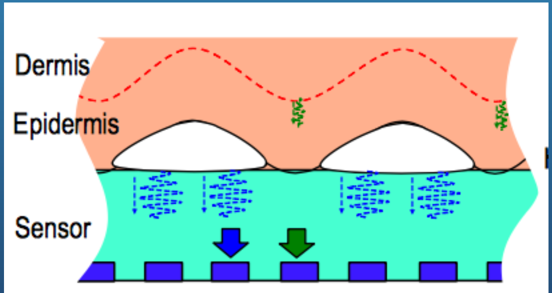
AXA2



AXA1

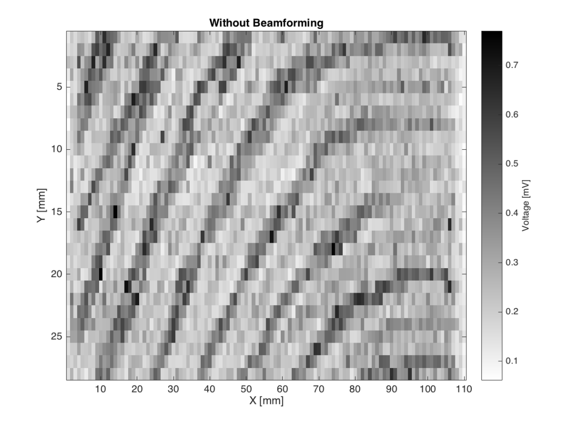
AXA3

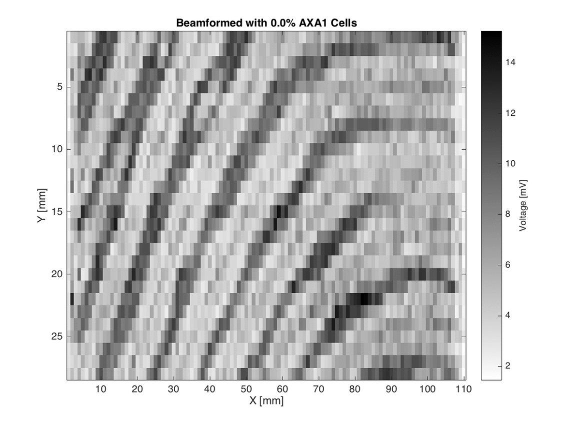
Ultrasonic Fingerprint Sensor

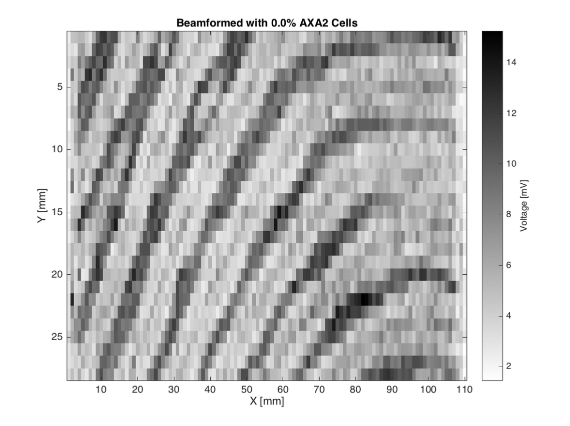


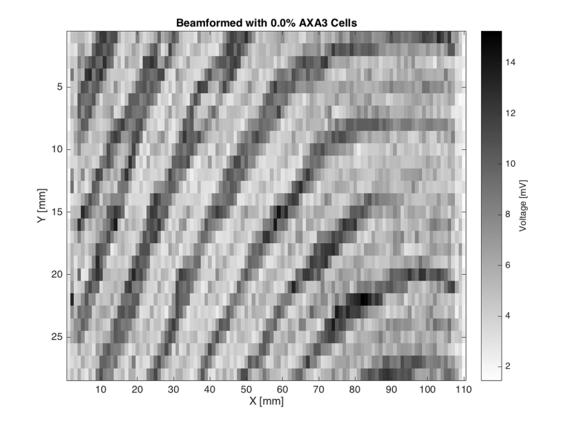
- 56 x 110 rectangular piezoelectric micromachined ultrasonic transducers (PMUTs)
- Aimed for smartphone application
- Signals recorded for all 110 columns and 28 rows
- Delay and sum beamforming along columns
- Gaussian noise added to degrade SNR

Approximate Delay and Sum Results





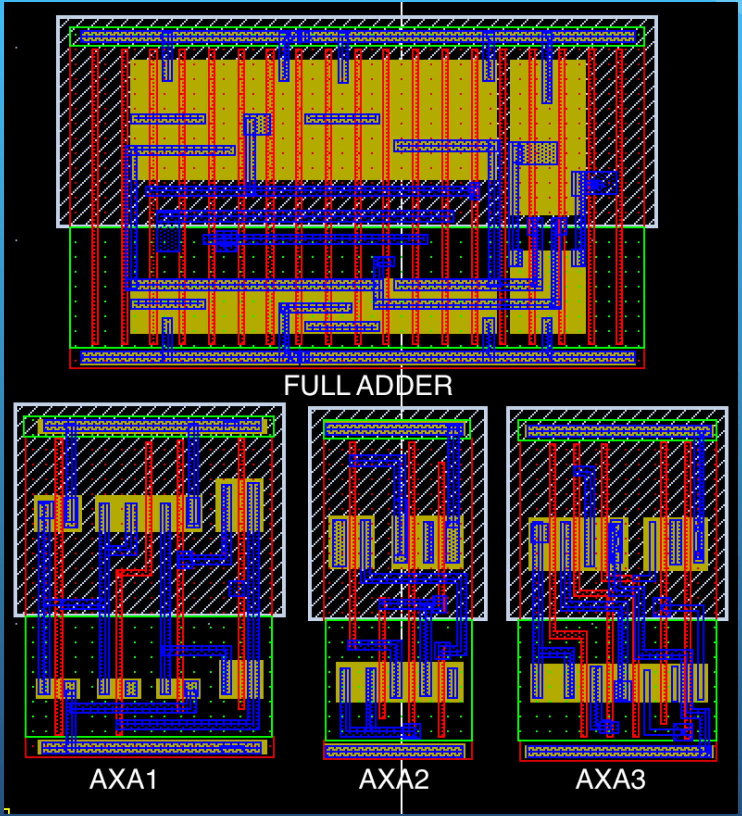




Power

Adder	FA	AXA1	AXA2	AXA3
Dynamic Power per adder [nW]	173	24.2883	14.2386	10.2828
Power savings with 77.3 % approx adders per array element [μW]	N/A	139.201	148.617	152.320
Total Power savings for fingerprint sensor [mW]	N/A	15.3130	16.3479	16.7552

Cell Layout



Area

Adder	FA	AXA1	AXA2	AXA3
Cell Area [μm^2]	5.712	2.568	1.687	2.63
Area Savings with 77.3 % approx adders per array element [μm^2]	N/A	2,943.1	3,767.8	2,885.1
Total Area savings for fingerprint sensor [mm^2]	N/A	0.3237	0.41428	0.31735

Summary

- Explored Approximate Compute as a power/area saving technique for Delay and Sum Beamformers
- Analyzed accuracy of system with respect to degree of approximation for 3 custom full adder cells
- Up to 16.7 mW power and 0.414 mm^2 area saved for approximate delay and sum beamformer

Thank You

Any Questions?