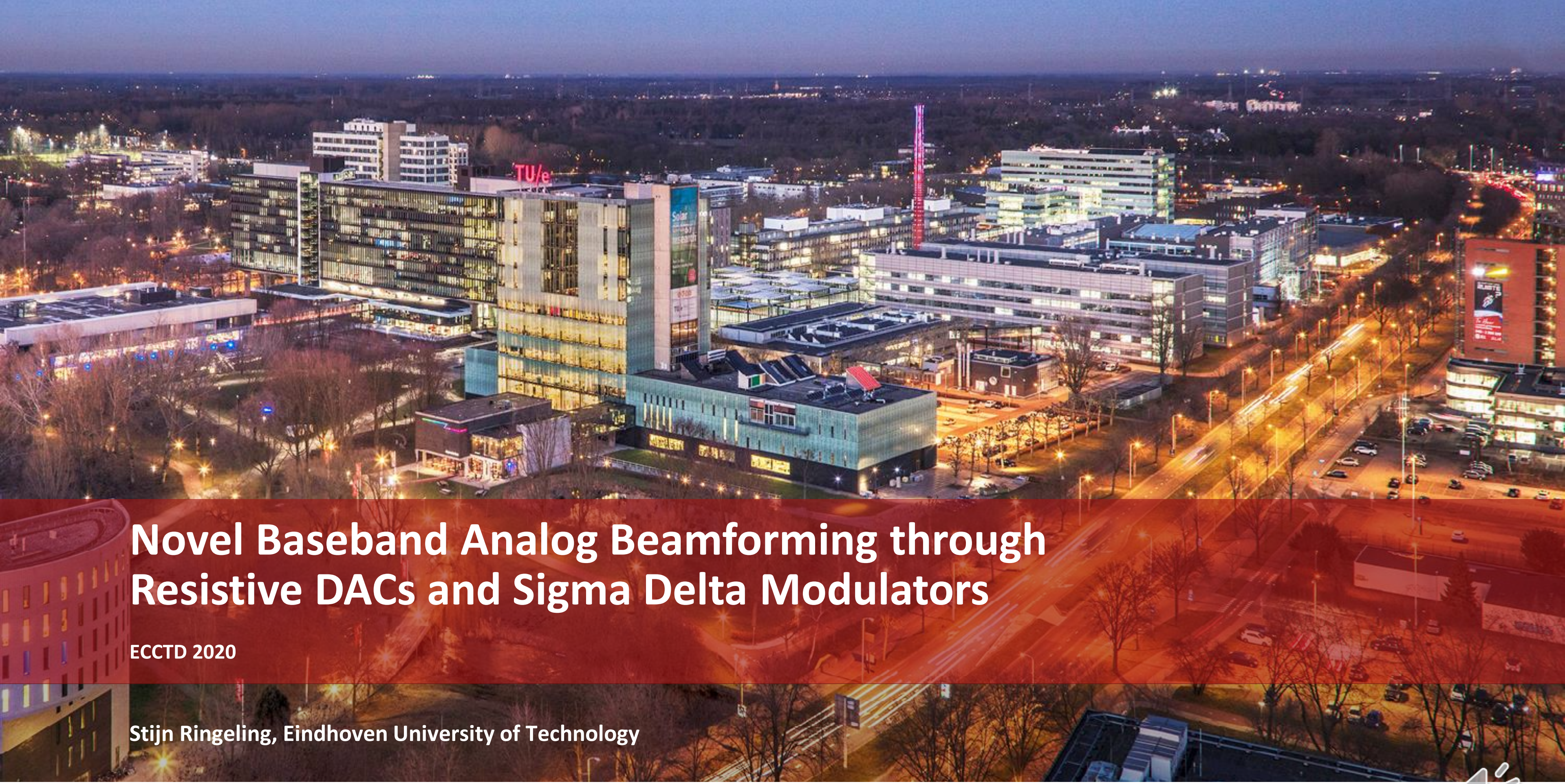

Novel Baseband Analog Beamforming through Resistive DACs and Sigma Delta Modulators

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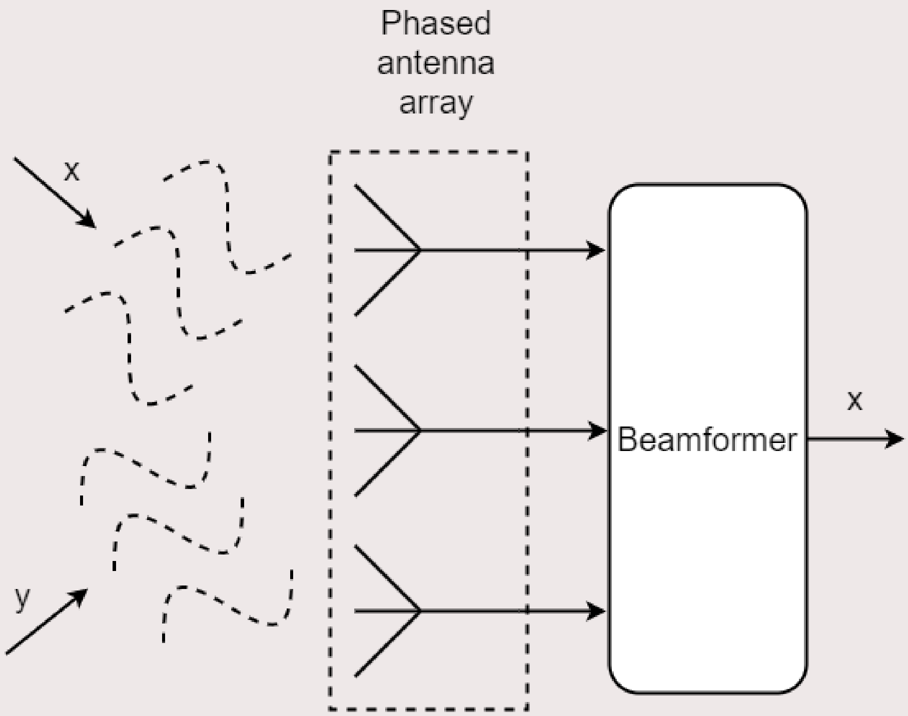
Purpose of beamforming

Beamforming is the process of filtering incoming signals based on their direction.

Beamforming advantages:

- Interferer attenuation
- SNR increase

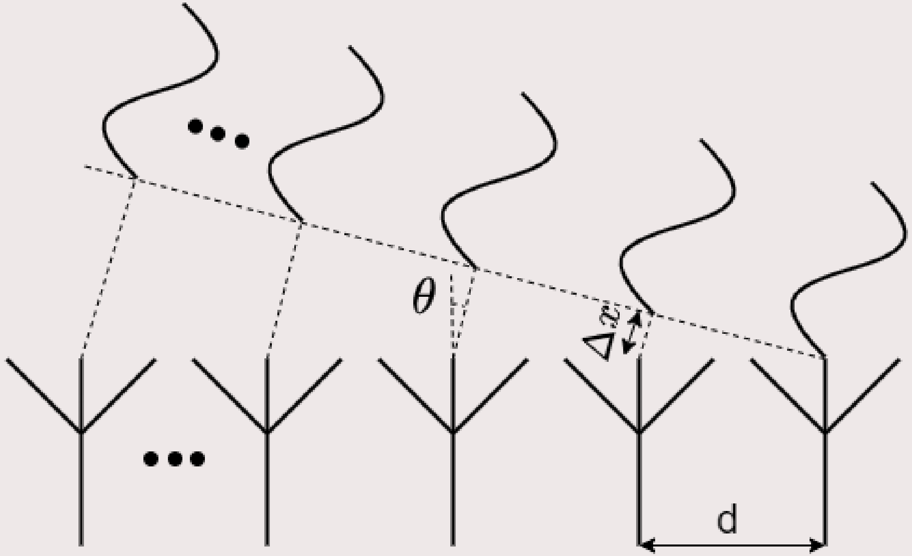
The figure on the right shows the incoming signal y being attenuated by the beamformer.



Beamforming fundamentals

Beamforming requires the signal to be sampled at different points in space.

- Extra distance travelled Δx due to incident angle θ results in a time delay Δt.
- Δt can then be used by the beamformer to filter the incoming signals.



Analog beamforming method (RF)

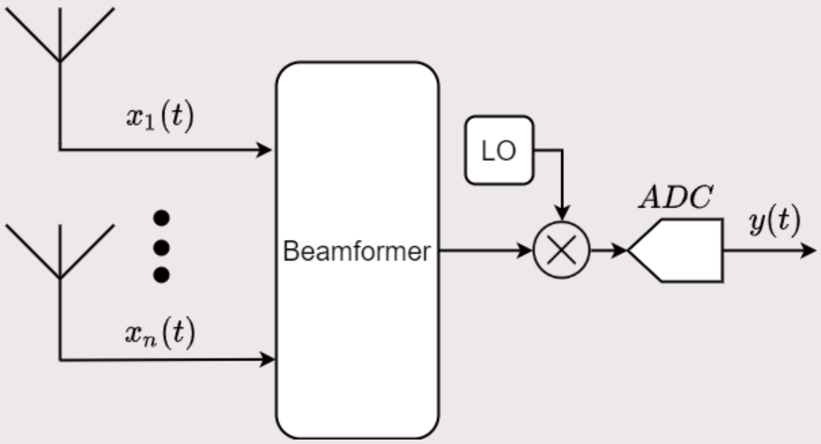
Analog RF beamforming is performed before the mixer.

This has several advantages:

- Only one ADC and mixer is required
- The ADC and mixer requirements are lowered due to the attenuation of interferers

There are also disadvantages:

- Changing the beamforming direction requires changing analog components.
- The beamformer has to operate at RF frequencies which lowers precision.



Analog beamforming method (baseband)

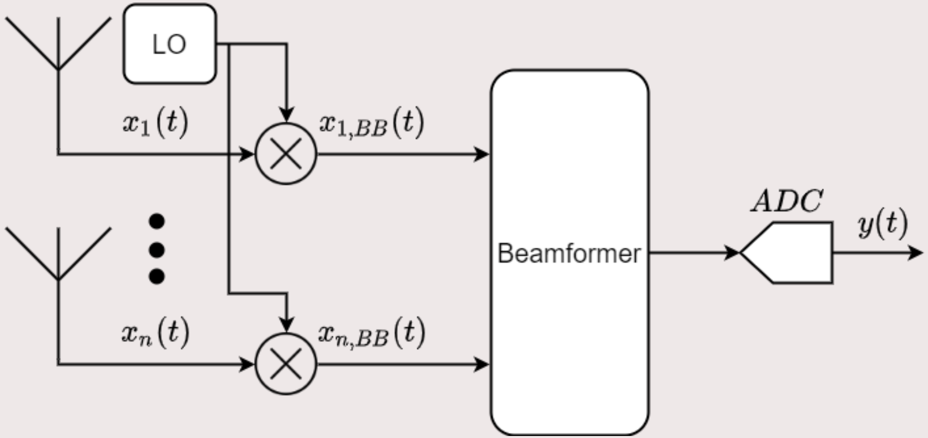
Analog baseband beamforming is performed before the ADC.

This has several advantages:

- Only one ADC is required
- The ADC requirements are lowered due to the attenuation of interferers
- The beamformer operates at baseband frequencies
- Δt is further increased due to demodulation.

There are also disadvantages:

- Multiple mixers are needed.
- Changing the beamforming direction requires changing analog components.
- Multiple beamformers are required to support multiple beams.

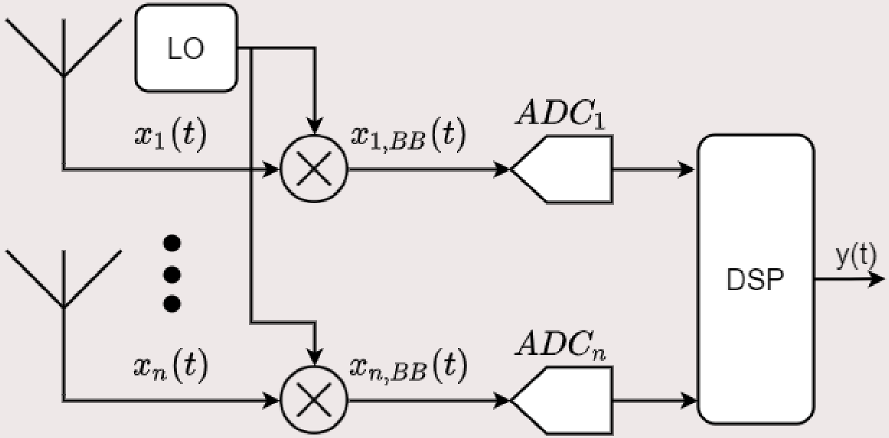


Digital beamforming method

Digital beamforming is performed after the ADC.

This has several advantages:
- Easily change the beamforming direction.
- Possible to support multiple beams.

There are also disadvantages:
- Multiple ADCs are needed to perform beamforming.
- The ADCs need higher requirements to support both the signal and the interferers.



Benefits of analog beamforming

- Analog beamforming lowers ADC requirements
- However, digital beamforming has more flexibility

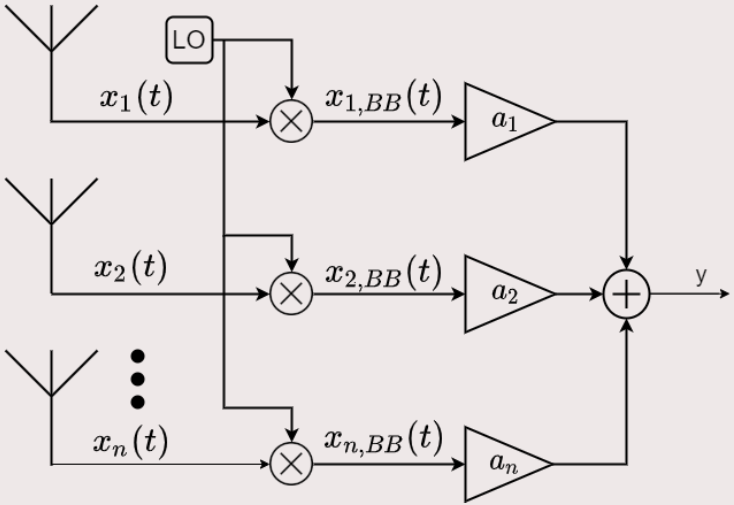
- Therefore, we introduce a novel method which incorporates an analog beamformer into a sigma delta ADC

Our novel beamforming method

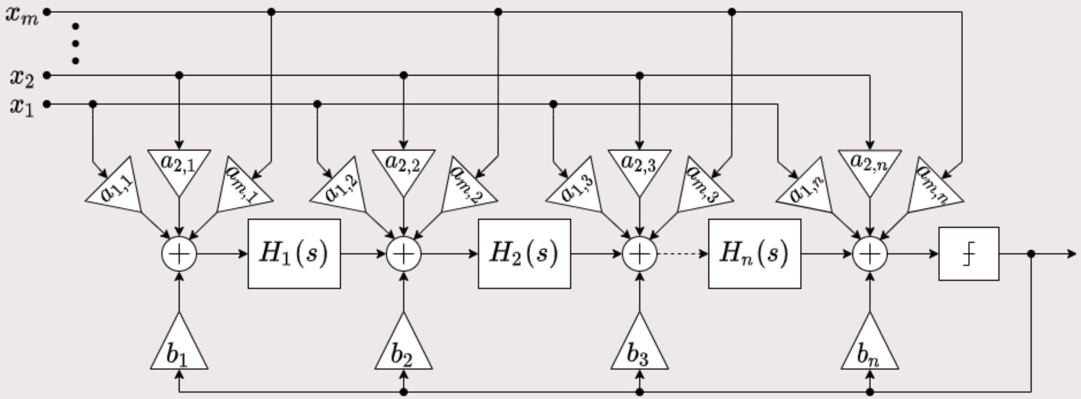
Beamforming can be performed using a spatial FIR filter.

This is similar to a normal FIR filter, only using the spatial frequency of the signal instead of the temporal frequency.

This frequency is then given by $f_{spat} = \frac{d\ sin(\theta)}{c}$, with c the speed of light in meters per second.



Our novel beamforming method

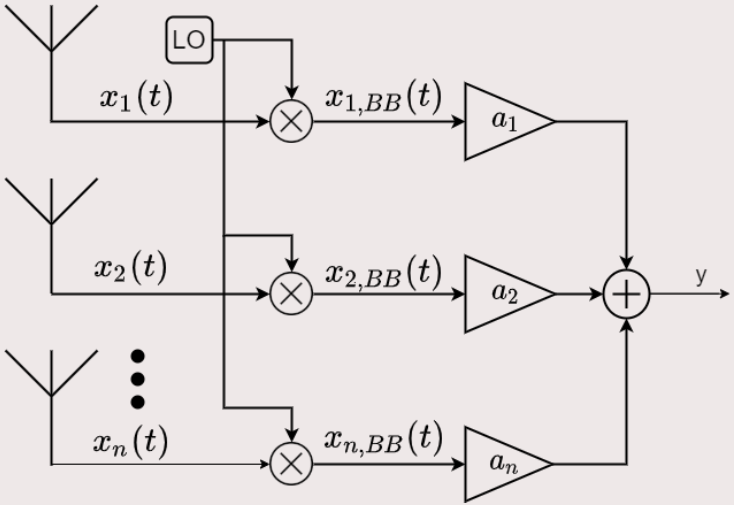


A general implementation of the spatial FIR filters in a Sigma Delta Modulator

Our novel beamforming method

By replacing the feed forwards with spatial FIR filters the signal transfer function becomes incident angle dependent.

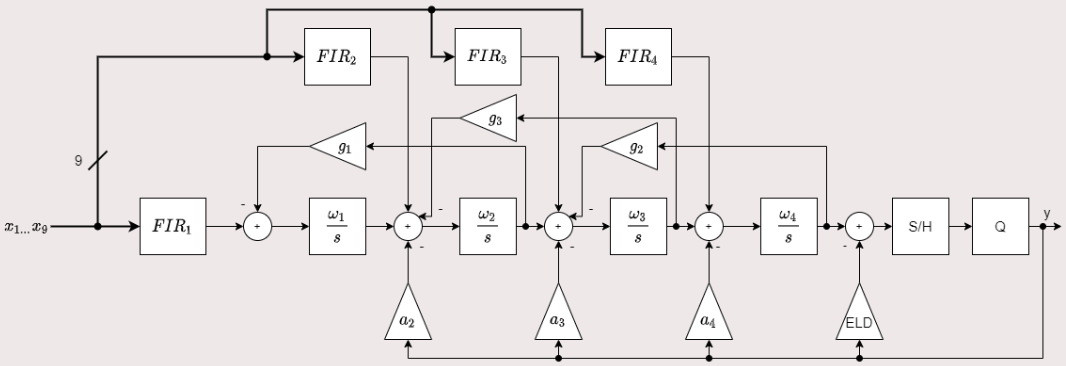
The new feed forward coefficients determine the beamforming response.



Proof of concept implementation

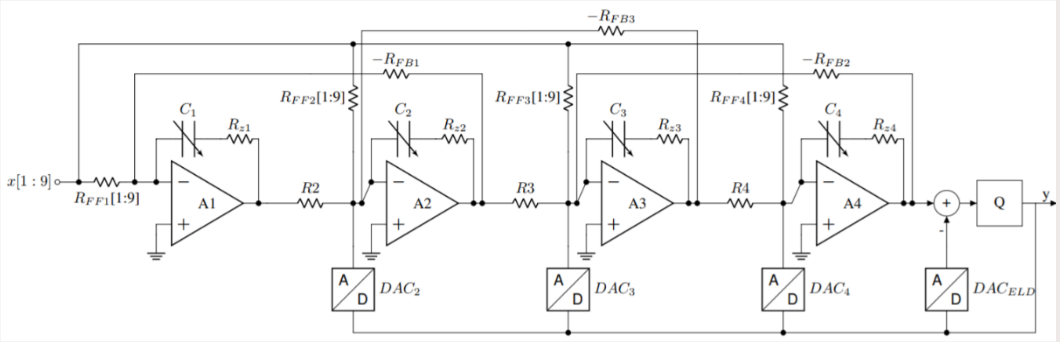
An existing fourth order SDM is fitted with beamforming capabilities.

This can then be compared with a more conventional digital beamformer.



Proof of concept circuit level

The coefficients are implemented using a bank of resistors. Scale currents which are summed at the amplifier virtual grounds.

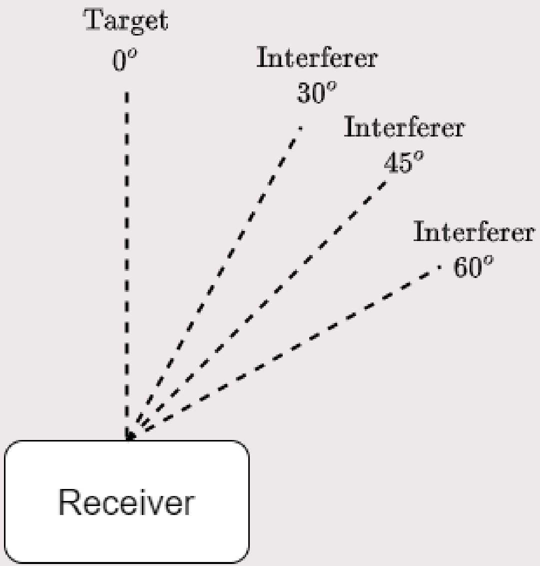


Implementing these resistors with resistive DACs allows the beamforming direction to change.

Simulation setup

The figure on the right shows the receiver with four transmitters.

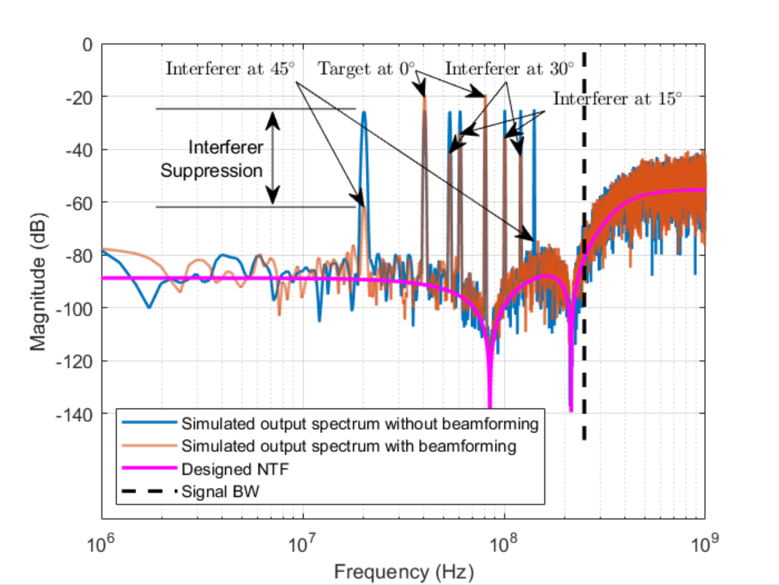
The transmitter positioned at 0 degrees is the target, while the others are interferers.



Simulation results

This figure shows the received spectrum both before and after beamforming is applied. Note that each transmitter transmits two tones at different frequencies.

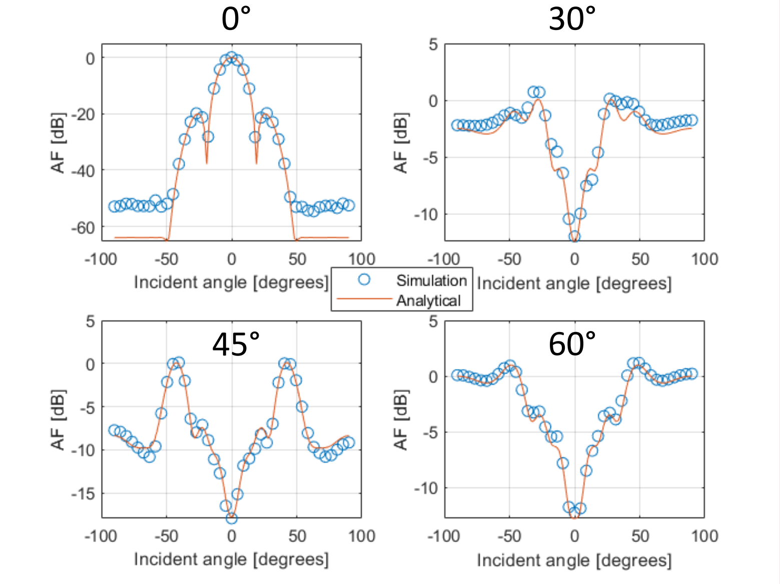
After beamforming the signal power can be increased while keeping the maximum amplitude equal. This is due to the interferer attenuation.



Simulation results

This figure shows the array factor for different beamforming directions.

The different beamforming directions are achieved by changing the digital codes provided to the resistive DACs.



Performance comparison

Compared to a digital beamformer this method uses significantly less power while supporting a higher bandwidth.

However, the digital beamformer supports multiple beams and has a higher SNDR.

[1]Simulation results
*More beams supported

	This work[1]	Digital beamformer[1]
Phased array antennas	9	8
Number of beams	1	2*
IF frequency (MHz)	1000	260
Bandwidth (MHz)	**250**	20
SNDR (dB)	57	63.3
3-dB Main beam width (degrees)	16.27	14
Side lobe level (dB)	-20	-7
Power consumption (mW)	**4**	123.7
Technology	40 nm CMOS	65 nm CMOS

Conclusions

This work introduces a novel beamforming method that uses a spatial FIR filter combined with a sigma delta modulator.

A proof of concept implementation is shown which extends an existing fourth-order SDM with beamforming capabilities using 9 antennas.

This beamformer is then compared to a digital beamforming technique which shows that this method uses significantly less power, but it is also less flexible than digital beamforming.

References

[1] J. Jeong, N. Collins, and M. P. Flynn, “A 260 MHz IF Sampling BitStream Processing Digital Beamformer With an Integrated Array of Continuous-Time Band-Pass ΔΣ Modulators,” IEEE Journal of SolidState Circuits, vol. 51, pp. 1168–1176, may 2016.