FFI Forsvarets forskningsinstitutt

UWB medical radar with array antenna

UWB Implementations Workshop

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FFI
MELODY project

Overview

- Role within the MELODY project.
- Stepped frequency continuous wave radar with gating.
- Motivation for implementing antenna array and array signal processing.
- UWB antenna array design challenges
- UWB array signal processing
- Measurement facilities
- Workplan

The MELODY project

R & D within the field of UWB technology for remote short-range sensing, localization and wireless communication for medical purposes.

Consortium of 4 institutions:
The Interventional Centre, Rikshospitalet
UIO Department of informatics
NTNU Department of Electronics and Telecommunications
The Norwegian Defence Research Establishment (FFI)

Funded by The Research Council of Norway (NFR)

Remote short-range sensing -> UWB radar -> FFI

MELODY at FFI

2 PhD students:

PhD #1:

Øyvind Aardal: *Time series analysis of heart movement measured with UWB medical radar.*

PhD #2:

Jan Hammerstad: *Implement antenna array and apply array signal processing to UWB medical radar measurements.*

1 Post Doc

To be determined

My role within the MELODY project

- Participate in the design of a UWB antenna array for gated SFCW UWB radar in the 3 – 10 GHz frequency range.
- Characterize relevant signal environments and define a suitable statistics for array signal processing.
- Provide and implement array signal processing algorithms for the final setup based on specific measurement scenarios and appointed statistical signal models.

Goals:

- Exploit array gain to improve time series analysis of heart motion (SNR optimization).
- Obtain coarse 3D resolving capability inside torso.
- Distinguish between heart motion of different individuals in a confined space.

Radars

Current radar:

- Stepped Frequency Continuous Wave (SFCW) radar with gating.
- Frequency range: 0.5 – 3 GHz.

(Dual-polarized Vivaldi antennas)

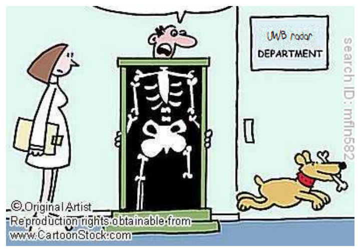
- Here as ground penetrating radar (GPR)

Radar under development:

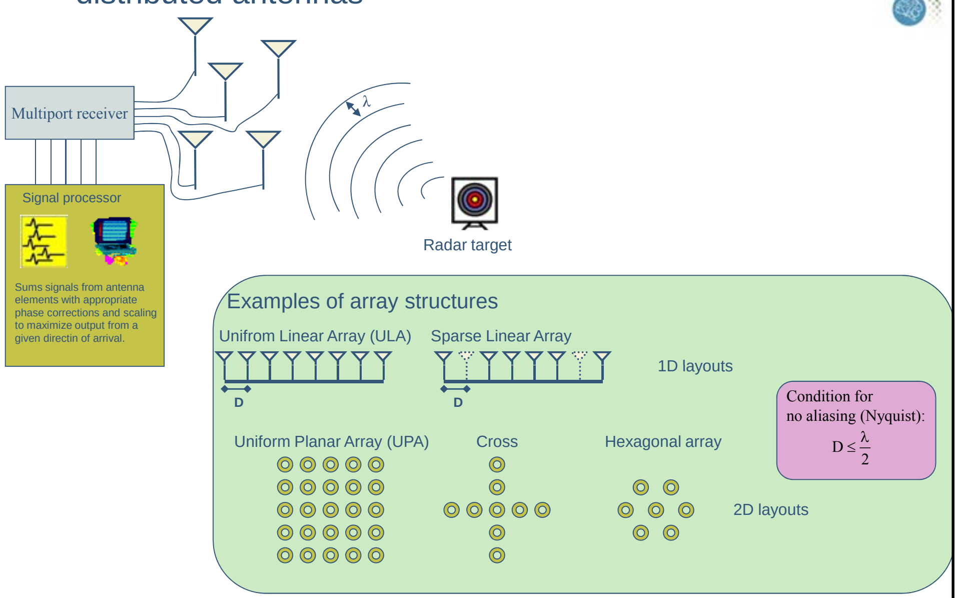
- Same as above, but with frequency range: 3 – 10 GHz

3-10 GHz SFCW radar in development

- In compliance with FCC frequency mask (3.1 – 10.6 GHz, -41.3 dBm/Mhz)
- Antenna sizes become practical for array implementation and clinical testing in a laboratory environment.
- Provides an extention of the frequency range 0.5 – 3 Ghz covered by our current radar.
- Able to use existing architecture – very little additional developement necessary..



Antenna array – a collection of spatially distributed antennas



Why antenna array?

- Overcomes directivity and beamwidth limitations of a single element i.e. increased gain and improved sidelobe handling.
- Able to separate signals on the basis of direction of propagation, without mechanical steering.
  - -> Possible to suppress noise and signals not of interest through digital post processing.
  - -> Possible to obtain radar image by post beamforming.
- Adaptive signal processing can be applied to accomodate a varying signal environment.

Hardware implications

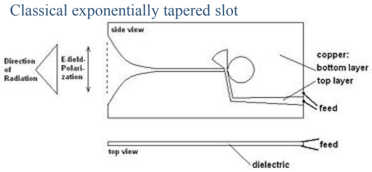
- Antenna elements and array structure must be judiciously chosen to fit the application -> Bandwidth, beamwidth, angular coverage, detection range, reciprocity, dispersion etc.
- Multichannel receiver:
  - - Interchannel coherence – channels must be synchronized.
  - - Short term phase stability (fast time – duration of a frequency sweep)
  - - Long term phase stability (slow time – multiple sweeps)
  - - A multichannel coherent receiver will be developed by the FFI project HUBRA.
- Transmitting antenna elements can be included in the array (duplexing), or be employed externally.

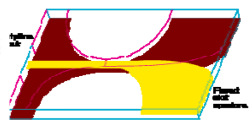
Candidate UWB antenna elements (short list)

Vivaldi antenna:

- Simple manufacturing (PCB).
- Frequency independent design.
- Comparable beamwidth in both cardinal planes.
- Stripline impedance matching to feeding network.

Classical exponentially tapered slot





Antipodal two-layer design

FFI HUBRA-project design

Open-ended TEM waveguide:

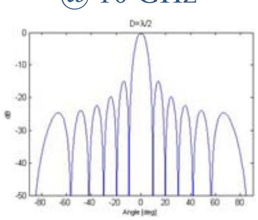
- Basically a TEM horn without flare.
- Elements can be mounted closely in an array.
- Frequency dependent beamwidth.
- Poorly matched to free space.

UWB antenna array challenges

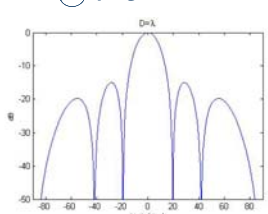
Beamwidth depends on signal wavelength.

Example: Uniform linear array (ULA), antenna separation D = 1.5 cm

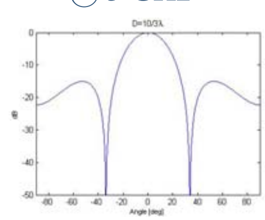
@ 10 GHz



@ 5 GHz



@ 3 GHz



- *Wavelength of UWB radar signals varies greatly, while antenna array structure remains fixed.*
- *Mechanical size of antenna elements needed to support lower frequency range may also conflict the nyquist criterium for maximum antenna separation at higher frequencies (D=wavelength/2).*
- *Small antenna separation may compromise impedance matching due to mutual coupling.*

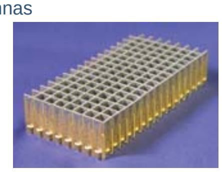
Starting point

- Planar array – 2D layout
- Gating enables use of the same antenna elements for both transmission and reception.
- Number of elements ~ 30
- For use in both near- and far field measurements.
- External collaboration partner: Dirk Plettemeier, Tehnical University of Dresden.
- A multichannel coherent receiver will be developed by the FFI project HUBRA.

Design considertions

- Sparse array structure – larger aperture with fewer elements than a full array.
- Ambiguity considerations, grating- and sidelobe handling.
- Considerations regarding conformity of beampatterns in asimuthal and elevation angle.
- Element separation, mechanical considerations.
- Element separation, electrical considerations.
- Production methods (Vivaldi -> PCB, Horns -> CNC).
- Transmit/receive schemes – alternate between different transmit elements?

Examples of a vivaldi array antennas



Far-field measurement scenario

Fraunhofer definition:

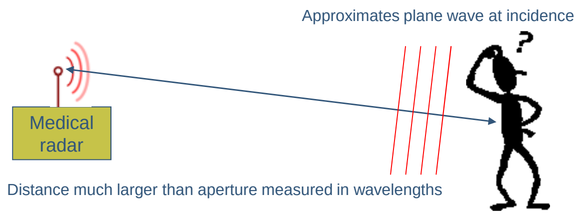
$$Range >> \frac{2d^2}{\lambda}$$

d = largest dimension of aperture

Maximum angular resolution given by Rayleigh limit

$$\theta_{Limit} \approx \frac{\lambda}{d}$$

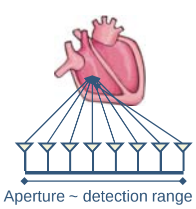
d = largest dimension of aperture



Unfocused array – angular beamsteering only!

Near-field measurement scenario: $Range \leq \frac{2d^2}{\lambda}$

- Array has to be focused on a point in space (3D).
- Higher degree of lateral resolution compared to far-field scenario.



UWB array signal processing

Different from a narrowband scenario - Frequency dependent signal and noise statistics.

Convert well-established narrowband methods to the realm of UWB:

Process single frequency components of a signal at a time – reducing UWB signal processing to a large number of narrowband operations.

- Spectral decomposition necessary e.g. FFT.
- Applicable methods: MUSIC, Capon, Min-Norm etc.
- Performance at a particular frquency bin might benefit from results obtained different bins.

Parameter estimation approach

Use complete time series from each antenna to estimate parameters such as directions of arrival .

- Computationally expensive.
- Special purpose algorithms dominate litterature.

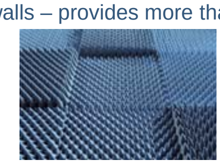
Challenge: Define suitable performance measures

Traditional measures like maximum SNR or minimum mean squared error (MMSE) lose integrity when noise is correlated with the signal – Signal + noise or noise alone?

UWB lab at FFI is in progress

Featuring:

- Mobile pyramidal absorber walls – provides more than -30dB attenuation from 0.5 GHz and upwards.



- ECG as reference apparatus for time series analysis.

- Test objects:

Aluminum spheres for radar cross section (RCS) calibration.

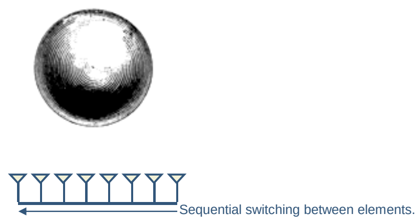
Homo Sapiens.

Calibration sphere

Homo sapiens

First experiment

- Use 0.5 - 3 Ghz radar against calibration spheres.
  - Switched array scheme – target must be stationary.
  - Similar to SAR processing – phase history is preserved.



Lessons learned and applicable techniques will be forwarded to the case of multiple receiving elements when 3-10GHz setup is ready. We will then go on to concentrate on measurements of the human heart with parallel array.

Workplan

Activity	2009		2010		2011	
	1	2	1	2	1	2
Litterature study Courses	■	■	■			
Establish co-operation	■					
Antenna design	■	■				
Antenna prototype realization			■			
Measurements with antenna prototype				■		
Establish algorithms		■	■	■		
Demonstration of algorithms					■	
Documentation						■

However beautiful the strategy, you should occasionally look at the results.
Sir Winston Churchill (1874 - 1965)

?