Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

Circular antenna array beamforming for ultra wideband short pulse applications

Mohammed Shalaby

Fachgebiet Hochfrequenztechnik

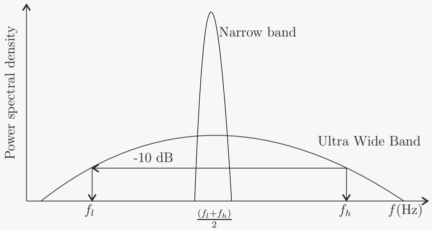
UNIVERSITÄT DUISBURG ESSEN

Bachelor Thesis Presentation
03.05.2007

Contents

1. Introduction and Motivation
2. Narrowband Beamforming
3. UWB Beamforming
4. Simulation Process
5. Future Work

Why UWB?

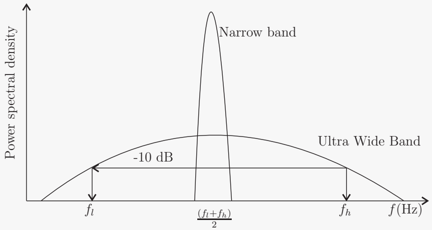


- Enormous bandwidth and therefore according to the shannon's formula

$$C = B\ log_2\,(1 + SNR)$$

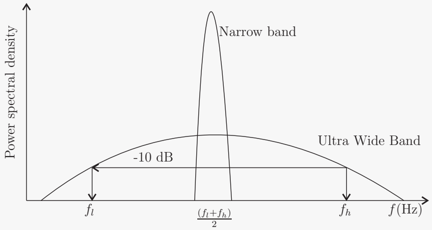
offers very high data rates.

Why UWB?



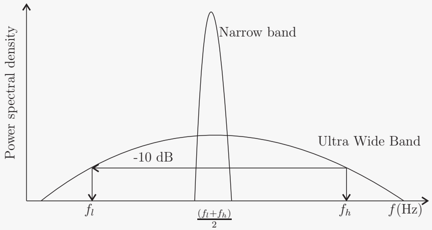
- No need for expensive licensing fees as it can co-exist with existing radio services due to its low power level

Why UWB?



- Immune against detection and interception (as it appears like background noise),has all-weather capabilities and higher angular resolution (very attractive to the military)

Why UWB?



- Baseband technique as the pulse can propagate well without any need for additional modulation stages.

Typical Problems and solution

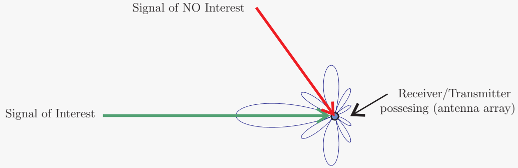
Problems

Like any other wireless technology UWB suffers from multipath propagation and different kind of interferences leading to decreased date rate level.

Solution

Array Beamforming

Why Array Beamforming?



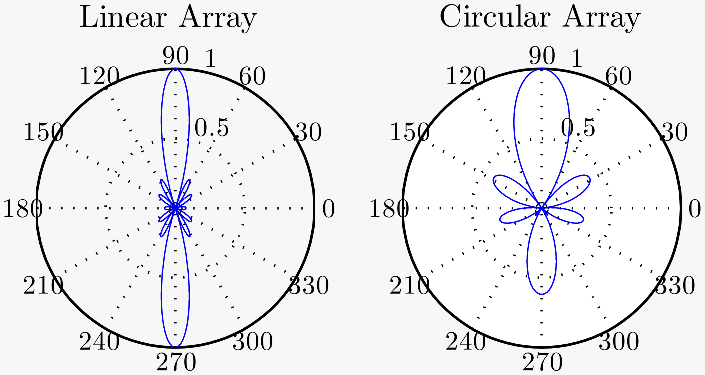
Based on exploiting the physical phenomena of the interference of Electromagnetic waves.
→ Constructive interference towards Signal of Interest.
→ Destructive interference towards Signal of NO Interest.
→ implemented using antenna arrays.
→ The extent depends on the phase shift kl.
→ The direction of the mainbeam and the nulls can be changed electronically

Why Circular Arrays?

Unique Features: Circular Symmetry and lack of edge elements

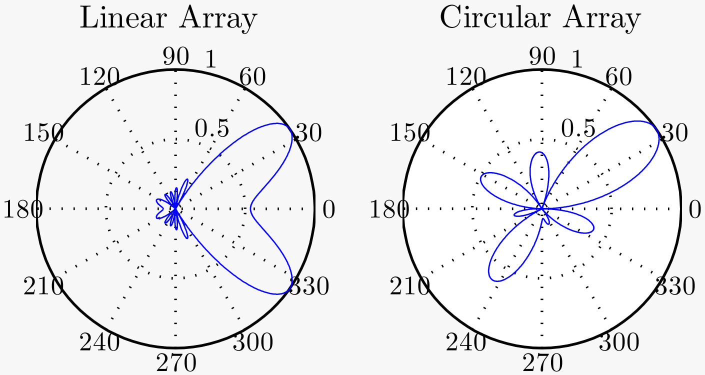
Consequences: It can scan a beam azimuthally through 360^o with little change in beamwidth and sidelobe levels in contrast to linear arrays as we see in the next diagram

Comparison bet. Linear and Circular Array Radiation Patterns



ϕ_o=90 ;N= 8 in both arrays

Comparison bet. Linear and Circular Array Radiation Patterns



ϕ_o=35

Comparison bet. Linear and Circular Array Radiation Patterns

Circular antenna array beamforming for UWB

Mohammed Shalaby

Contents

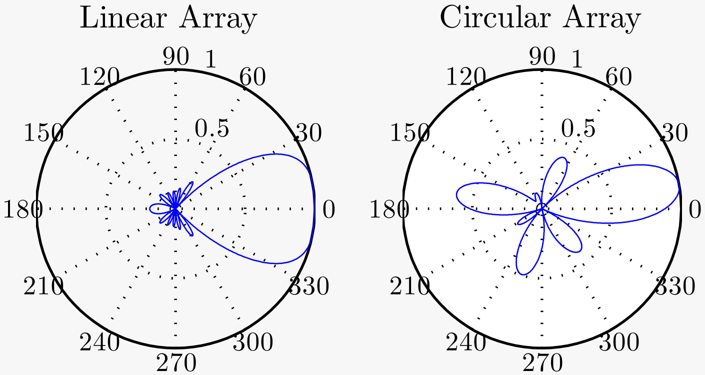
Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

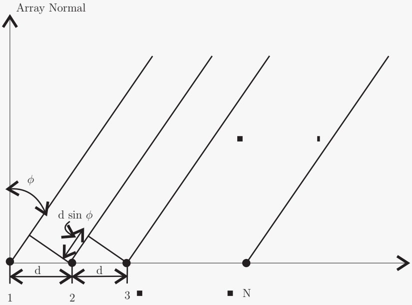
Simulation Process

Future Work



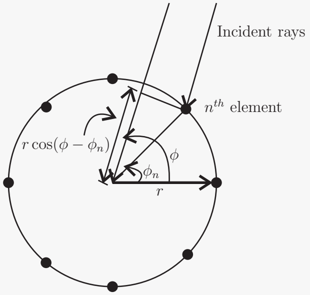
ϕ_o=10

Linear Narrowband Arrays



$$AF = 1 + \exp\{jkd\sin\phi\} + \ldots = \sum_{n=1}^{N} \exp\{j(n-1)kd\sin\phi\}$$

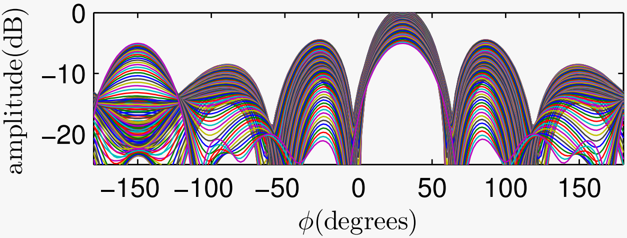
Circular Narrowband Arrays



$$AF_c = \sum_{n=1}^{N} \exp\{jkr\cos(\phi-\phi_n)\}$$

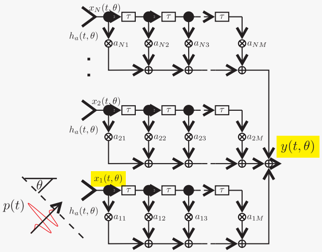
- $\phi_n = \frac{2\pi(n-1)}{N}$
- Assumption:the elevation angle $\theta = 90$

Difference to Narrowband Beamforming



- UWB signal has a very wide bandwidth
- *Each* frequency in that band generates its own radiation pattern as seen in the diagram which is undesired
- Additional Degree of freedom is needed to ensure frequency independency
- Digital solution is not yet possible as current samplers do not offer the need sampling rates

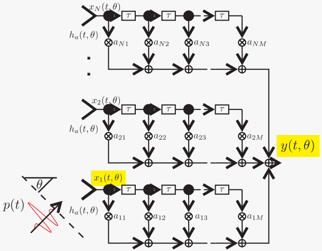
FIR based Beamforming



Advantages of FIR based Arrays

- They are easy to realize as a typical FIR branch consists of *delay elements* which can be implemented using microstrip lines and *multipliers* which can be implemented using FET Technology, thus eliminating the need for the complex phase-shifting circuits used in the narrowband case.

FIR based Beamforming



Advantages of FIR based Arrays

- The array physical size is compact as the inter-element spacing d is determined by

$$d \leq \frac{c}{2f_h}$$

FIR based Beamforming

Circular antenna array beamforming for UWB

Mohammed Shalaby

Contents

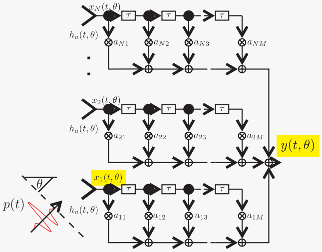
Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

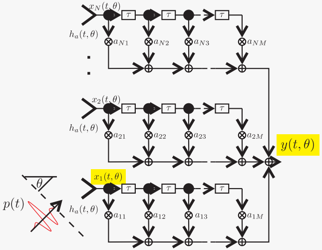
Future Work



Advantages of FIR based Arrays

- Since it has wideband properties, it eliminates the need for different antenna spacing for applications involving various carrier frequencies.

FIR based Beamforming



Advantages of FIR based Arrays

- They can compensate for the frequency responses of the transmitting antenna, receiving antenna and channel (Equalization),so the pulse shape is faithfully reproduced.

Linear UWB Arrays

Circular antenna array beamforming for UWB

Mohammed Shalaby

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

Procedure to determine the coefficients of the FIR filter

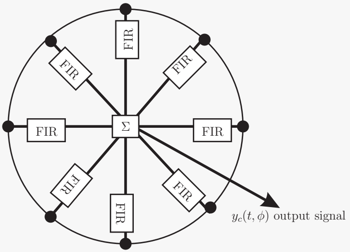
1. we first equate the desired radiation pattern $H_d(f, \phi)$ to the array radiation pattern $H_{arr}(f, \phi)$

$$H_{arr}(f, \phi) = \sum_{n=1}^{N} \sum_{m=1}^{M} a_{nm} \exp\{-j2\pi f[(n-1)\tau_o + (m-1)\tau]$$

2. careful examination of equation 4.2.6 reveals that it looks like a DFT.Thus,by choosing preliminary N and M and applying the IDFT, we get the sought-after coefficients a_{nm}s
3. we autocorrelate the desired radiation pattern H_d and the radiation pattern constructed using the coefficients from step 2 and see whether they are similar enough(a criteria should be defined for that),if not step 2 should be repeated with different values of M and N until a satisfactory result

Circular UWB Arrays

Contents
Introduction and Motivation
Narrowband Beamforming
UWB Beamforming
Simulation Process
Future Work



Time-Domain output signal

$$y_c(t, \phi) = p(t) * \sum_{n=1}^{N} \sum_{m=1}^{M} a_{nm} \delta(t - (m-1)\tau) * (t - ((r/c) \cos(\phi - \phi_n)))$$

where $\phi_n = \frac{2\pi(n-1)}{N}$

Analytical problem

Circular antenna array beamforming for UWB

Mohammed Shalaby

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

Frequency-Domain output signal

$$Y_c(f,\phi) = \sum_{n=1}^{N}\sum_{m=1}^{M} a_{nm} \exp\{-j2\pi f[(m-1)\tau + (r/c)\cos(\phi-\phi_n)$$

where $\phi_n = \frac{2\pi(n-1)}{N}$

- Power of the exponential function not a linear function of n
  $\Rightarrow$ IDFT can not be applied to calculate the coefficients
- attempts to linearize the cosine function
  $\Rightarrow$ proves to be very complicated
  $\Rightarrow$ that's why a numerical solution is preferred

Simulation Process

The influence of the following parameters will be investigated:

- The number of the antenna elements N
- The order of the FIR filters M

Simulation Process

The influence of the following parameters will be investigated:

- The number of the antenna elements N
- The order of the FIR filters M
- The bandwidth of input pulse

Simulation Process

Circular antenna array beamforming for UWB

Mohammed Shalaby

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

The influence of the following parameters will be investigated:

- The number of the antenna elements N
- The order of the FIR filters M
- The bandwidth of input pulse
- The radius of the circular array r

Simulation Process

The influence of the following parameters will be investigated:

- The number of the antenna elements N
- The order of the FIR filters M
- The bandwidth of input pulse
- The radius of the circular array r

Simulation Process

The influence of the following parameters will be investigated:

- The number of the antenna elements N
- The order of the FIR filters M
- The bandwidth of input pulse
- The radius of the circular array r

Finally a Time-Domain example is given to give an impression of the whole Procedure involving typical Parameters.

Variation of the number of the antenna elements N

simulation conditions

3 circular arrays are compared with same:

- radius r
- filter order $M = 8$
- target angle $\phi_o = 80^o$
- signal bandwidth $f_h = 2f_l$ where $f_l = 3.1$ GHz

but with different number of antenna elements $N=$

- 4
- 8
- 16

Variation of the number of the antenna elements N

Contents

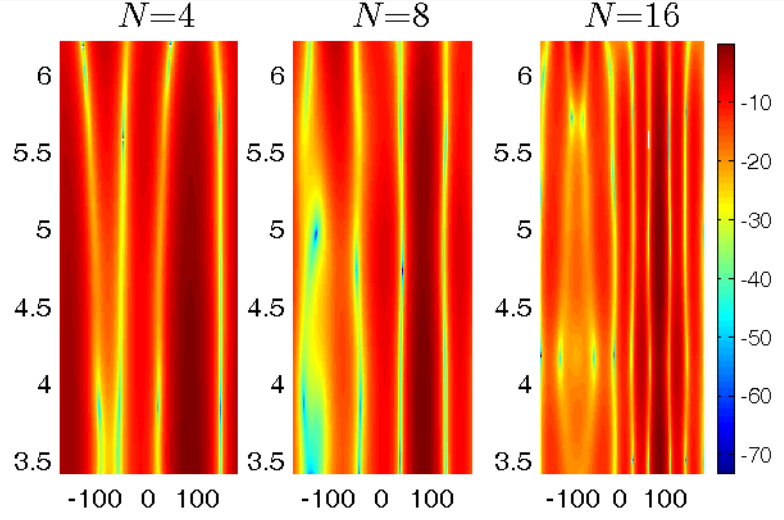
Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work



Variation of the number of the antenna elements N

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

Conclusions

As the number of antenna elements N increases:

- The mainlobe narrows
- The number of sidelobes increases
- Their peak level decreases
- At some value of N saturation is reached

Note: N can not be arbitrarily increased for a fixed radius because of the limitations imposed by the antenna size and the mutual coupling

Variation of the order of the FIR filters M

simulation conditions

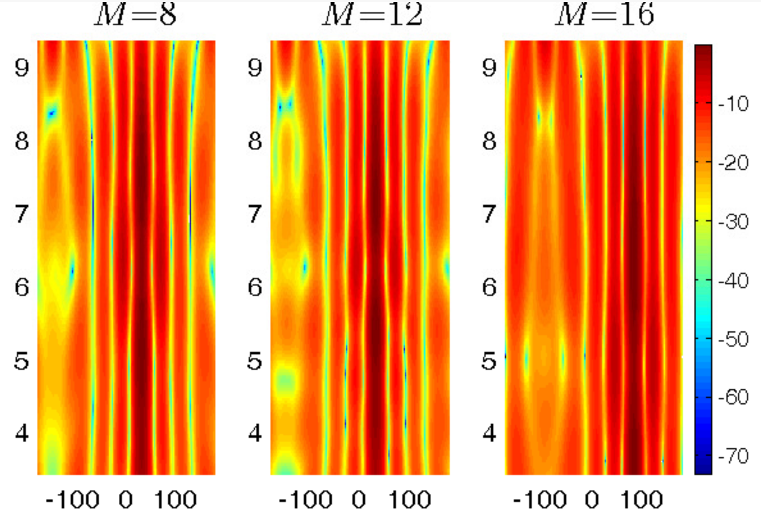
3 circular arrays are compared with same:

- radius r
- number of antenna elements N = 16
- target angle ϕ_o $=30^o$
- signal bandwidth $f_h = 3f_l$ where f_l =3.1 GHz

but with different filter order M=

- 8
- 12
- 16

Variation of the order of the FIR filters M



Variation of the order of the FIR filters M

Conclusions

As the Filter Order M increases:

- The deviation from the desired radiation pattern decreases
- Frequency independency increases
- At some value of M saturation is reached

Variation of the bandwidth of input pulse

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

simulation conditions

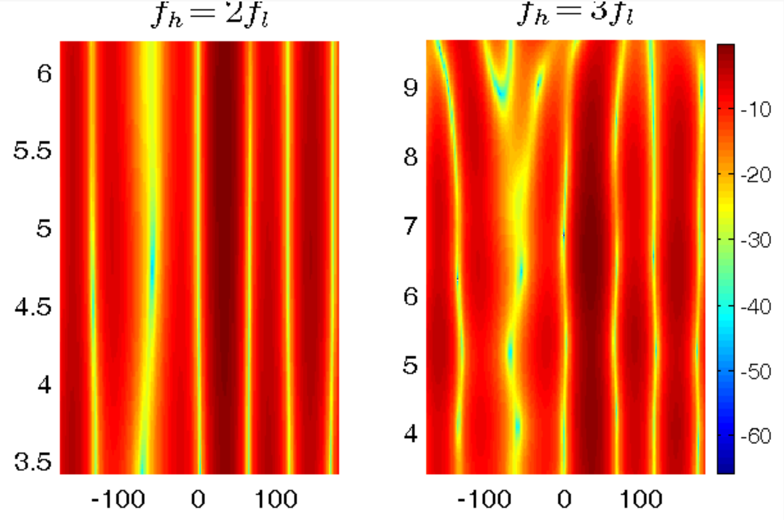
2 circular arrays are compared with same:

- radius r
- number of antenna elements $N = 8$
- target angle $\phi_o = 30^o$
- filter order $M = 8$

but with different relative badnwidth=

- $f_h = 2f_l$
- $f_h = 3f_l$

Variation of the bandwidth of input pulse



Variation of the bandwidth of input pulse

Conclusions

As the bandwidth of the input pulse increases:

- Frequency independency decreases especially at the edges of the band
- Higher Filter order is needed

Variation of the radius of the circular array r

simulation conditions

3 circular arrays are compared with same:

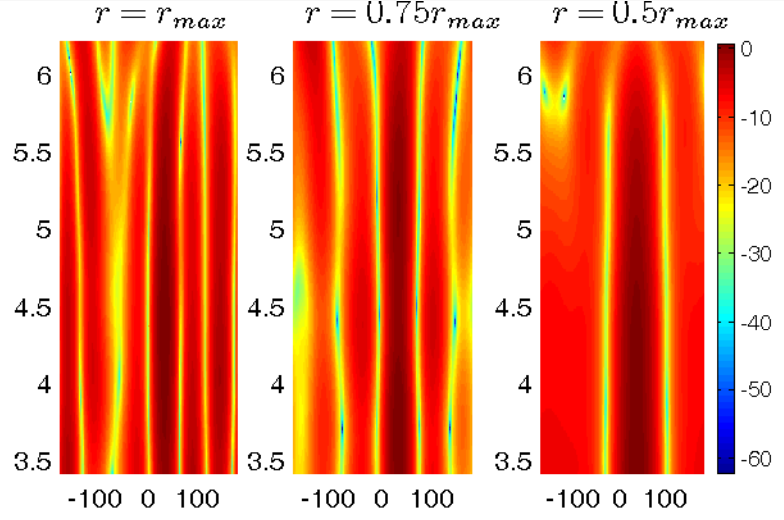
- number of antenna elements $N = 8$
- target angle $\phi_o = 30^o$
- filter order $M = 8$
- relative bandwidth $f_h = 2f_l$

but with different radius $r =$

- r_{max} where r_{max} is $\frac{c}{2f_h \sin(\frac{2\pi}{N})}$
- 0.75 r_{max}
- 0.5 r_{max}

Variation of the radius of the circular array r

Circular antenna array beamforming for UWB
Mohammed Shalaby
Contents
Introduction and Motivation
Narrowband Beamforming
UWB Beamforming
Simulation Process
Future Work



Variation of the radius of the circular array r

Conclusions

As the radius of the antenna elements r decreases:

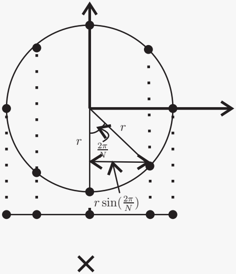
- The number of sidelobes decrease
- The the mainbeam widens

Radius and Grating lobes

- Circular arrays have the inherent characteristics of the presence of undesired higher sidelobe levels compared to linear arrays
- That can be minimized by exerting a limit on the maximum interelement spacing and hence a maximum radius as well
- According to [Balanis 2004] the maximum interelement spacing is the arc $\frac{2\pi r}{N}$.
  $\Rightarrow$ not convincing
- I suggested that r_{max} is $\frac{c}{2f_h \sin(\frac{2\pi}{N})}$ according to the following diagram.

Radius and Grating lobes

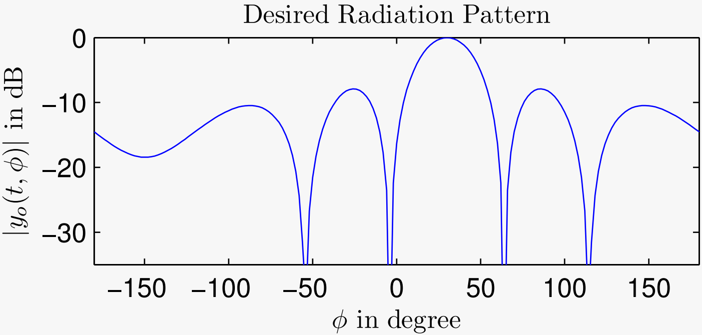
Circular antenna array beamforming for UWB
Mohammed Shalaby
Contents
Introduction and Motivation
Narrowband Beamforming
UWB Beamforming
Simulation Process
Future Work



- Not totally*physically* correct due to the double weighting and interference of opposite elements but *mathematically* correct as long as it is less and not less than or equal
- with a radii in the order 1-2 cm the maneuvering space is very limited due to the antenna physical size
- Smart engineering sense is needed for estimation

Typical Time-Domain Example

GOAL⇒ to realize a Radiation Pattern for a short pulse application using a FIR Circular array. This Broadband Radiation Pattern should resemble (as far as possible) a desired Radiation Pattern of a Narrowband Circular Array with number of antenna elements N=16.



Typical Time-Domain Example

Procedure

1. The number of antenna Elements N is given.
2. f_l and f_h are determined by the -10 dB marks of the Fourier transformed pulse

Typical Time-Domain Example

Procedure

1. The number of antenna Elements N is given.
2. f_l and f_h are determined by the -10 dB marks of the Fourier transformed pulse
3. The radius of the array is determined using f_h to avoid Grating lobes

Typical Time-Domain Example

Procedure

1. The number of antenna Elements N is given.
2. f_l and f_h are determined by the -10 dB marks of the Fourier transformed pulse
3. The radius of the array is determined using f_h to avoid Grating lobes
4. An initial Filter order M is tried and see whether the desired and the synthesized agree (a criteria should be defined)
5. Step 4 is repeated with different values of M until a satisfactory result is reached

Typical Time-Domain Example

Procedure

1. The number of antenna Elements N is given.
2. f_l and f_h are determined by the -10 dB marks of the Fourier transformed pulse
3. The radius of the array is determined using f_h to avoid Grating lobes
4. An initial Filter order M is tried and see whether the desired and the synthesized agree (a criteria should be defined)
5. Step 4 is repeated with different values of M until a satisfactory result is reached

Contents

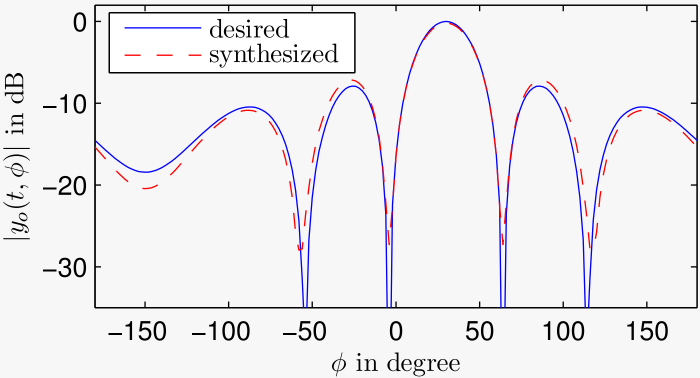
Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work



- $N = 16$; $\phi_o = 30^o$
- $f_h = 3\ f_l$ where $f_l =$ 3.1 GHz
- $M = 14$; $r = 0.016$ m

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

Future Work

- Investigate the influence of the real antenna in terms of physical size,frequency characteristic and mutual coupling
- Try to find an analytical solution for circular arrays

Future Work

- Investigate the influence of the real antenna in terms of physical size,frequency characteristic and mutual coupling
- Try to find an analytical solution for circular arrays
- Examine other geometries, for instance: elliptical arrays

Future Work

Circular antenna array beamforming for UWB

Mohammed Shalaby

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

- Investigate the influence of the real antenna in terms of physical size,frequency characteristic and mutual coupling
- Try to find an analytical solution for circular arrays
- Examine other geometries, for instance: elliptical arrays
- Choose a phase reference other than the array center

Future Work

- Investigate the influence of the real antenna in terms of physical size,frequency characteristic and mutual coupling
- Try to find an analytical solution for circular arrays
- Examine other geometries, for instance: elliptical arrays
- Choose a phase reference other than the array center
- Investigate the effect of the tolerances of electronic components

Future Work

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

- Investigate the influence of the real antenna in terms of physical size,frequency characteristic and mutual coupling
- Try to find an analytical solution for circular arrays
- Examine other geometries, for instance: elliptical arrays
- Choose a phase reference other than the array center
- Investigate the effect of the tolerances of electronic components

Acknowledgments

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

I would like to thank Prof.Solbach for letting me do my thesis in his institute under his supervision.
I would like as well to express my endless gratitude to Mr.Neinhues for his invaluable support and sincere advices.
Last but not least I would like to thank the audience for their attention

Contents

Introduction and Motivation

Narrowband Beamforming

UWB Beamforming

Simulation Process

Future Work

Questions?