Silicon-Based Ultra-Wideband Beamforming

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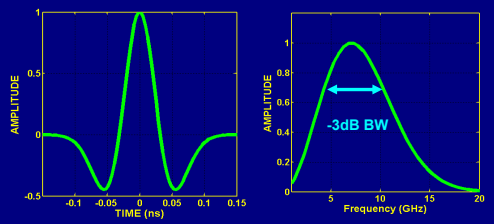
Concept

UWB beamforming yields millimeter depth resolution and high azimuth resolution.

Potential Applications
- Ground and wall penetrating radar
- Biomedical imaging
- Automotive navigation

The first fully integrated UWB beamformer on silicon.

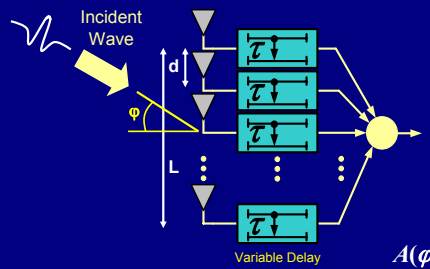
Typical UWB Impulse Signal



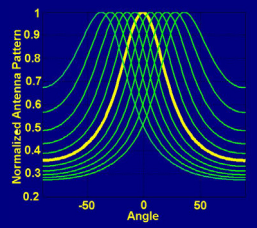
Depth resolution ∝ Pulse width ∝ $\frac{1}{\text{Bandwidth}}$

Azimuth resolution ∝ Beam width ∝ $\frac{1}{\text{Bandwidth}}$

UWB Beamforming Array



UWB Array Pattern



$$A(\varphi) = \frac{erf\left(\sqrt{\pi}L(\sin\theta - \sin\varphi)/2\Delta Tc\right)}{\left(\sqrt{\pi}L(\sin\theta - \sin\varphi)/2\Delta Tc\right)}$$

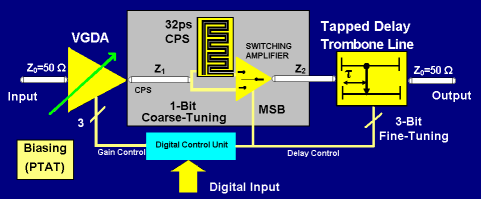
Requirements
- Monocycle Gaussian signal
- True time delay architecture

Features
- Higher depth resolution
- High azimuth resolution
- No distinct side lobes in the array pattern

Implementation
- Standard silicon process

Design

UWB Beamformer System Diagram

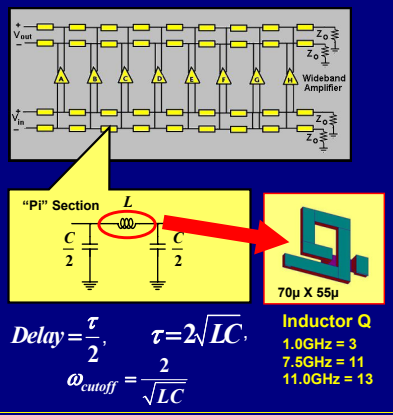


Delay
- 4-bit delay control
- 4ps resolution
- 64ps maximum

Gain Variation
- 5dB variation
- 1dB resolution
- 10dB maximum

Impedance
- 50Ω input/output
- 50Ω inter-stage CPS

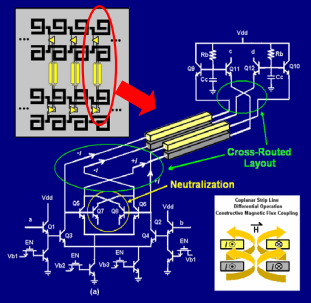
Tapped Delay Trombone Line



$$Delay = \frac{\tau}{2}, \quad \tau = 2\sqrt{LC}, \quad \omega_{cutoff} = \frac{2}{\sqrt{LC}}$$

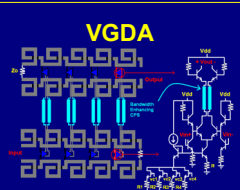
Inductor Q
1.0GHz = 3
7.5GHz = 11
11.0GHz = 13

Wideband Amplifier

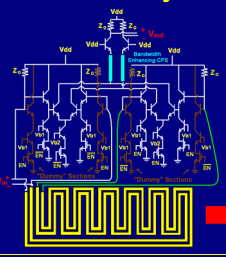


CPS
Width=4μm
Length=250μm
Separation=20μm
Vertical Separation=2μm

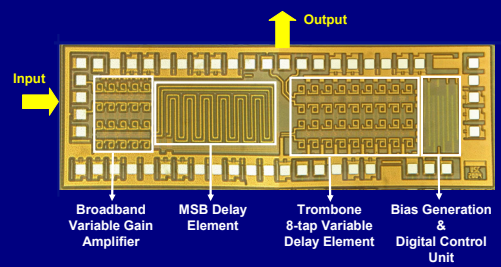
VGDA



MSB Delay



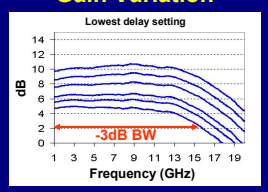
CPS
Length = 4.9mm
Z_0 = 100Ω
Spacing = 10μm
Width = 10μm
ε_{eff} = 5
α(1GHz) = 0.113dB/mm
α(11GHz) = 0.205dB/mm



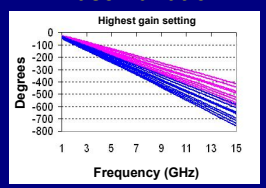
Total Chip Size: 2.5mm x 0.9mm

Results

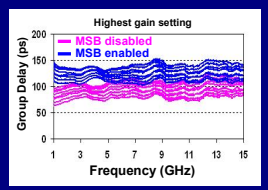
Gain Variation



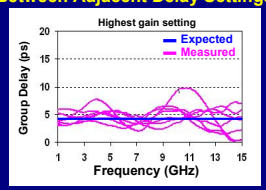
Phase Variation

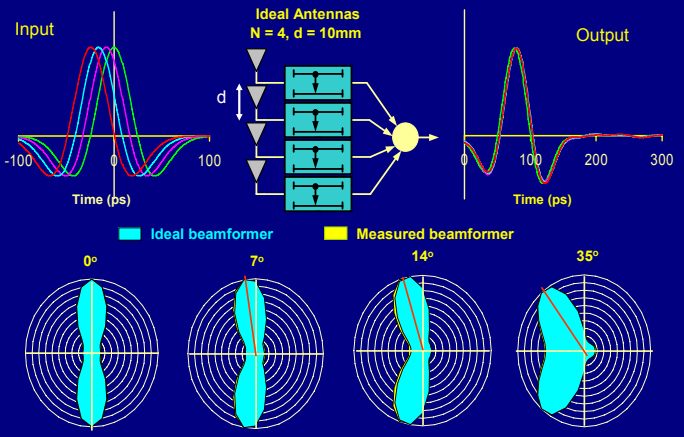


Group Delay Variation



Group Delay Difference
(Between Adjacent Delay Settings)





Performance	Result
UWB delay resolution	4ps
Total achievable delay	64ps
Worst case -3dB bandwidth	13GHz
Gain peaking over bandwidth	1dB
Gain difference over delay settings	2dB
Maximum system power gain	10dB
Power gain tuning range	5dB in 1dB steps
UWB steering resolution	7° (4 elements)
Narrow band steering resolution	3.5° (4 elements)
Power consumption	87.5mW (2.5V)
Area	2.25mm²
Technology	0.18μm BiCMOS SiGe