22G1

Narrowband Multi-Cycle
vs.
Ultra-Wideband Mono-Cycle Signaling
A Comparison of Antenna Array Patterns

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Acknowledgements

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Goals

Major Goal:

To increase awareness of the potential benefits of using the emerging technology of Ultra-short pulse RF signaling.

In particular how to achieve an RF radiating system with:

- No side lobes
- No grating lobes
- High element sparsity
- Increased tolerance to structural flexing
- Substantially reduced system complexity
- Ultra-wideband widths with high spatial resolution
- Graceful pattern degradation due to element failure
- Agile and Multi-beam True Time Delay (TTD) beam positioning

Cost: Working in the time-domain and developing some new technology.

Two Ways to Radiate

There are two ways to radiate energy in general: Harmoniclly & Anharmoniclly.

Harmoniclly

- Period of E = Period of H
- Ratio of E/H = constant in a medium
- Time evolution characterized by $(t \pm zv^{-1})$, where v = phase velocity

These properties do not come directly from Maxwell's equation but are imposed by those who solve equations in the form of continuous emission conditions.

Anharmoniclly

- Period of E $\neq$ Period of H
- Ratio of E/H $\neq$ constant in a medium
- Time evolution characterized by factors like $(t \pm zc^{-1})$ and $(t^2 \pm z^2c^{-2})^{1/2}$

Many familiar properties of classical EM like incident and reflection angles of a signal appear to be subject to generalization.

Why the Historical Bias for Narrowband Signaling?

Question:

Who's to "blame" and what were the circumstances that lead to the present focus on narrow band solutions to signaling?

One Possible Answer:

Johann Bernoulli

- **Johann Bernoulli (1667-1748) a contemporary of Sir Isaac Newton who introduced the principle of the *separation of variables* to the solution of partial differential equations. He was *too* successful!**

- **The principle of the separation of variables *restricts* the class of possible solutions of PDE's and the Klein-Gorden or wave equation in particular. It was so successful that it diverted attention from other possibilities.**

- **Theory compliments experiment but, only simple long duration, i.e. narrowband experiments have been possible during most of the last one hundred years further adding to the historical bias.**

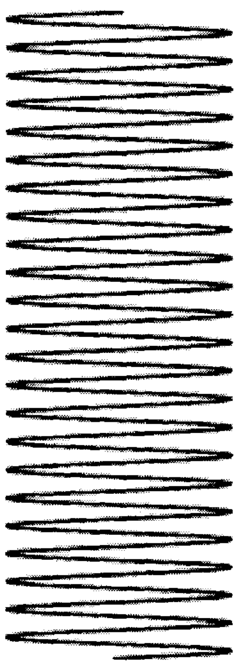
- **Most contemporary scientists have never even seen the "other" exact *anharmonic* solutions which were only recently discovered in 1993 by Shvartsburg, although the idea of its existence has been around for a couple of decades.**

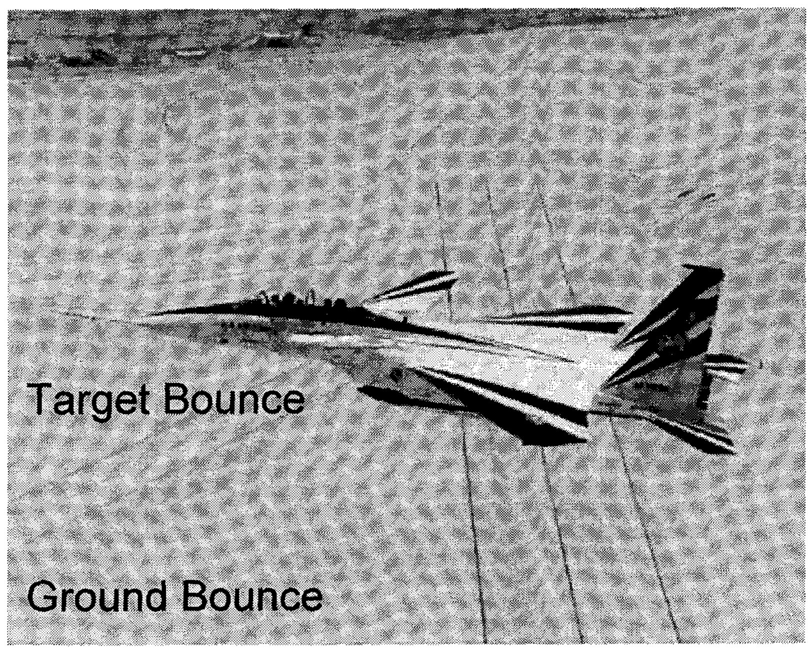
- **Much of the information contained in Maxwell's equation is lost by Bernoulli's technique. However, investigating new physics can reasonably be expect to lead to new technology applications.**

AMTI Processing is Simple

The narrow spatial extent of an ultra-wideband RF pulse makes the discrimination of the aircraft from the ground based on time-domain reflection possible.

Narrow band RF pulse





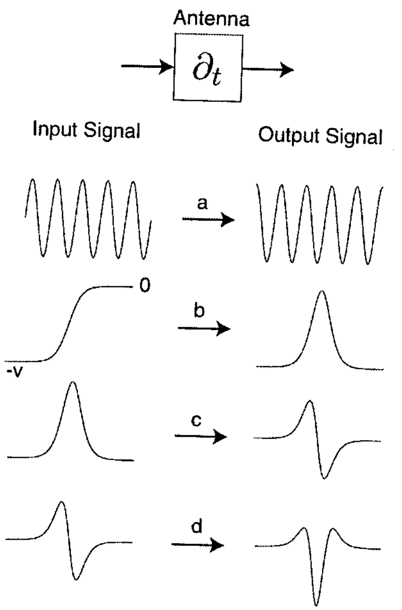
Ultra-Wideband RF pulse

Art courtesy of Jim Stephens

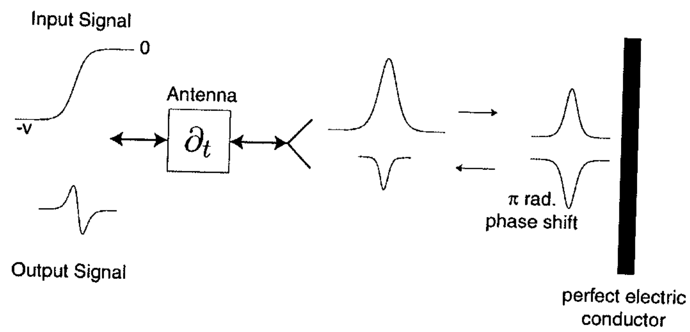
Basic Response of Pulsed Antennas

The Derivative Property

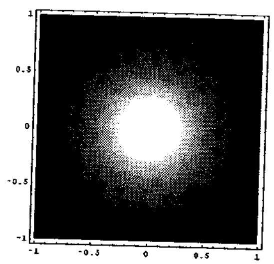
All antennas take the derivative of the signal being processed in the far field.



A Simple Radar System

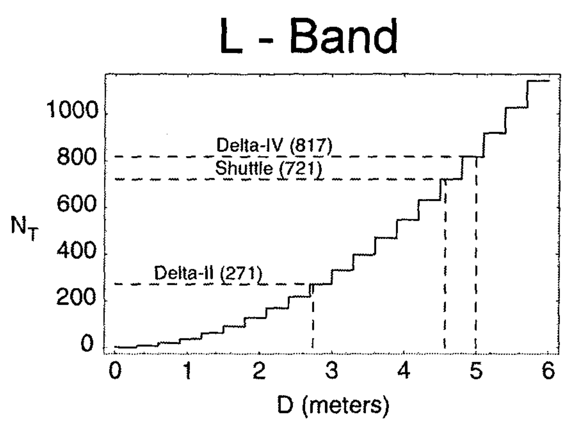


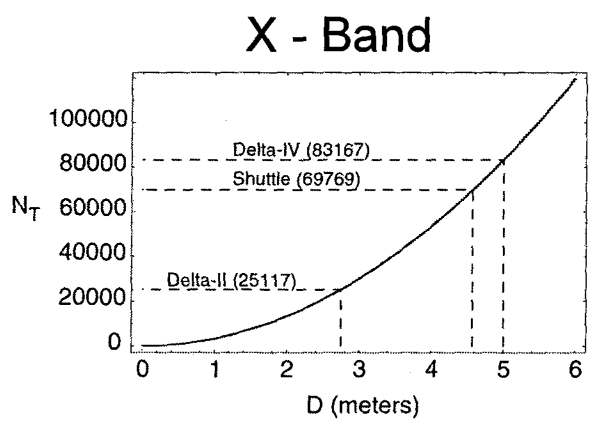
$$AF = \frac{\mathrm{erf(x)}}{x}$$



An array of antennas like that shown in the simple system above will give a radiation foot-print at the target as shown above. The foot-print dimensions could, in principle, be on the order of the minimum wavelength (highest energy) component used in the waveform. To achieve this atmospheric dispersion must be accounted for in the transmitted signal.

T/R Module Quantities Limit Deployable Array Size





IF

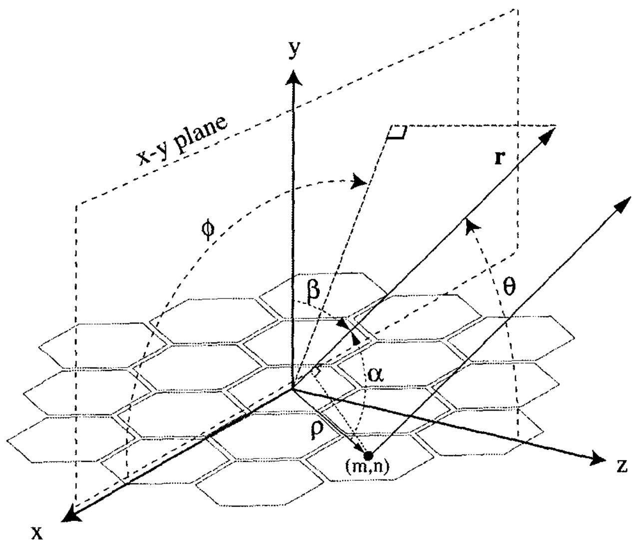
- Fully filled array
- Half wavelength spacing
- 4.57 meter diameter payload
- 19 panels in array
- Sinusoidal signaling at X and L bands

THEN LASR REQUIRES

- Total of 70,490 antenna elements per panel
- 1,339,310 elements per complete LASR array

Designs may vary but the number of elements will always be large when using a fully populated array structure for a narrow band system.

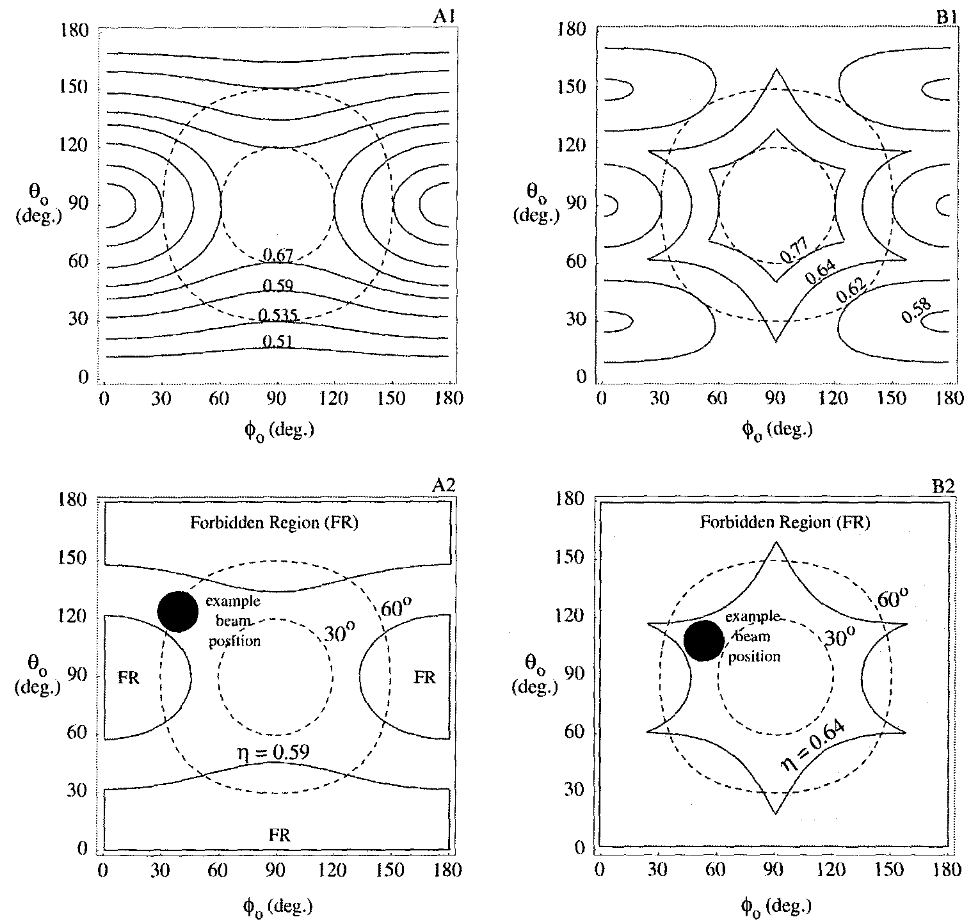
Narrow Band T/R Modules Limit Deployable Array Performance



Coordinate System

- Grid determines general shape of forbidden region.
- Inter element spacing determines allowable scan angles.
- Beam width reduces the visible scan region by half a beam width.
- Narrowband fully packed arrays are inefficient.

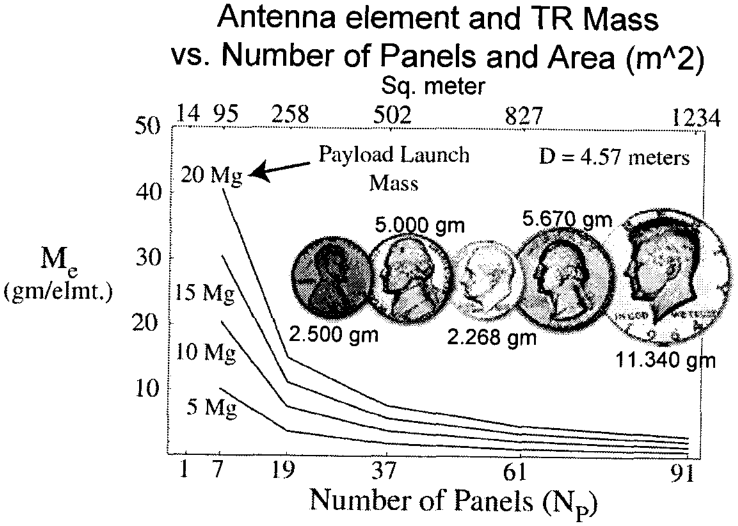
Onset of Grating Lobes



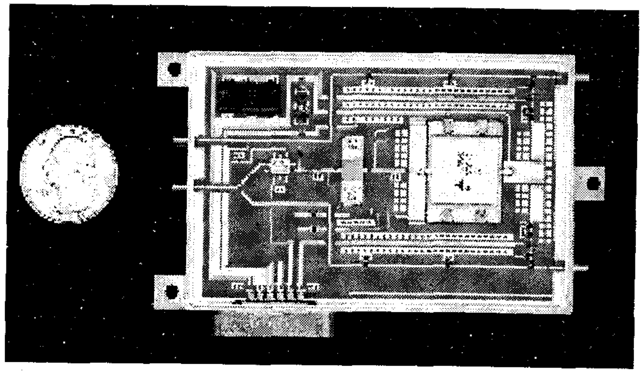
Rectangular (A) Hexagonal (B)

Allowed scan angles parameterized by inter-element spacing is measured in wavelengths.

T/R Module Mass Limit Deployable Array Size

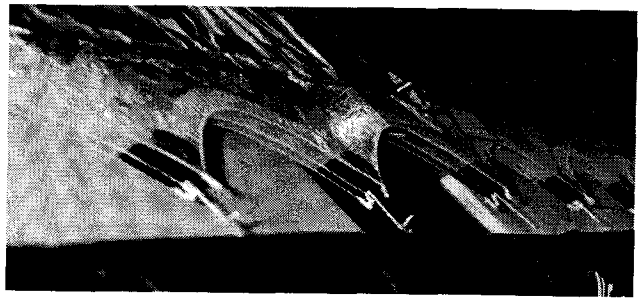


Here we see that a fully populated array can not have an antenna element that exceeds the value M_e as an upper limit. In a practical array the value of M_e should be a fraction of the limit stated here so that other systems can be integrated into the LASR structure (ex. solar power etc. and attitude control.)



Current rigid T/R modules are incompatible with flexible satellite structures and are also too massive and power hungry to be practical on a fully populated array. Here is an example.

The T/R modules need to fit into the form factor of a flexible membrane if we were to use the current state of the art in low mass antenna arrays. The multi-layer structure of such an antenna is shown.



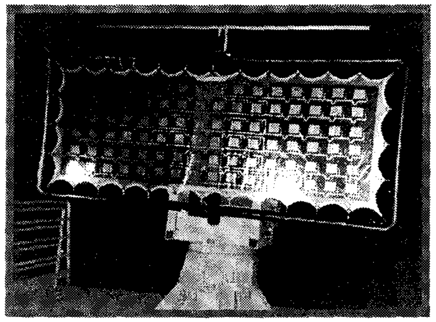
Motivational Problem for using Anharmonic Signaling

Design a low mass, low cost, very large aperture satellite with dual scientific and defense applications.

- Either Orbiting or Stationary
- Extremely Large Aperture (> 1000 m^2)
- Communications Capability
- Multiple Simultaneous Missions
- Frequency Diverse
- High Resolution Imaging
- GMTI and AMTI
- Tracking

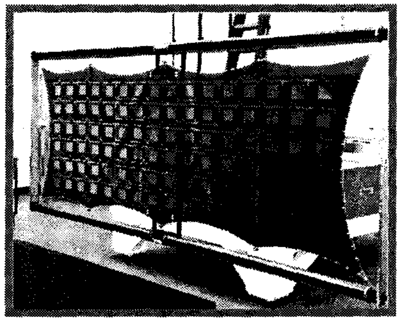
Technology Horizon: 2010+

Low Mass Inflatable Satellites
Still a Traditional EM Approach



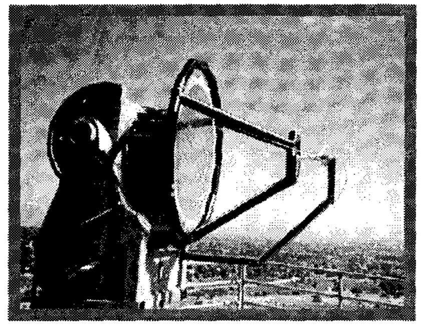
Specs:
- Frequency: L-Band (1.25 GHz)
- Measured Gain: 30 dB
- 3 dB Bandwidth: 4.5 deg
- Surface Flatness: < +/- 0.075 cm
- Aperture: 1m x 3.3m
- Mass: 15.5 kg
- Materials: Urathane Coated Kevlar Tubes, Kapton Membrane, Copper Patches

4.7 Kg/m^2



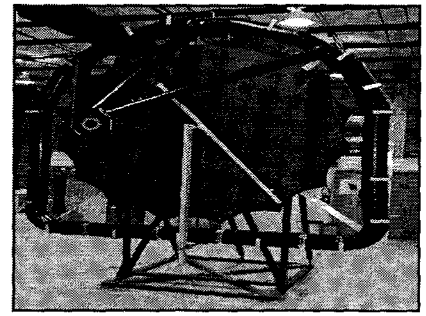
Specs:
- Frequency: L-Band (1.25 GHz)
- Measured Peak Gain: 27 dB
- **Peak Efficiency: 74%**
- Surface Flatness: +/- 0.024 cm
- Aperture: 1m x 3.3m
- Mass: 11 kg
- Materials: Rigidizable Al Laminate, Kapton Membrane, Copper Patches

3.3 Kg/m^2



Specs:
- Frequency: X-Band (8.4 GHz)
- Measured Gain: 33.7 dB
- 3 dB Bandwidth: 2.4 deg
- **Efficiency: 37%**
- Surface Flatness: < +/- 0.075 cm
- Aperture: 1 meter diameter
- Mass: 1.2 kg
- Materials: Urathane Coated Kevlar, Kapton Membrane, Copper Patches

1.5 Kg/m^2



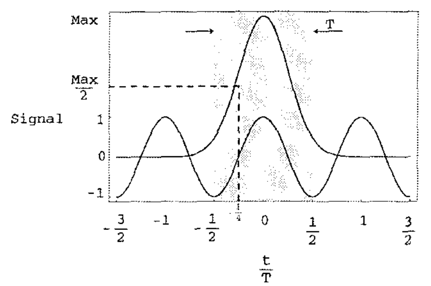
Specs:
- Frequency: Ka-Band (32 GHz)
- Measured Gain: 50 dB
- **Efficiency: 10%**
- Surface Flatness: < +/- 0.05 cm
- Aperture: 3 meter diameter
- Mass: 12.9 kg
- Materials: Urathane Coated Kevlar and Kapton Membrane, Copper Patches

1.8 Kg/m^2

- These are fully populated arrays
- The arrays have no active electronics
- Increasing sparsity could reduce mass per unit area
- Low mass flexible arrays have historically had low efficiencies

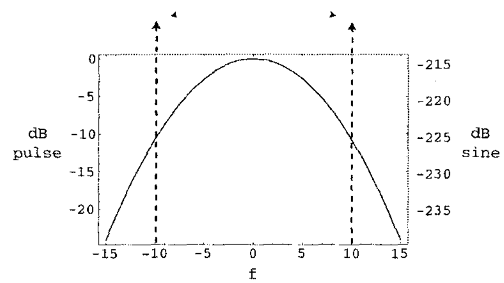
Basic Processing Principles

Waveforms Patterns

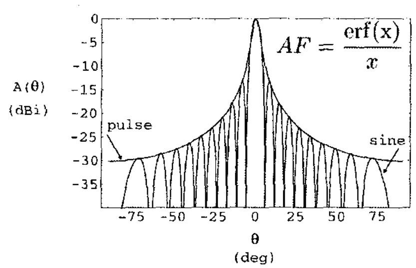


(A)

0 dB_sine
not to scale

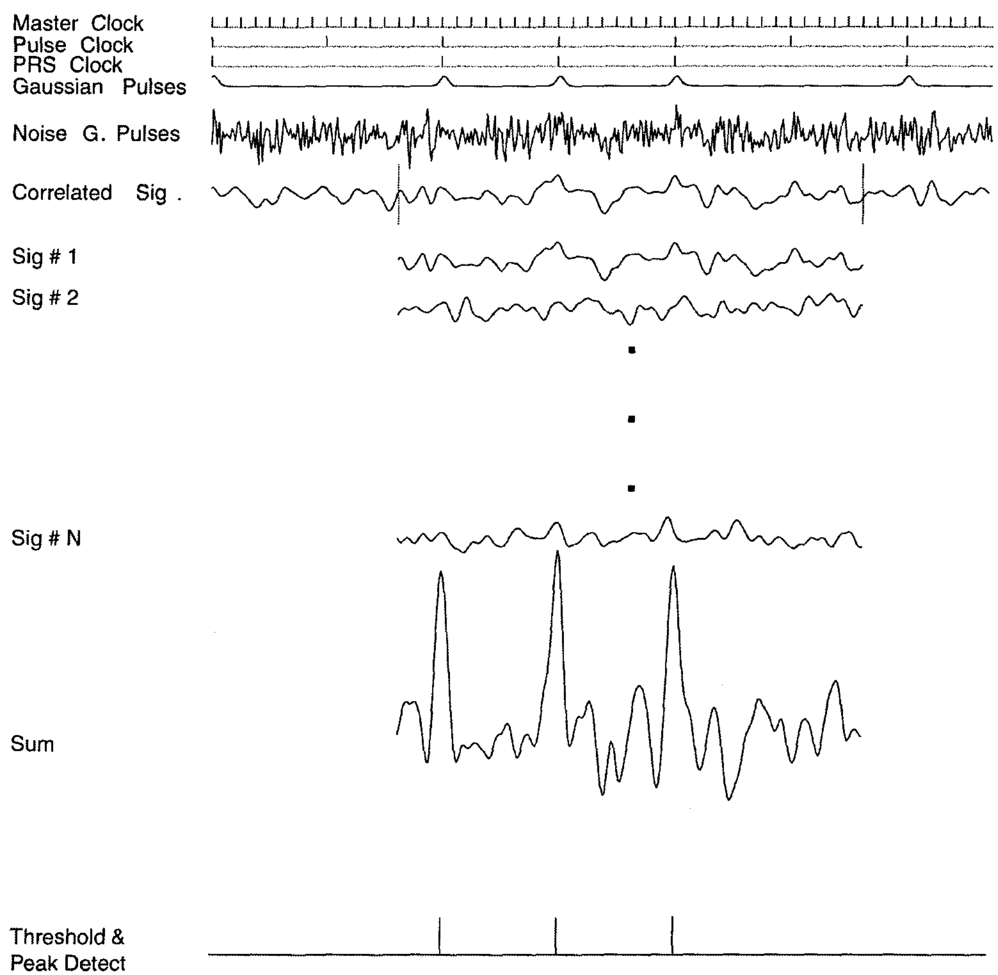


(B)

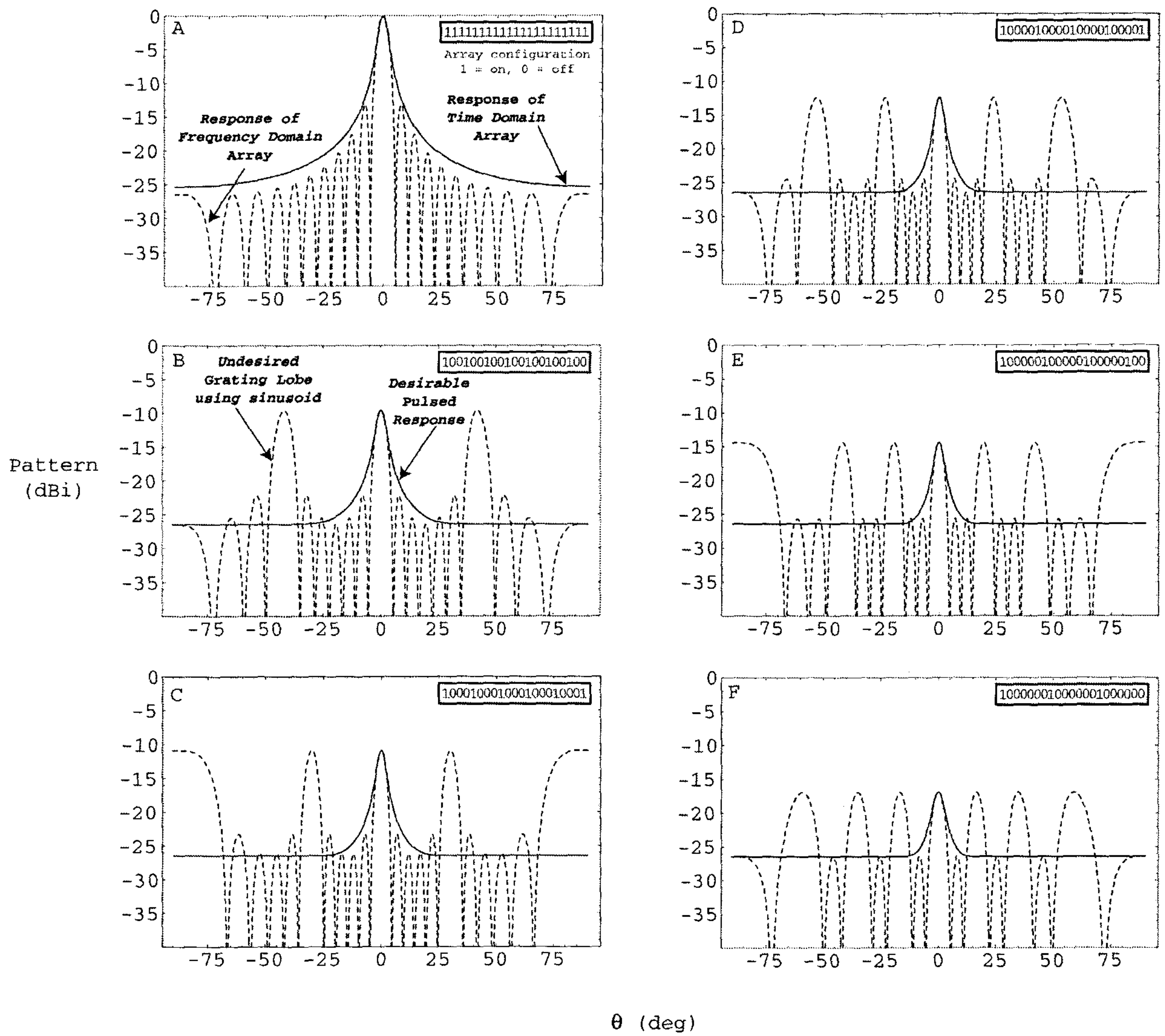


(C)

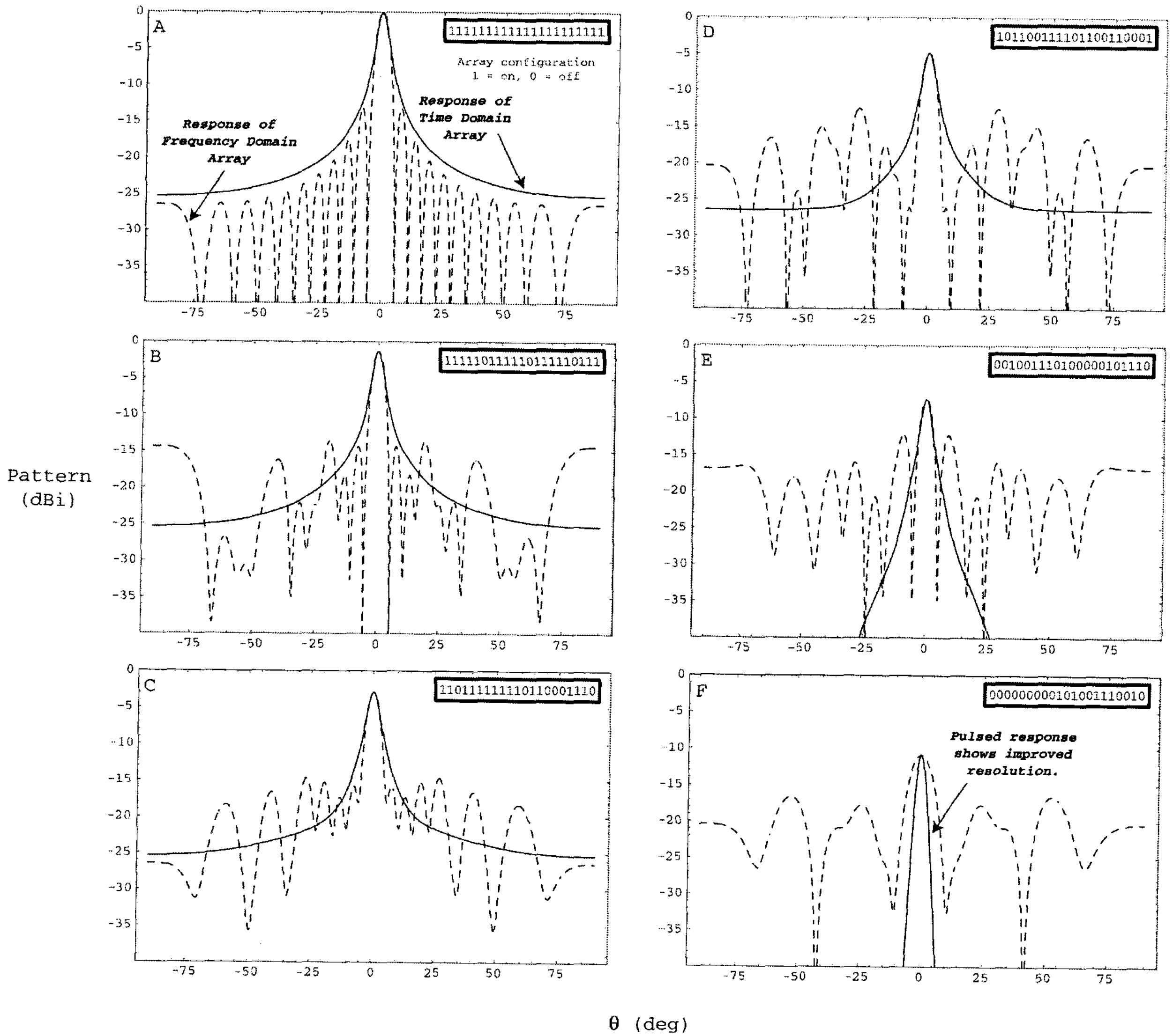
A Simple Processing Example



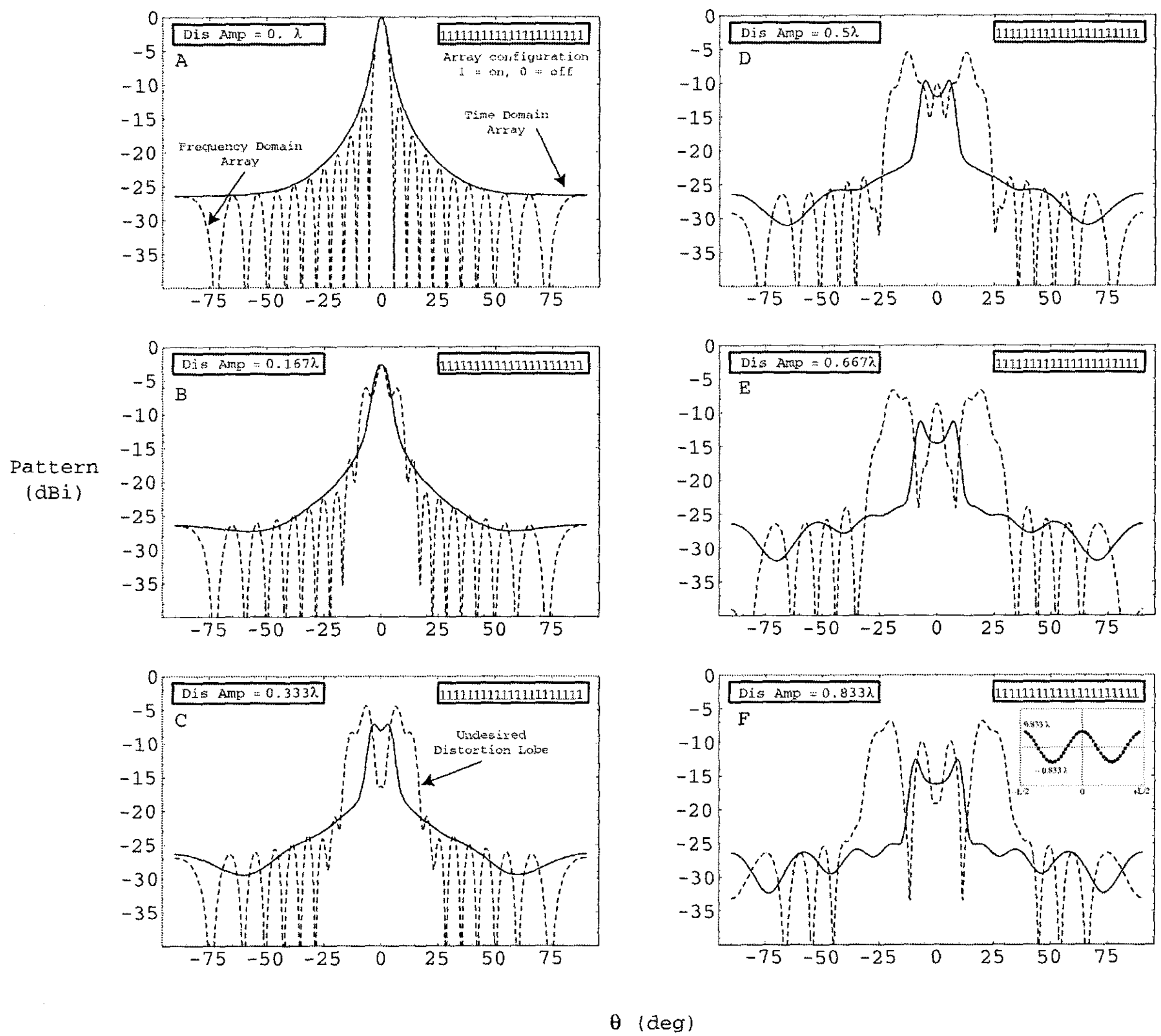
Periodic Array Thinning



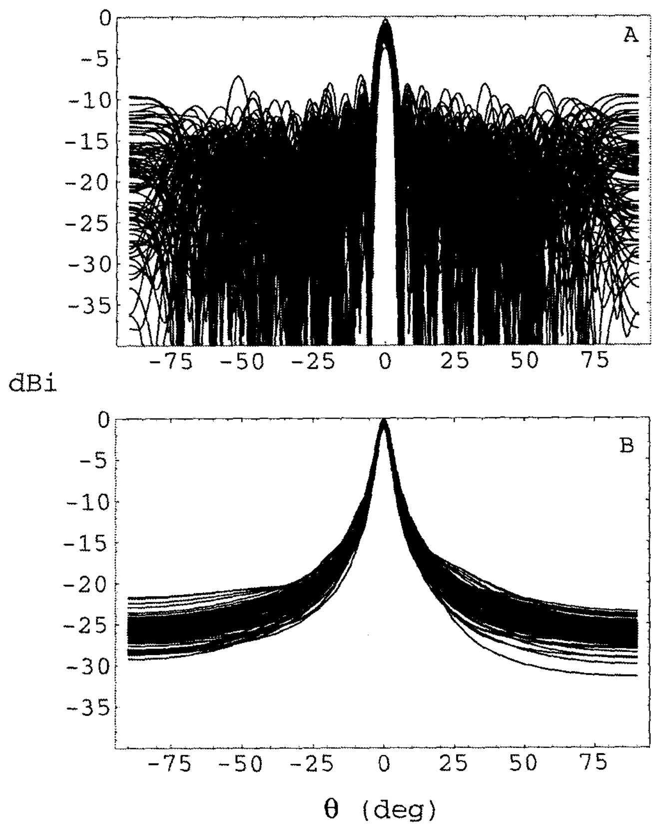
Random Array Thinning



Distorted Antenna Platform



Monte Carlo Simulation

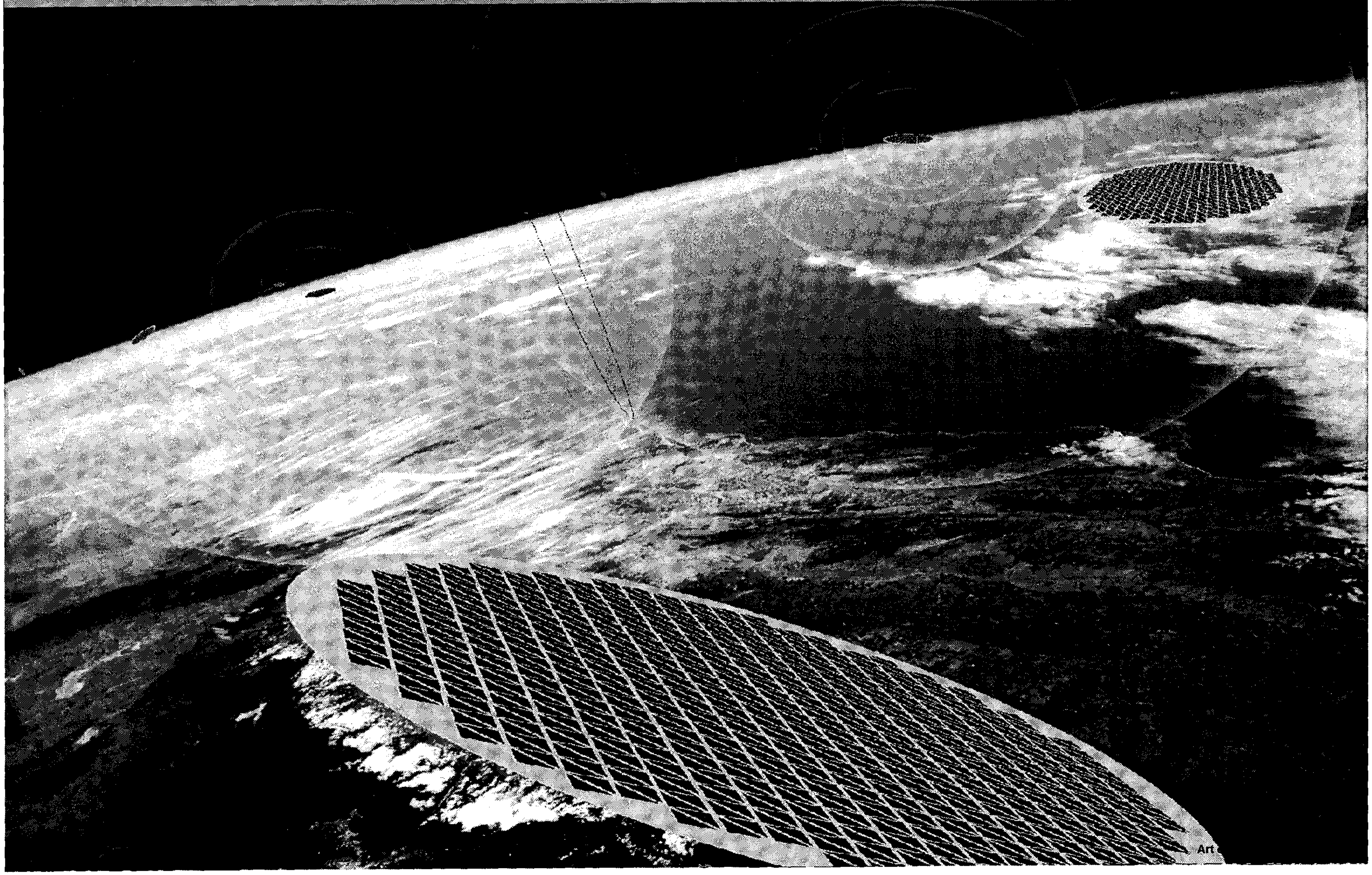


When normally distributed timing and position errors were introduced with a large std. dev. = 10% T the time domain response is shown to be much more robust.

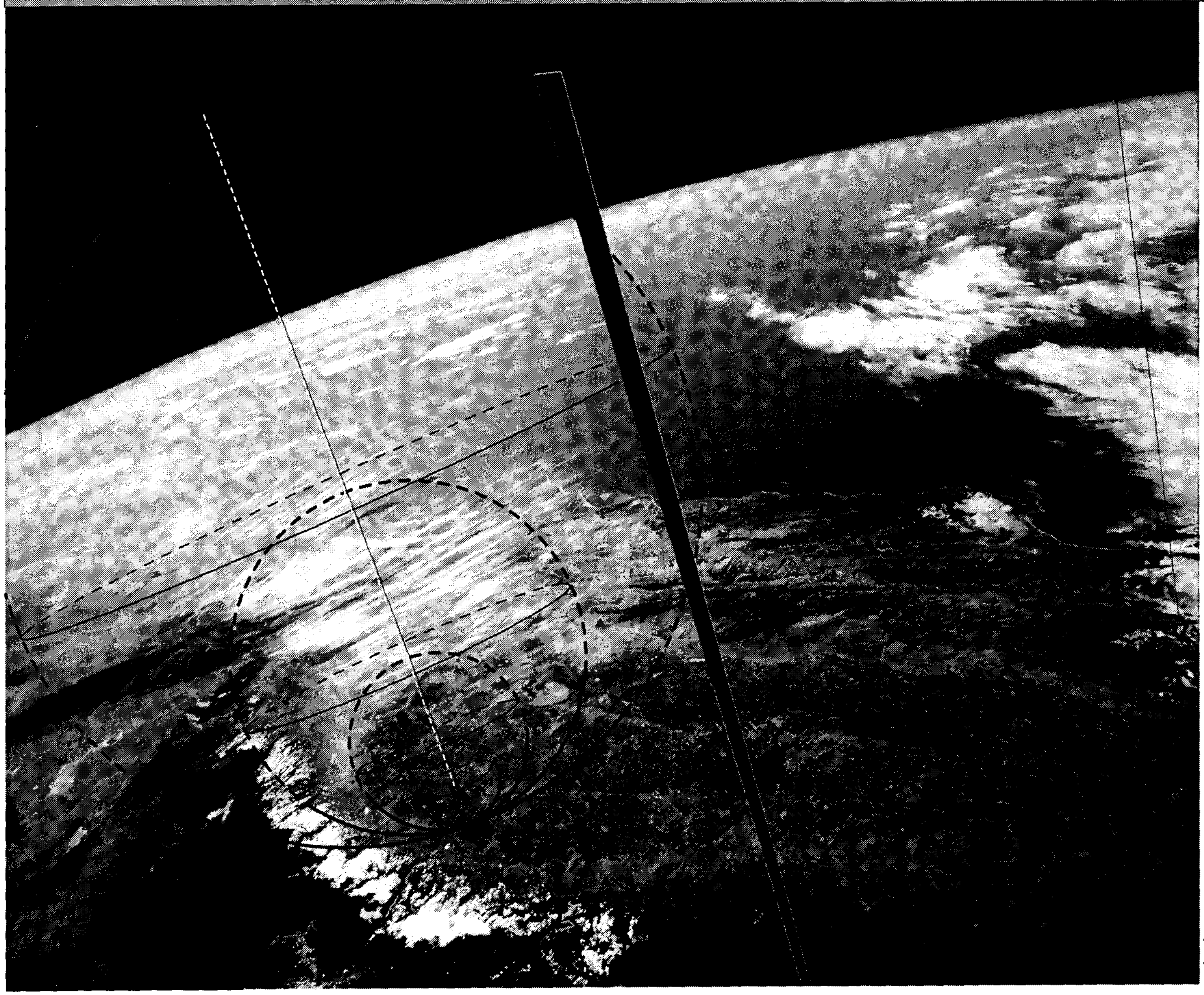
Both responses used the exact same array geometry and excitation strength.

Number of antenna elements = 21
Number of simulations = 100
Interelement spacing = cT/2

EMP Based Ultra-Wideband Radar Satellites



EMP Based Ultra-Wideband Radar Satellites



In the image to the left gravity gradient stabilized satellites interrogate the earth's surface. In the case shown the impulses focus to a point.

Narrow Band vs. Ultra-Wideband

	Narrowband Frequency Domain	Ultra-Wideband Time Domain
Scan Angle	Grating Limited	Almost Unlimited
# Beams	1 to 4	10^1 to 10^2
# Elements	10^5 to 10^6	10^3 to 10^4
Structure Tolerance	c T/20	cT /3
RF Feeds	10^5 to 10^6	None
RF Phase shifters	10^5 to 10^6	None
RF TDU's	10^3 to 10^4	None
Timing Control	1 ps	1 ps
Beam Forming	Closed Loop & Complex	Open Loop & Easy
# ADC's	Compromise: one per subarray	One per Element
Comm Array	Required	Can reuse existing array
Failed Elements	Closed Loop & Complex	Open Loop & Easy
SAR	YES	Under development
Imaging	No	Under development
AMTI	Hard	easy
GMTI	Many techniques	No research data found

Conclusions

- Anharmonic signaling is a mostly unexplored area of EM. Research needs to be done!
- The pattern of a narrow-pulse ultra-wideband antenna does not exhibit any side-lobes or any grating lobes. Only well behaved side "levels" are present.
- Spacing of many 10's of wavelengths between elements is possible. Fundamental physics is not now limiting the performance. We just need more powerful devices.
- Pulsed signaling can achieve extremely high resolution in principle.
- Pulsed signals are steered by true-time-delay thus giving complete spatial coverage.
- RF distribution networks might be eliminated as only high voltage DC is required at each antenna element.
- An ultra-short pulse has a low probability of intercept and should have unique spectroscopy target-identification modes not available with traditional narrow band radars.
- Requires new ways of thinking about radar and wireless communications that may pave the way for much greater system sensitivity.
- Leverages off of research from DOE, private companies, and other institutions involved in EMP weapon effects studies, radar, and communications.
- Theories, patents, US companies, and intense interest is now reaching a critical level.
- Represents a high level of technology risk *but* with a very substantial reward if successful.
- Those that do not participate may be left behind.