Phased Array Radar Basics

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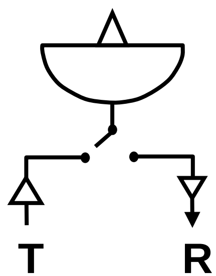
Outline

- History and Evolution of Phased Arrays
- Phased Array Radar Fundamentals
  - Array Beamforming
  - Electronic Scanning
  - Active Transmit-Receive Modules
- Summary

Radar Antenna Architectures

Dish Antenna

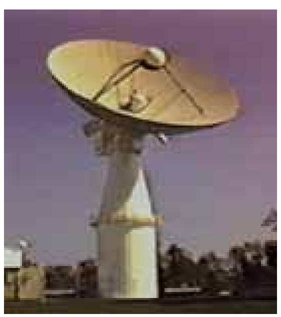


PRO

- Very low cost
- Frequency diversity

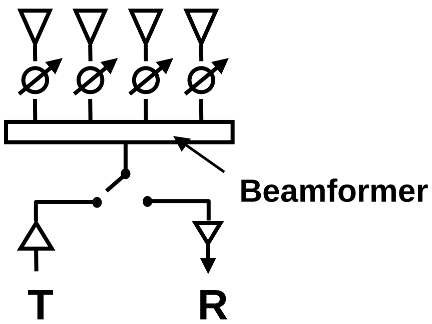
CON

- Slow scan rate
- High distribution loss
- Single point of failure



MILLSTONE

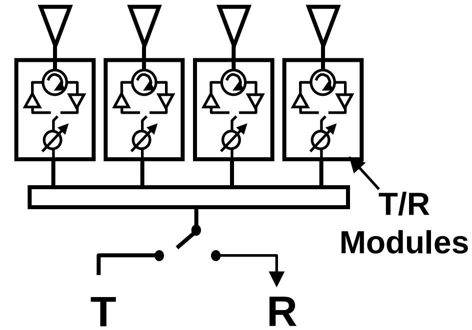
Passive Phased Array



- Beam agility
- Effective radar resource management
- High distribution loss
- Higher cost

SPY-1

Active Phased Array



- Highest performance
- Effective radar resource management
- Low distribution loss
- Highest cost

THAAD

Dish Radar Example

- **MIT LL Millstone Radar**
  - **2 Klystrons with 3 MW peak power**
  - **120 kW avg power**
  - **Center Frequency of 1295 MHz**
  - **8 MHz bandwidth**

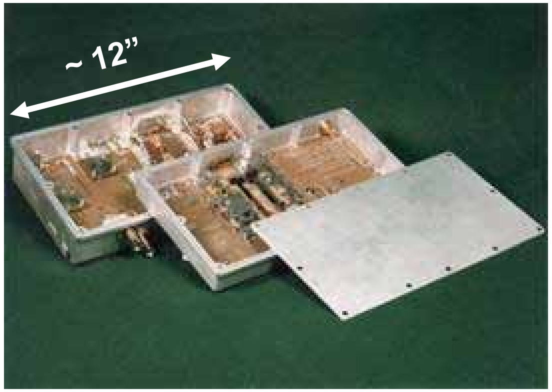
- **$400,000/tube**
- **7 ft x 1ft**
- **600 lbs**
- **3% duty cycle**
- **42 dB gain**

Millstone Klystron Tube

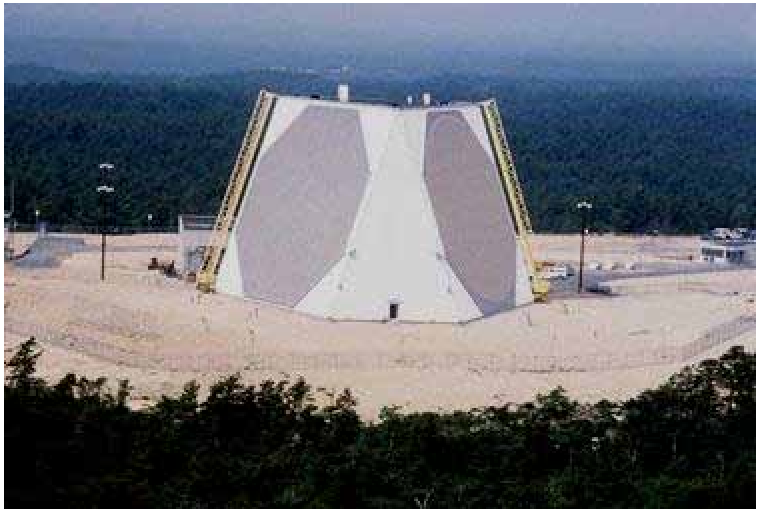
- **Advantages**
  - **High output power**
  - **Low cost per watt**
- **Disadvantages**
  - **Single point of failure**
  - **Large size**

Solid State Array Radar Example

- **PAVE PAWS**
  - First all-solid-state array radar
  - UHF Band
  - 1800 active transceiver T/R modules, 340 W of peak power each



Transmit and Receive Modules



- **Advantages**
  - Electronic beam agility
  - Low maintenance (no moving parts)
  - Graceful degradation
- **Disadvantages**
  - Higher cost per watt

Phased Array Radar Evolution

Passive Arrays

(Phase Shifter at Element)

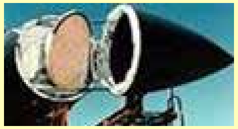
Active Arrays

(Amplifiers + Phase Shifter at Element)

Increasing Beam Agility

Airborne

B-1B
X-Band



JSTARS
X-Band

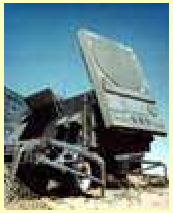
F/A-22
X-Band

JSF
X-Band

MP-RTIP
X-Band

1975 | 1980 | 1985 | 1990 | 1995 | 2000 | 2005 | 2010 | 2015

Surface



Patriot
C-Band

SPY-1
S-Band

THAAD
X-Band

SBX
X-Band

SPY-3
X-Band

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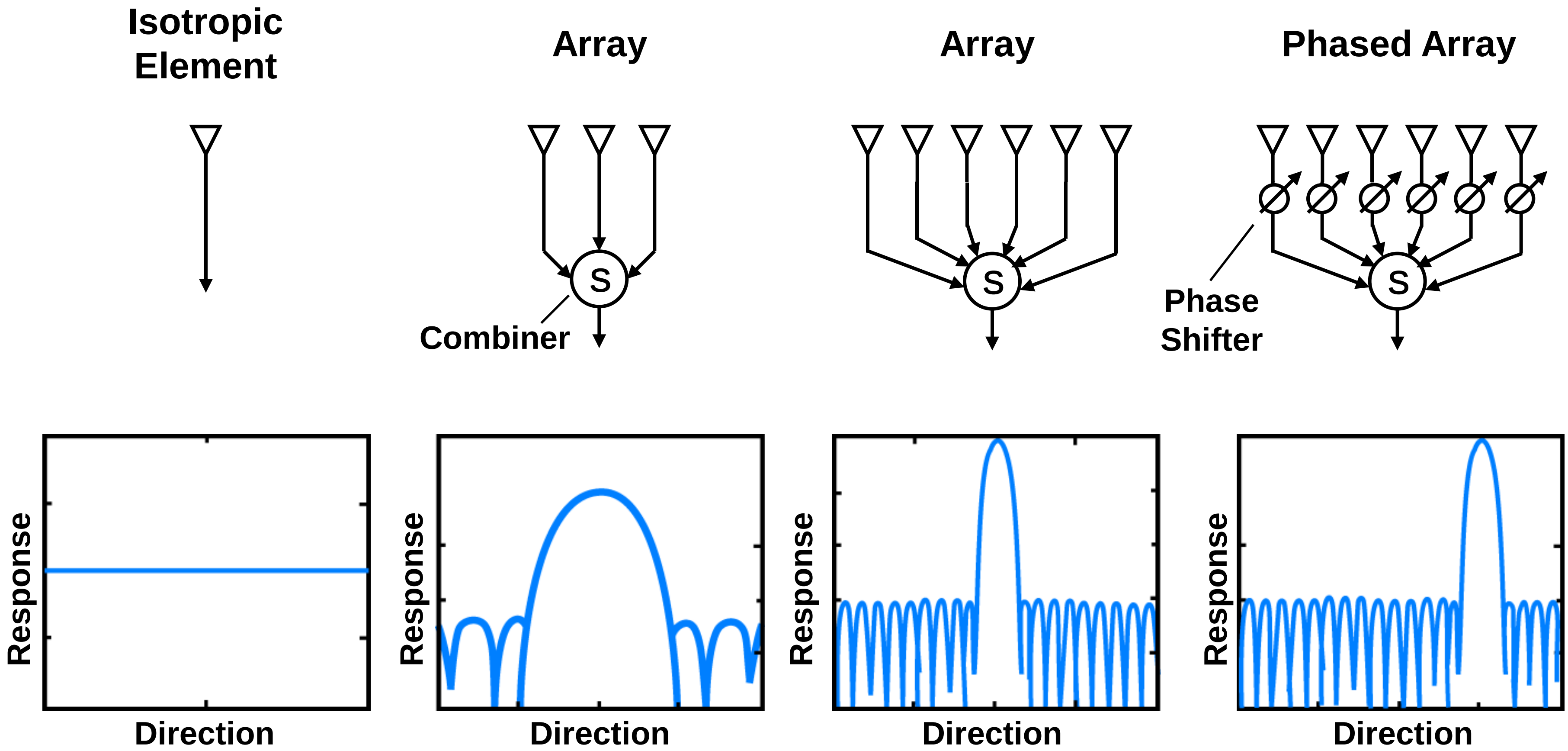
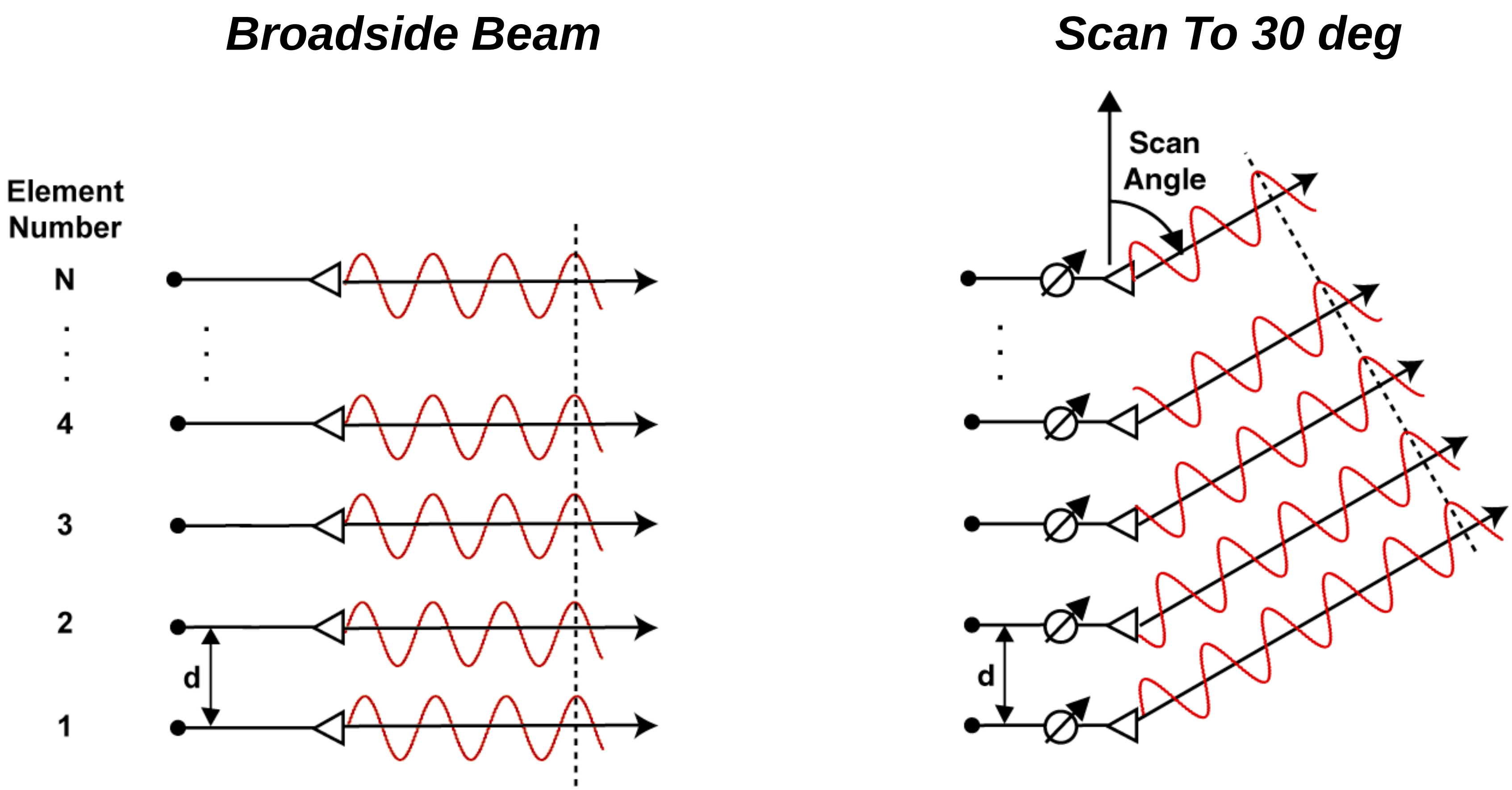
Array Beamforming

- **Multiple antennas combined to enhance radiation and shape pattern**



Array Beamforming (Beam Collimation)

- **Want fields to interfere constructively (add) in desired directions, and interfere destructively (cancel) in the remaining space**



Broadside Uniform Linear Array

Design Goal

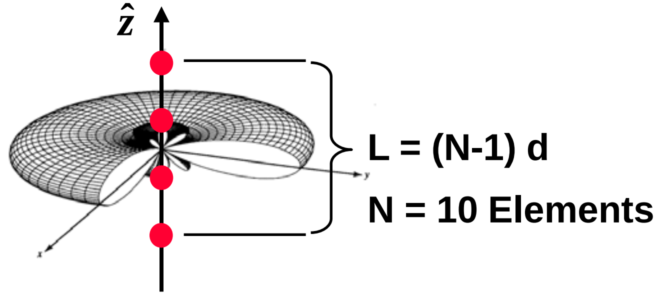
Maximum at $\theta = 90^\circ$

$$\psi = k\,d\cos\theta + \beta\Big|_{\theta=90^\circ} = 0$$

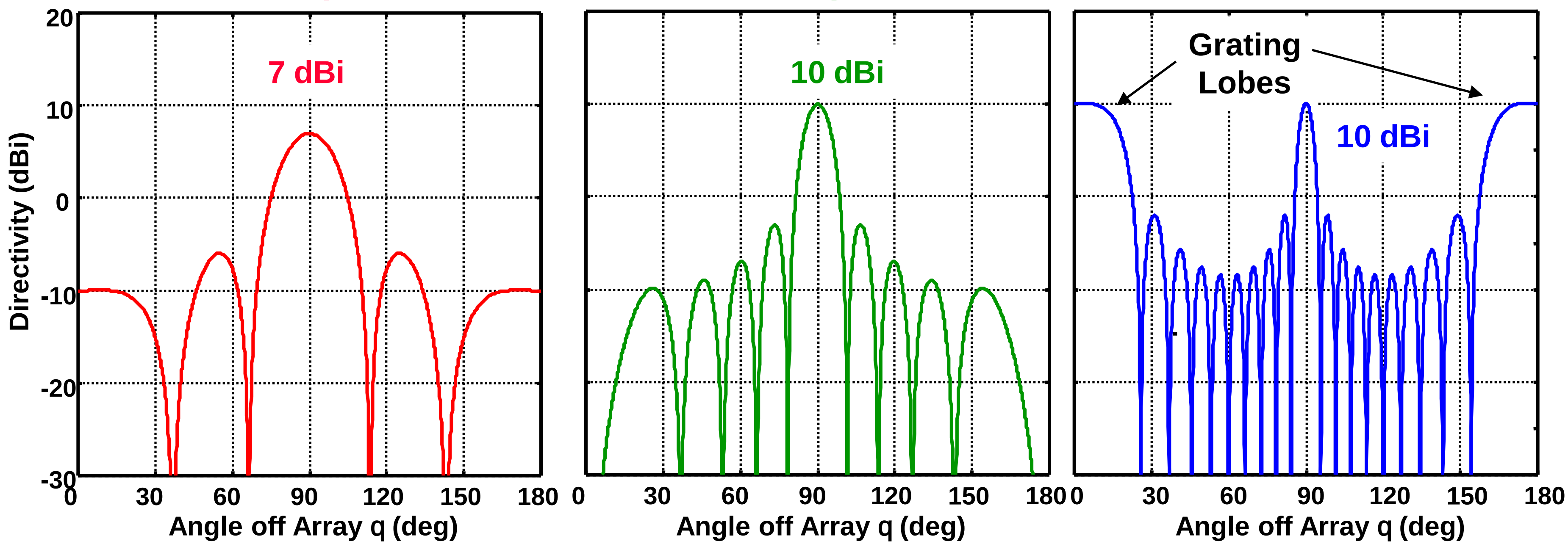
➡

Required Phase

$$\beta = 0$$



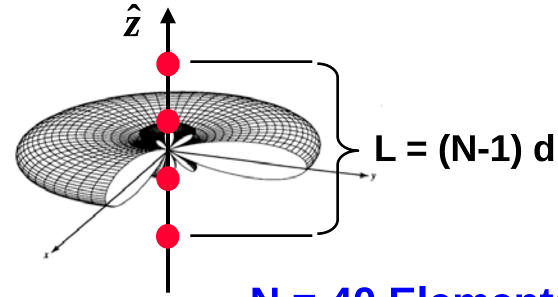
d = λ/4 separation | **d = λ/2 separation** | **d = λ separation**

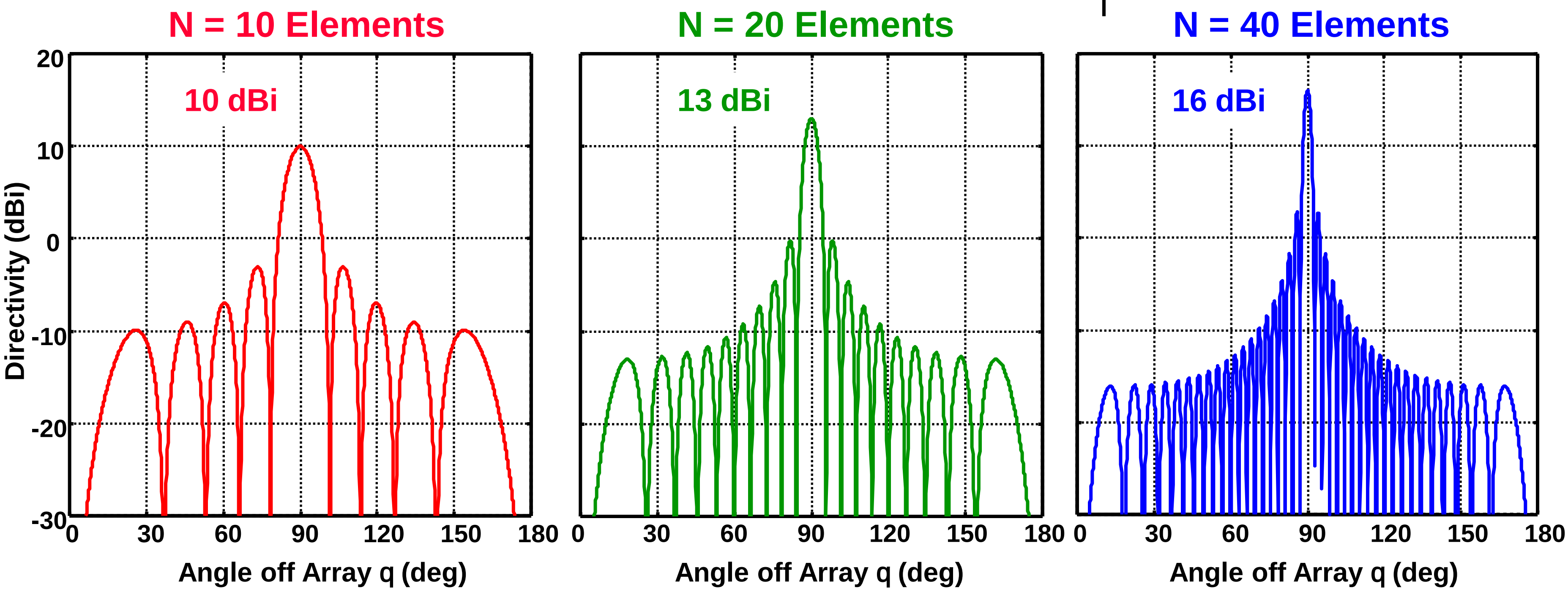


Limit element separation to d < λ to prevent grating lobes for broadside array

Increasing Broadside Linear Array Size by Adding Elements

- Element Separation d = l /2

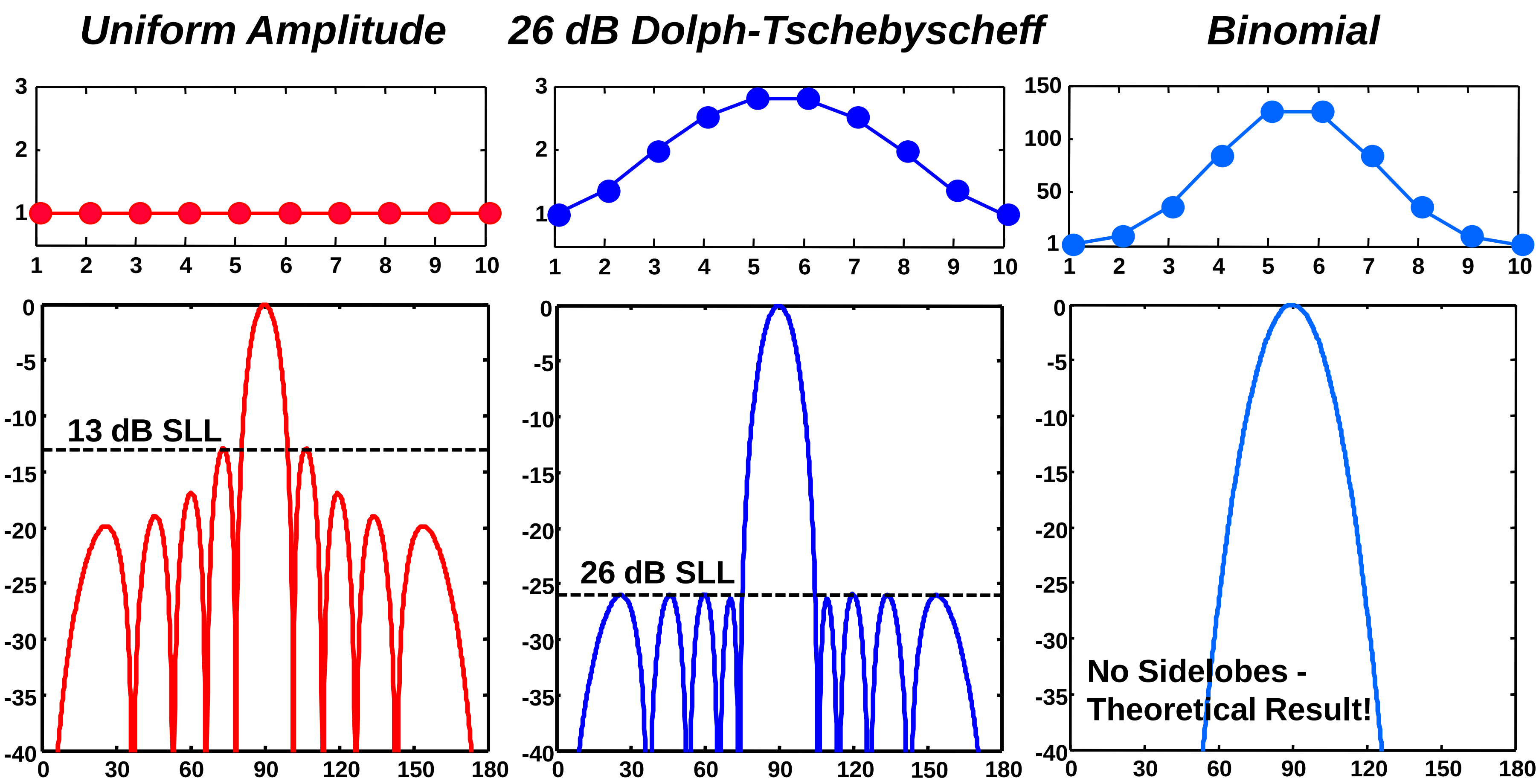




Gain ~ 2N(d / l) ~ 2L / l
for long broadside array *without grating lobes**

* d < l

Excitation Amplitudes
Tapers Across 10 Element Linear Array

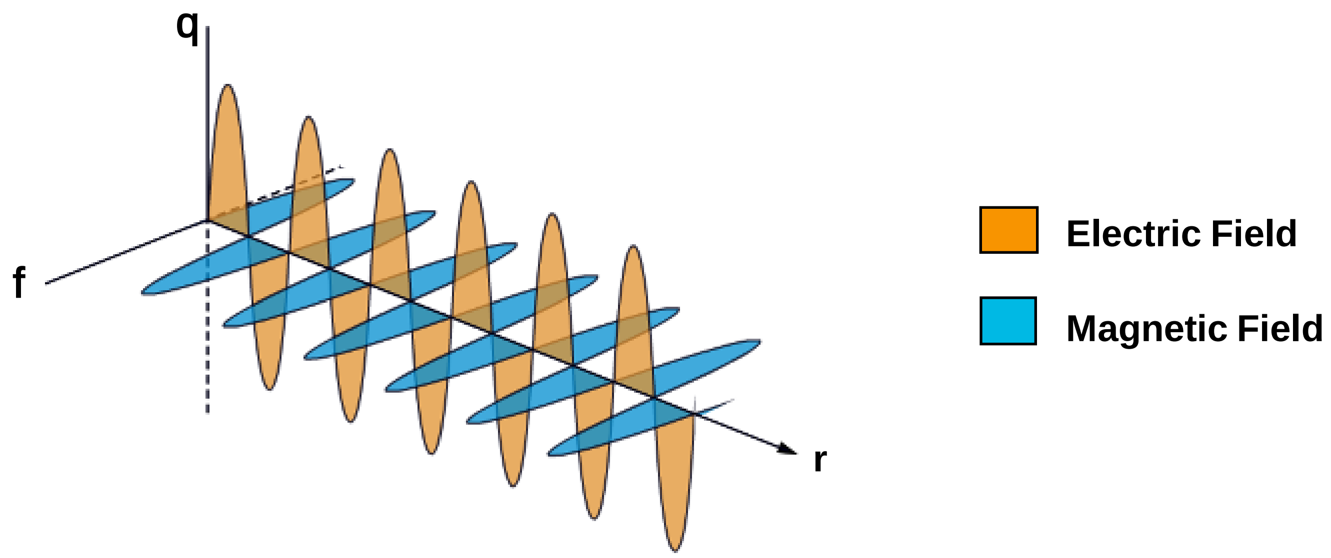


Amplitude & Phase Errors Limit the Sidelobe Level (SLL) That Can Be Achieved in Practice: > 40 dB is Challenging

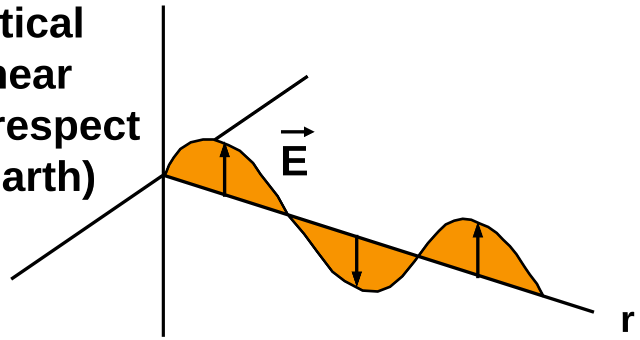
Polarization

- **Defined by behavior of the electric field vector as it propagates in time**

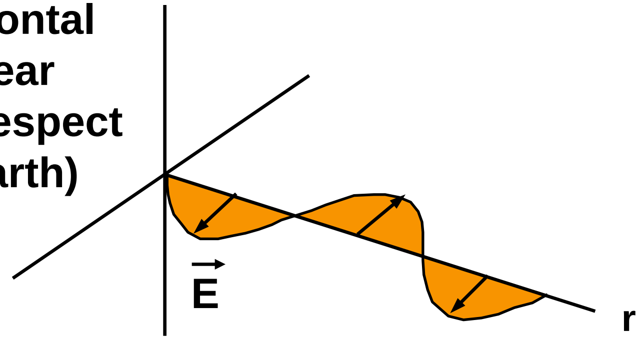
Electromagnetic Wave



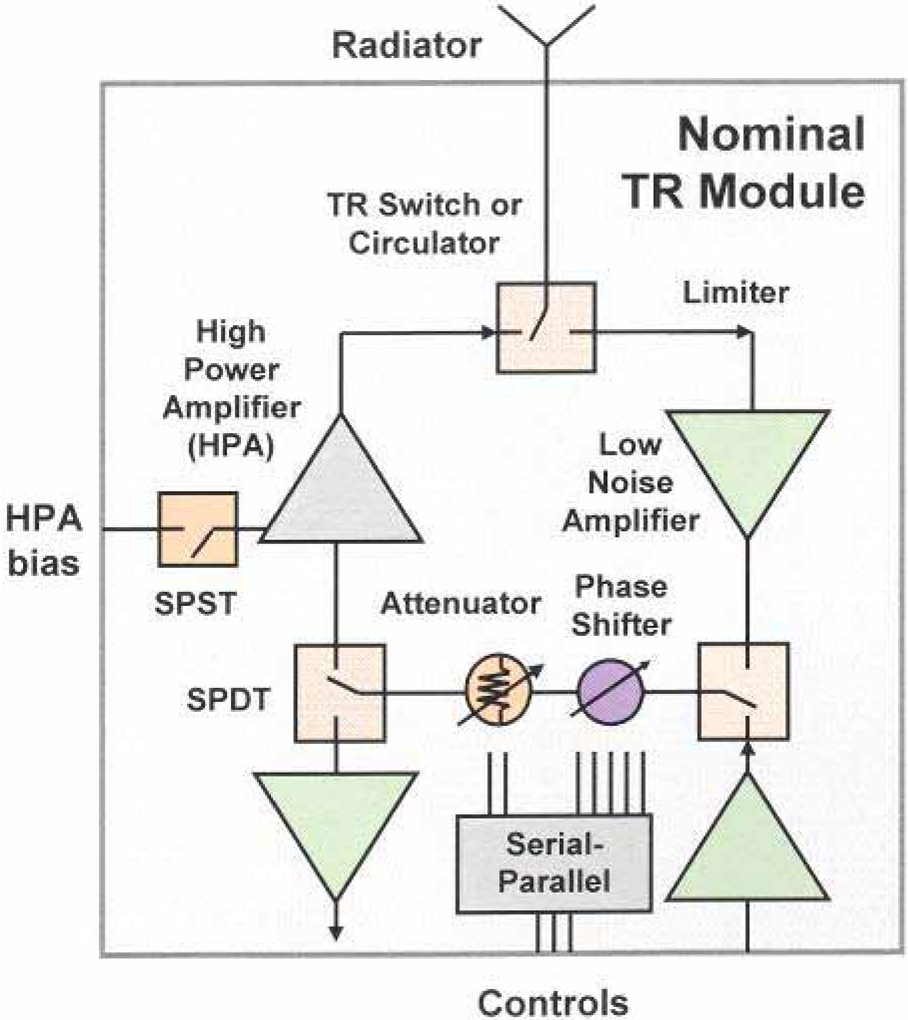
Vertical Linear (with respect to Earth)



Horizontal Linear (with respect to Earth)



Active Array T/R Module

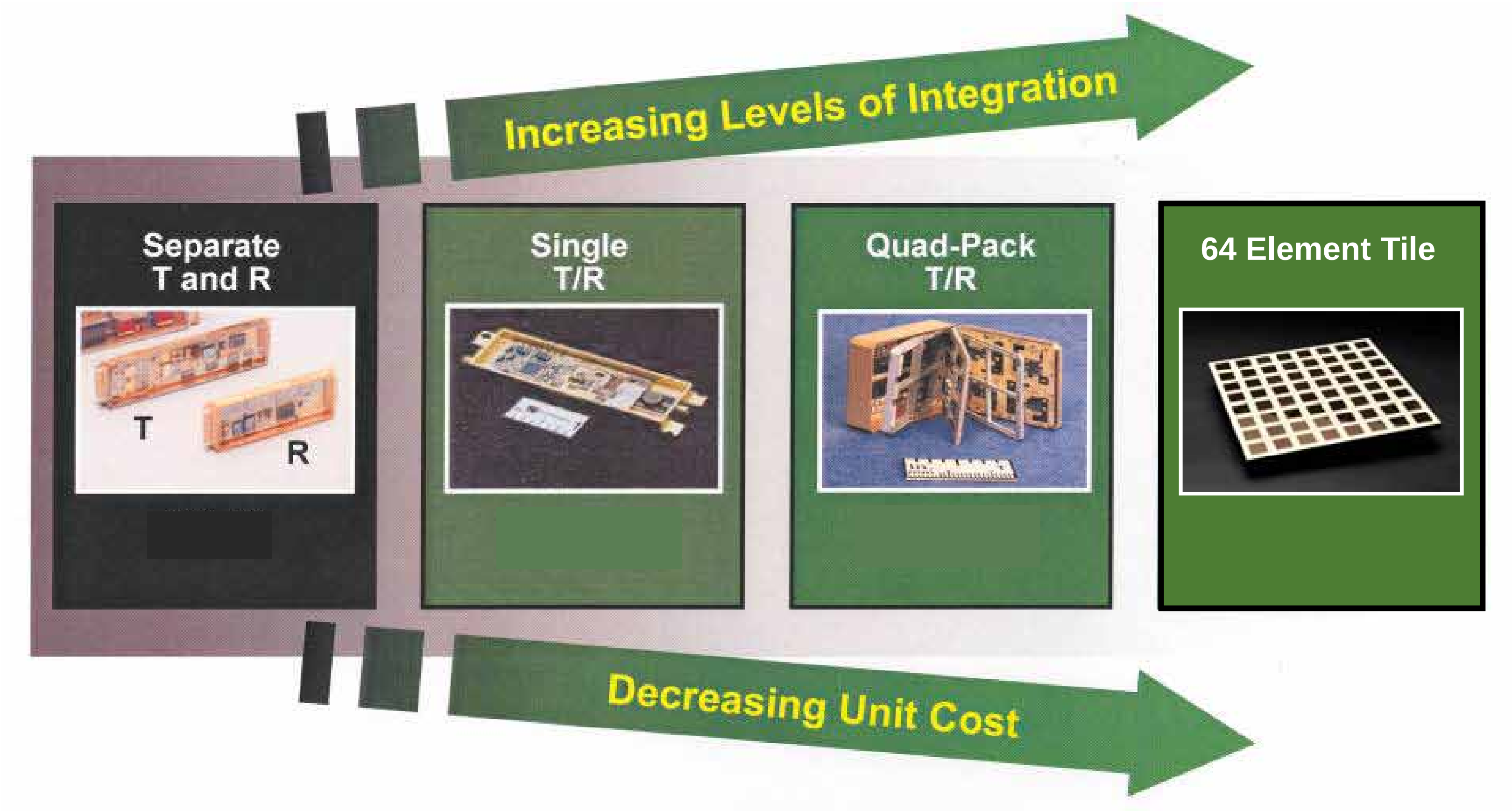


F-35 Radar

Critical Technologies:

- Power amplifiers
  - High gain
  - High efficiency
- Low noise amplifiers
  - Low signal intermodulation
  - Low drain power
- Packaging
  - Thermal management
  - Light weight

T/R Module / Subarray Integration



- High levels of integration reduce unit cost
- Automated assembly and test reduces touch labor cost

Summary

- **Phased array provides improvements in radar functionality and performance**
  - **Beam agility**
  - **Effective radar resource management**
  - **Graceful degradation with module failures**
- **Current trend is towards active arrays with distributed T/R modules**
  - **Large number of distributed active components and control**
  - **High levels of integration required to achieve low cost**

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