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Radar Systems

Lecture10.

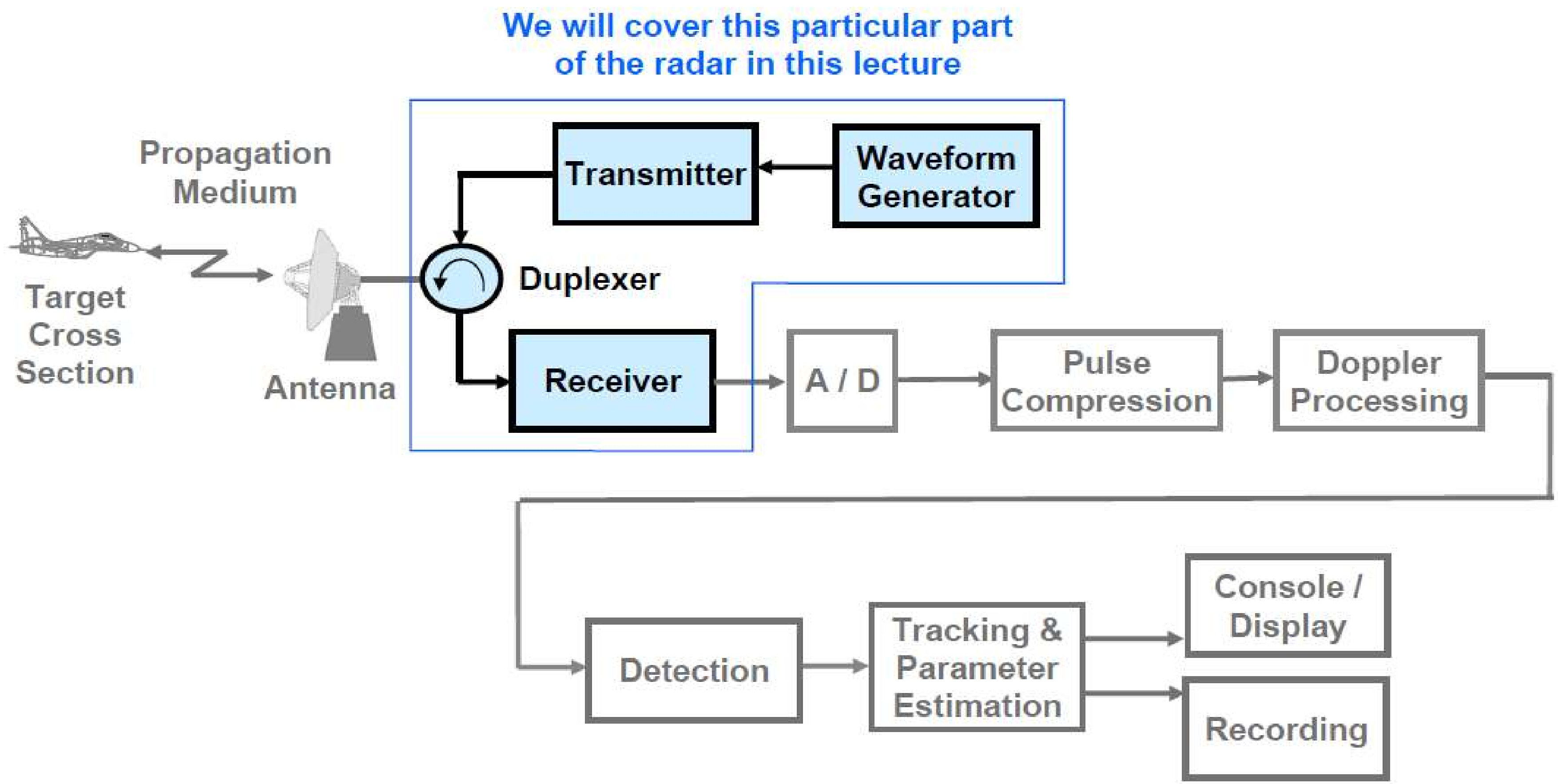
Radar Transmitter/Receiver

구 자 열

차　　례

- Introduction
- Radar Transmitter
- Radar Waveform Generator and Receiver
- Radar Transmitter/Receiver Architecture

Radar Block Diagram



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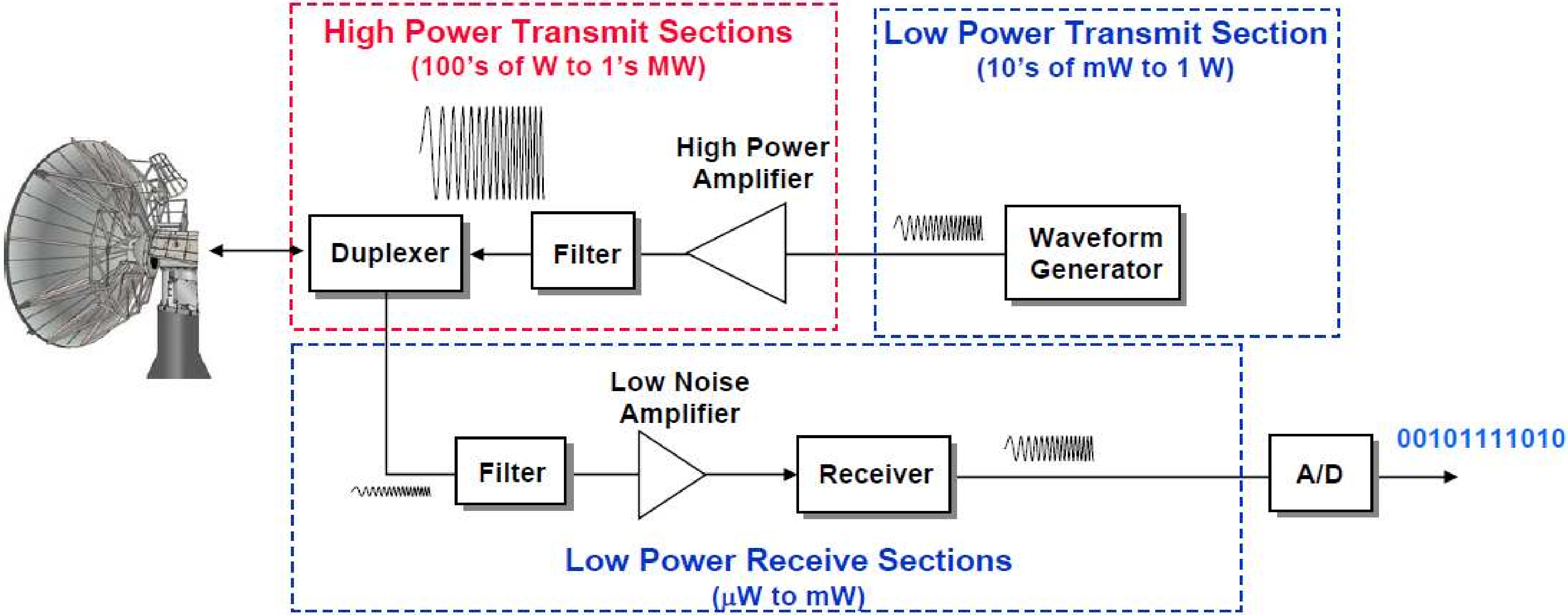
Simplified Radar Transmitter/Receiver System Block Diagram



- Radar transmitter and receiver can be divided into two important subsystems
  - High power transmitter sections
  - Low power sections

    Radar waveform generator and receiver

Radar Range Equation Revisited

Parameters Affected by Transmitter/Receiver

- Radar range equation for search (S/N = signal to noise ratio)

$$S/N = \frac{\boxed{P_{av}}\, A_e\, t_s\, \sigma}{4\pi\, \Omega\, R^4\, k\, \boxed{T_s}\, \boxed{L}}$$

P_{av} = average power
A_e = antenna area
t_s = scan time for Ω
P_{av} = average power
σ = radar cross section
Ω = solid angle searched
R = target range
T_s = system temperature
L = system loss

- S/N of target can be enhanced by
  - Higher transmitted power P_{av}
  - Lower system losses L
  - Minimize system temperature T_s

The design of radar transmitter/receiver affects these three parameters directly

Introduction

- Ideal Transmitter
  - Provides sufficient energy to detect the target
  - Easily modulated to produce desired waveforms
  - Generate stable noise free signal for good clutter rejection
  - Provide needed tunable bandwidth
  - High efficiency
  - High reliability
  - Easily maintainable
  - Long life
  - Small and light weight for the intended application
  - Affordable
- Obviously compromise is necessary !

차　　례

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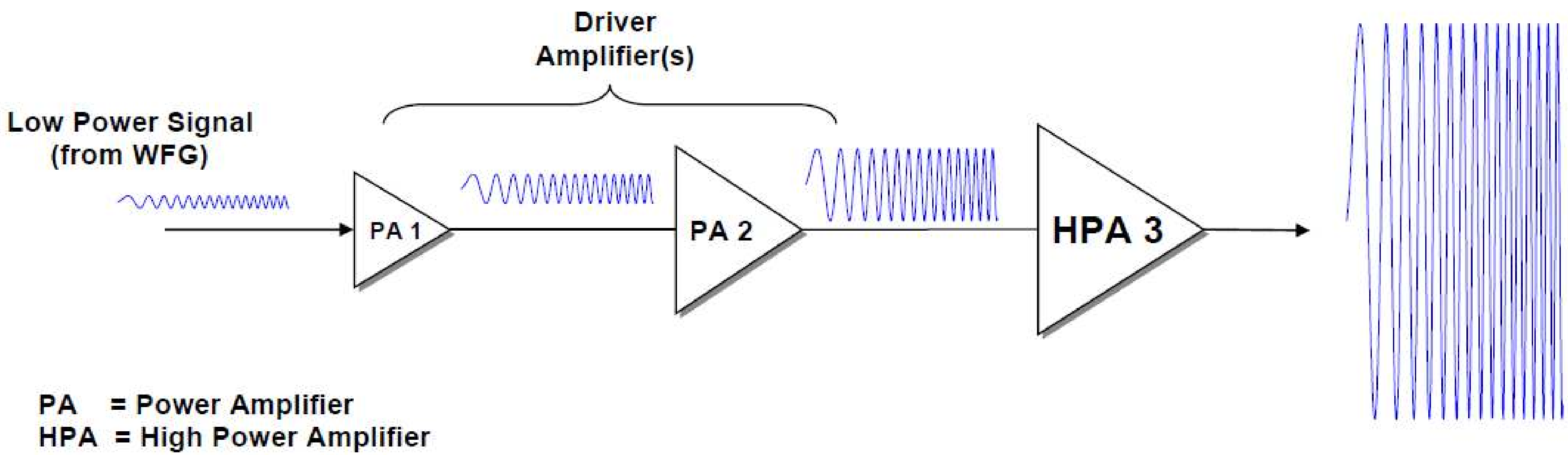
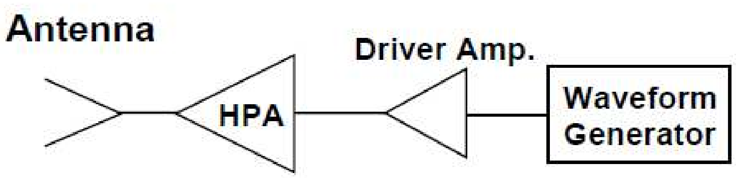
- Radar Transmitter/Receiver Architecture

Power Amplification Process

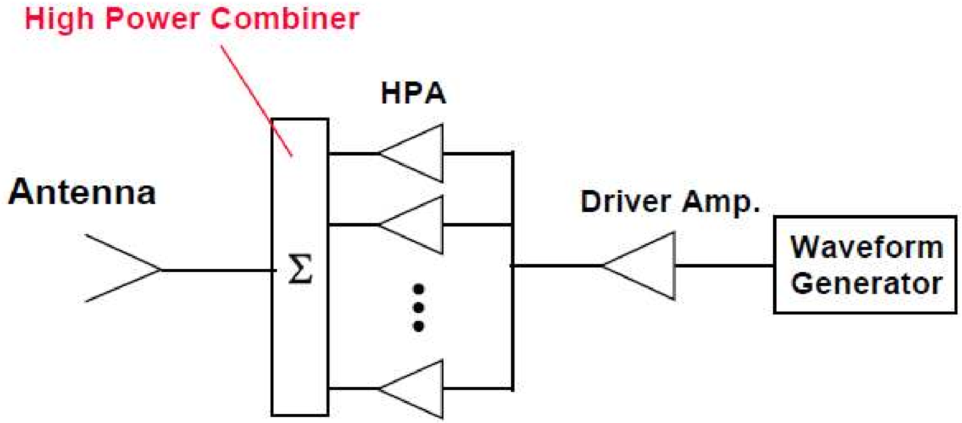


- Amplification occurs in multiple stages
  - Driver amplifiers
  - High power amplifier
- Requirement for power amplifier
  - Low noise
  - Minimum distortion to input signal

Method to Obtain Higher Power



1 – Single amplifier transmitter
Single antenna



2 – Parallel combining of HPA's
Single antenna

- Higher transmitted power can be obtained by combining multiple amplifiers in parallel
  - Lower efficiency (due to combiner losses)
  - Increased complexity

HPA = High Power Amplifier

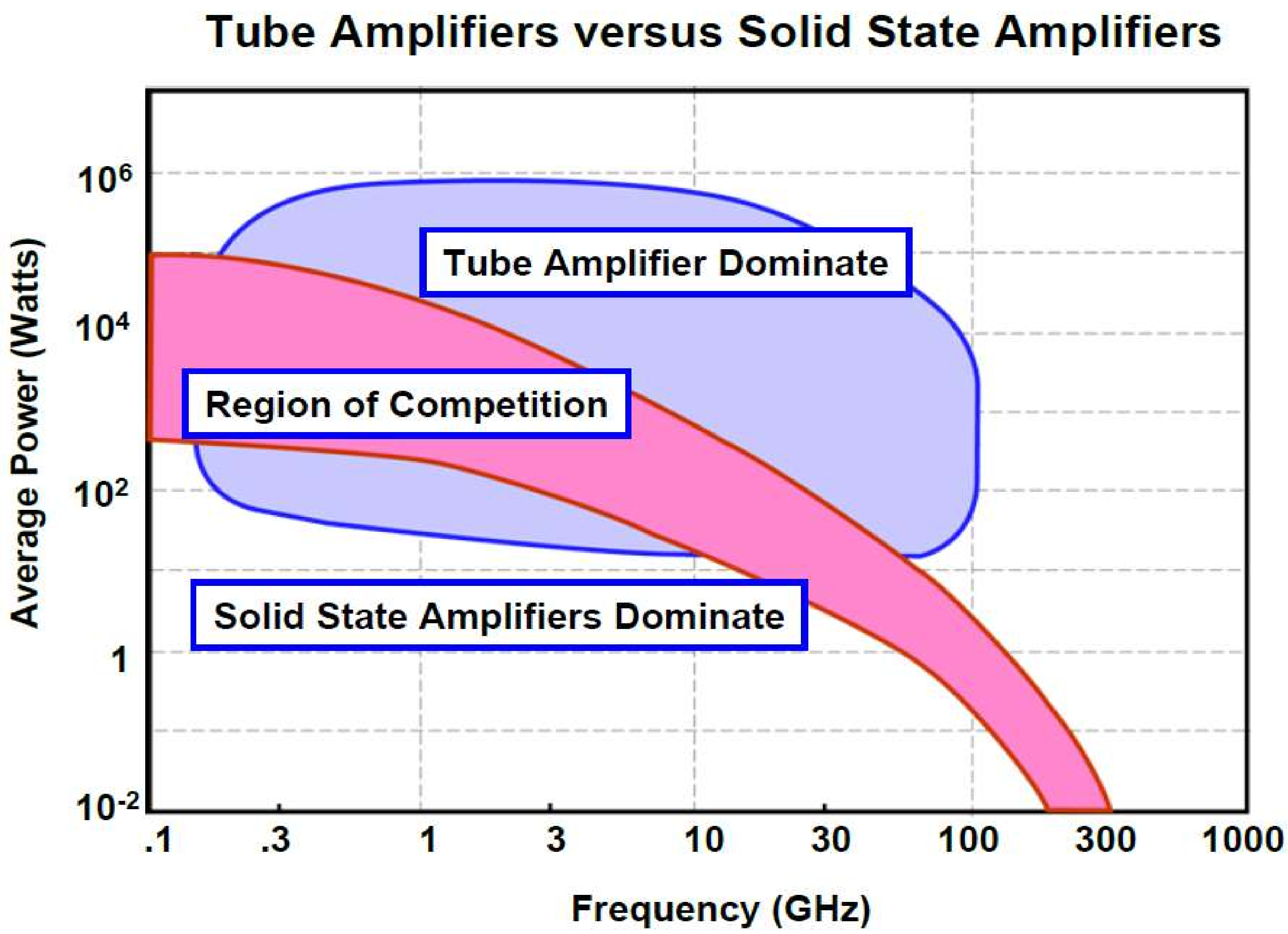
Types of High Power Amplifiers

- Vacuum tube amplifiers and solid state amplifiers

	Vacuum Tube Amplifiers	Solid State Amplifiers
Output Power	High (10 kW to 1 MW)	Low (10's to 100's W)
Cost per Unit	High ($10's K to $300 K)	Low ($100's)
Cost per Watt	$1 – 3	Varied
Size	Bulky and heavy	Small foot print
Applications	• Dish antenna • Passive array	• Active array • Digital array

Average Power Output Versus Frequency

Tube Amplifiers versus Solid State Amplifiers



Methods of Power Amplification

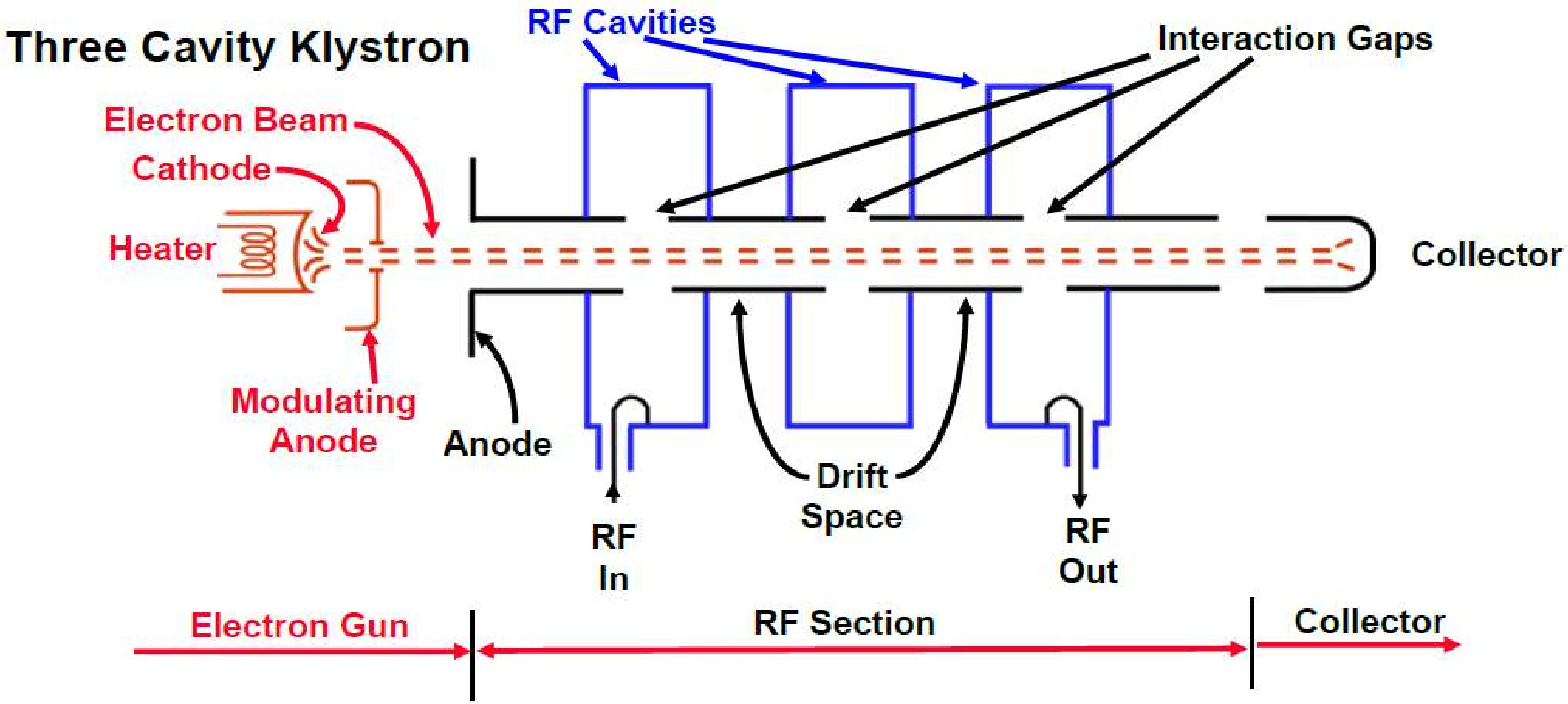
- Tube amplifiers
  - Krystrons
  - Travelling wave tubes
  - CFAs

- Solid State amplifiers
  - Solid state power transistors

<u>Issues to be traded off in choice of high power amplifier</u>

- Average power output at desired operating frequency
- Amplifier efficiency
- Instantaneous and tunable bandwidth
- Duty cycle
- Gain
- Reliability
- Cost

Klystron – High Power Amplifier



- First developed in early 1950s
- Bandwidth as great as 12%
- RF conversion efficiency 35 - 50%
- Coherent- pulse to pulse

Adapted from Skolnik
Reference 1

MIT/LL Millstone Hill Radar

Klystron Tubes (Vacuum Devices)

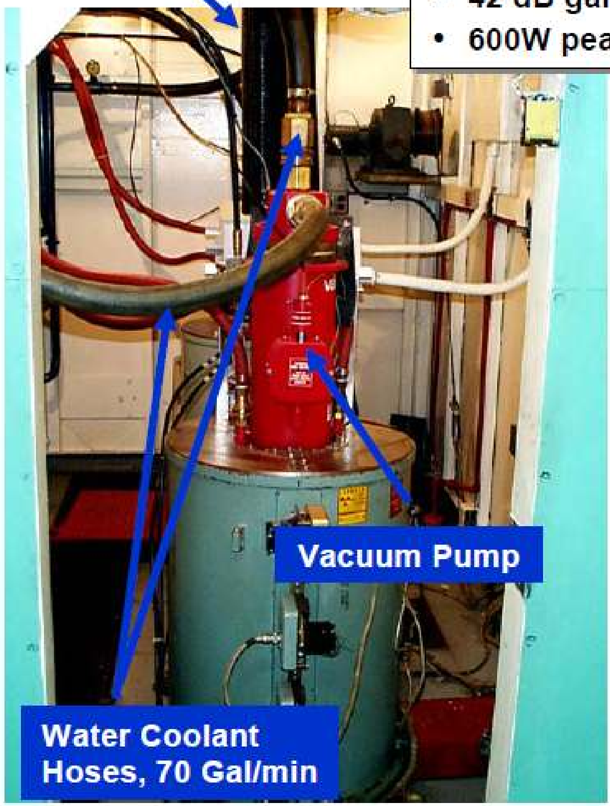
Output device	Klystrons (2)
Center Frequency	1295 MHz
Bandwidth	8 MHz
Peak Power	3 MW
Average Power	120 kW
Pulse Width	1 ms
Beam Width	0.6°
Antenna Diameter	84 ft

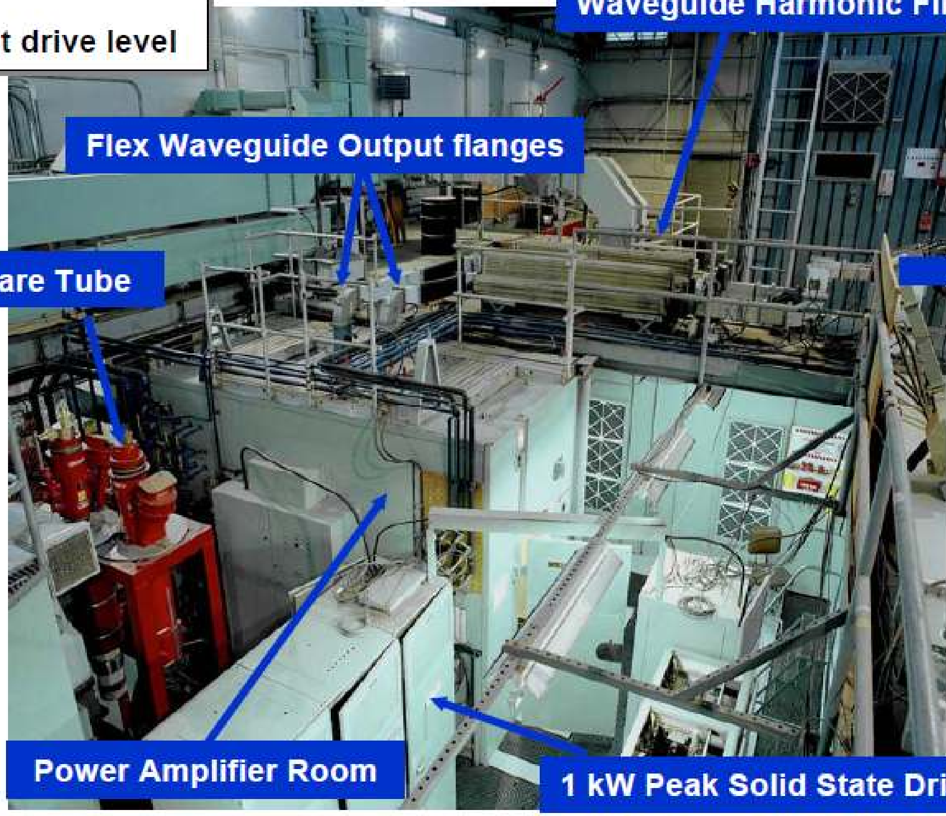
- Originally designed in early 1960's

How Big are High Power Klystron Tubes ?

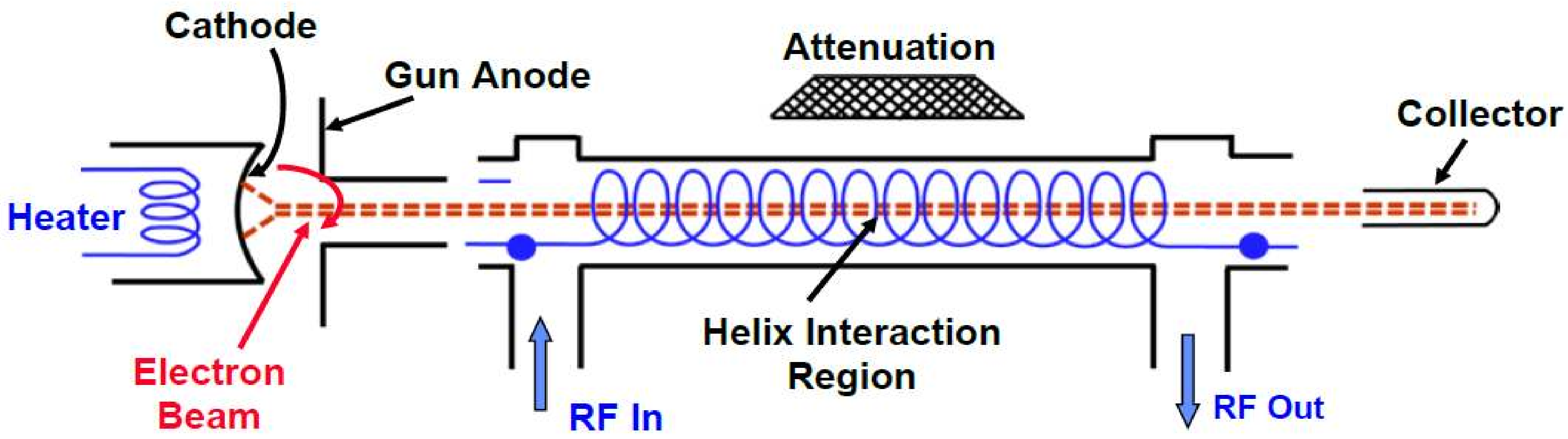
Millstone Hill Radar Transmitter Room

Varian X780 Klystron
- $400,000/tube
- 7 ft (height) x 1ft (diameter)
- 600 lbs
- 3% duty cycle
- 42 dB gain
- 600W peak input drive level





Traveling Wave Tube



Adapted from Skolnik
Reference 1

- Capable of wide bandwidth at high power
- Expensive
- Similar to Klystron, linear beam tubes
- Interaction between RF field and electron beam over length of tube
  - RF wave mixes with electron beam and transfers DC energy from electron beam to increase energy of RF wave, causing wave to be amplified

Photograph of Traveling Wave Tubes

Another Type of Tube Amplifiers

Center Freq : 3.3 GHz
Bandwidth : 400 MHz
Peak Power : 160 kW
Duty Cycle : 8 %
Gain : 43 dB

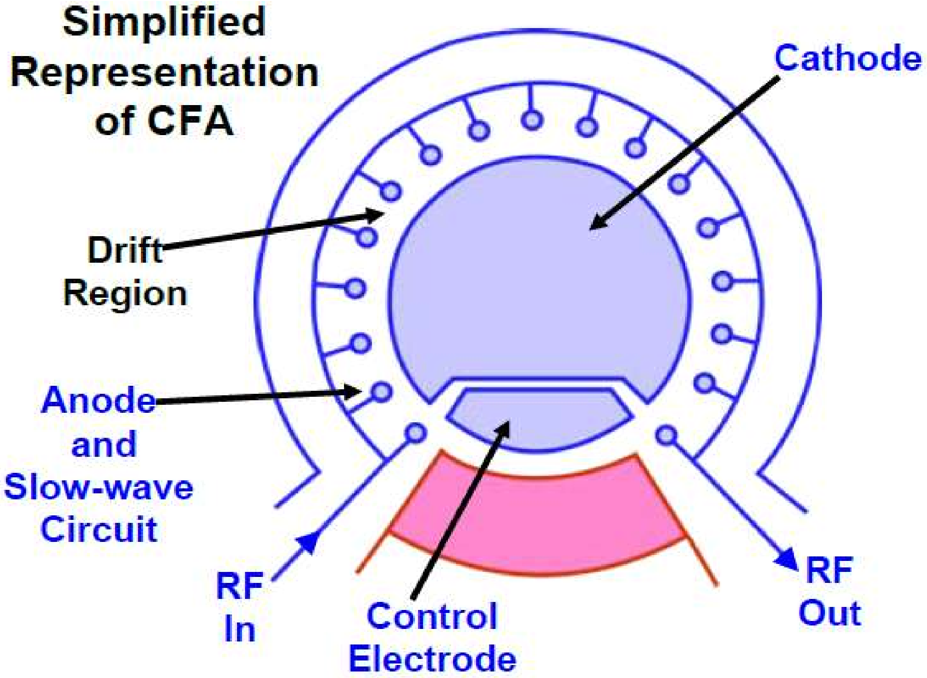
S Band
VTS-5753
COUPLED CAVITY
TWT

X Band
VTX-5681C
COUPLED CAVITY
TWT

Center Freq : 10.0 GHz
Bandwidth : 1 GHz
Peak Power : 100 kW
Duty Cycle : 35 %
Gain : 50 dB

S-Band Transmitter

Crossed Field Amplifier (CFA)



- Capable of :
  - High coherent power
  - Good efficiency
  - Wide bandwidth
- Relatively low gain (10 dB)
- Generally noisier and less stable

- Resembles magnetron and employs crossed electric and magnetic fields
  - Electrons emitted from cylindrical cathode
  - Under action of crossed electromagnetic fields, electrons form rotating bunches
  - Bunches of electrons drift in phase with RF signal and transfer their DC energy to the RF wave to produce amplification

Crossed Field Amplifier

CPI SFD 233G

Courtesy of CPI. Used with permission.

X-Band (9.0 to 9.5 GHZ)

Peak Output Power 900 kW

Duty Cycle .1%

Pulsewidth 0.83 μsec

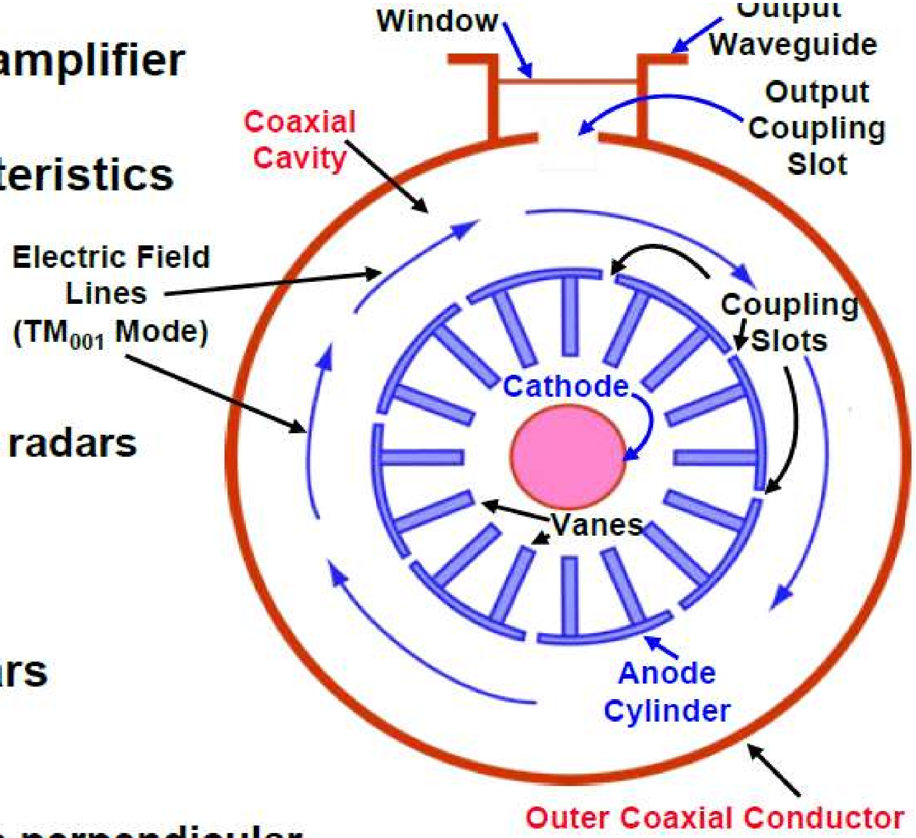
Liquid cooled

Comparison of Different Types of High Power Amplifier Tubes

	Klystron	Traveling Wave Tube	Crossed Field Amplifier
Voltage	1 MW requires 90kV	1 MW requires 90kV	1 MW requires 40kV
Gain	30 - 70 dB	30 - 70 dB	8 - 30 dB
Bandwidth	1 - 8 %	10 - 35 %	10 - 15 %
X-Rays	Severe, but lead is reliable	Severe, but lead is reliable	Not a Problem
Efficiency			
Basic	15 - 30 %	15 - 30 %	35 - 45 %
With Depressed Collectors	40 - 60 %	40 - 60 %	NA
Ion Pump	Required with Large Tubes	Required with Large Tubes	Self Pumping
Weight	Higher	Higher	Lower
Size	Larger	Larger	Smaller
Cost	Medium	Higher	Medium
Spurious Noise	- dB 90	- dB 90	- dB 55 to 70
Usable Dynamic Range	40-80 dB	40-80 dB	a few dB

Coaxial Cavity Magnetron

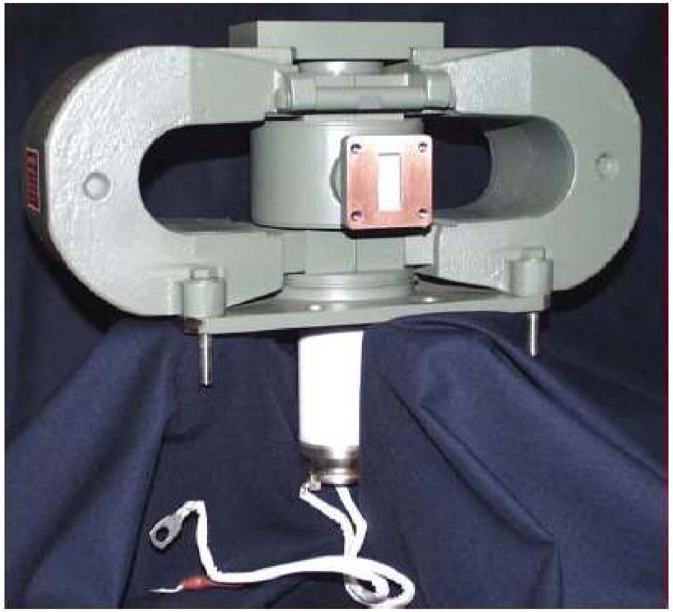
- Power Oscillator not an power amplifier
- Poor noise and stability characteristics
  - Restricted use for MTI
- Average power is limited
  - 1 - 2 kilowatts
  - Good for short-medium range radars
- Not coherent pulse to pulse
- Coaxial Cavity Magnetron
- Well suited for civil marine radars
- Magnetron Operation
  - Electric and magnetic field are perpendicular
  - Electrons emitted from cathode travel around circular path in bunches
  - Electrons interact with e-m fields and give up their DC energy to the RF field
  - RF energy is output with coupling slot



Adapted from Skolnik
Reference 3

Coaxial Magnetrons

X-Band (9.275 to 9.325 GHZ)



S-Band (2.7 to 2.9 GHZ)

Courtesy of CPI. Used with permission.

Model SFD 303B

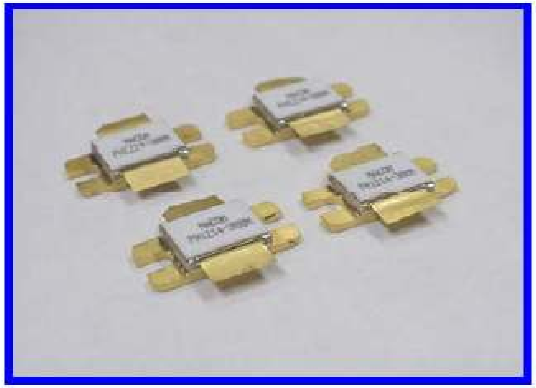
Peak Output Power 1 MW
Duty Cycle .1%
Pulsewidth 3.5 μsec
Liquid cooled
Fixed frequency

Model VMS 1143B

Peak Output Power 3 MW
Duty Cycle .08%
Pulsewidth 2.0 μsec
Liquid cooled
Mechanically tunable

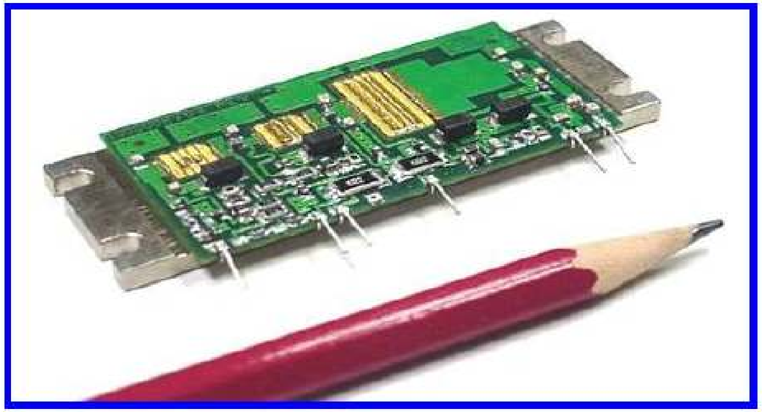
Solid State Power Transistors

Available Commercial Devices



Bipolar PH3135-90S Pulsed Power Transistor
3.1-3.5 GHz, 90 W

UF28150J MOSFET Power Transistor
100-500 MHz, 150 W



PHA2731-190M Pulsed Power Amplifier Module
190 Watts 2.7 - 3.1 GHz, 200 us Pulse, 10% Duty

- Solid state power transistors are basic building blocks of solid state amplifiers
- Advantages of solid state power amplifiers
  - Small footprint
  - Low profile
  - High reliability

Courtesy of MA/COM Technology Solutions
Used with permission

Solid State RF Power Amplifiers

- Solid state power generation device
  - Transistor amplifier (silicon bipolar and gallium arsenide)
- Inherently low power and low gain
- Operates with low voltages and has high reliability
- To increase output power, transistors are operated in parallel with more than 1 stage
- A module might consist of 8 transistors
  - Four in parallel as the final stage, followed by
  - Two in parallel,as the second stage, followed by
  - Two in series, as the driver stages
- Solid state power devices cannot operate at high peak power
  - Fifty watt average power transistor cannot operate at much more than 200 watts of peak power without overheating
  - Pulse compression needed for reasonable range resolution

Uses of Solid State Amplifiers in Radar

- Transmitter for low power application
- High power transmitter
  - A large number of microwave transistors are combined with microwave circuitry
- Many modules distributed on a mechanically steered planar array
  - A "3 D" radar
- A module at each of the many elements of an electronically scanned phased array
  - Called an "active aperture"

Solid State Radar Examples - TPS-59

TPS-59

- Air surveillance radar developed for the US Marine Corps
- Rotating planar L-Band array
  30 ft by 15 ft
- Each transmitter module has 10 of 100 watt amplifier units consisting of two 55 watt silicon bipolar transistors (7 watts of gain) driven by a smaller 25 watt device
- Each transmitter module feeds one of 54 rows

Courtesy of Lockheed Martin
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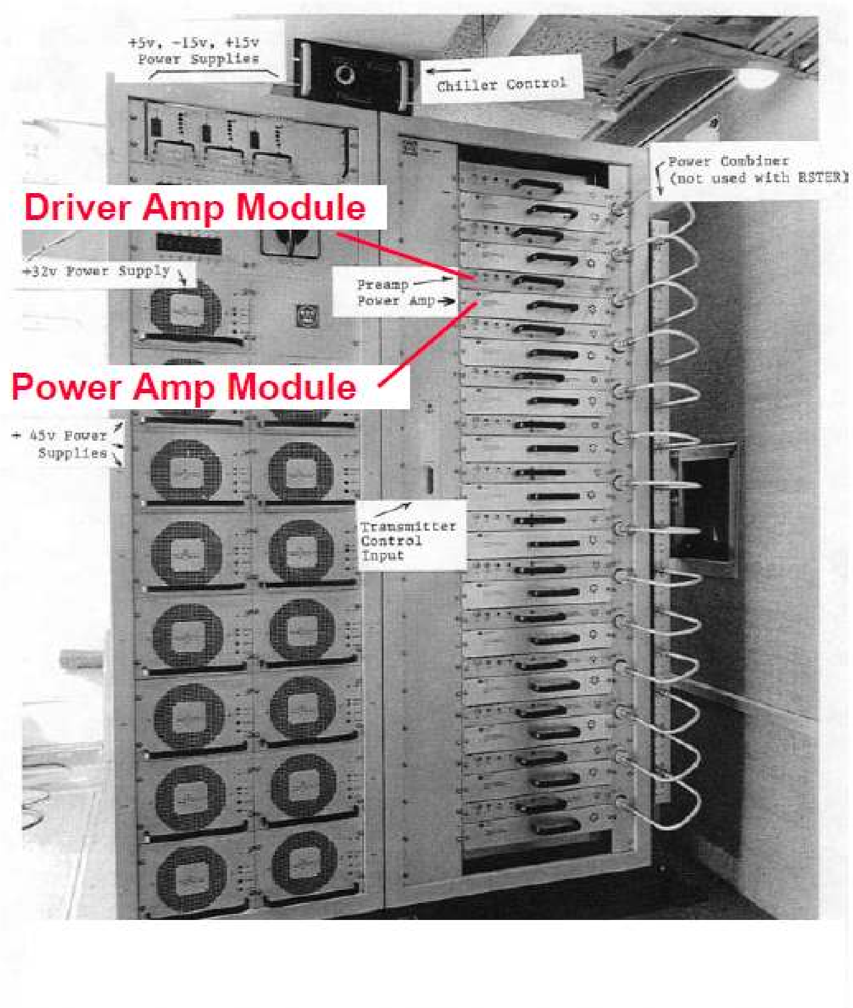
Example of Solid State Transmitter

Radar Surveillance Technology Experimental Radar (RSTER)

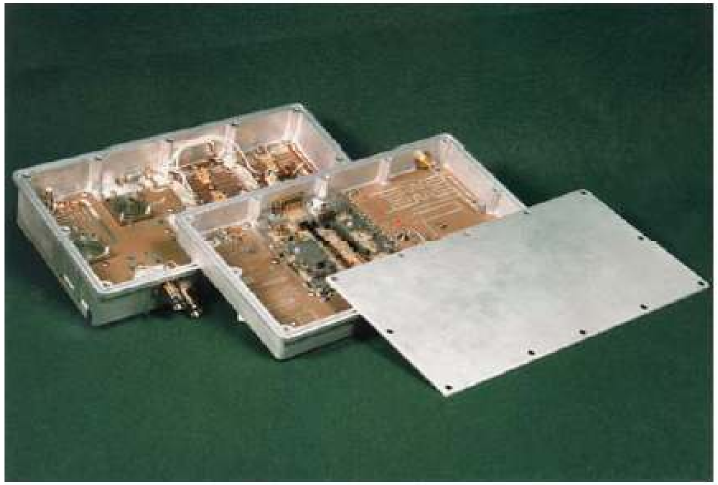


- 14 channels with 140 kW total peak power
  - 8 kW average power
- Each channel is supplied by a power amplifier module
  - 10 kW peak power

Solid State Active Phased Array Radar PAVE PAWS

- **PAVE PAWS**
  - First all solid state active aperture electronically steered phased array radar
  - UHF Band
  - 1792 active transceiver T/R modules, 340 W of peak power each

Courtesy of Raytheon. Used with permission.



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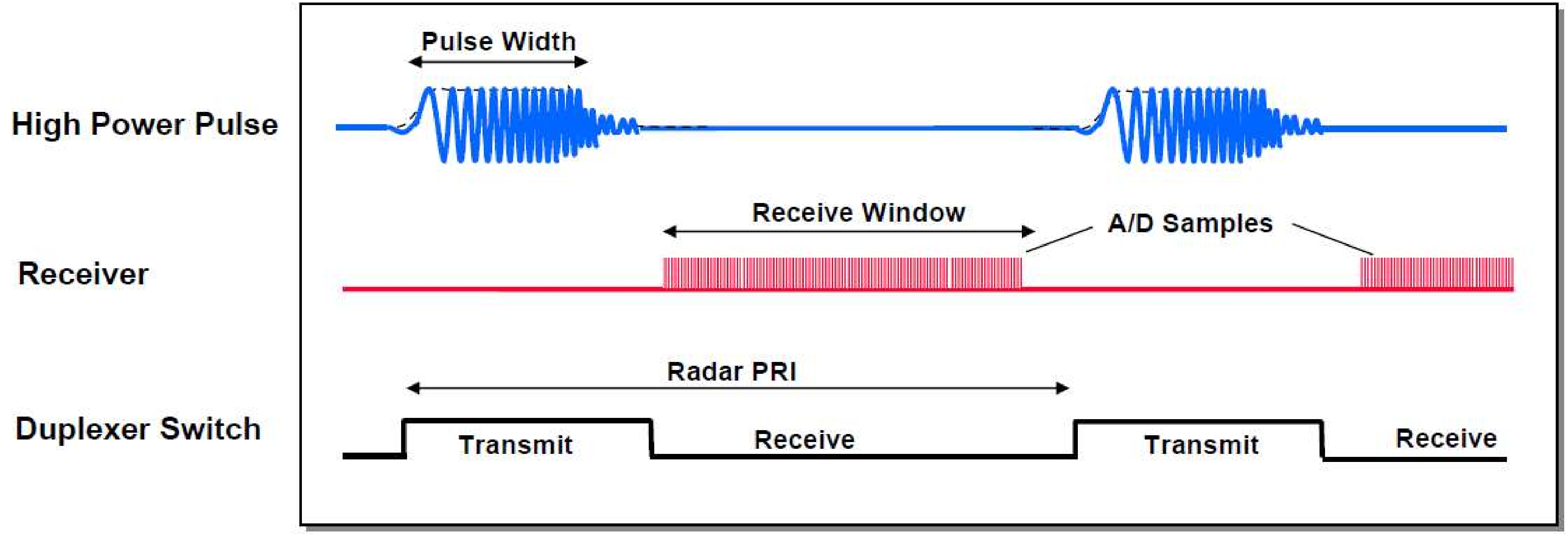
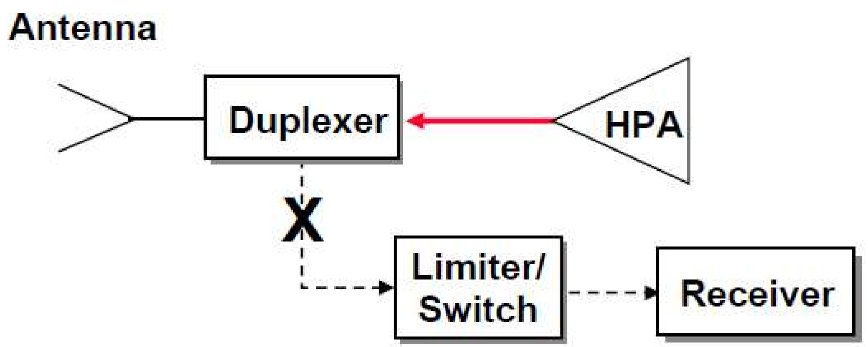
Radar Transmitter/Receiver Timeline



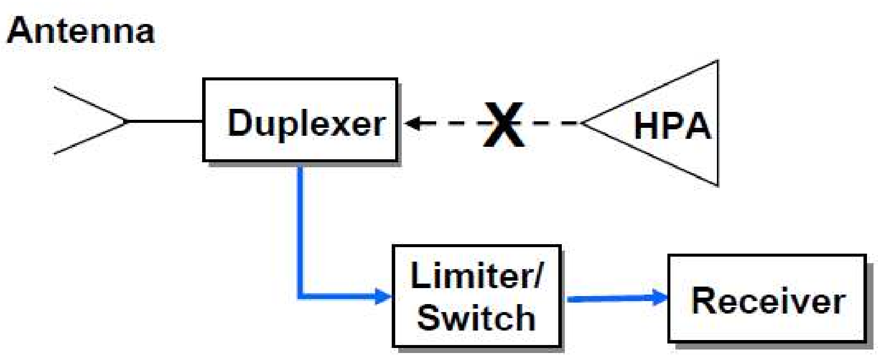
- Sensitive radar receiver must be isolated from the powerful radar transmitter
  - Transmitted power typically 10 kW – 1 MW
  - Receiver signal power in 10's μW – 1 mW
- Isolation provided by duplexer switching

PRI = Pulse Repetition Interval

Duplexer Function



Transmit Interval



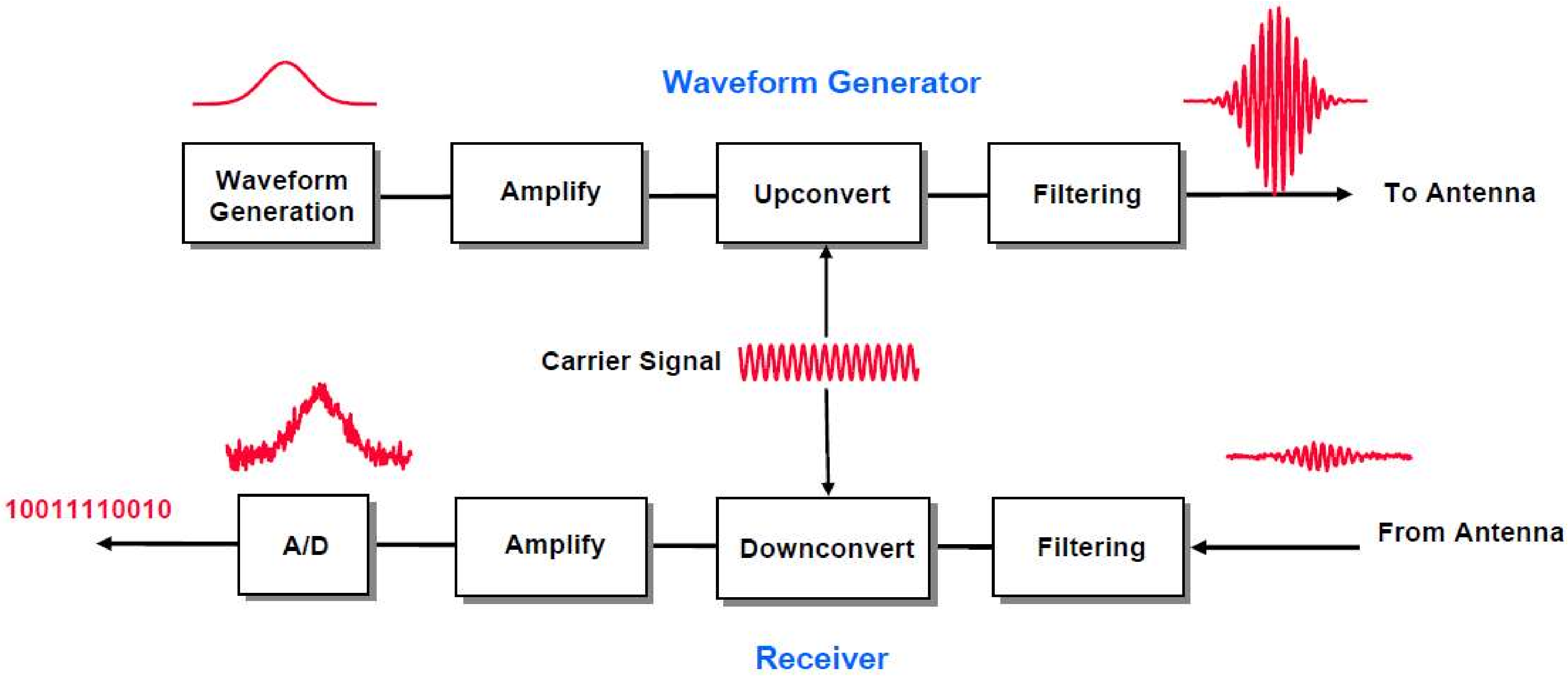
Receive Interval

- Transmitter ON
  - Connect antenna to transmitter with low loss
  - Protect receiver during transmit interval
- Receiver ON
  - Connect Antenna to receiver with low loss
  - (transmitter must be turned off in this interval)
  - Limiter/switch is used for additional protection against strong interference

HPA = High Power Amplifier

차　　례

Simplified Functional Descriptions

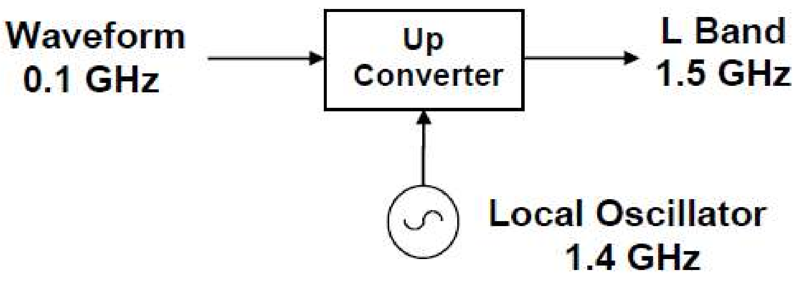


- Waveform generator and receiver share several similar functions
  - Amplification, filtering and frequency conversion

Frequency Conversion Concepts

Waveform Generator

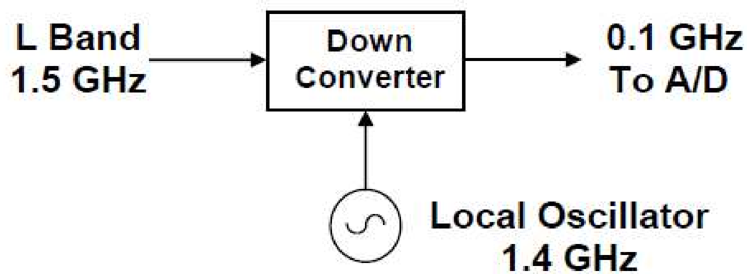
Frequency Upconversion
Baseband to L Band



- Upconverter translates the waveform frequency to a higher frequency
- Reason:
  - Waveform generation less expensive at lower frequency

Receiver

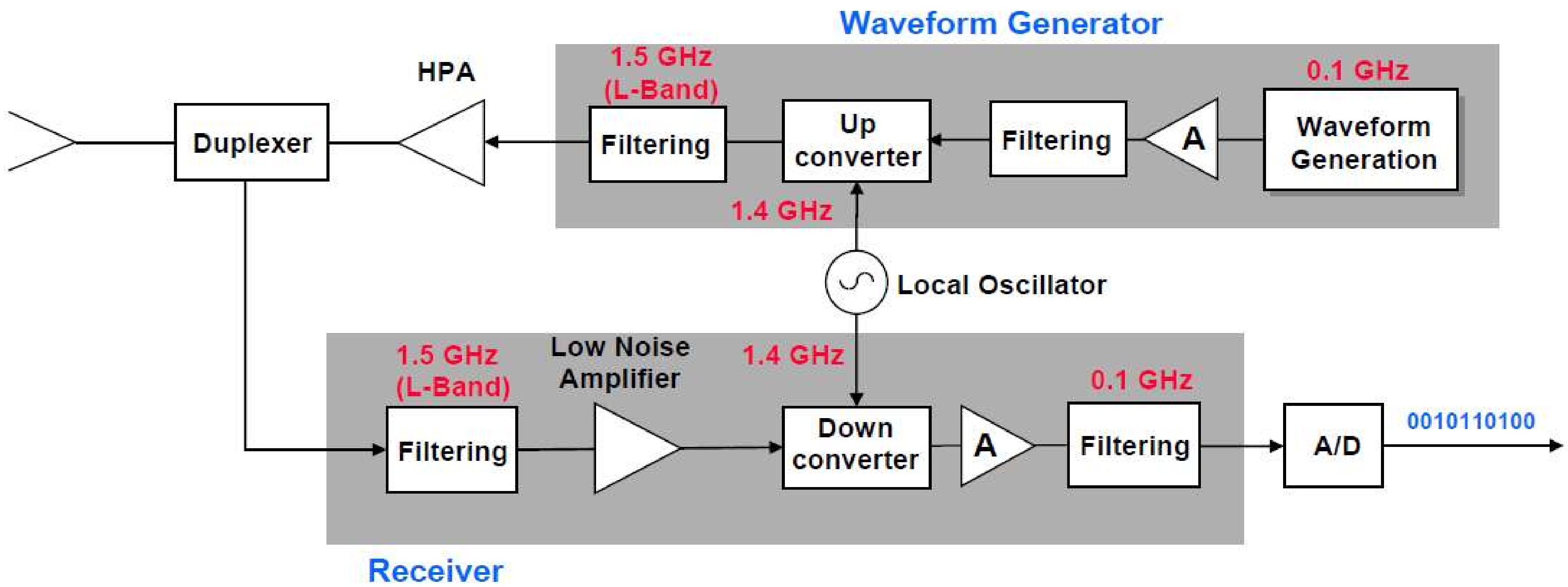
Frequency Downconversion
L Band to Baseband



- Downconverter translates the receive frequency to a lower frequency
- Reason:
  - Dynamic range of A/D converter higher at lower frequency

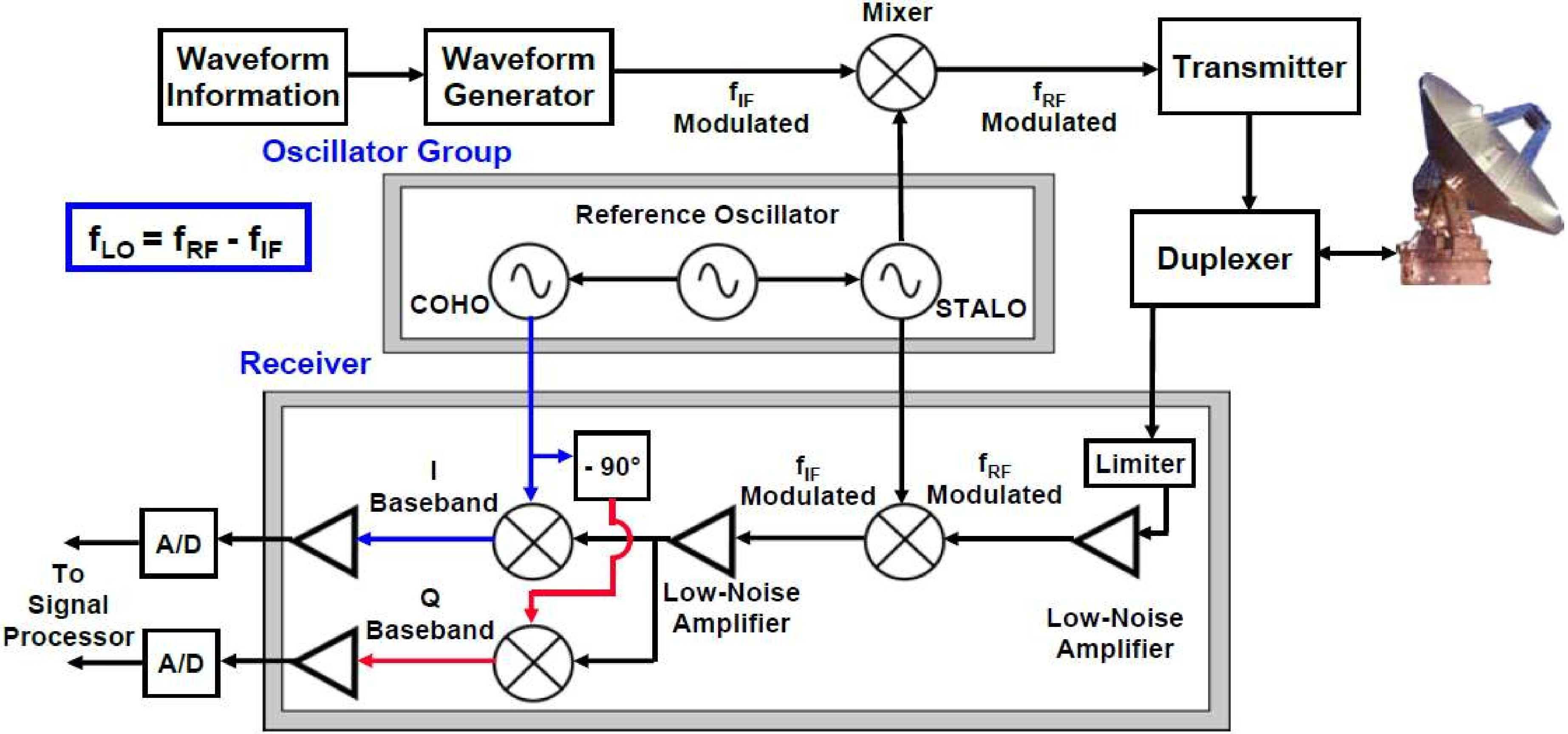
Simplified System Block Diagram

Waveform Generator and Receiver



- This example shows only a single stage conversion
  - In general, design based on multiple stage of frequency conversion are employed
- Multiple stages of amplification and filtering are also used

Block Diagram of Radar Receiver



Components from the Antenna to the First Amplifier are the most Important in Determining the Noise Level of a Radar Measurement

차 례

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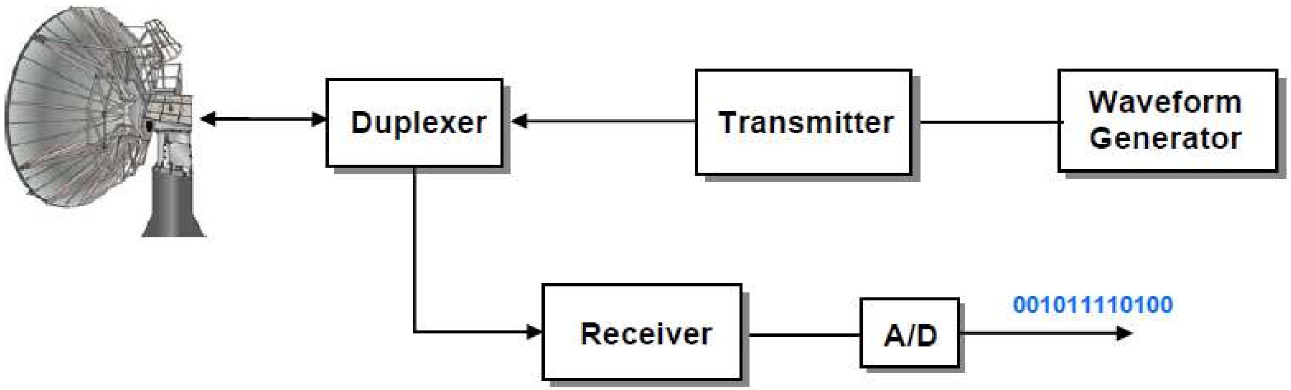
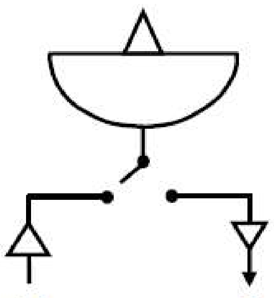
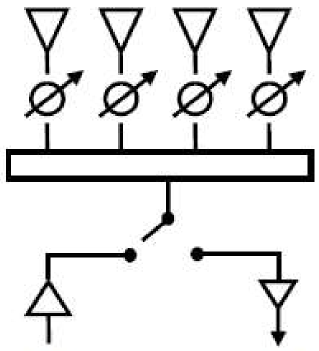
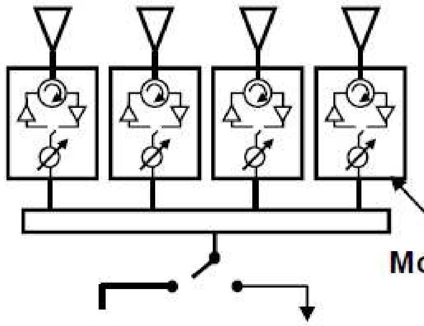
Dish Radars

KWAJALEIN



- Conventional radar transmitter/receiver design employed

Radar Antenna Architecture Comparison

	Dish Radar	Passive Array Radar	Active Array Radar
			
PRO	• Very low cost • Frequency diversity	• Beam agility • Effective radar resource management	• Beam agility • Effective radar resource management • Low loss
CON	• Dedicated function • Slow scan rate • Requires custom transmitter • High loss	• Higher cost • Requires custom transmitter and high-power phase shifters • High loss	• High cost • More complex cooling

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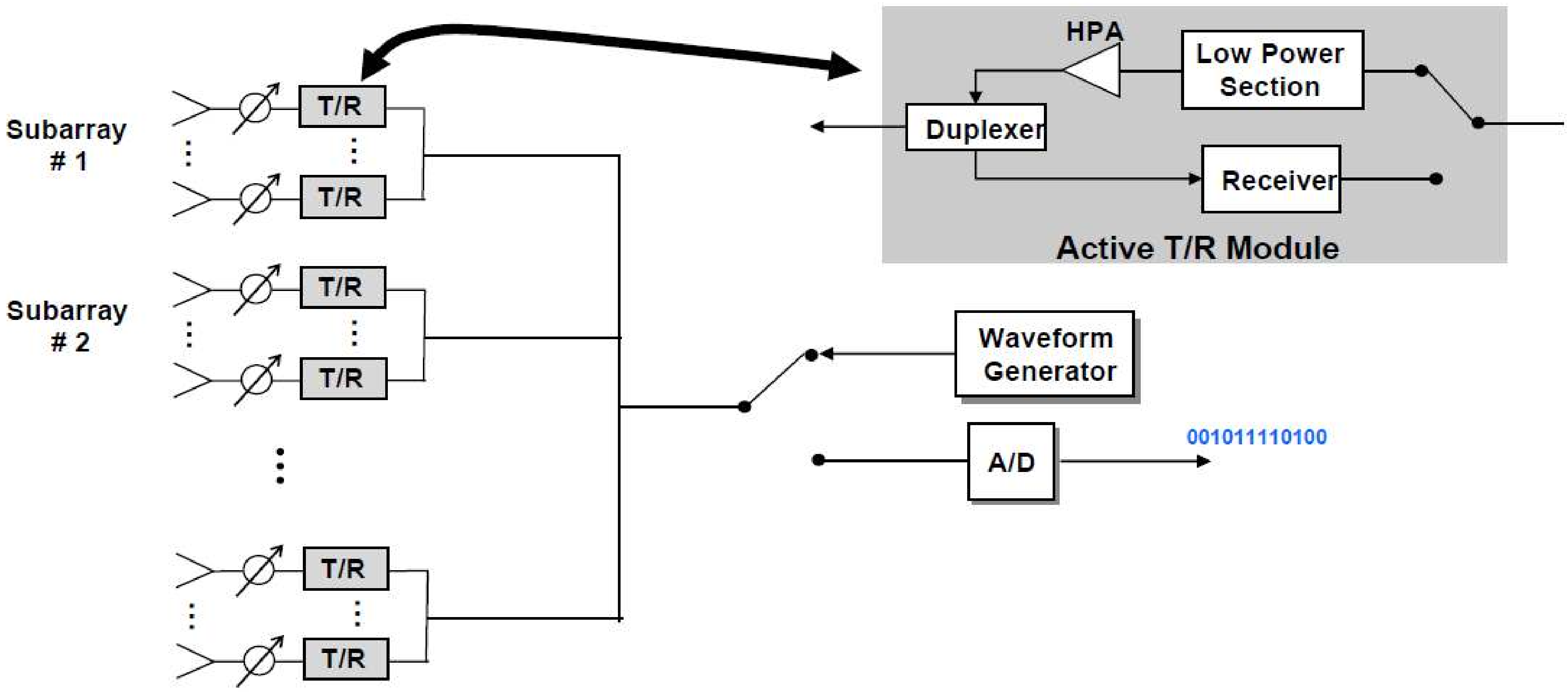
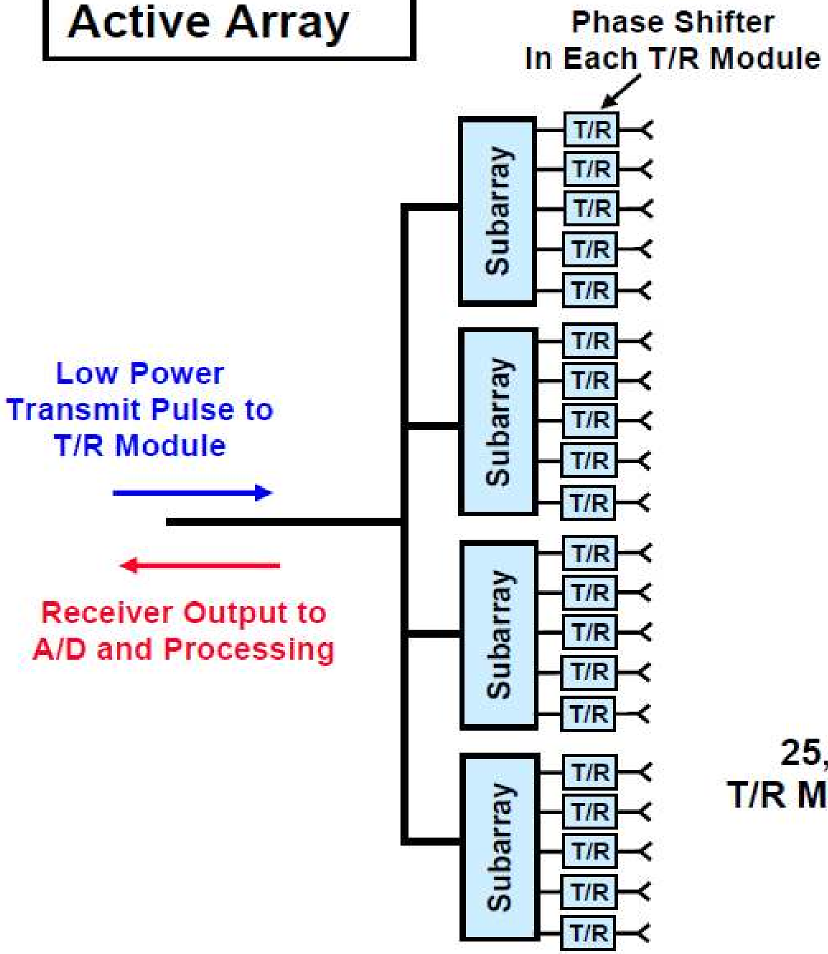
Active Phased Array Radar



- Transmit/Receive function distributed to each module on array

Active Array Radars

Active Array



SBX X-Band Phased Array Radar

45,056
T/R Modules

Courtesy of US MDA

THAAD X-Band Phased Array Radar

25,334
T/R Modules

Large Phased Arrays

Passive Array Radar

Active Array Radar

THAAD Radar

Courtesy of Raytheon. Used with permission.

Passive Array Radar

Cobra Dane
15.3K active elements

Courtesy of Raytheon. Used with permission.

Courtesy of Raytheon.
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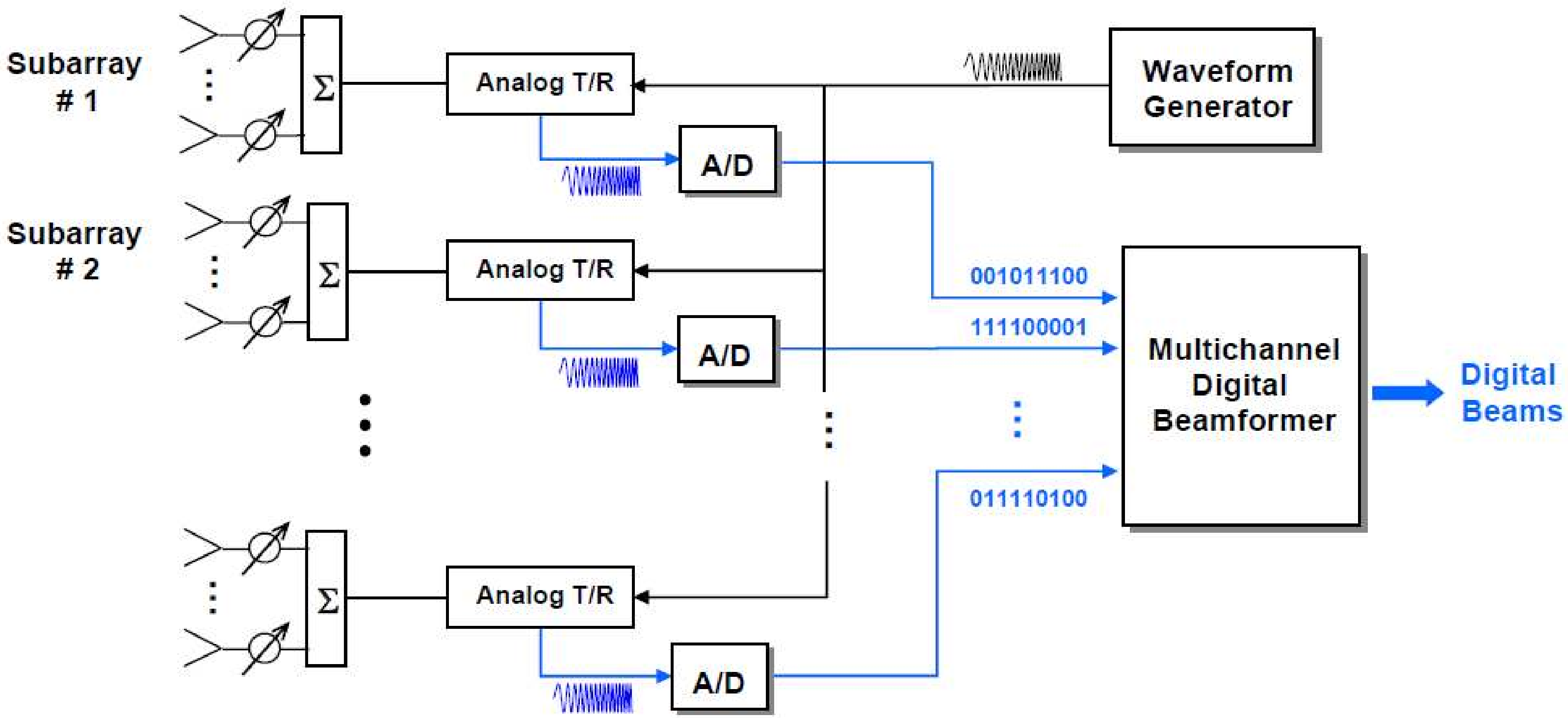
Digital Array Radar Architecture

Digital on Receive



- Each active analog T/R module is followed by an A/D for immediate digitization
  - Multiple received beams are formed digitally by the digital beamformer

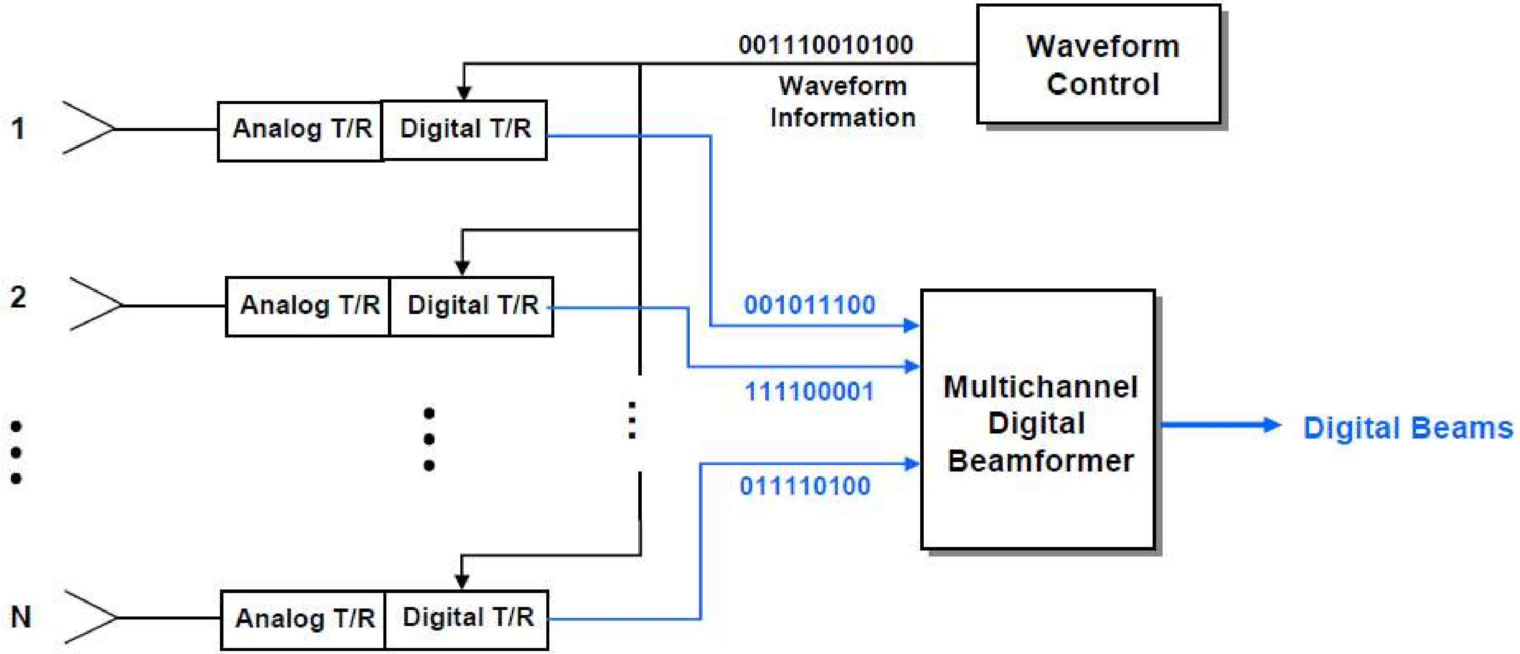
Digital Array Example

Digital On Receive

RSTER
(14 Digital Receivers)

Digital Array Radar Architecture II

Digital on Transmit & Receive



- Both waveform generation and receiver digitization are performed within each T/R module
  - Complete flexibility on transmit and receive

Q & A