Introduction to Radar Systems

Radar Transmitter/Receiver

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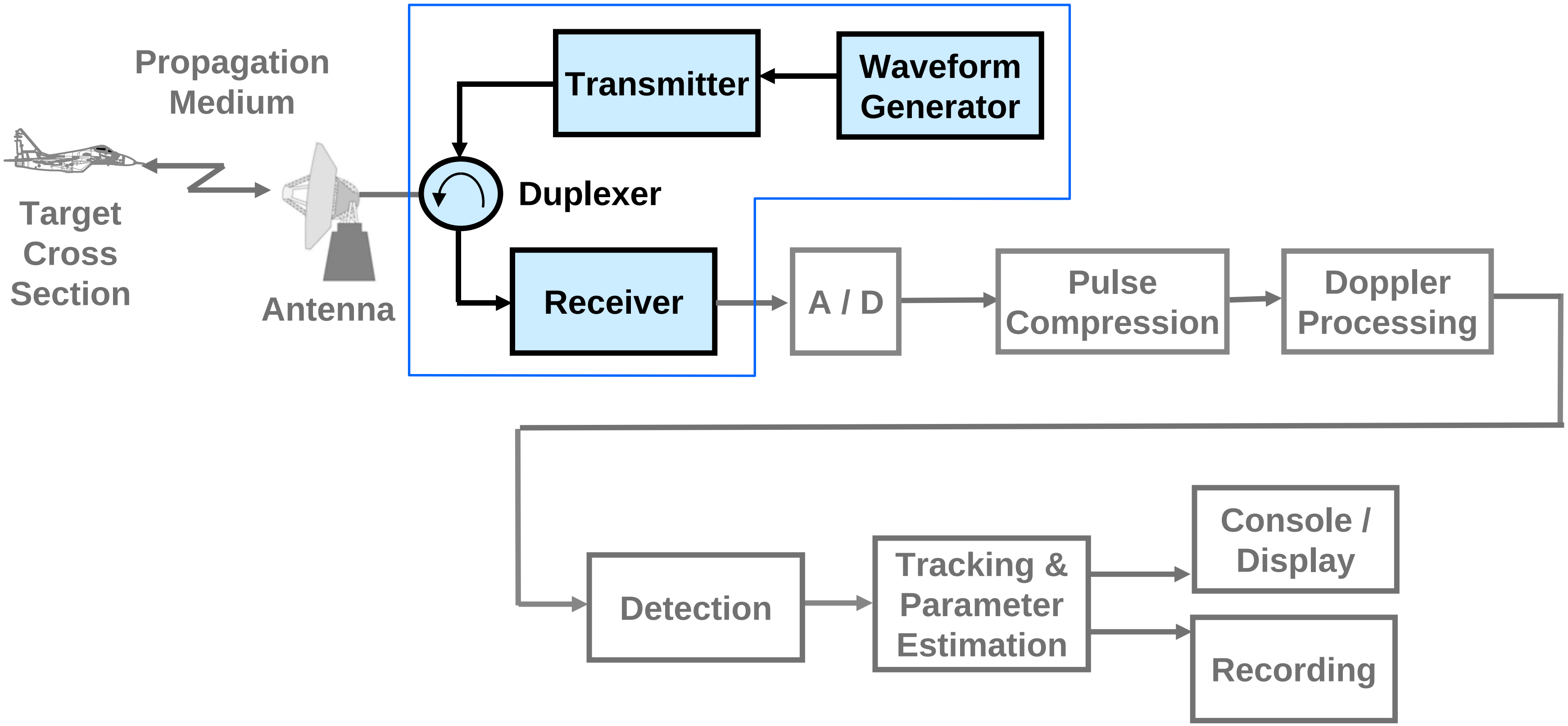
Outline

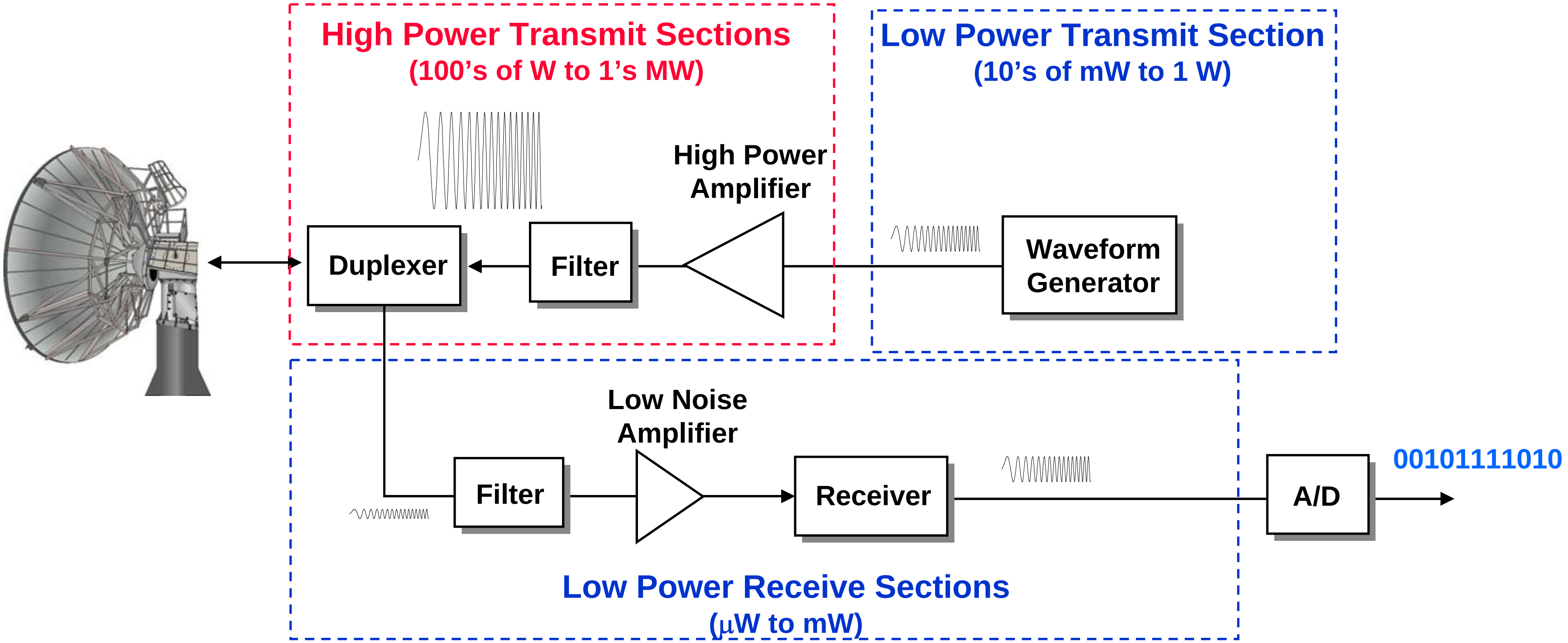
- Introduction
- Radar Transmitter
- Radar Waveform Generator and Receiver
- Radar Transmitter/Receiver Architecture
- Summary

Radar Block Diagram

We will cover this particular part
of the radar in this lecture



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)**

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

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

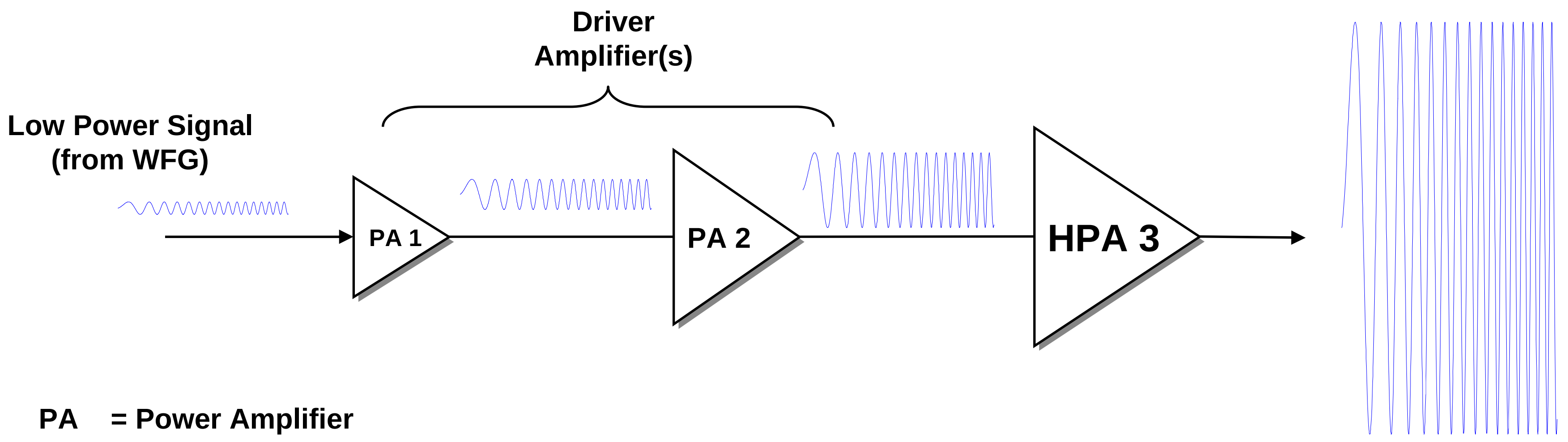
- **S/N of target can be enhanced by**
  - **Higher transmitted power P_{av}**
  - **Lower system losses L**
  - **Minimize system temperature T_s**

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

Outline

- **Introduction**
- **Radar Transmitter Overview**
  - **High Power Amplifier**
- **Radar Waveform Generator and Receiver**
- **Radar Transmitter/Receiver Architecture**
- **Summary**

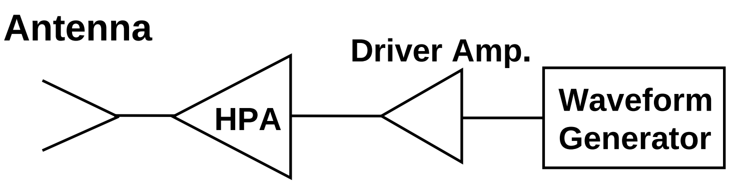
Power Amplification Process



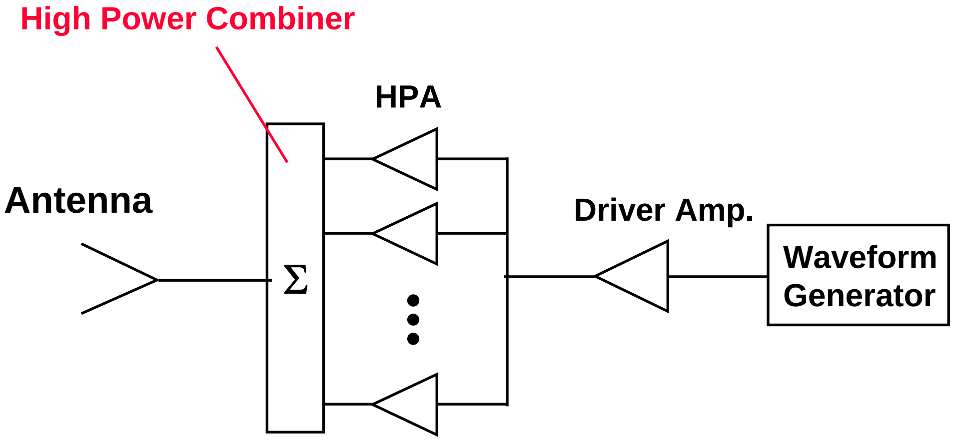
PA = Power Amplifier
HPA = High Power Amplifier

- **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**

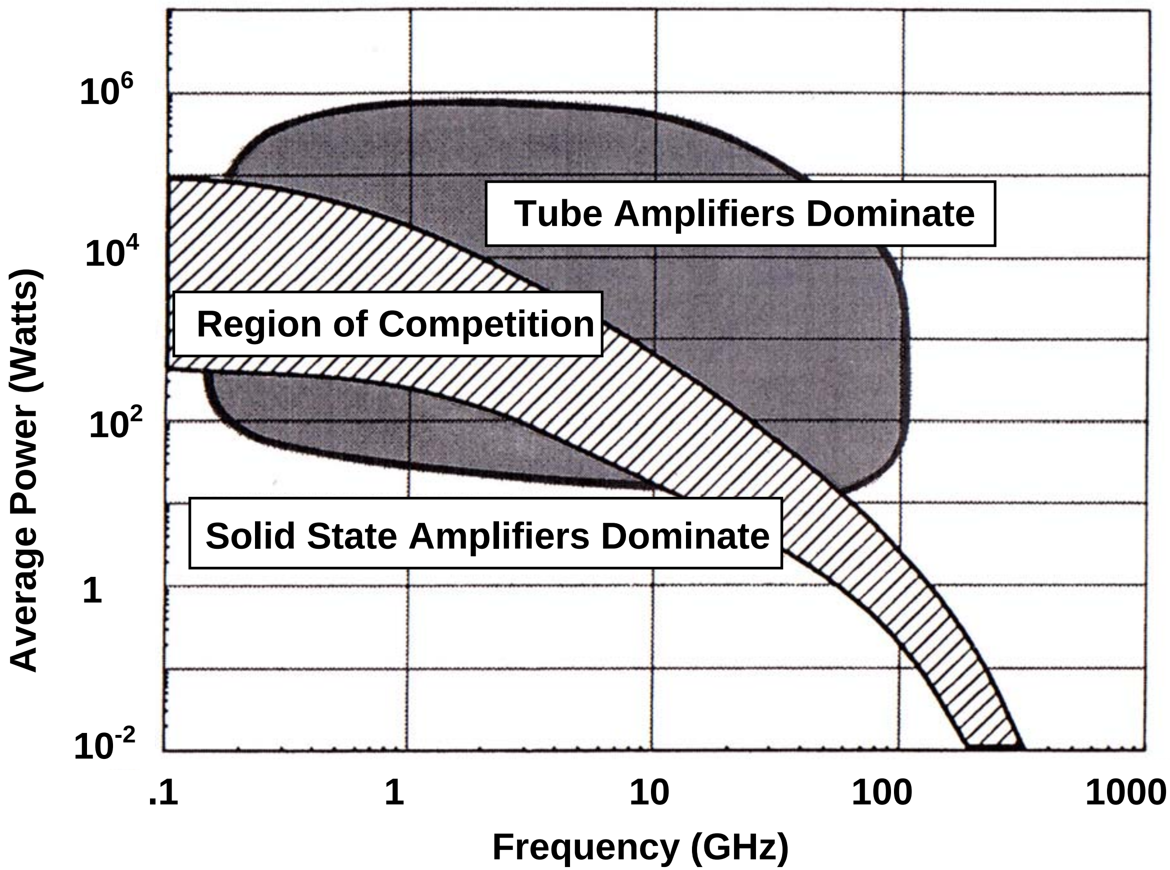
HPA = High Power Amplifier

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



Power Amplifier Examples

- **Tube amplifiers**
  - **Klystrons**
  - **Travelling wave tubes**

- **Solid State amplifiers**
  - **Solid state power transistors**

Criteria for choosing high power amplifier

- **Average power output as a function of frequency**
- **Total bandwidth of operation**
- **Duty cycle**
- **Gain**
- **Mean time between failure (MTBF)**
- **etc…**

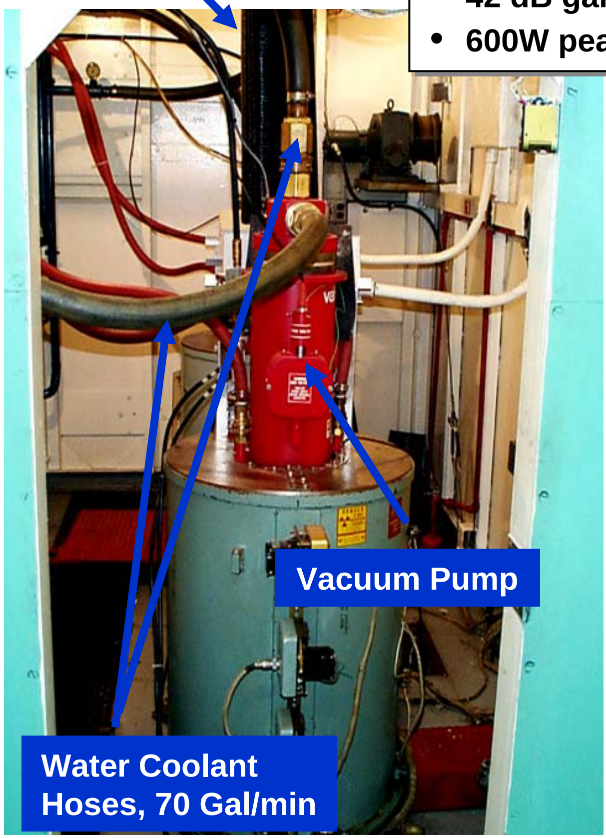
MIT/LL Millstone Hill Radar
Klystron Tubes (Vacuum Devices)

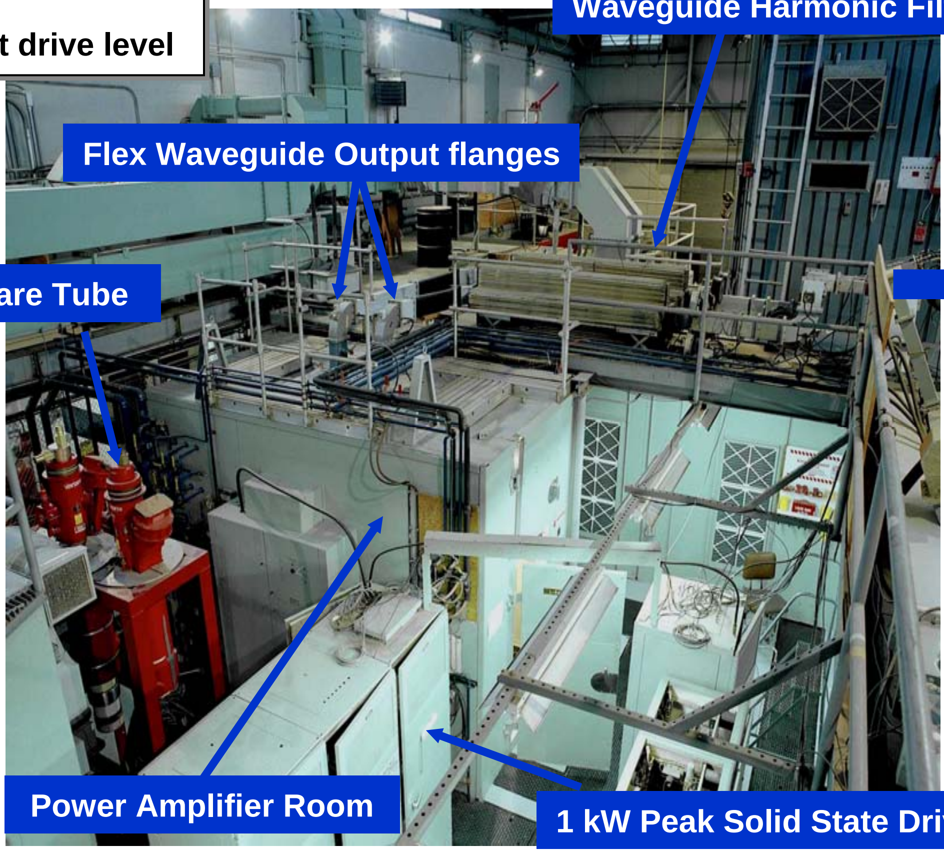
Output device	Klystrons (2)
Center Frequency	1295 MHz
Bandwidth	8 MHz
Peak Power	3 MW
Average Power	120 kW
Pulse Width	1 ms
Beam Width	0.6^o
Antenna Diameter	84 ft

- 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





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

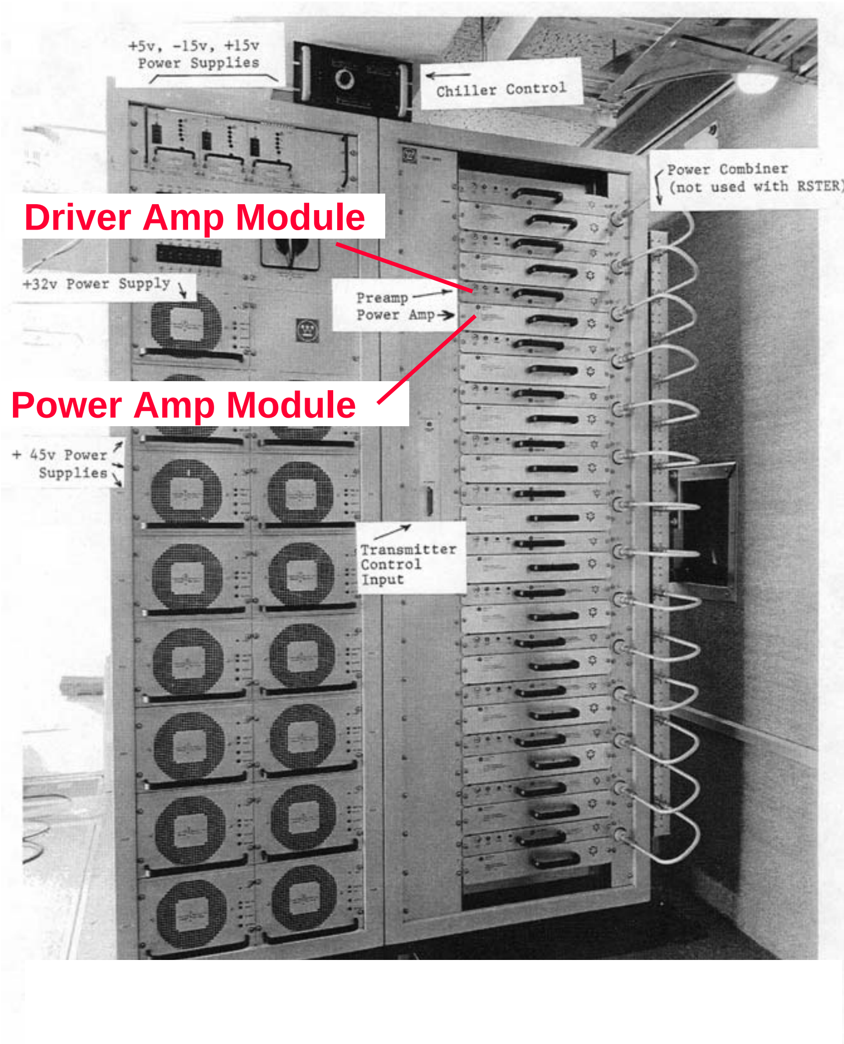
X Band
VTX-5681C
COUPLED CAVITY
TWT

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

S-Band Transmitter

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

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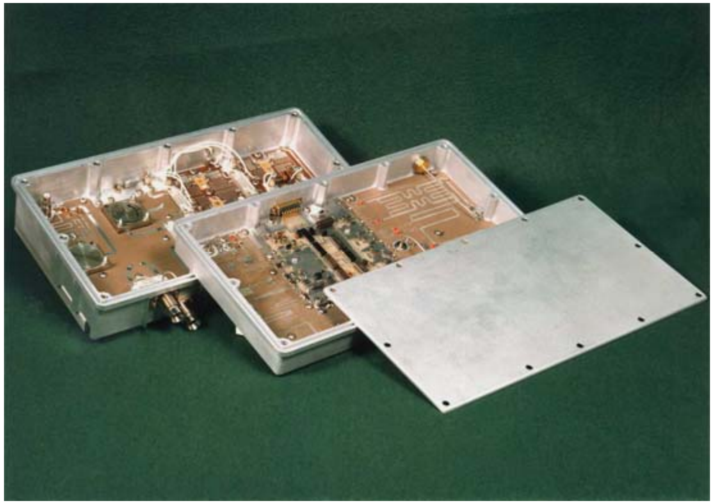

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Outline

- Introduction
- Radar Transmitter Overview
  - High Power Amplifier
  - Duplexer
- Radar Waveform Generator and Receiver
- Radar Transmitter/Receiver Architecture
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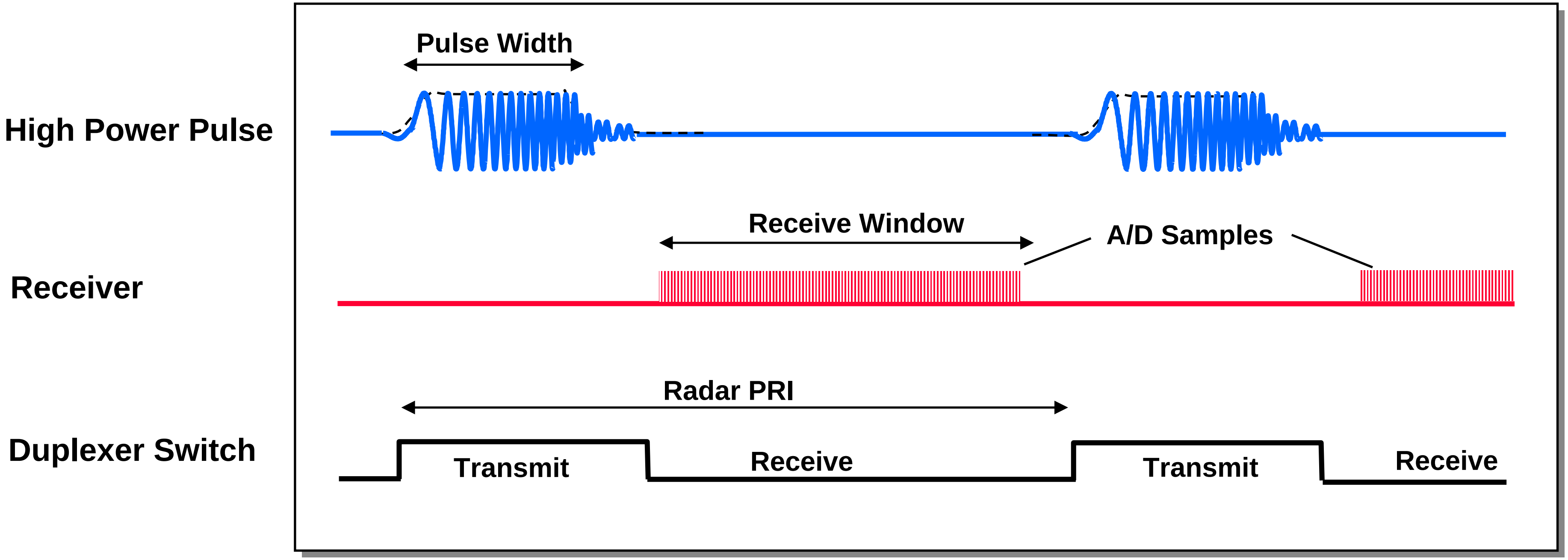
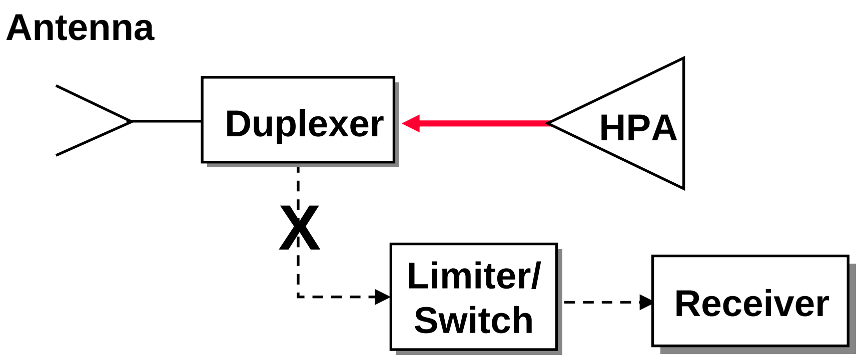
Radar Transmitter/Receiver Timeline



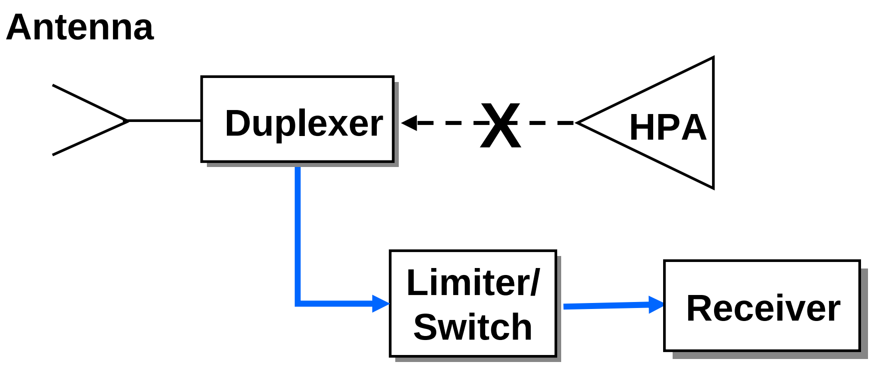
- Sensitive radar receiver must be isolated from the powerful radar transmitter
  - Transmitted power typically 10 kW – 1 MW
  - Receiver signal power in 10's μW – 1 mW
- Isolation provided by duplexer switching

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

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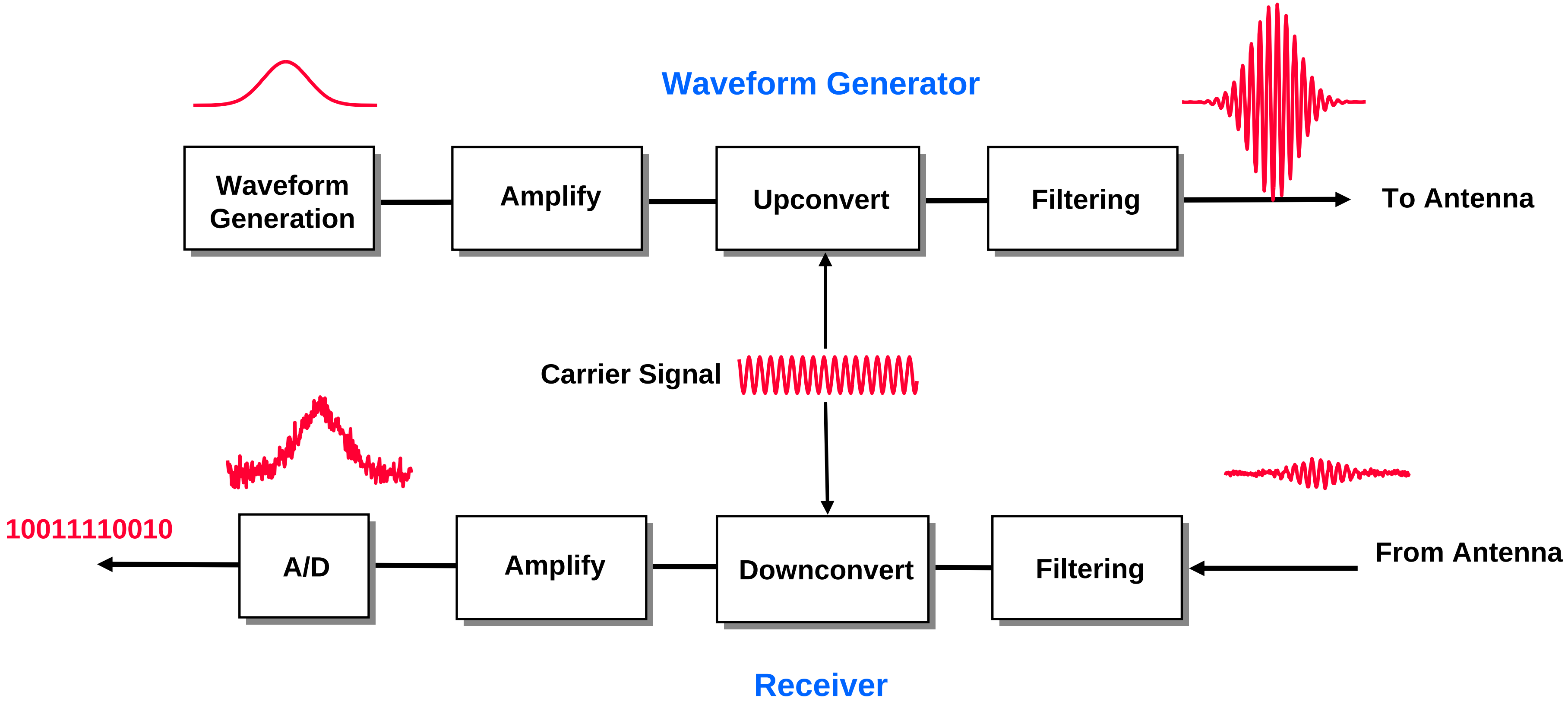
Simplified Functional Descriptions

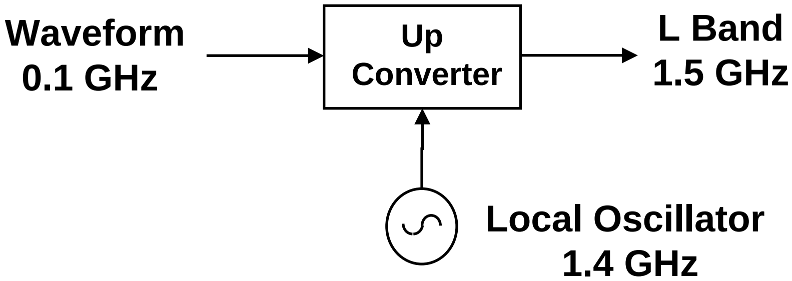


- **Waveform generator and receiver share several similar functions**
  - **Amplification, filtering and frequency conversion**

Frequency Conversion Concepts

Waveform Generator

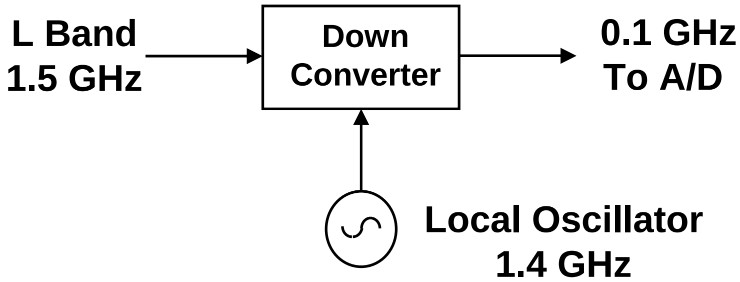
Frequency Upconversion
Baseband to L Band



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

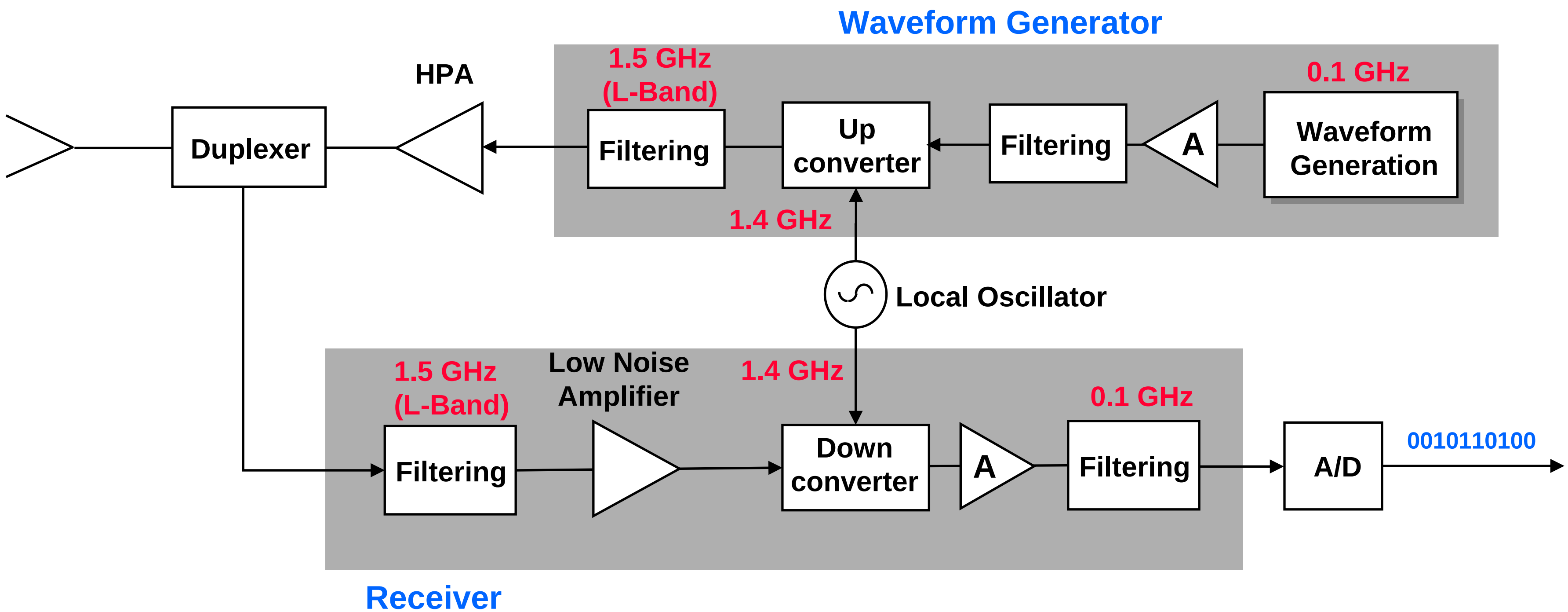
Receiver

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

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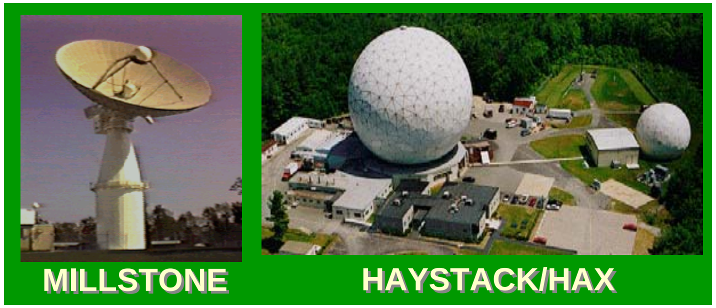
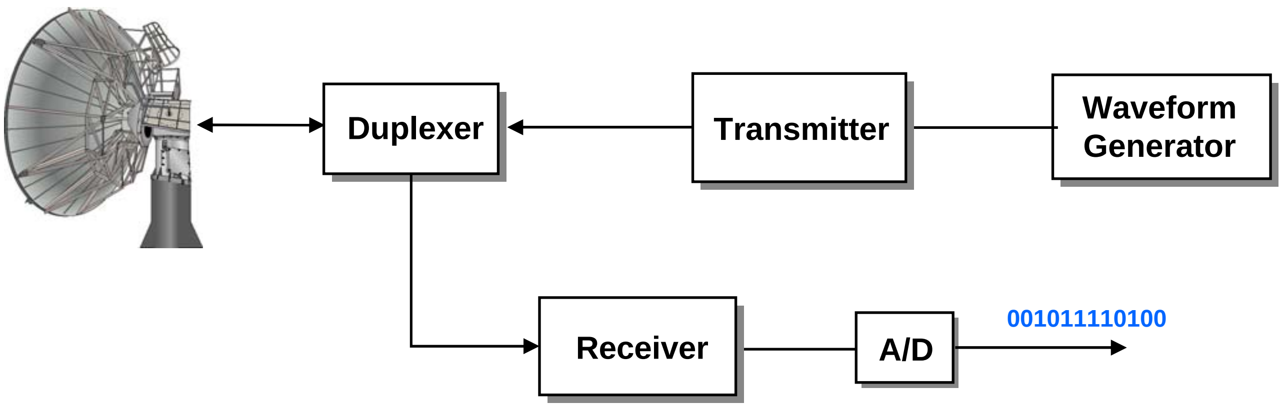
Dish Radars

KWAJALEIN

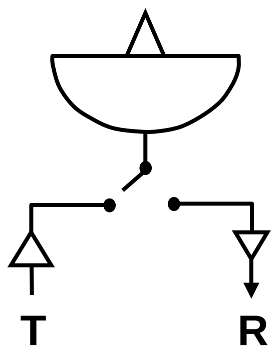




- **Conventional radar transmitter/receiver design employed**

Radar Antenna Architecture Comparison

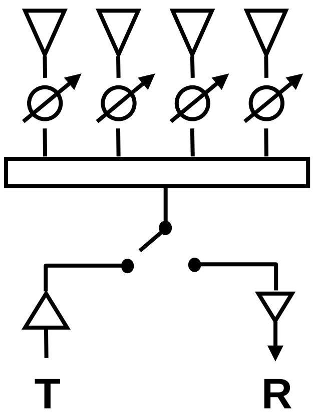
Dish Radar



PRO
- Very low cost
- Frequency diversity

CON
- Dedicated function
- Slow scan rate
- Requires custom transmitter
- High loss

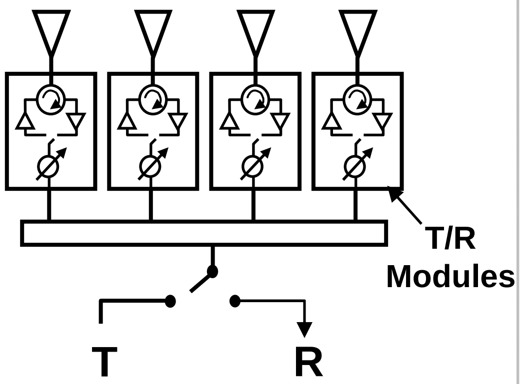
Passive Array Radar



PRO
- Beam agility
- Effective radar resource management

CON
- Higher cost
- Requires custom transmitter and high-power phase shifters
- High loss

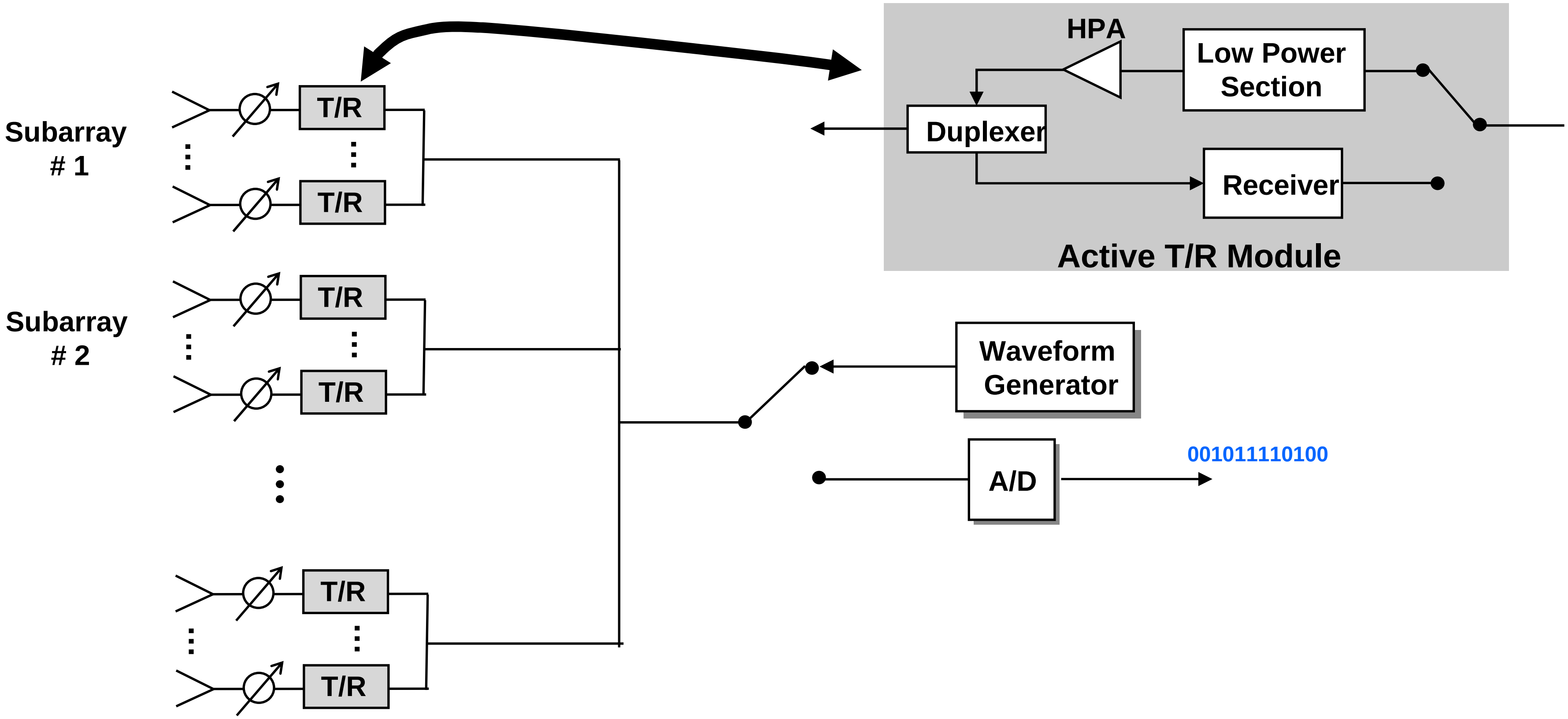
Active Array Radar



PRO
- Beam agility
- Effective radar resource management
- Low loss

CON
- High cost
- More complex cooling

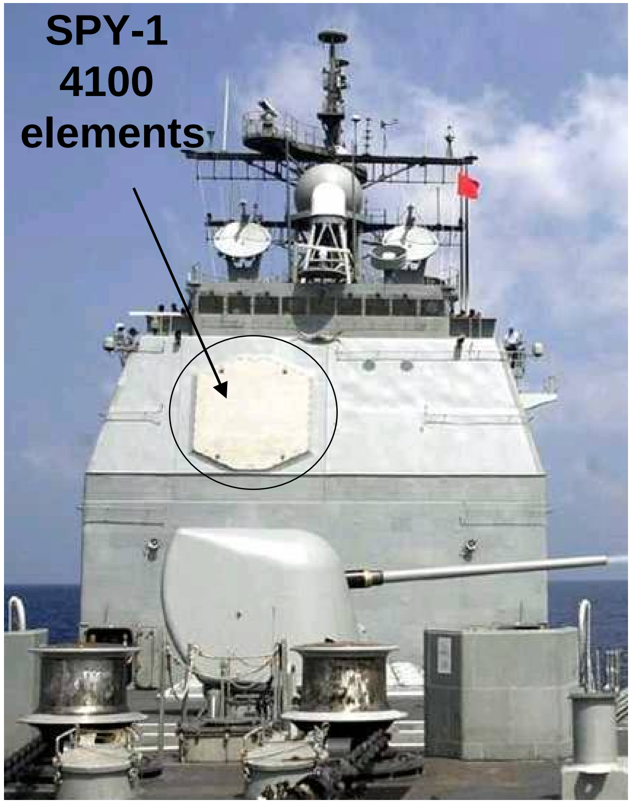
Active Phased Array Radar



- **Transmit/Receive function distributed to each module on array**

Large Phased Arrays

Passive Array Radar



Active Array Radar

THAAD Radar

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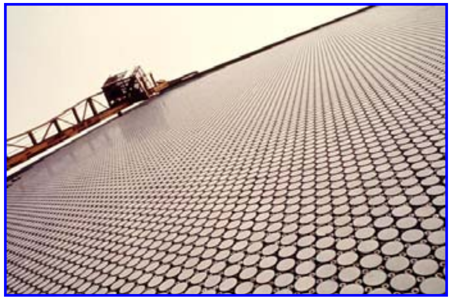
Passive Array Radar

Cobra Dane

15.3K active elements



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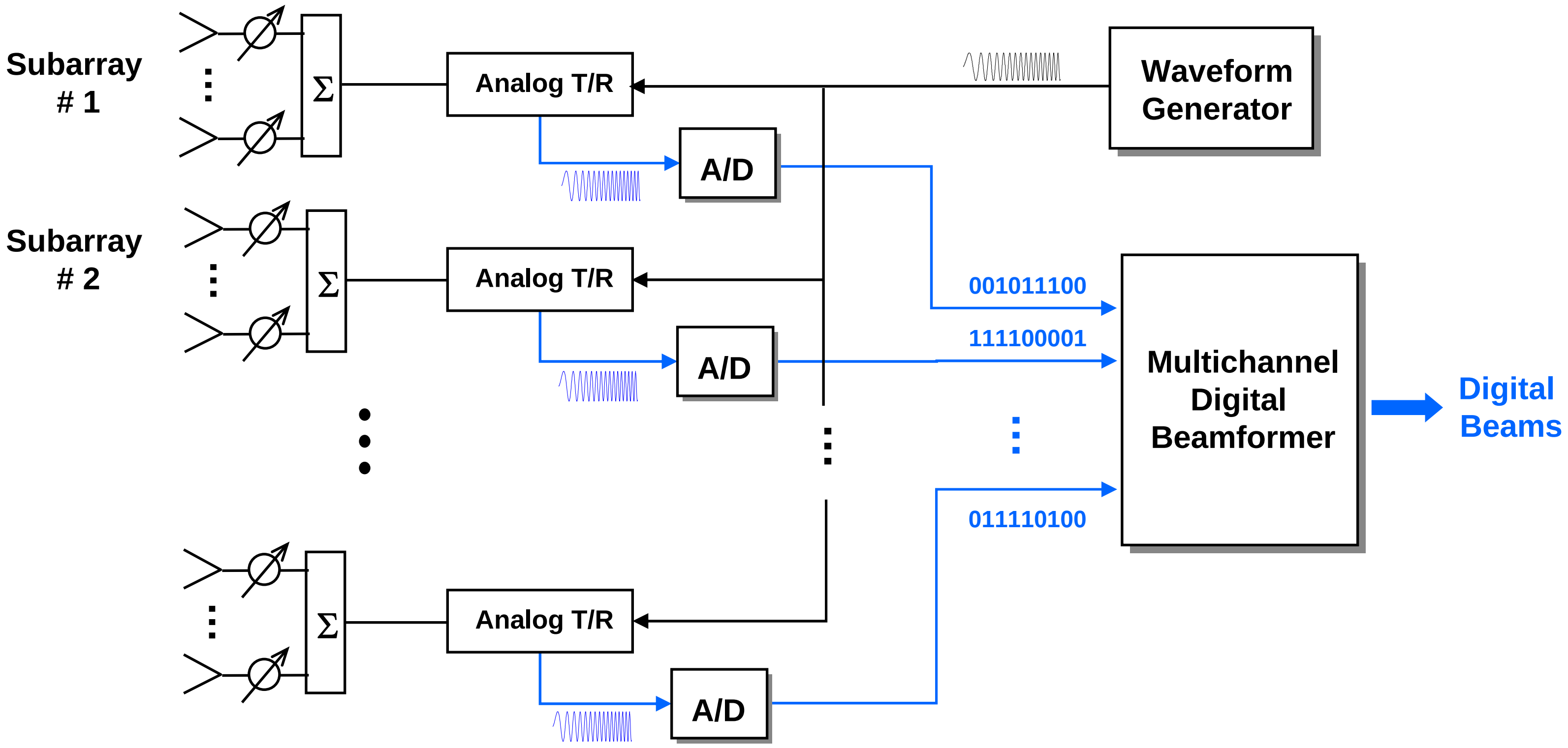
Digital Array Radar Architecture
Digital on Receive

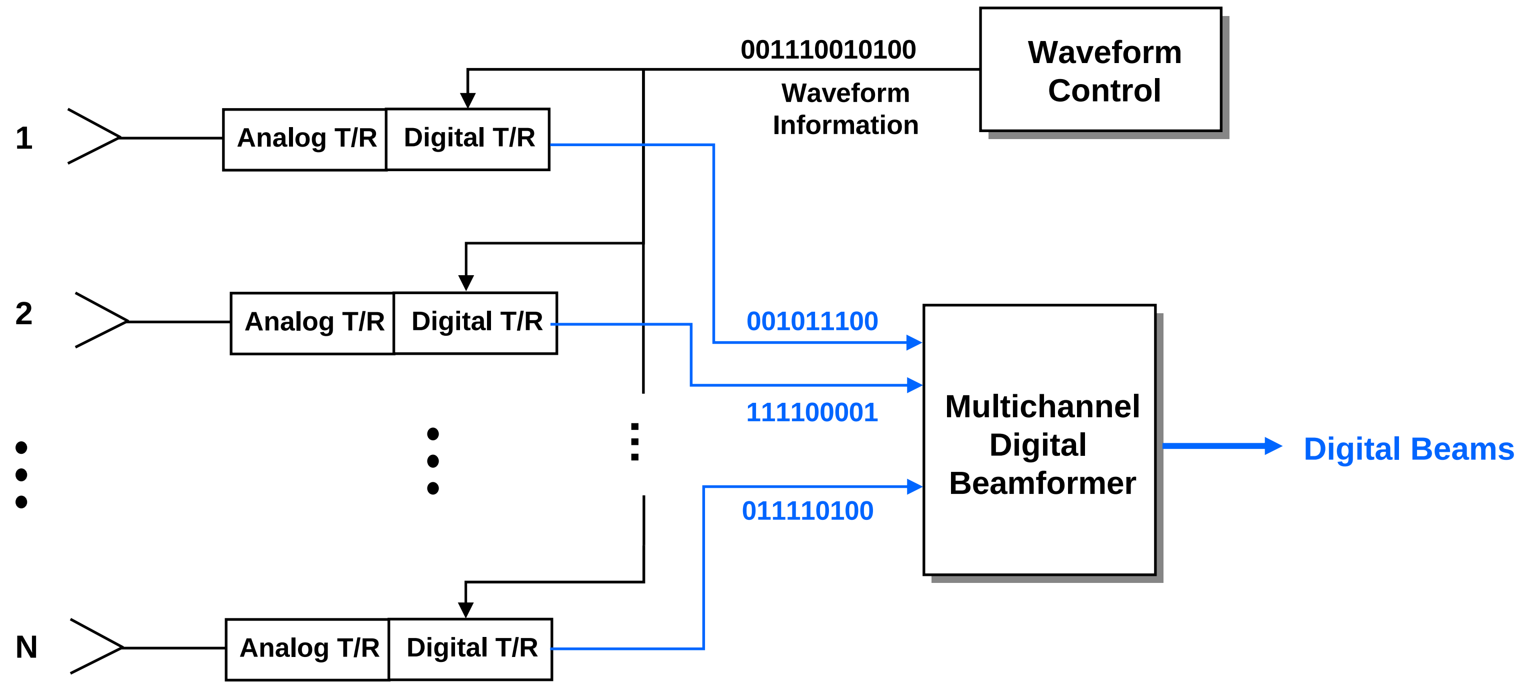


- **Each active analog T/R module is followed by an A/D for immediate digitization**
  - **Multiple received beams are formed digitally by the digital beamformer**

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**

Summary

- **Radar transmit function is accomplished in two stages:**
  - **Waveform generator creates low power waveform signal and upconverts it to RF**
  - **Transmitter amplifies waveform signal**
- **Radar receiver performs filtering, amplification and downconversion functions**
  - **Final received signal is fed to an A/D for digitization**
- **Radar transmit/ receive architecture is highly dependent on the antenna type**
  - **Centralized architecture: dish radars, passive array radars**
  - **Distributed architecture: active array and digital array radars**

References

- Skolnik, M., Introduction to Radar Systems, New York, McGraw-Hill, 3rd Edition, 2001
- Skolnik, M., Radar Handbook, New York, McGraw-Hill, 2nd Edition, 1990