Introduction to Radar Systems

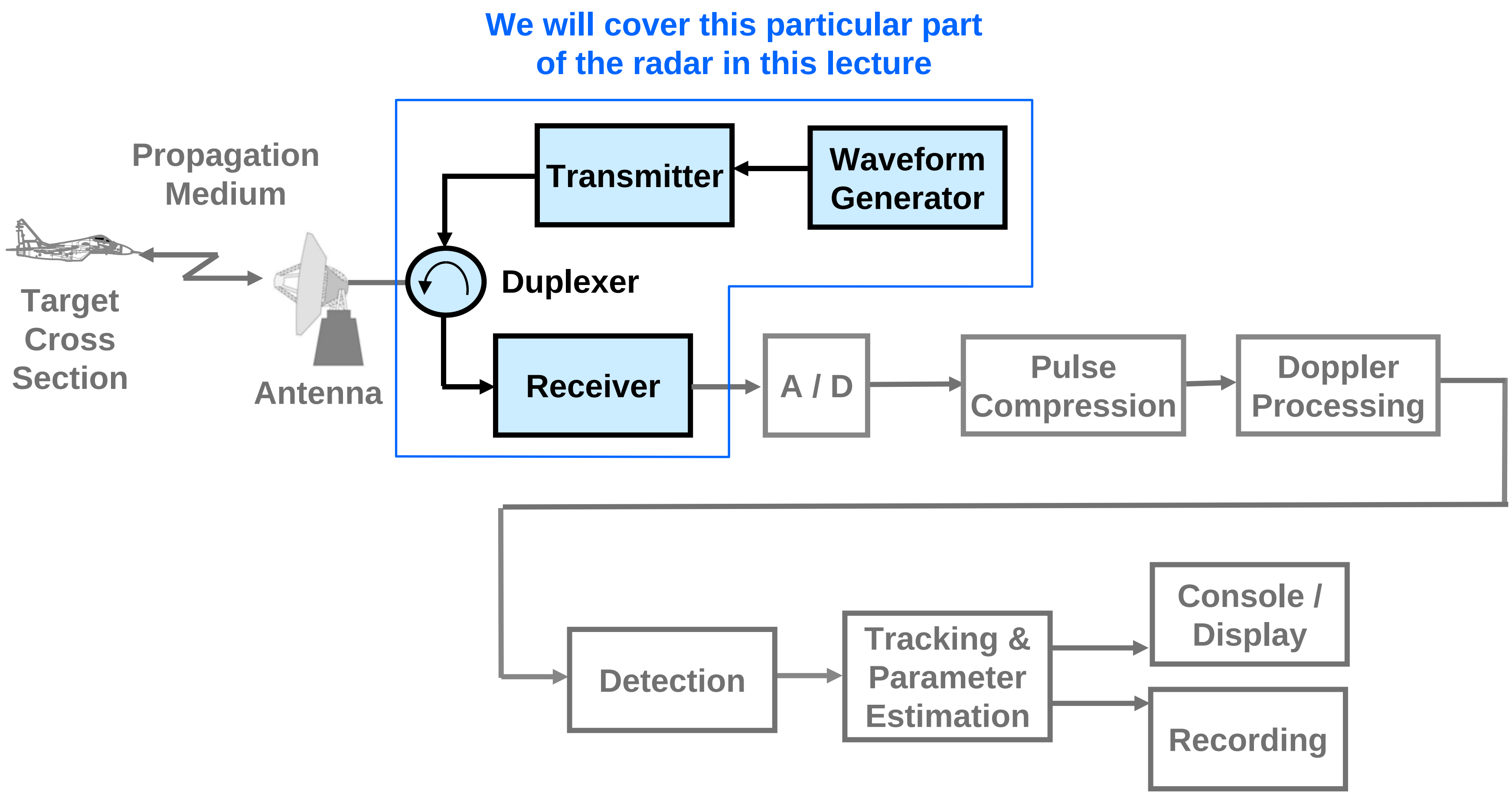
Radar Transmitter/Receiver

Disclaimer of Endorsement and Liability

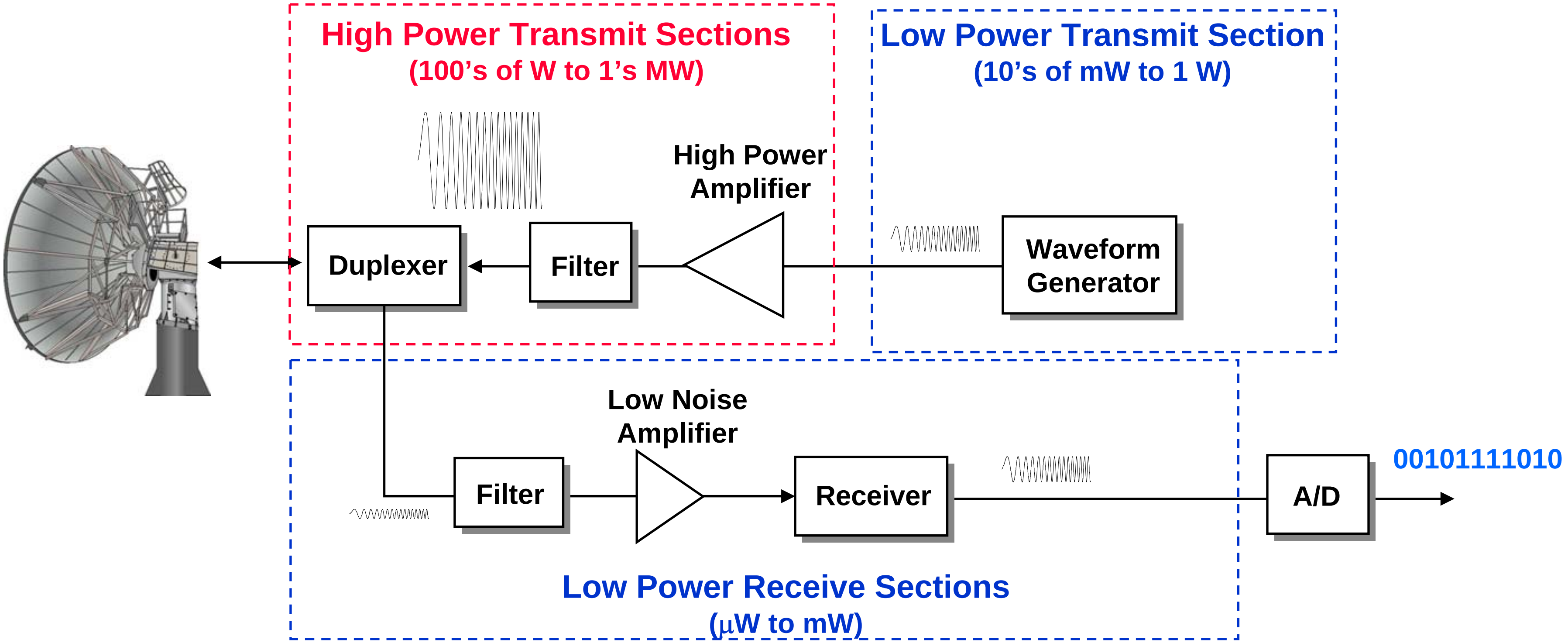
Outline

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

Radar Block Diagram



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

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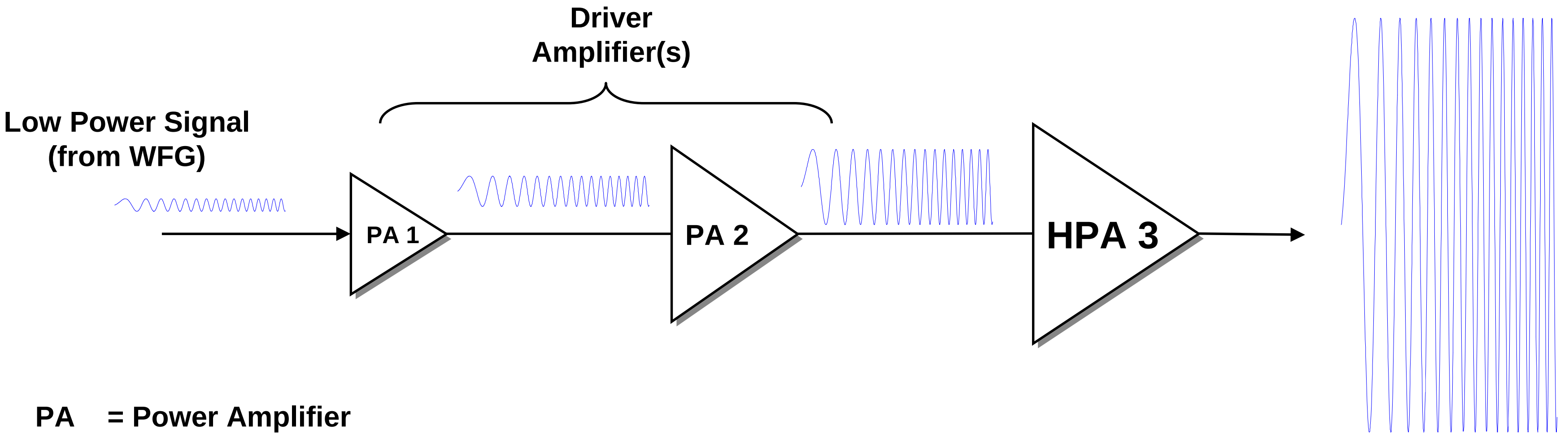
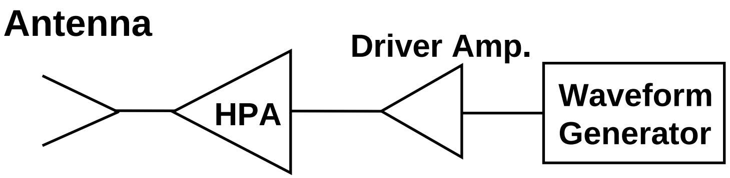
Power Amplification Process



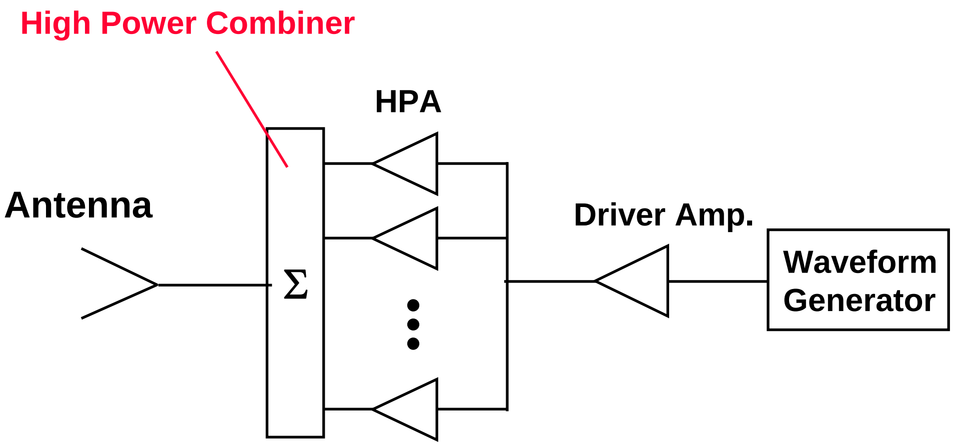
PA = Power Amplifier
HPA = High Power Amplifier

- **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

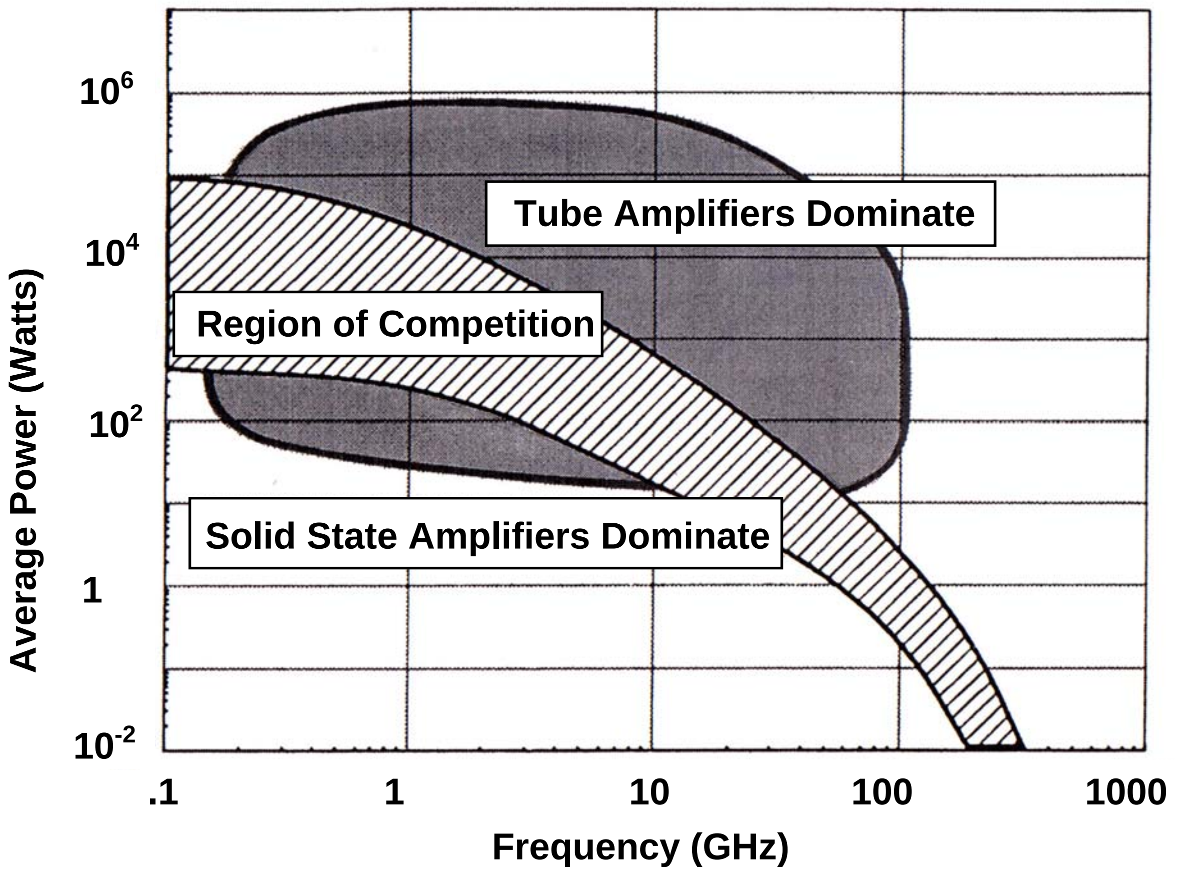
HPA = High Power Amplifier

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…**

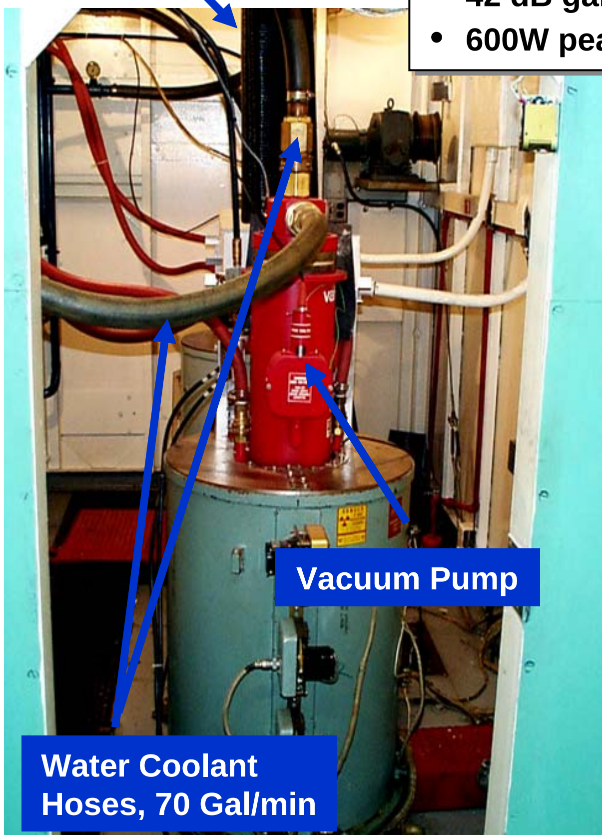
MIT/LL Millstone Hill Radar
Klystron Tubes (Vacuum Devices)

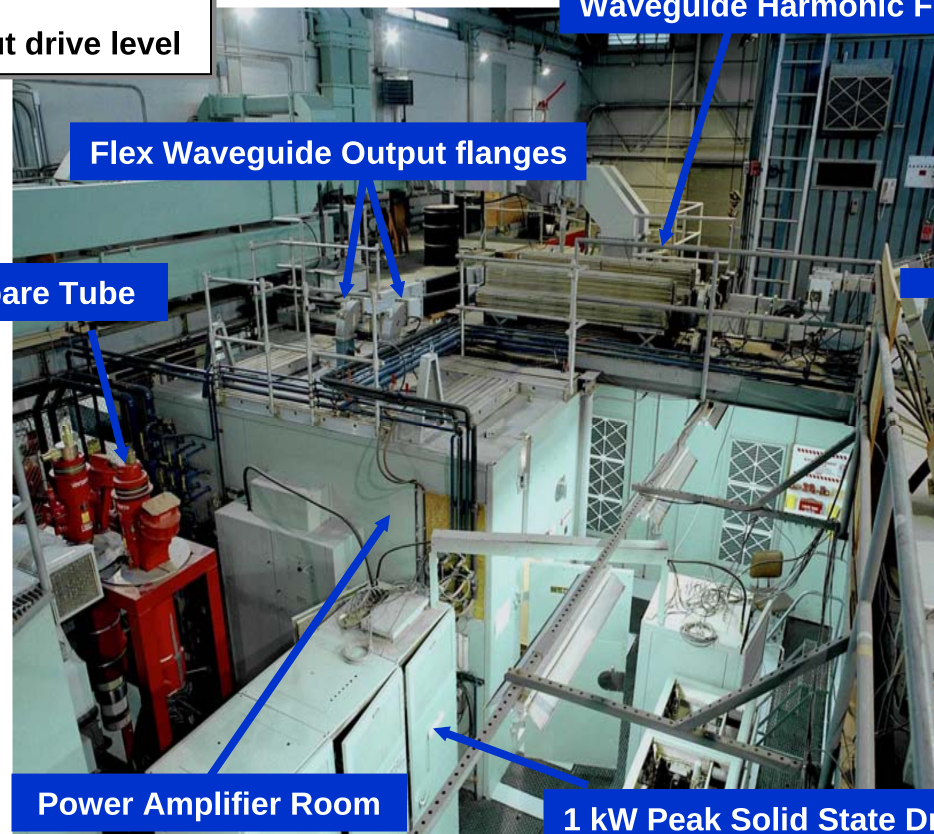
Output device	Klystrons (2)
Center Frequency	1295 MHz
Bandwidth	8 MHz
Peak Power	3 MW
Average Power	120 kW
Pulse Width	1 ms
Beam Width	0.6^o
Antenna Diameter	84 ft

- 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

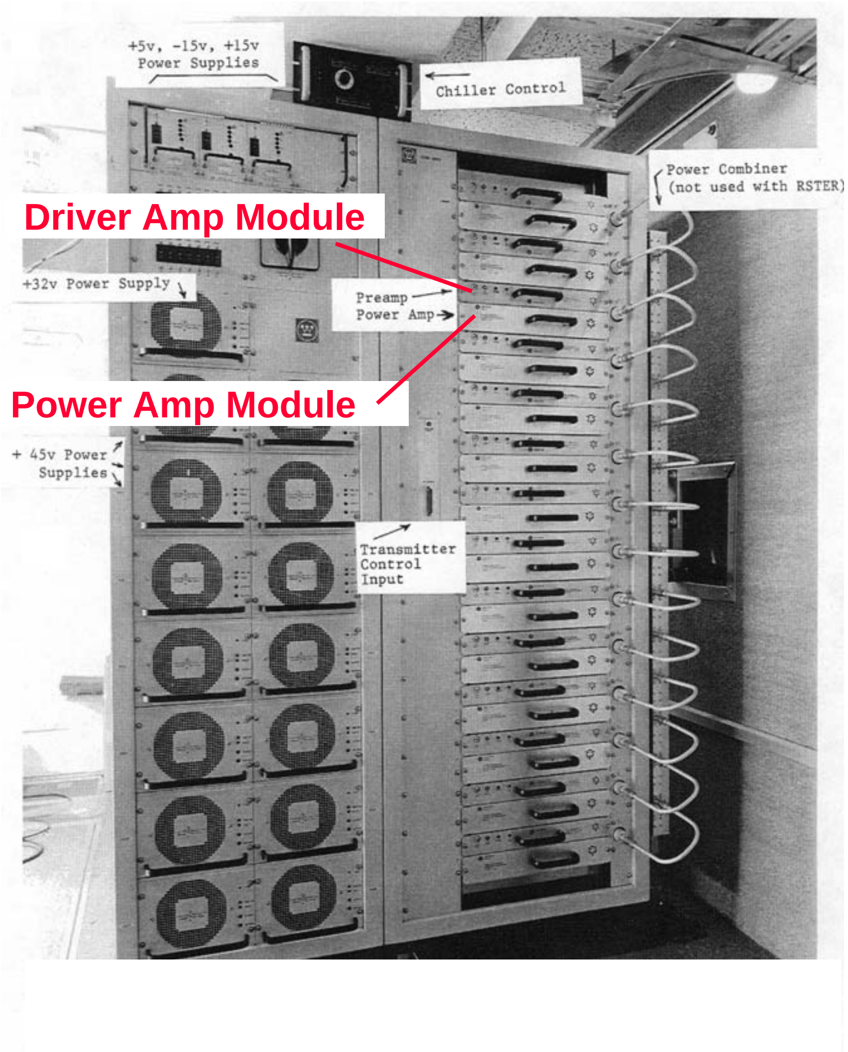
X Band
VTX-5681C
COUPLED CAVITY
TWT

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)

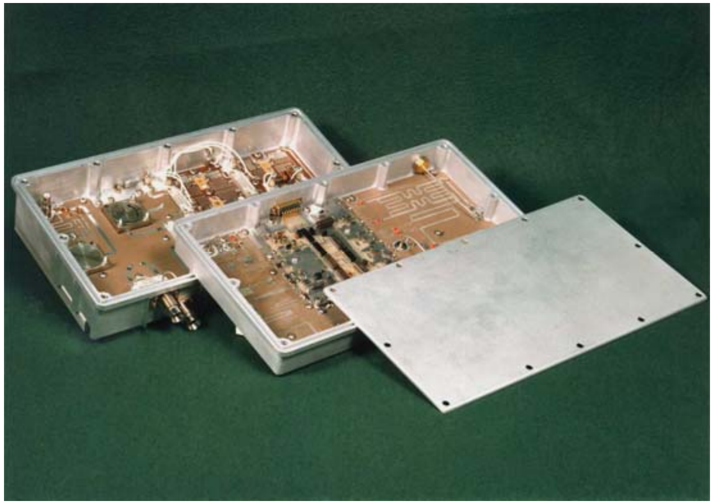


- **14 channels with 140 kW total peak power**
  - **8 kW average power**
- **Each channel is supplied by a power amplifier module**
  - **10 kW peak power**

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**

Courtesy of Raytheon. Used with permission.



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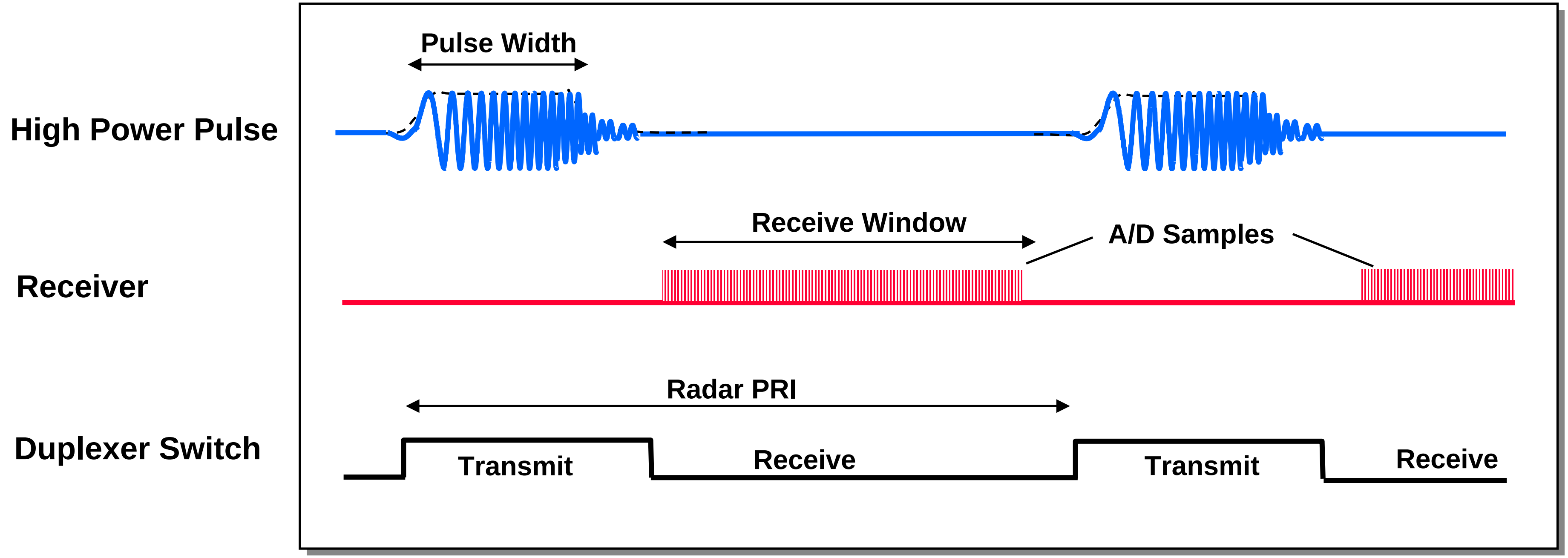
Outline

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

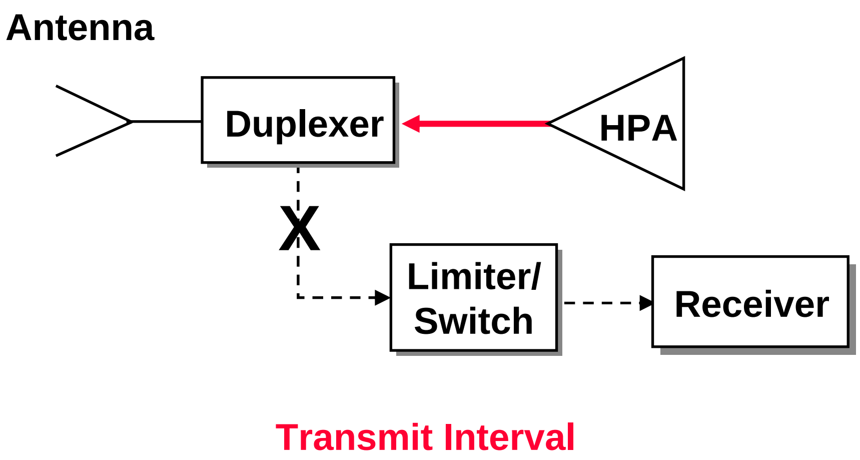
Radar Transmitter/Receiver Timeline

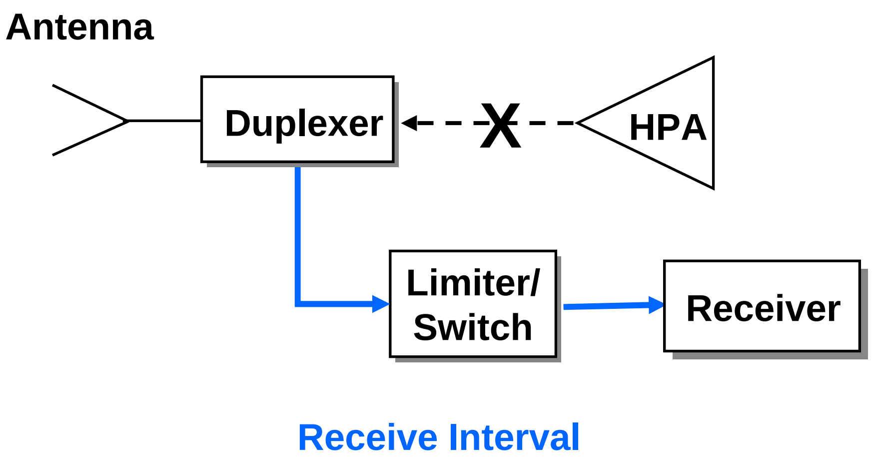


- **Sensitive radar receiver must be isolated from the powerful radar transmitter**
  - **Transmitted power typically 10 kW – 1 MW**
  - **Receiver signal power in 10's μW – 1 mW**
- **Isolation provided by duplexer switching**

PRI = Pulse Repetition Interval

Duplexer Function





- 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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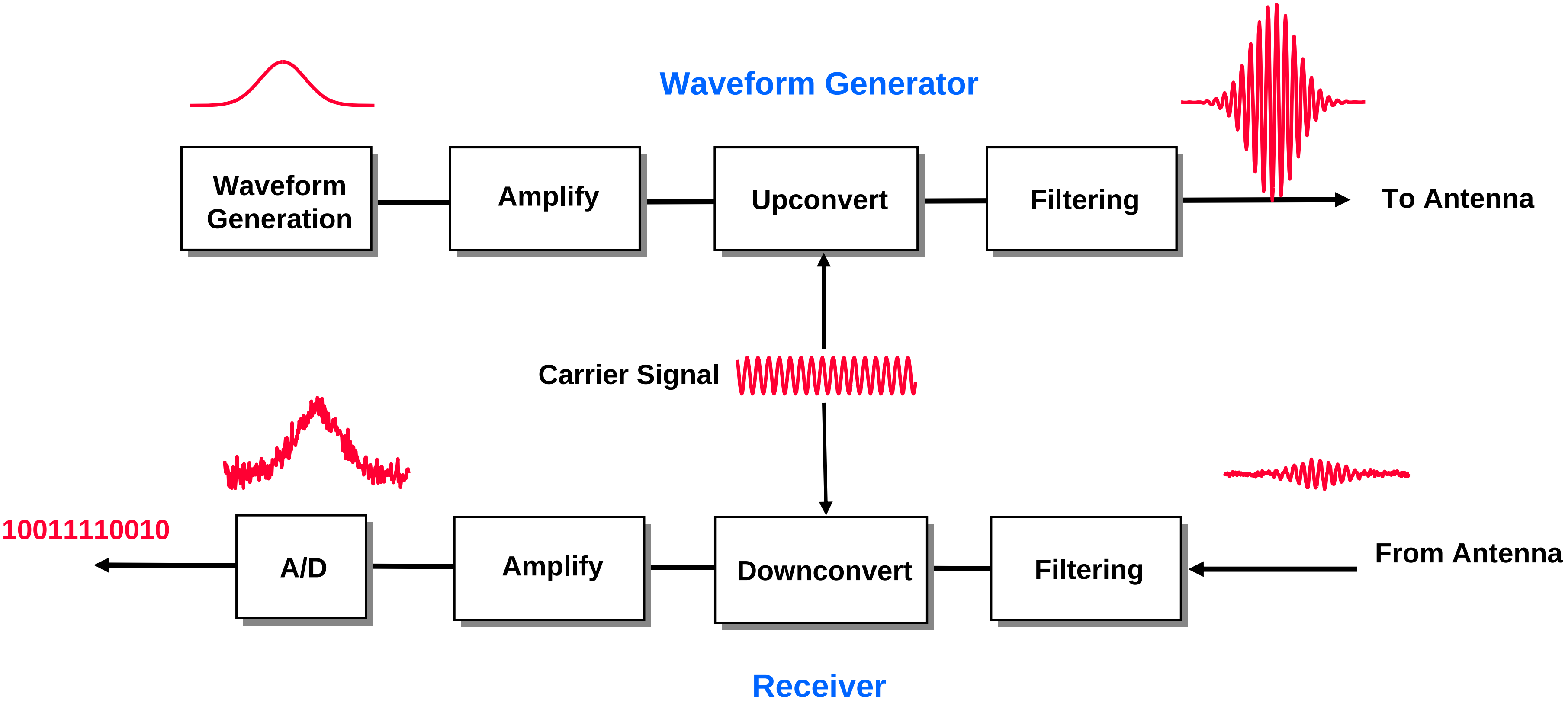
Simplified Functional Descriptions

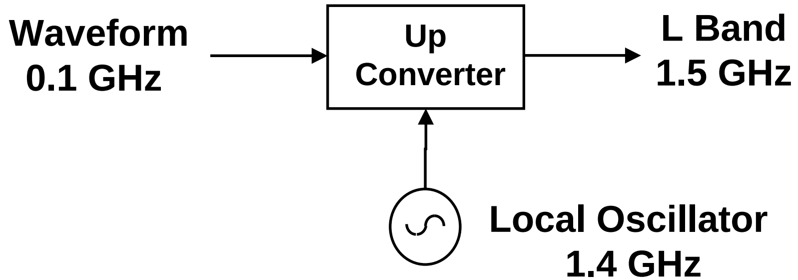


- **Waveform generator and receiver share several similar functions**
  - **Amplification, filtering and frequency conversion**

Frequency Conversion Concepts

Waveform Generator

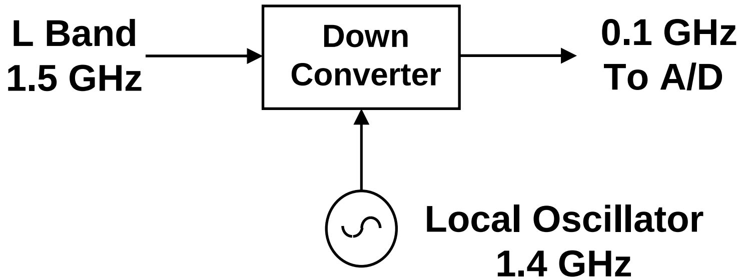
Frequency Upconversion
Baseband to L Band



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

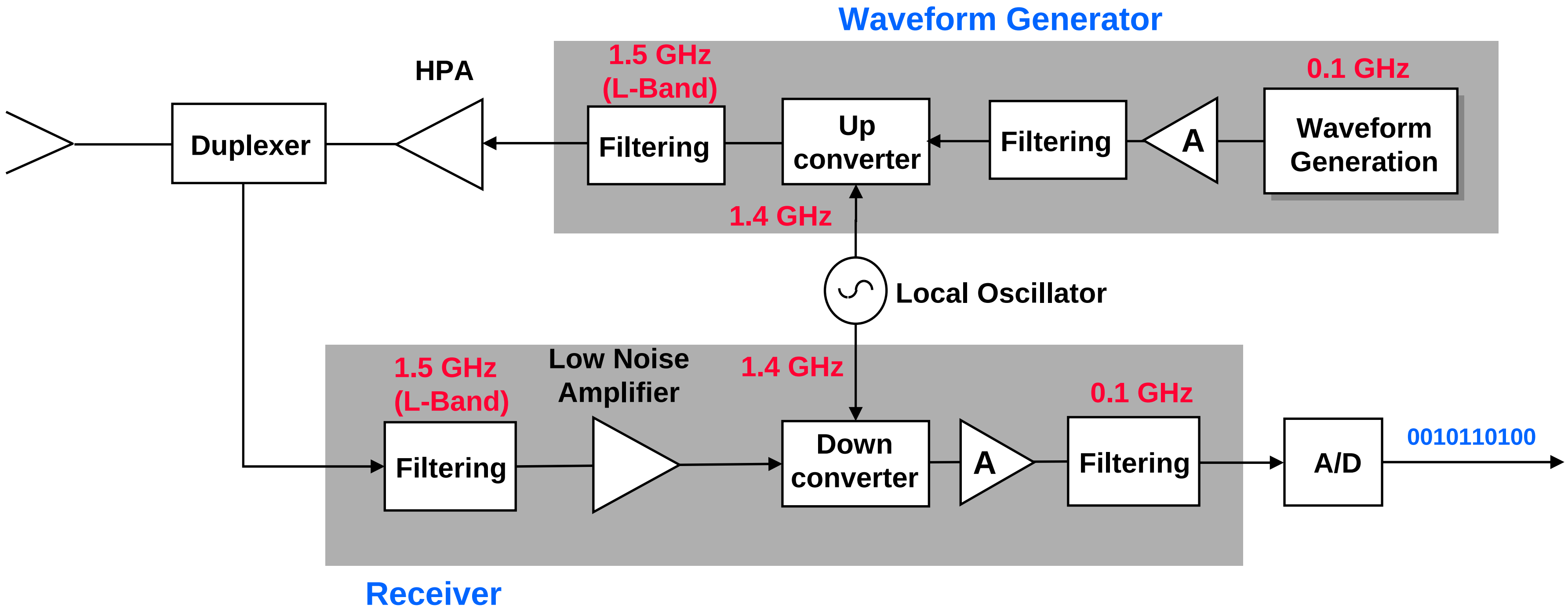
Receiver

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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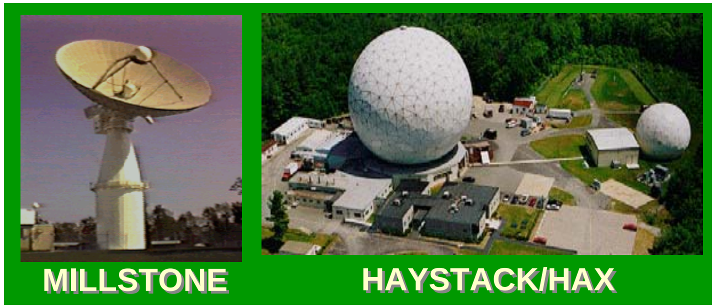
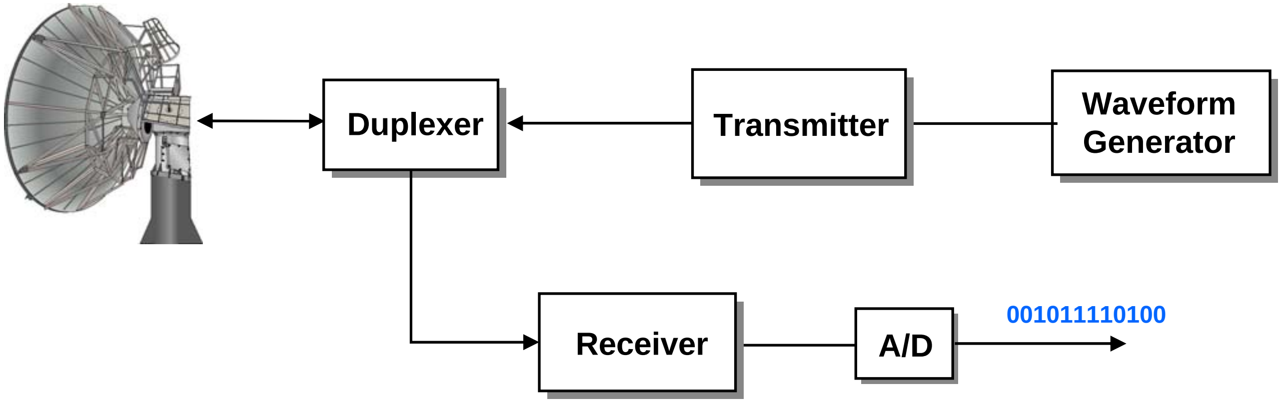
Dish Radars

KWAJALEIN

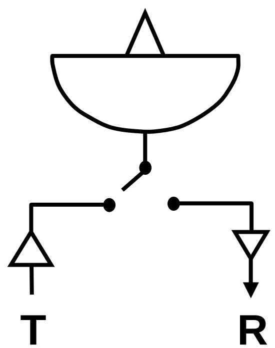




- Conventional radar transmitter/receiver design employed

Radar Antenna Architecture Comparison

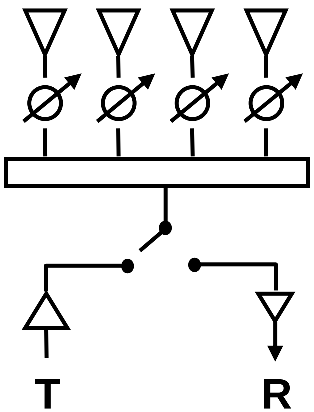
Dish Radar



PRO
- Very low cost
- Frequency diversity

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

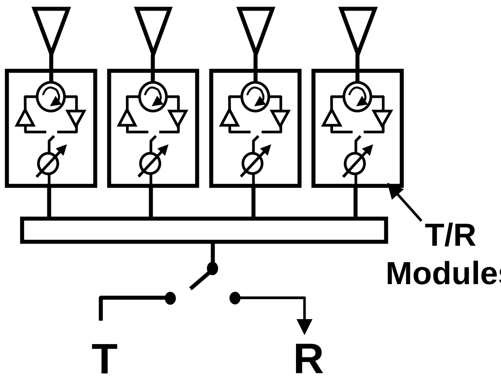
Passive Array Radar



PRO
- Beam agility
- Effective radar resource management

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

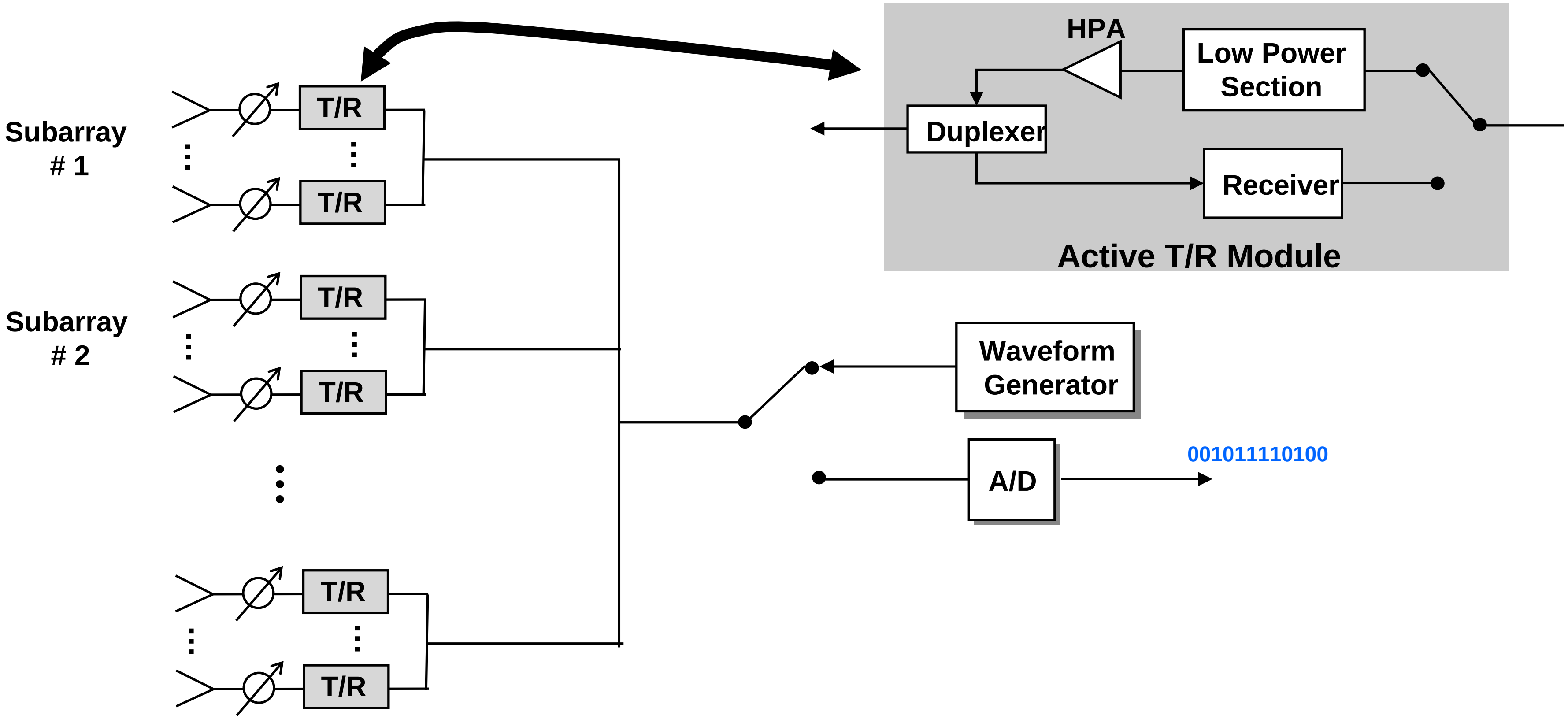
Active Array Radar



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

25,344 elements

Courtesy of Raytheon. Used with permission.

Passive Array Radar

Cobra Dane

15.3K active elements

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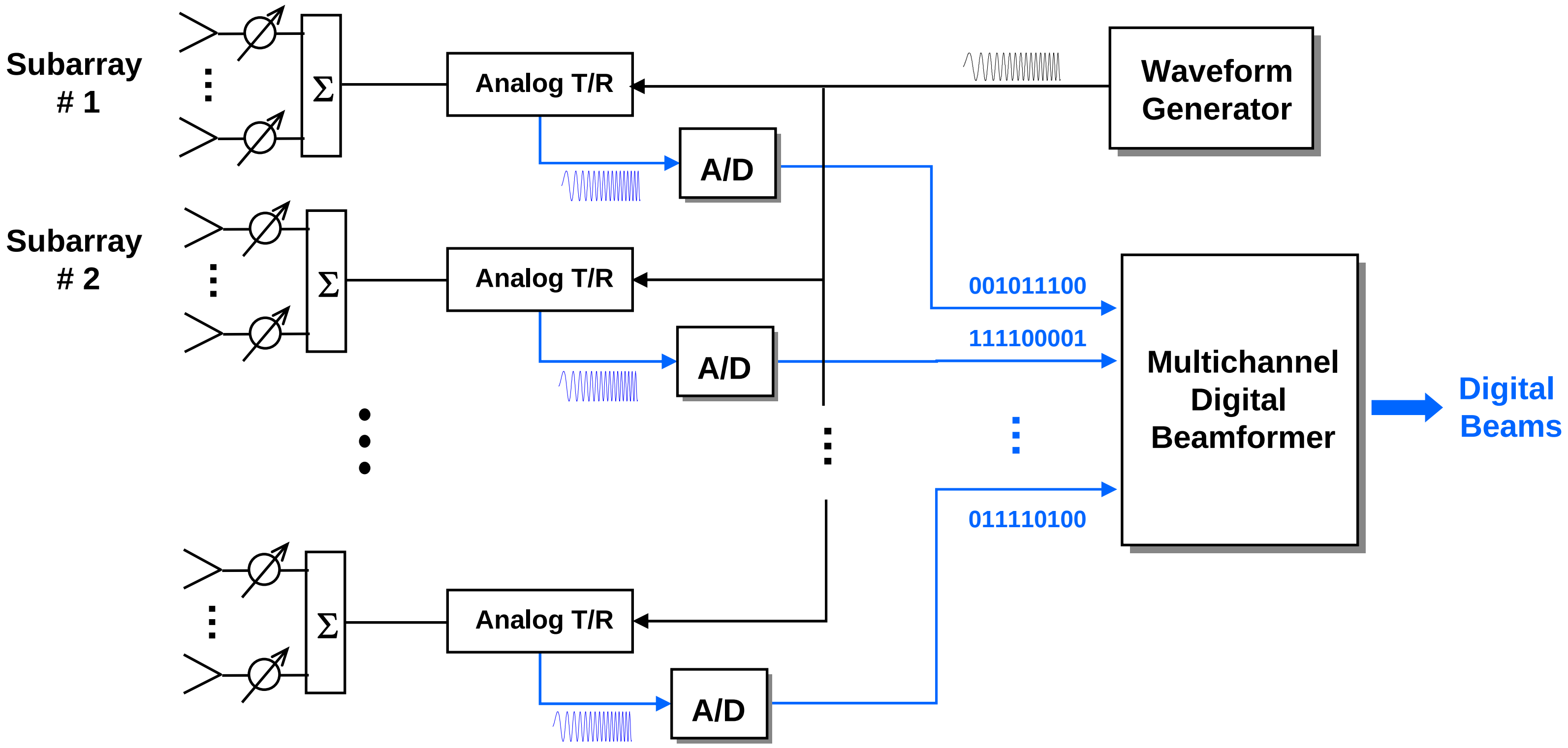
Digital Array Radar Architecture
Digital on Receive

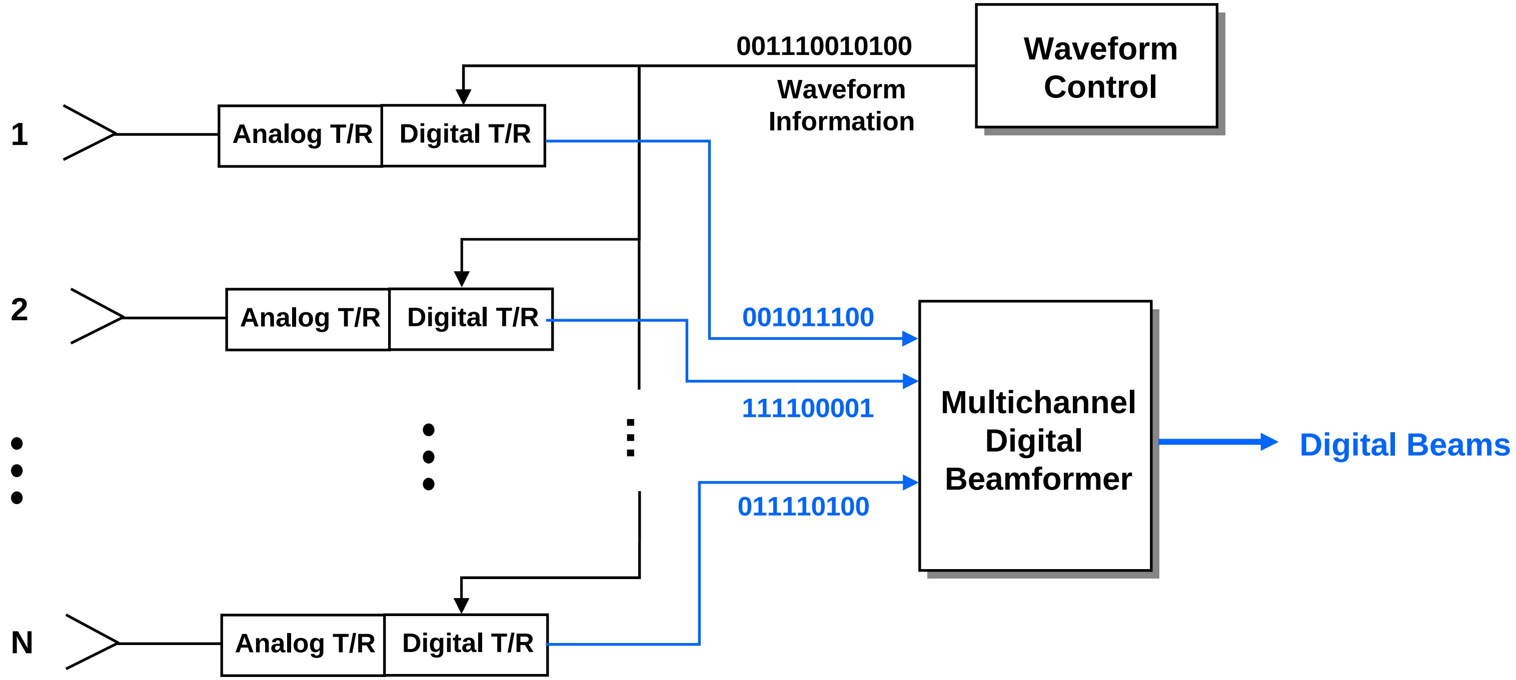


- **Each active analog T/R module is followed by an A/D for immediate digitization**
  – **Multiple received beams are formed digitally by the digital beamformer**

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**