# RADAR Transmitter Overview Tube and Solid State

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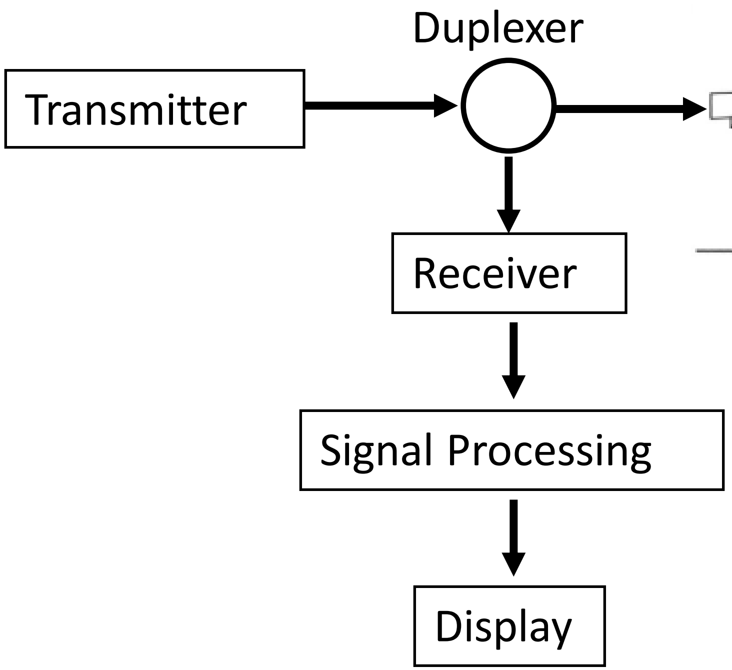
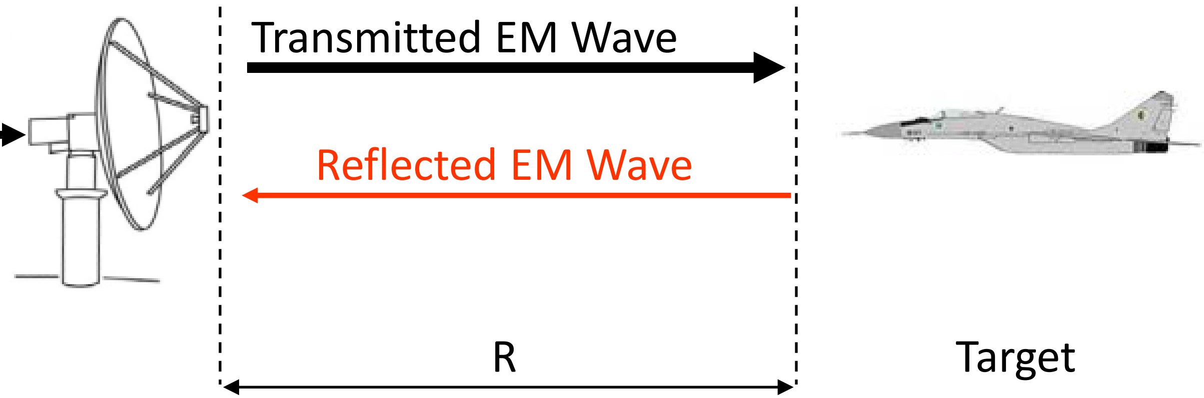
# Overview

- Radar Preliminaries
- Waveform Characteristics
- Radar Frequency Bands
- Radar Transmitters
  - Tube
  - Solid State
- Electromagnetic Compatibility (EMC)
- Charles Baylis, Baylor University

# Elements of Basic Idealized Radar System




<u>Time Delay</u>

$$t_d = \frac{2R}{c}$$

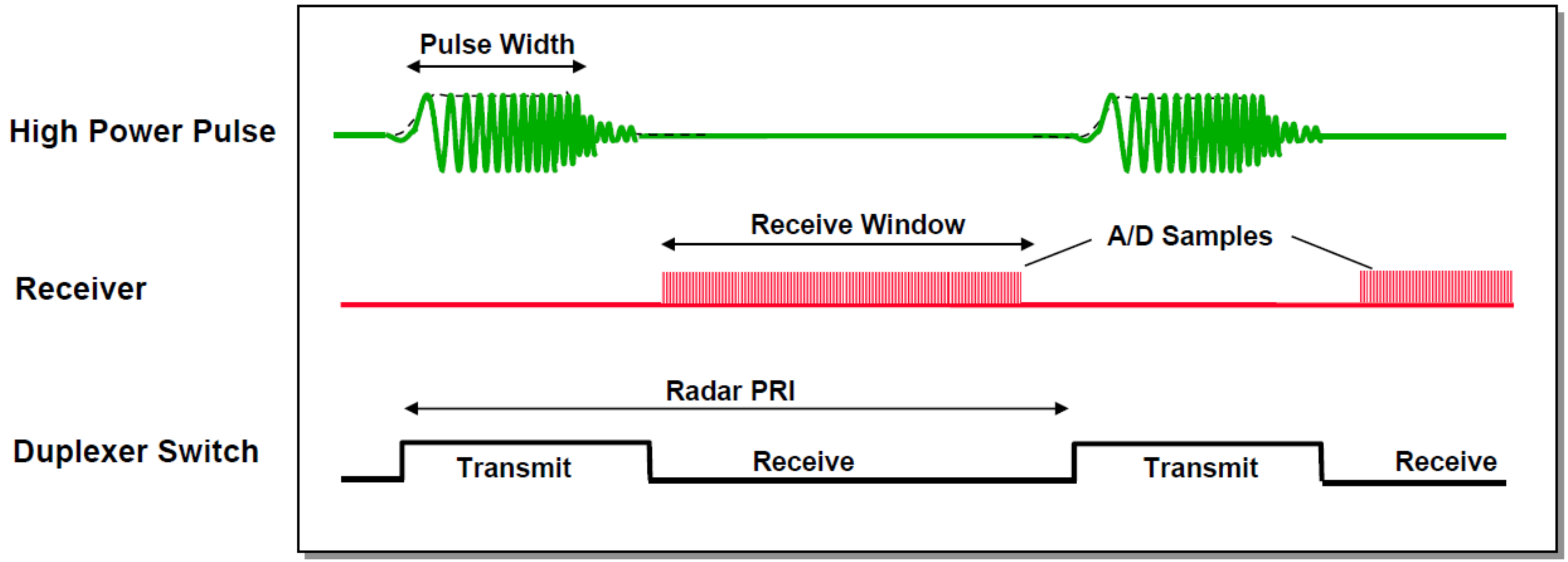
<u>Doppler Frequency</u>

$$f_D = \frac{2v_r f_o}{c} = \frac{2v_r}{\lambda}$$

R = Range
$t_d$ = Time delay
c = Wave Velocity (Speed of Light)
$\lambda$ = wavelength

$f_D$ = Doppler frequency
$f_o$ = radar frequency
$\nu_r$ = radial velocity

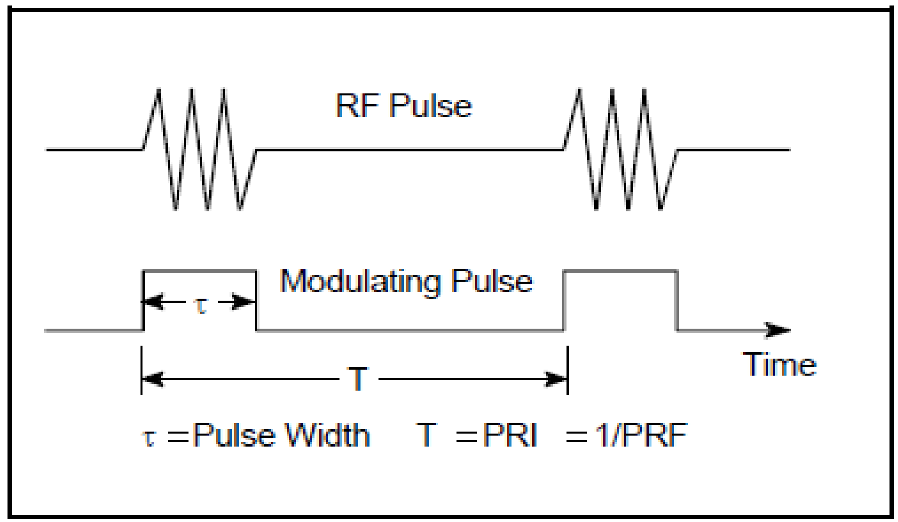
# Radar Transmitter/Receiver Timeline

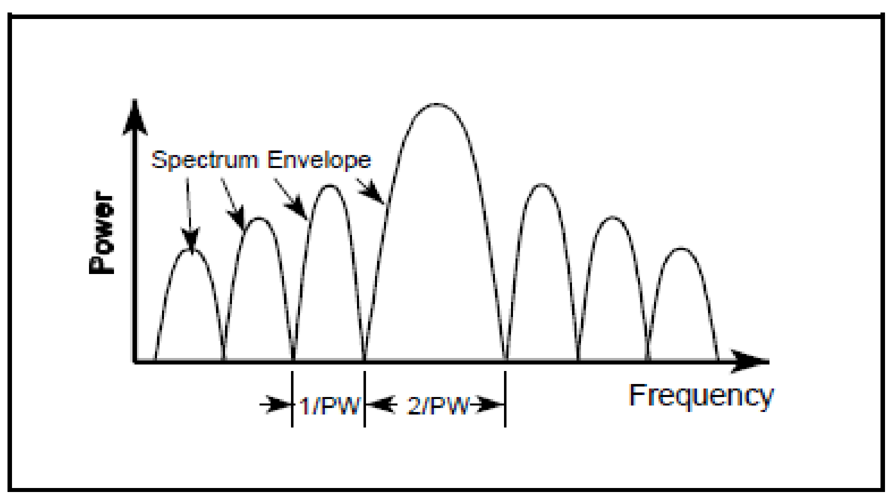



- **Sensitive radar receiver must be isolated from the powerful radar transmitter**
  - **Transmitted power typically 10 kW – 1 MW**
  - **Receiver signal power in 10's μW – 1 mW**
- **Isolation provided by duplexer switching**

**PRI = Pulse Repetition Interval**

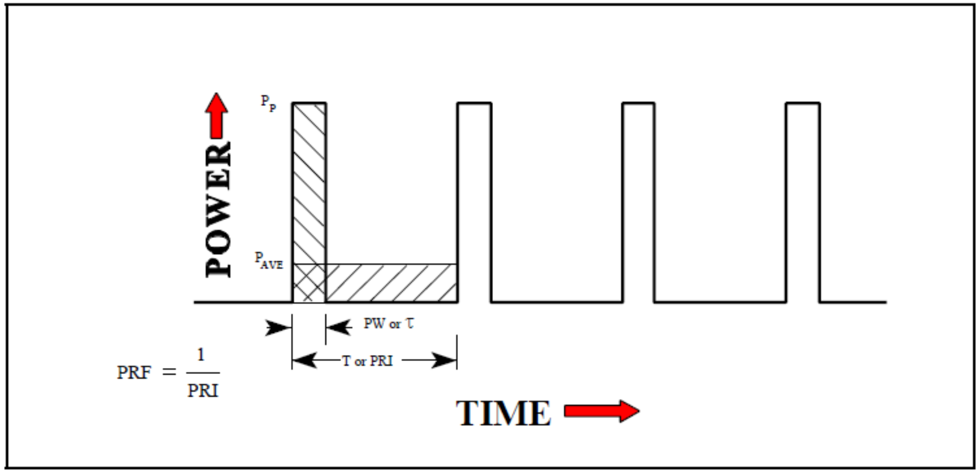
# Pulse Modulation



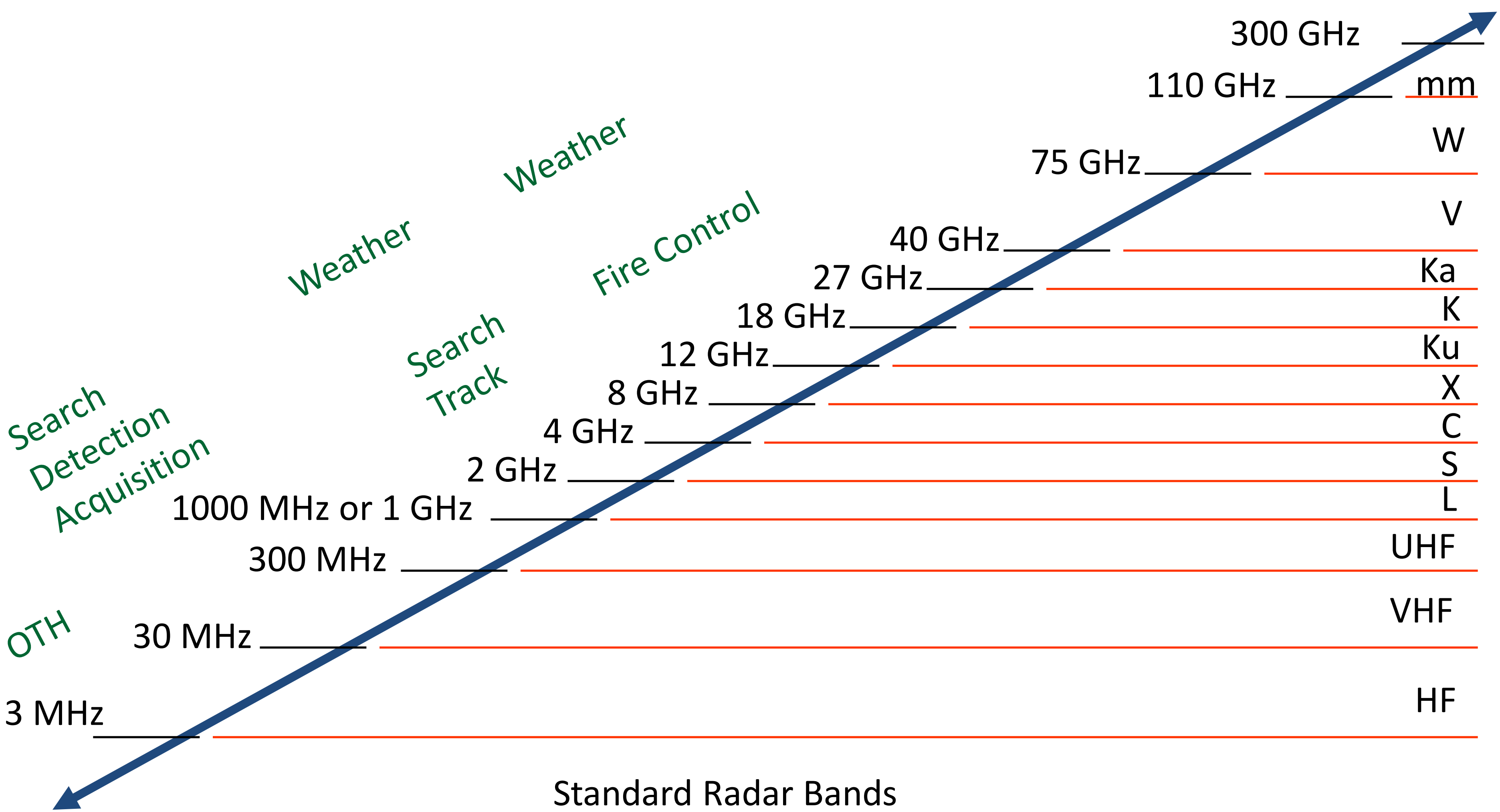
# Peak and Average Power

$P_{AVE} = P_{Peak}$ X PW*PRF



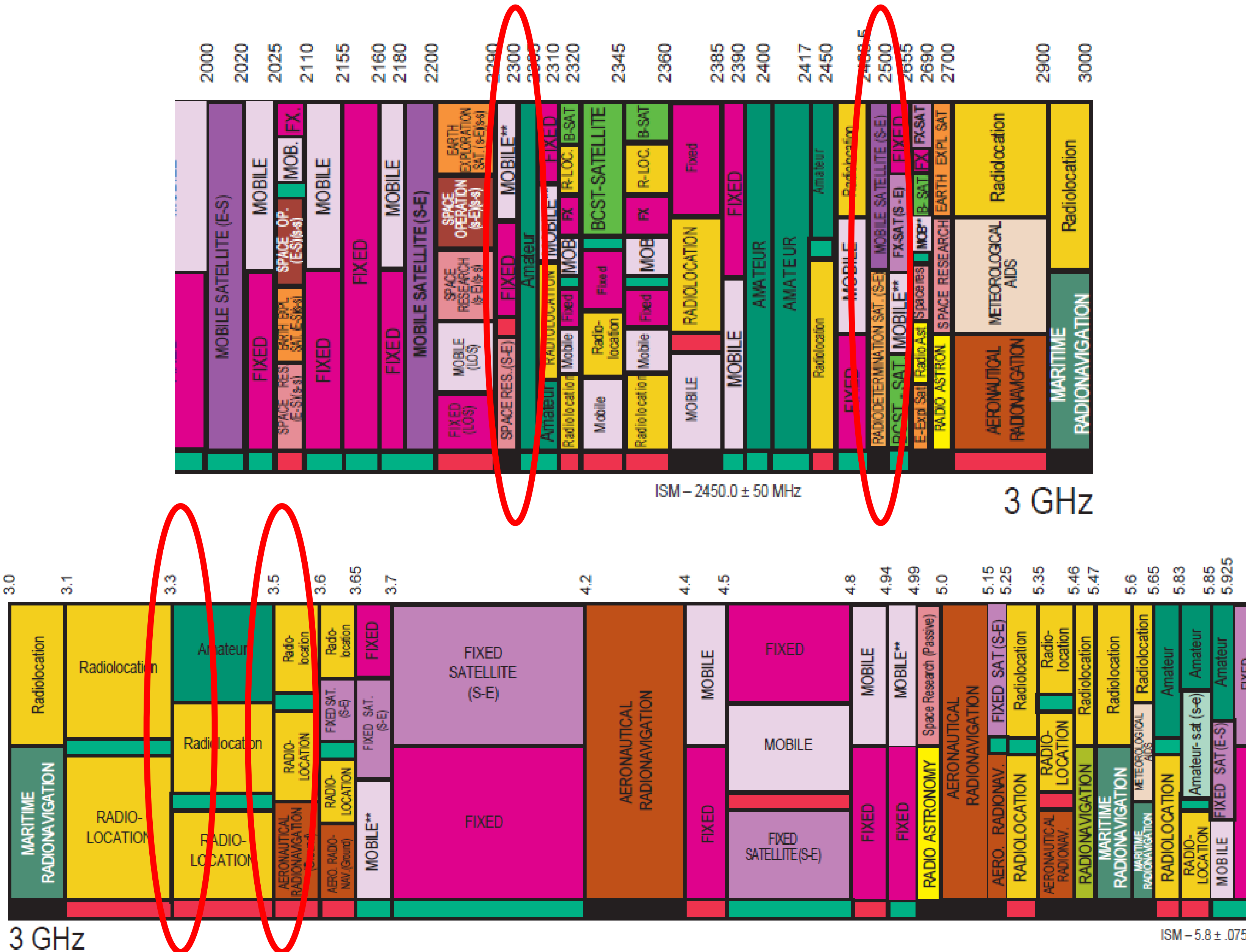

Recall: Average Power (not Peak) determines Radar performance!

# Radar Bands & Related Applications



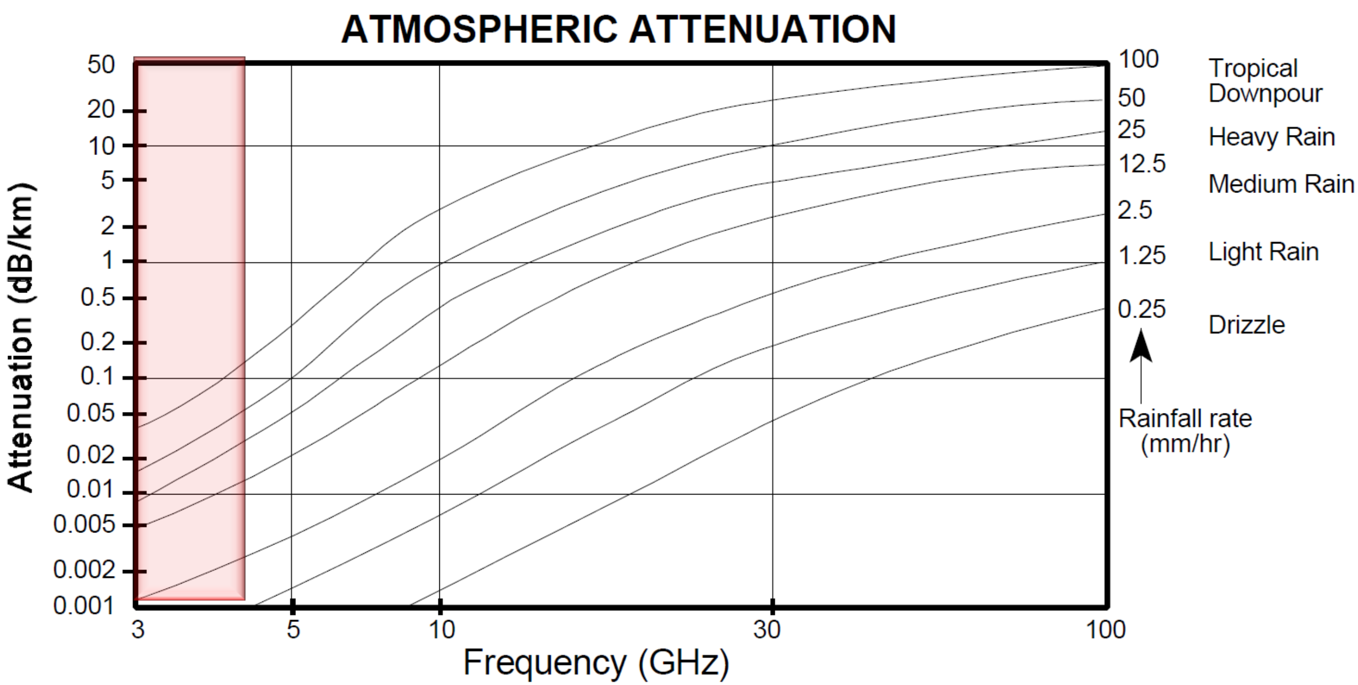

Standard Radar Bands
Based on IEEE Standard 521-2002

# The Radio Spectrum – S-Band Example

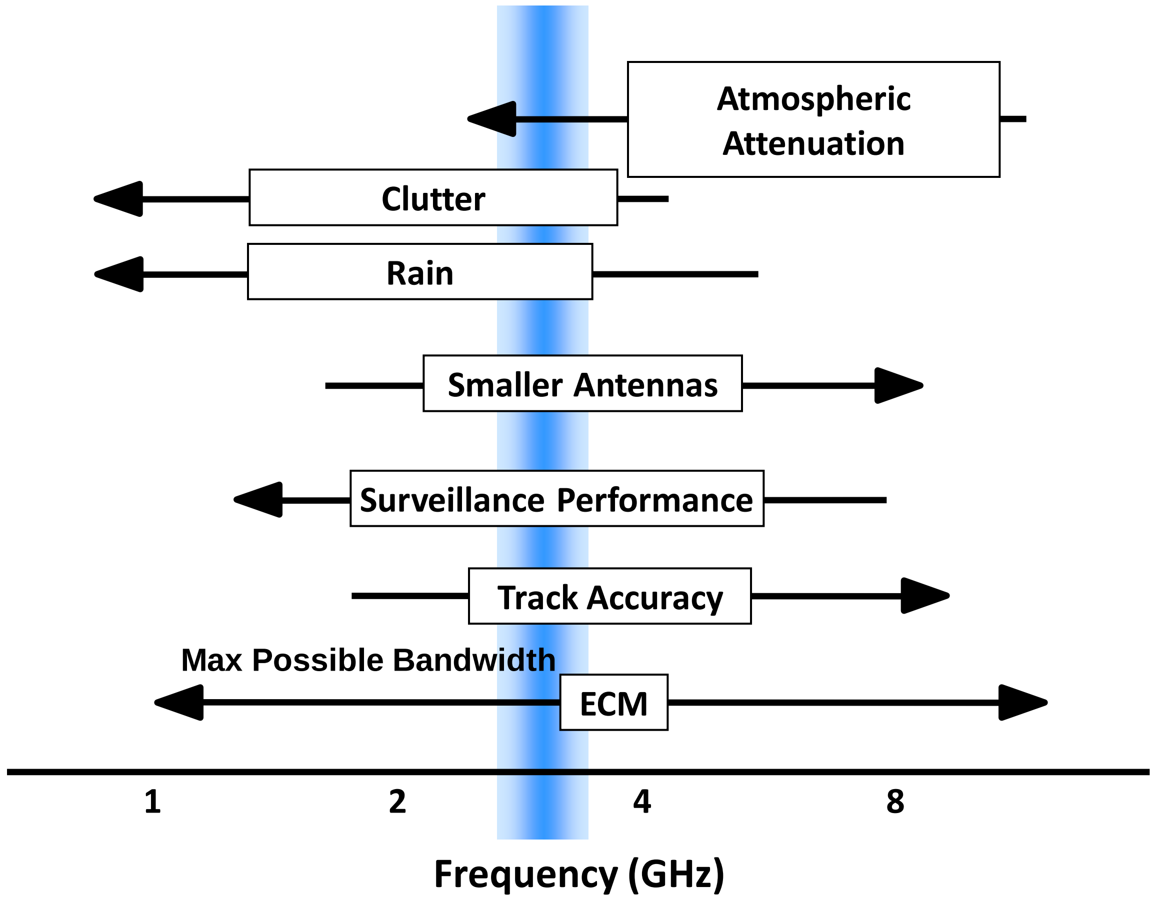


# Propagation Sweet Spot

Simultaneous Search and Track



# Microwave Radar Performance Tradeoffs

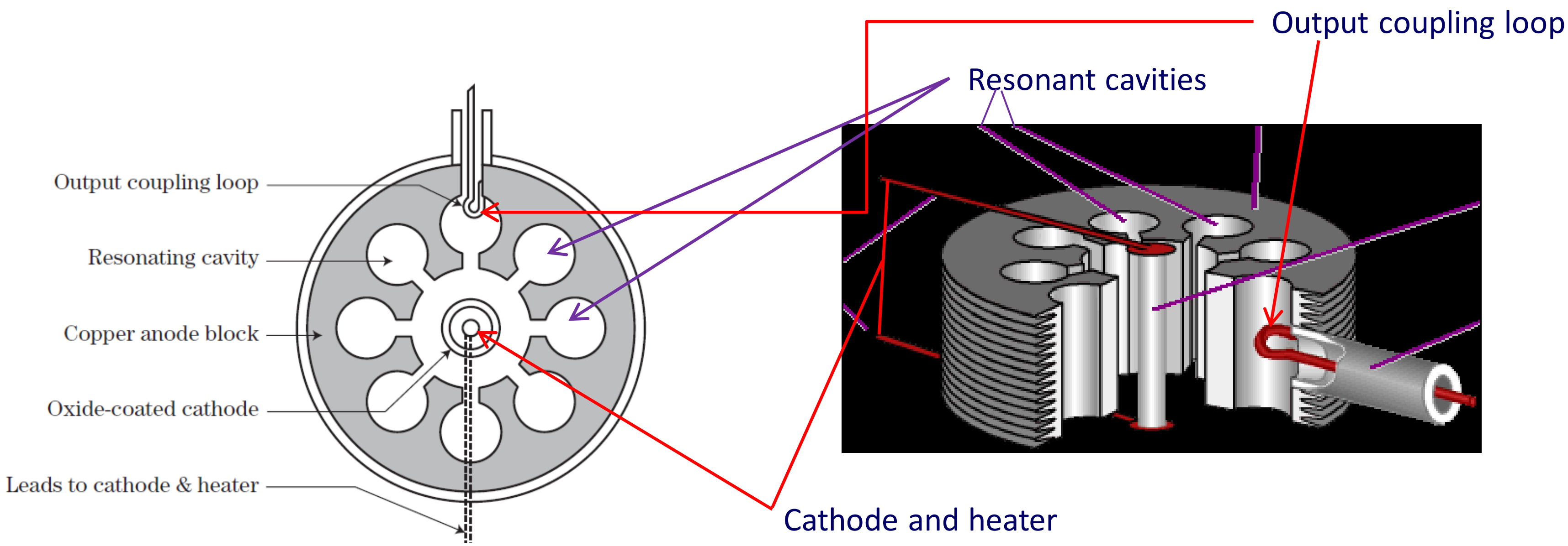


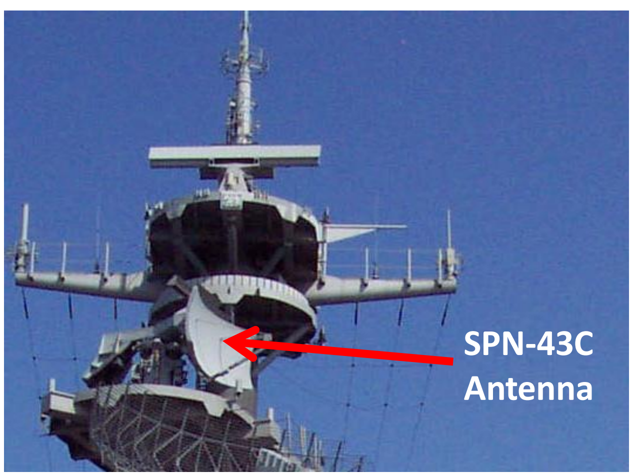

**Long range surveillance is better at lower frequencies and precision tracking is better at higher frequencies**

# Transmitter Attributes

- Attributes of ideal transmitter
  - Generate stable, noise-free signal (useful for clutter rejection)
  - Generate required waveforms to identify target
  - Generate enough energy to detect target
  - Provide required bandwidth for transmitted/received signal
  - High efficiency and reliability
  - Easily maintained
  - Low cost of acquisition and operation
- Difficult in getting all of this at once!

# Magnetron

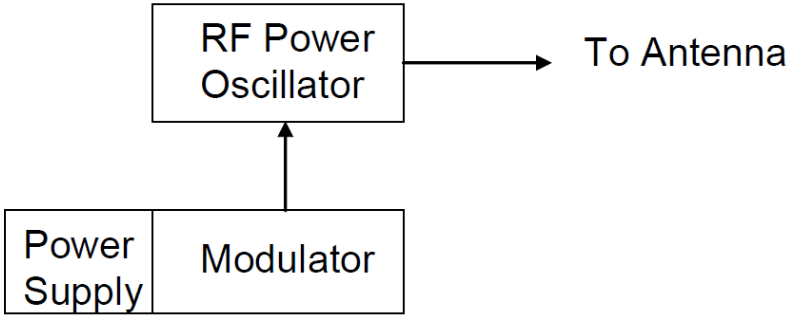


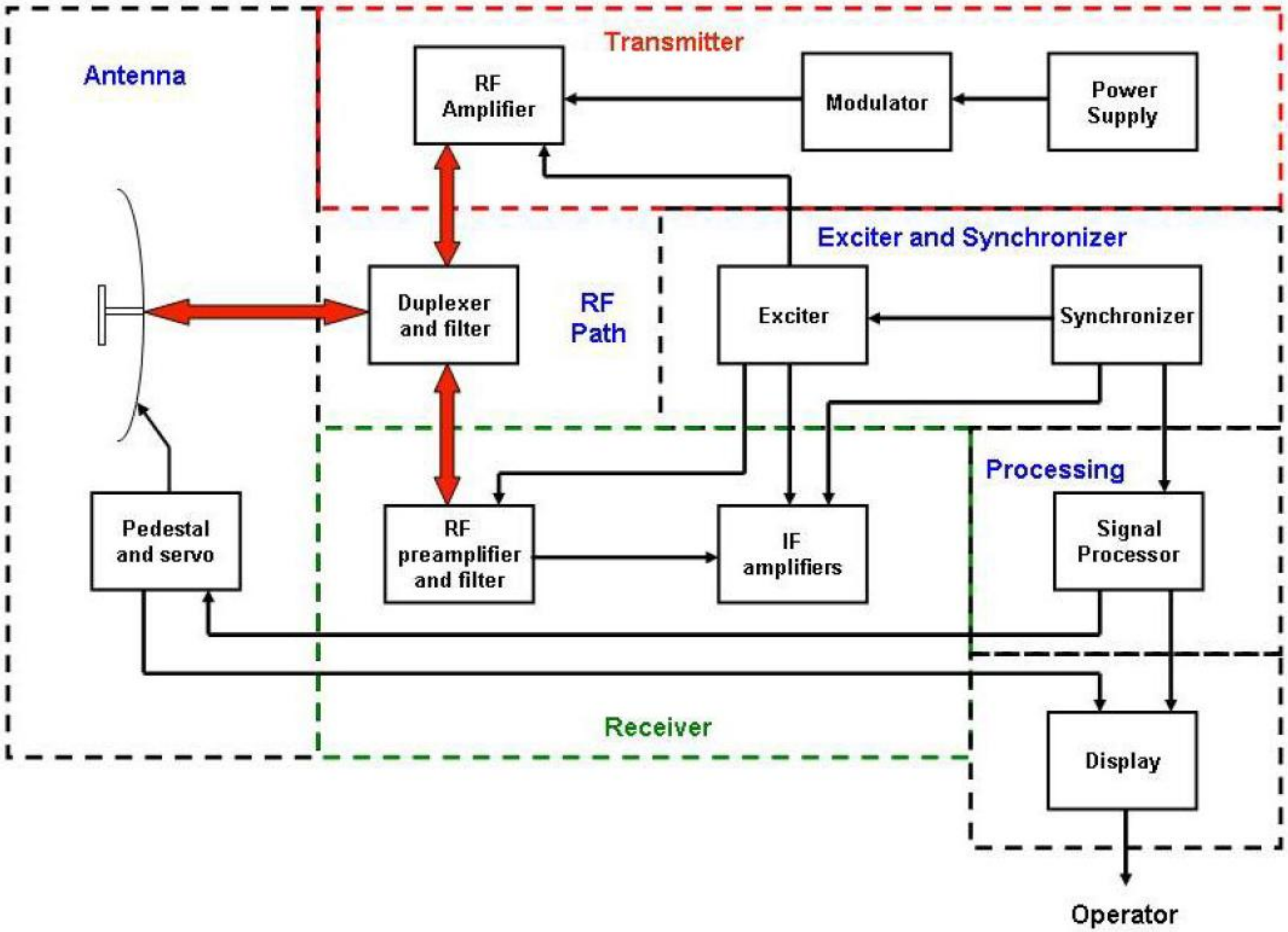

## Magnetron Characteristics

- Oscillator only
- Cross-field, **E** and **H** are at right angles
- Relatively inexpensive
- Very noisy
- Can generate large spectral sidelobes
- Non-Doppler radars

# Magnetron Tube Example

# Notional Pulsed Radar Example



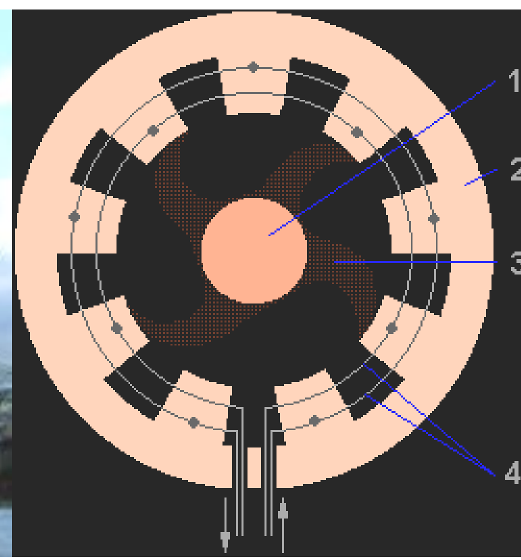
# Cross-field Amplifier (CFA)

## CFA Characteristics

- Peak power levels of megawatts, average power in kilowatts
- Efficiency of greater than 50% possible
- Allows RF energy to pass through the tube unaffected when not pulsed
- Requires added stages of amplification because of low gain, e.g. 10 dB
- Relative small size compared to klystron
- Bandwidths of 10 to 20 percent

**AEGIS Cruiser with AN/SPY-1 Radar**


**CFA Plan View**




1. Cathode
2. Anode with resonant cavities
3. Electron space charge

# Circular CFA Example

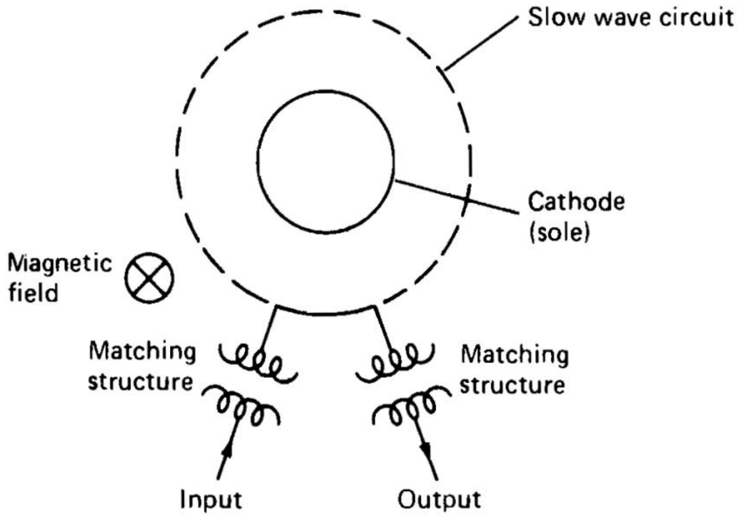
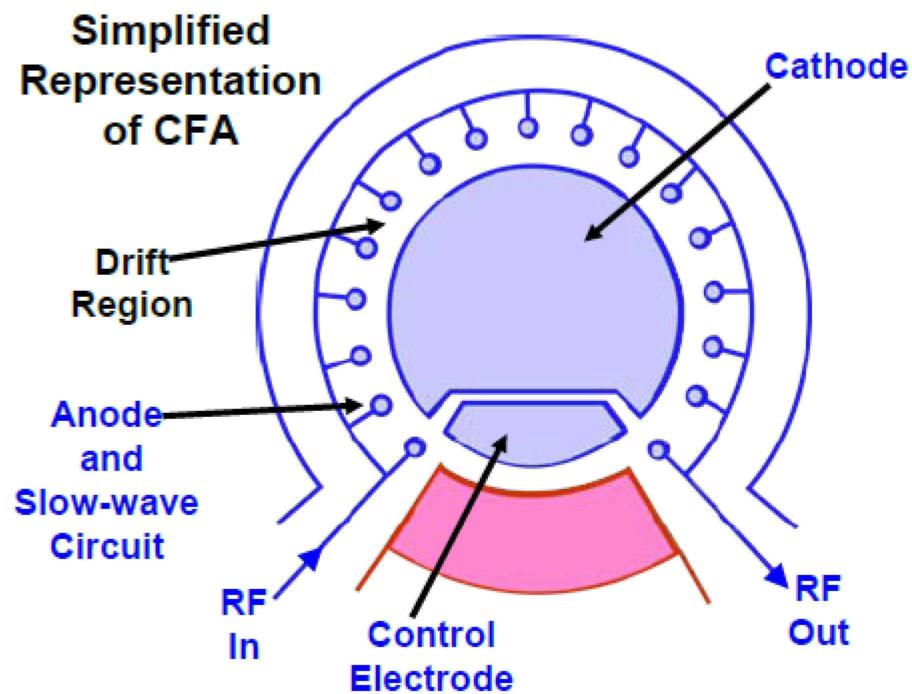



Photo courtesy of CPI

# Cross Field Amplifier Theory of Operation

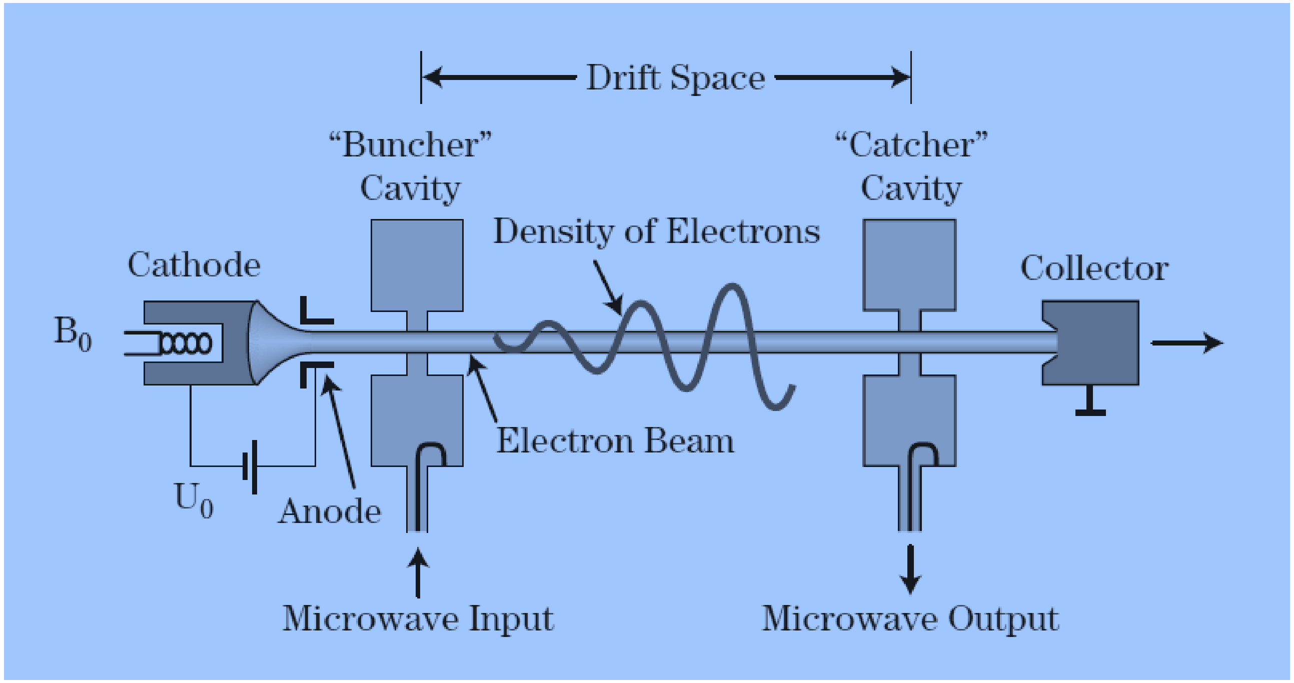



- Capable of :
  - High coherent power
  - Good efficiency
  - Wide bandwidth
- Relatively low gain (10 dB)
- Generally noisier and less stable

- 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

Slide courtesy of the IEEE AES Society

# Klystron




US Navy SPS-49 UHF Radar

## Klystron Characteristics

- Linear beam tube
- Efficiencies approaching 60%
- Relatively narrower bandwidths
- Lower spectral re-growth and in-band noise

# Klystron Example

Slide courtesy of TMD

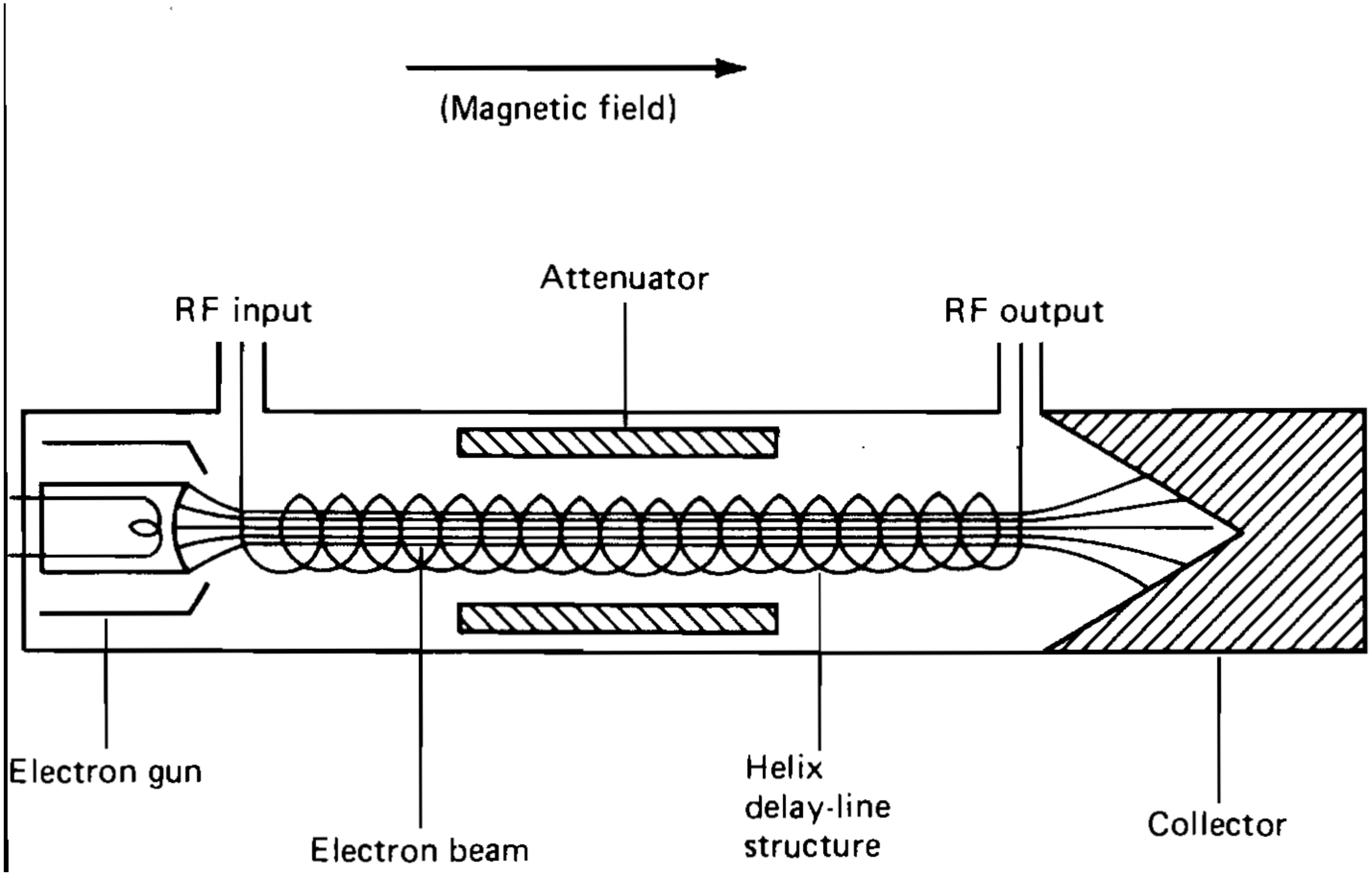
Type: Cathode pulsed
Frequency: 1.2-1.4 GHz
Peak Power: 100 kW
Duty Cycle: 0.0115 maximum
Gain: 25 dB minimum
Pulse Length: 8.5 us
Peak Beam Volts: 33 kV
Peak Beam Current: 12.6 A
Modulation: Cathode
Focusing: Solenoid
Cavities: 8
Weight: 85 kg

# X-Band AN/SPQ-9B

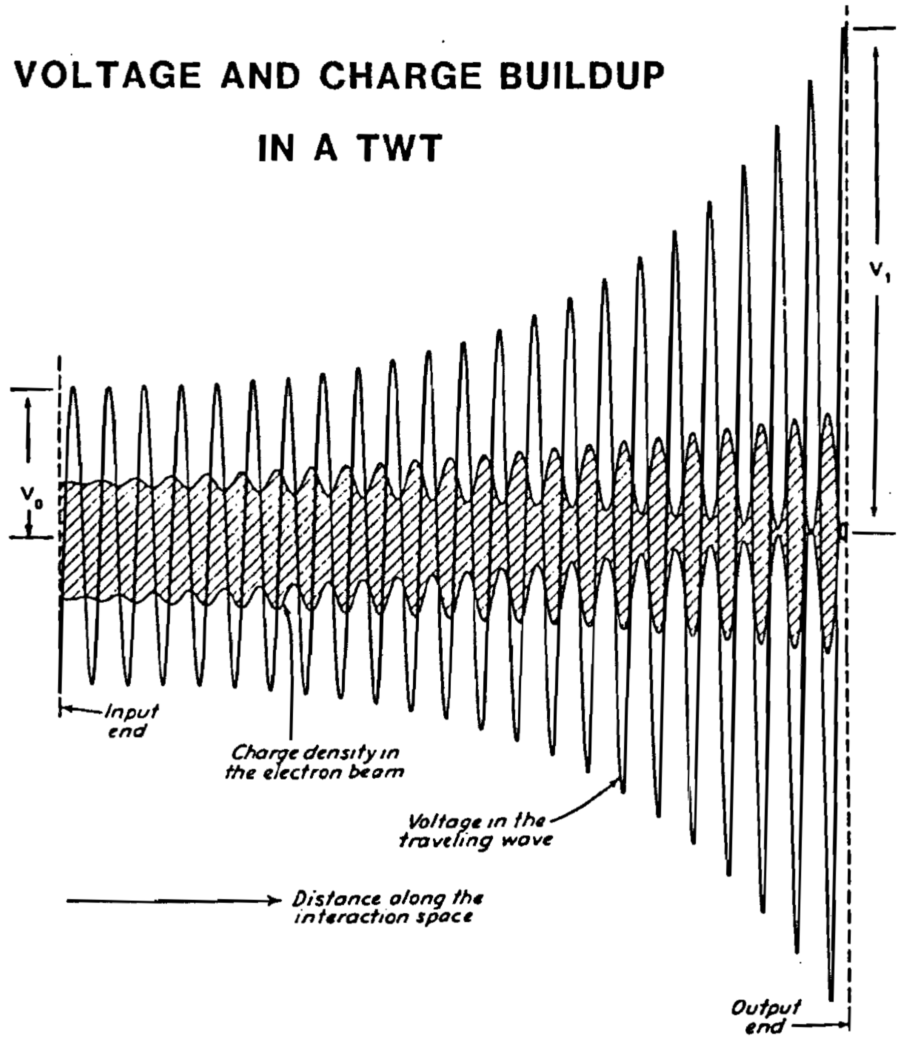
## TWT Characteristics

•Wide Bandwidths (e.g. octave)
•High Gain (40 dB)
•Low Noise
•Lower Efficiency (≤ 25%)

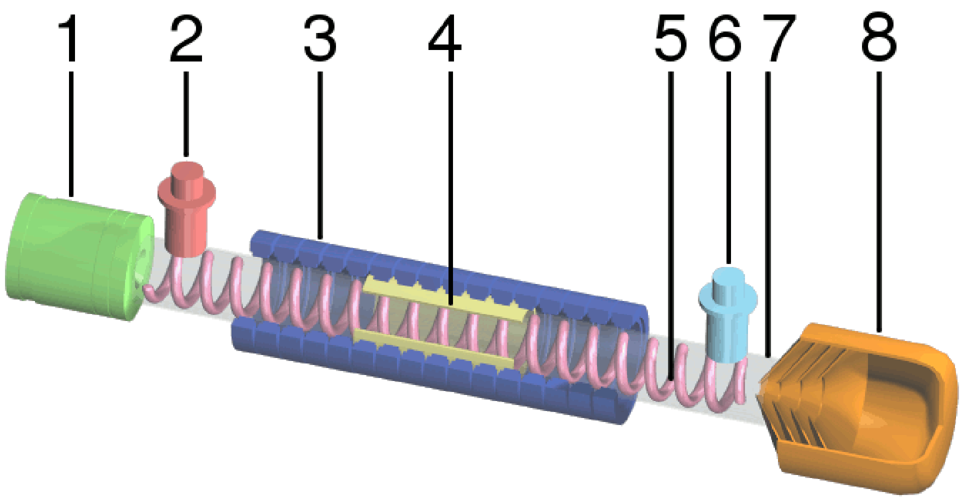
# Travelling Wave Tube



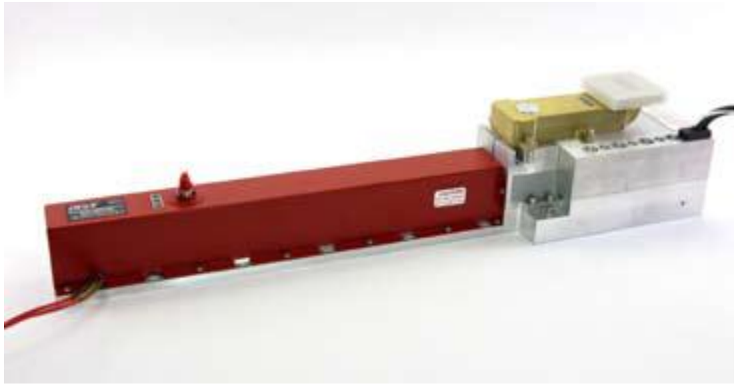
# Electron (E Field) Interaction with the Slow Wave Structure



# Helix Travelling Wave Tube




1. Electron gun
2. RF input
3. Magnets
4. Attenuator
5. Helix coil
6. RF output
7. Vacuum tube
8. Collector.

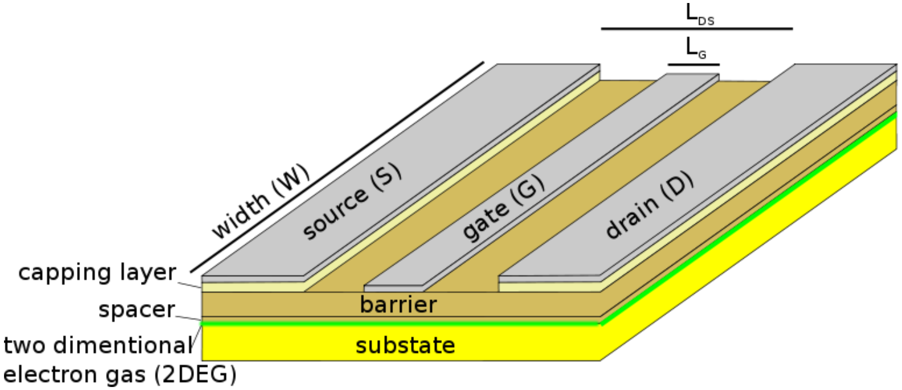


Courtesy of CPI

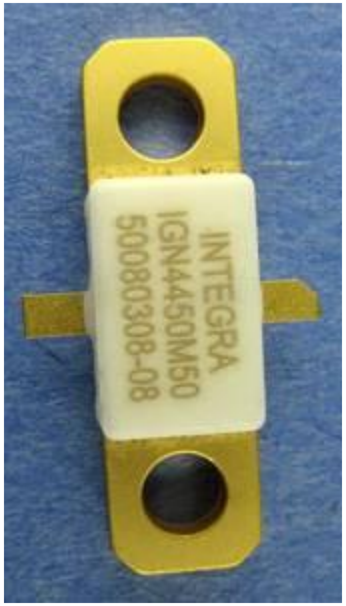
# Solid State RF Power Amplifiers

- **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**

# Gallium Nitride (GaN) Example




Gate

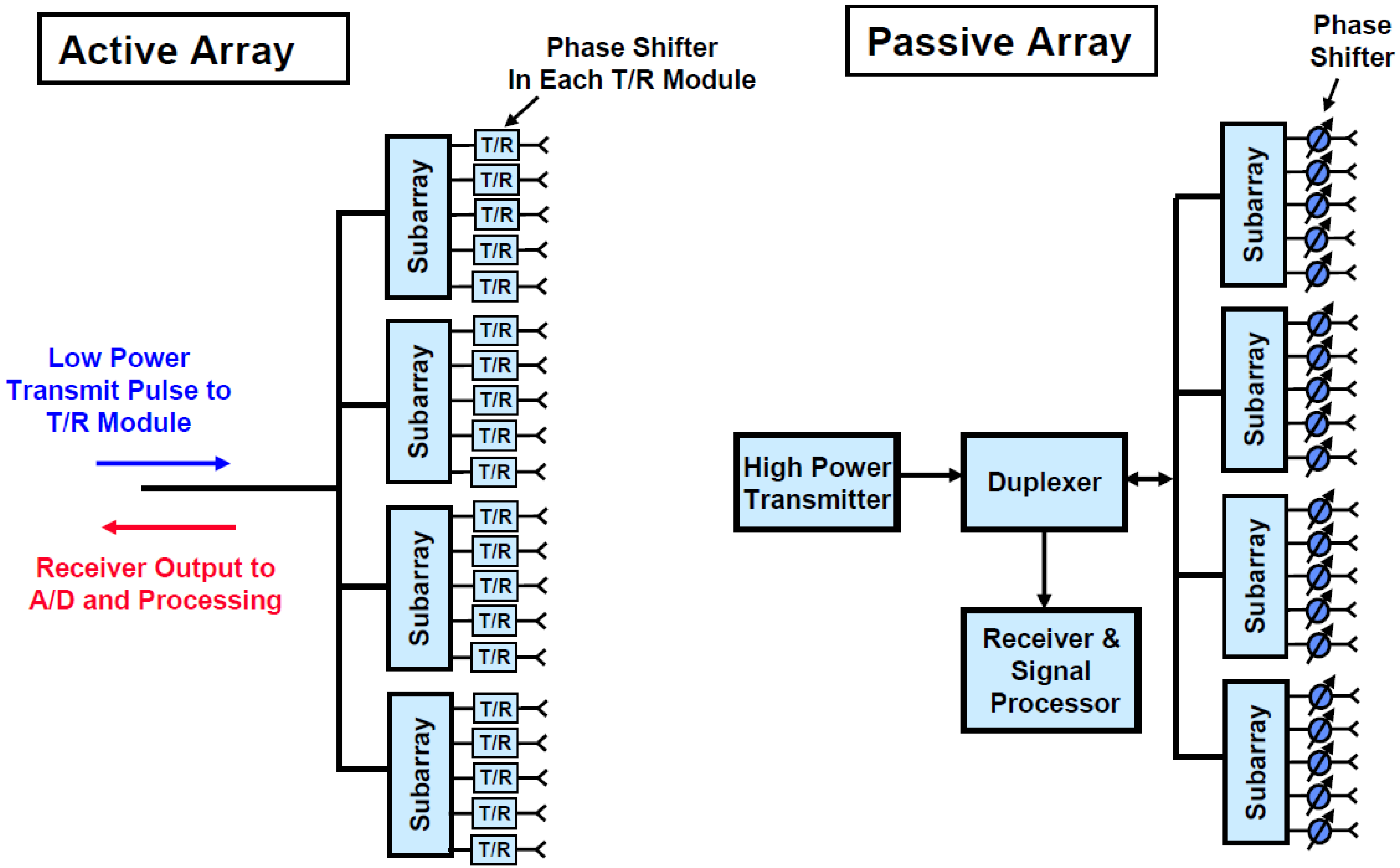



Drain

Source

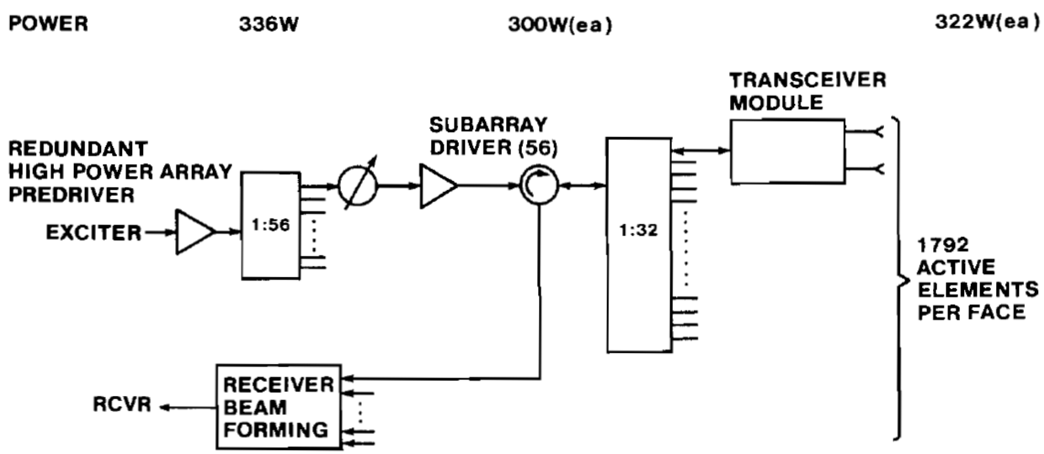
Courtesy of Integra

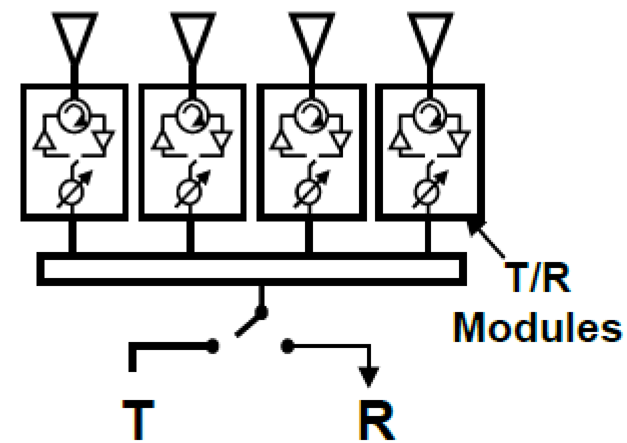
# Antenna Array Examples



# Pave Paws Radar

# Pave Paws Radar Configuration

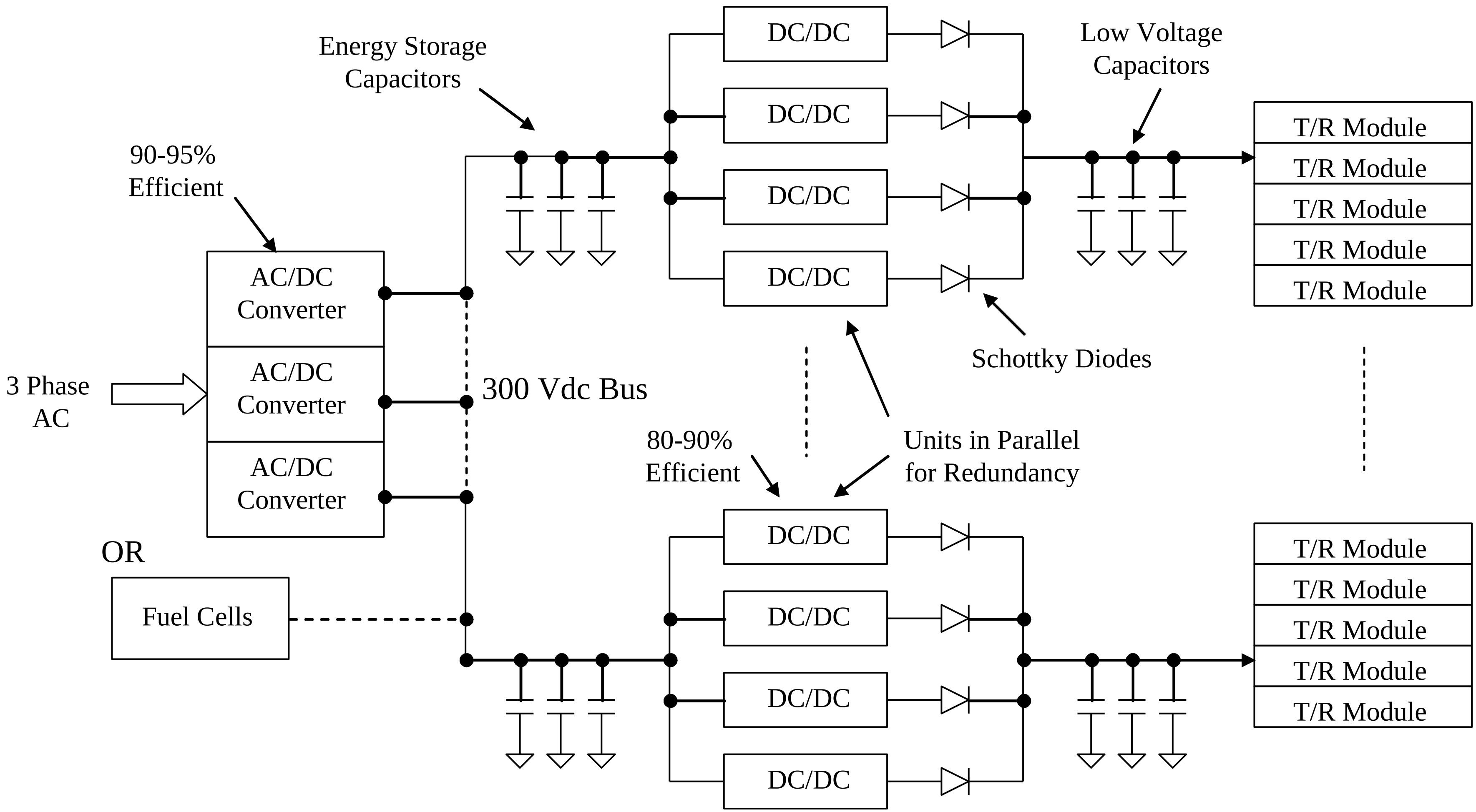


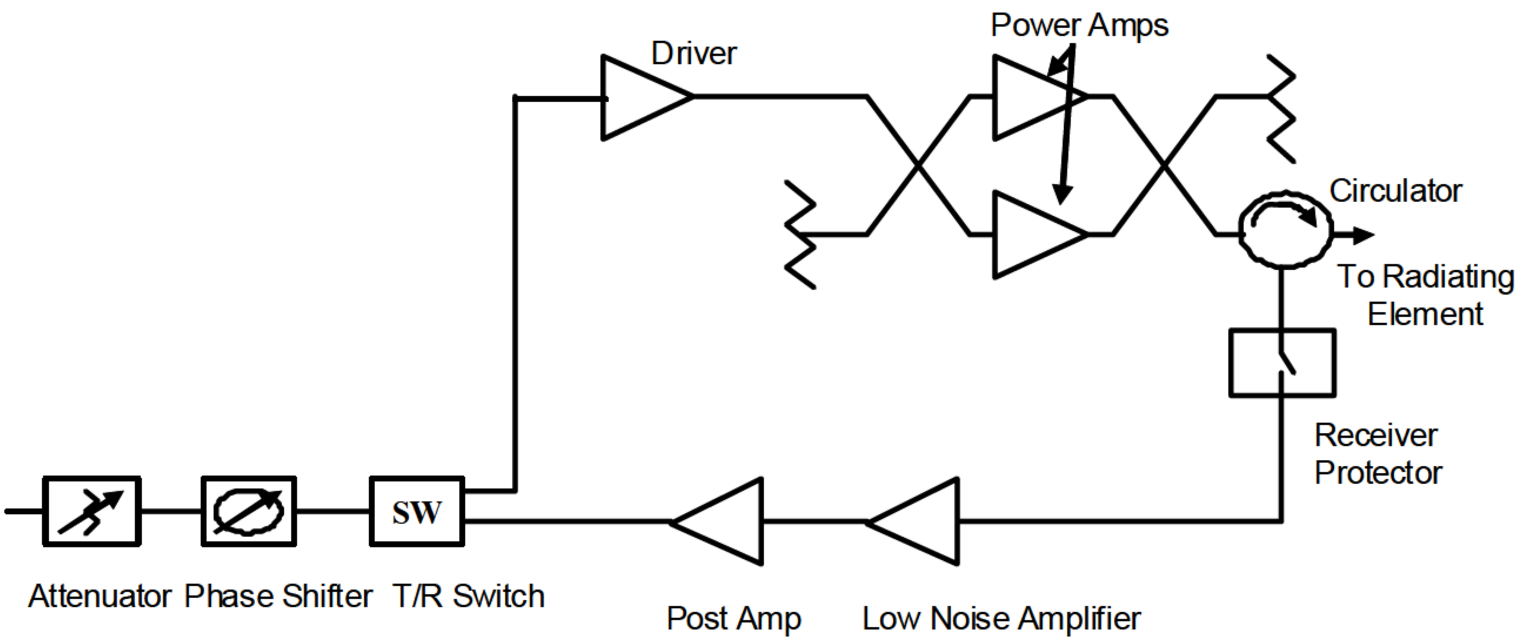
# Thales Active Phased Array Multifunction Radar (APAR)

1. Automatic detection and tracking
2. Greater than 3000 T/R modules per face
3. Coverage by multiple beams-120 degrees in azimuth, 85 degrees in elevation

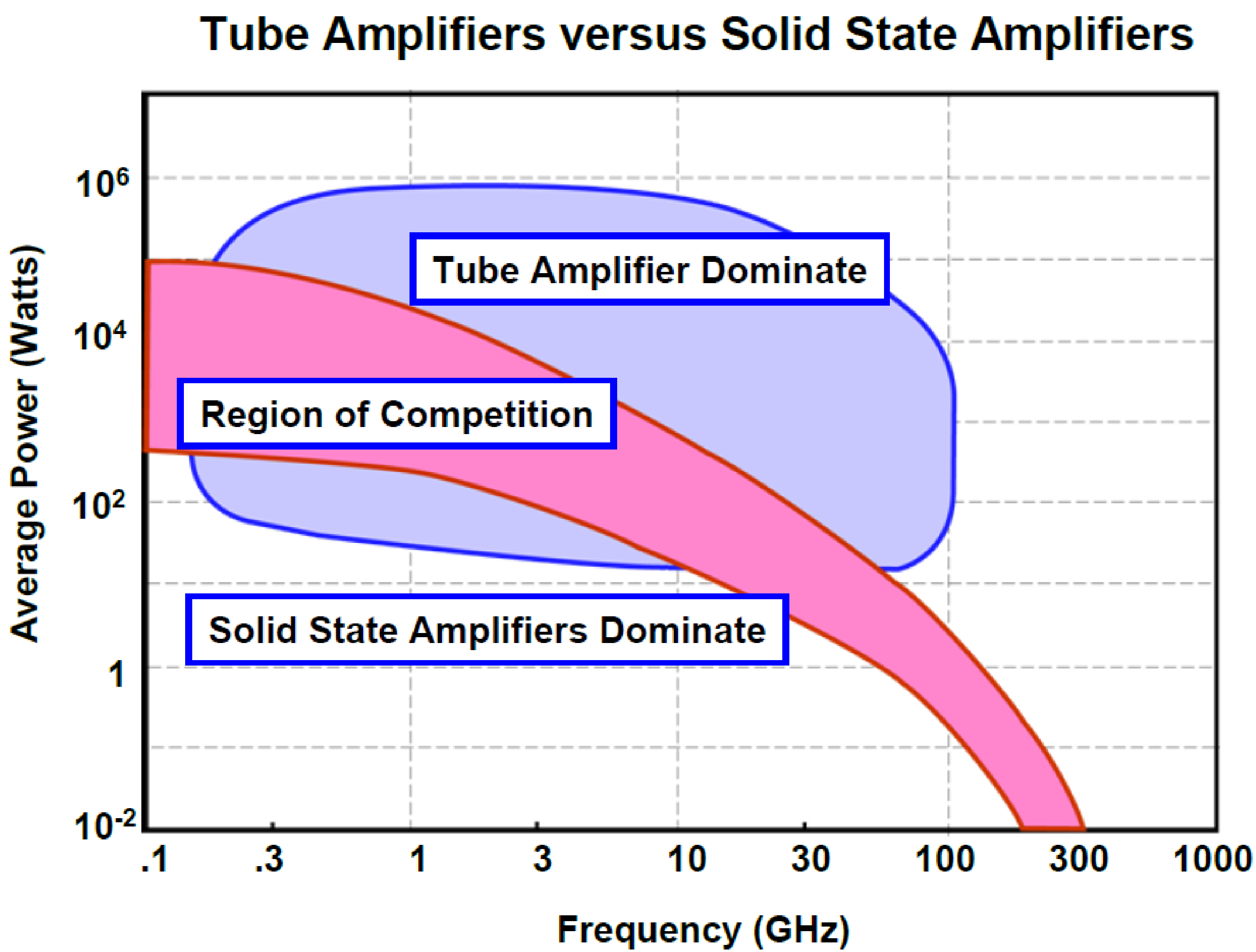
# Active Aperture Power System Configurations



# Example of T/R Module Architecture



# Power capabilities of Transmitter Sources versus Frequency



# Electromagnetic Compatibility

- Electromagnetic compatibility (EMC) is concerned with the unintentional generation, propagation and reception of electromagnetic fields.
- EMC addresses two kinds of issues
  - The generation or radiation of EM energy
  - The susceptibility or immunity against EM energy
- System EMC is achieved when both issues are addressed: the equipment is not an interference source, while the equipment is "hardened" against man-made and natural interference.
- EMC in radar systems is a significant issue
  - high power (MW) transmitters are collocated with very sensitive ($\mu$W) receivers.

# Electromagnetic Interference (EMI)

- Interference occurs when unwanted EM energy is propagated from a signal generator (a source) into a signal receiver (a victim) or itself.
- The unwanted energy can be propagated by either radiated or conductive means or a combination of both.
- Radiated coupling occurs when the source and victim are separated by a large distance, typically one or more wavelengths apart.
- When the source and victim are less than a wavelength apart, the coupling occurs by capacitive and/or inductive mechanisms.
- Conductive transfer of energy can occur over distances small and large, depending upon the amplitude of the unwanted energy.

# EMI Mechanisms

- High power RF transmitters can cause a number of problems to both equipment and personnel in the vicinity of radars, as well at great distances from the antenna.
- Issues arising with electronic equipment are known as radiofrequency interference (RFI) or electromagnetic interference (EMI).
- The broad field of EMC addresses the causes and solutions to these problems.
- EMC is most effective and lowest cost when designed in from the beginning.

# Design for EMC

- RFI/EMI mitigation is dependent upon multiple approaches, including
  - Proper design for EMC
    - Mechanical Design
      - Chassis/Enclosure
      - Bonding & Grounding
    - Electrical Design
      - PCB Layout & Construction
      - Hardware Partitioning & Location
    - System Design
      - Signal Distribution
      - Power Conversion & Distribution
  - Grounding and shielding
    - Source & Victim
  - Emissions control
    - Suppression of undesired spectrum products

# Out-of-Band Spectrum Mitigation Strategies for Solid-State Amplifiers

- Increase (greater) rise and fall times of input waveforms
- Employ filtering, e.g. bandpass, on output
- Back-off
- Utilize linearization techniques
  - Pre-distortion
  - Doherty
  - Outphasing
  - Envelope tracking
- Use waveforms that do not have sharp transitions (phase, etc) when changing states

Charles Baylis, Baylor University