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

Transmitted EM Wave

Reflected EM Wave

Target

Transmitter

Duplexer

Receiver

Signal Processing

Display

\[ t_d = \frac{2R}{c} \]

\[ f_D = \frac{2v_r f_o}{c} = \frac{2v_r}{\lambda} \]

R = Range

\( t_d \) = Time delay

\( c \) = Wave Velocity (Speed of Light)

\( \lambda \) = wavelength

\( f_D \) = Doppler frequency

\( f_o \) = radar frequency

\( v_r \) = radial velocity
Sensitivity of the 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

\[ T = \text{Pulse Width} \]
\[ T = \text{PRI} = \frac{1}{\text{PRF}} \]
Peak and Average Power

\[ P_{AVG} = P_{Peak} \times PW \times PRF \]

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

3 GHz
Propagagation Sweet Spot

Simultaneous Search and Track

ATMOSPHERIC ATTENUATION

Frequency (GHz)

Attenuation (dB/km)

Rainfall rate (mm/hr)

- Tropical Downpour
- Heavy Rain
- Medium Rain
- Light Rain
- Drizzle
Microwave Radar Performance Tradeoffs

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

- Clutter
- Rain
- Smaller Antennas
- Surveillance Performance
- Track Accuracy
- Max Possible Bandwidth
- ECM
- Atmospheric Attenuation

Frequency (GHz)
1 2 4 8

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, $\mathbf{E}$ and $\mathbf{H}$ are at right angles
- Relatively inexpensive
  - Very noisy
- Can generate large spectral sidelobes
  - Non-Doppler radars
Magnetron Tube Example

![Magnetron Tube Image]

Diagram:
- RF Power Oscillator
- To Antenna
- Power Supply
- Modulator
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 Characteristics

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

US Navy SPS-49 UHF Radar
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

(Magnetic field)

RF input  Attenuator  RF output

Electron gun  Electron beam  Helix delay-line structure  Collector
Electron (E Field) Interaction with the Slow Wave Structure

VOLTAGE AND CHARGE BUILDUP IN A TWT

- Input end
- Charge density in the electron beam
- Voltage in the traveling wave
- Distance along the interaction space
- Output end

V₁

V₀
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

Quality of Integra
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
Example of T/R Module Architecture
Power capabilities of Transmitter Sources versus Frequency

Tube Amplifiers versus Solid State Amplifiers

- Tube Amplifier Dominate
- Region of Competition
- Solid State Amplifiers Dominate
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 (μW) 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