

# Microwave Devices & Radar

## Table of Contents

(Ver5.0)

---

I-1	Electromagnetic Fields and Waves (1)	I-58	Jammer Burnthrough Range (2)
I-2	Electromagnetic Fields and Waves (2)	I-59	Noise Figure
I-3	Electromagnetic Fields and Waves (3)	I-60	Probability & Statistics Refresher (1)
I-4	Electromagnetic Fields and Waves (4)	I-61	Probability & Statistics Refresher (2)
I-5	Electromagnetic Fields and Waves (5)	I-62	Probability & Statistics Refresher (3)
I-6	Electromagnetic Fields and Waves (6)	I-63	Probability & Statistics Refresher (4)
I-7	Electromagnetic Fields and Waves (7)	I-64	Rayleigh Distribution (1)
I-8	Electromagnetic Fields and Waves (8)	I-65	Rayleigh Distribution (2)
I-9	Wave Reflection (1)	I-66	Central Limit Theorem
I-10	Wave Reflection (2)	I-67	Transformation of Variables
I-11	Wave Reflection (3)	I-68	Fourier Transform Refresher (1)
I-12	Wave Reflection (4)	I-69	Fourier Transform Refresher (2)
I-13	Wave Reflection (5)	I-70	Fourier Transform Refresher (3)
I-14	Wave Reflection (6)	I-71	Fourier Transform Refresher (4)
I-15	Antenna Patterns, Directivity and Gain	I-72	Fourier Transform Refresher (5)
I-16	Polarization of Radiation	I-73	Modulation of a Carrier (1)
I-17	Wave Polarization	I-74	Modulation of a Carrier (2)
I-18	Electromagnetic Spectrum	I-75	Modulation of a Carrier (3)
I-19	Radar and ECM Frequency Bands	I-76	Fourier Transform of a Pulse Train (1)
I-20	Radar Bands and Usage	I-77	Fourier Transform of a Pulse Train (2)
I-21	Joint Electronics Type Designation	I-78	Fourier Transform of a Pulse Train (3)
I-22	Examples of EW Systems	I-79	Response of Networks (1)
I-23	Radio Detection and Ranging (RADAR)	I-80	Response of Networks (2)
I-24	Time Delay Ranging	I-81	Response of Networks (3)
I-25	Information Available From the Radar Echo	I-82	Signals and Noise Through Networks (1)
I-26	Radar Classification by Function	I-83	Signals and Noise Through Networks (2)
I-27	Radar Classification by Waveform	I-84	Signals and Noise Through Networks (3)
I-28	Basic Form of the Radar Range Equation (1)	I-85	Rician Distribution
I-29	Basic Form of the Radar Range Equation (2)	I-86	Probability of False Alarm (1)
I-30	Basic Form of the Radar Range Equation (3)	I-87	Probability of False Alarm (2)
I-31	Characteristics of the Radar Range Equation	I-88	Probability of False Alarm (3)
I-32	Maximum Detection Range	I-89	Probability of Detection (1)
I-33	Generic Radar Block Diagram	I-90	Probability of Detection (2)
I-34	Brief Description of System Components	I-91	Probability of Detection (3)
I-35	Coordinate Systems	I-92	Probability of Detection (4)
I-36	Radar Displays	I-93	SNR Improvement Using Integration
I-37	Pulsed Waveform	I-94	Illustration of Noncoherent Integration
I-38	Range Ambiguities	I-95	SNR Improvement Using Integration
I-39	Range Gates	I-96	Approximate Antenna Model
I-40	Range Bins and Range Resolution	I-97	Number of Pulses Available
I-41	Radar Operational Environment	I-98	Integration Improvement Factor
I-42	Ground Clutter From Sidelobes	I-99	RRE for Pulse Integration
I-43	Survey of Propagation Mechanisms (1)	I-100	RRE for Pulse Integration
I-44	Survey of Propagation Mechanisms (2)	I-101	RRE for Pulse Integration
I-45	Survey of Propagation Mechanisms (3)	I-102	Radar Cross Section (1)
I-46	Radar System Design Tradeoffs	I-103	Radar Cross Section (2)
I-47	Decibel Refresher	I-104	Radar Cross Section of a Sphere
I-48	Thermal Noise	I-105	Radar Cross Section of a Cylinder
I-49	Noise in Radar Systems	I-106	Target Scattering Matrix (1)
I-50	Noise in Radar Systems	I-107	Target Scattering Matrix (2)
I-51	Ideal Filter	I-108	Example: Antenna as a Radar Target
I-52	Noise Bandwidth of an Arbitrary Filter	I-109	Scattering Mechanisms
I-53	Signal-to-noise Ratio (S/N)	I-110	Scattering Sources for a Complex Target
I-54	Example: Police Radar	I-111	Two Sphere RCS (1)
I-55	Attack Approach	I-112	Two Sphere RCS (2)
I-56	Defeating Radar by Jamming	I-113	RCS of a Two Engine Bomber
I-57	Jammer Burnthrough Range (1)	I-114	RCS of a Naval Auxiliary Ship

I-115	RCS of a Geometrical Components Jet	II-45	PD and MTI Problem: Velocity Ambiguities
I-116	Geometrical Components Jet	II-46	Velocity Ambiguities (2)
I-117	Fluctuating Targets	II-47	Airborne MTI and Pulse Doppler Operation
I-118	Swirling Types	II-48	Surface Clutter (1)
I-119	Correction & Improvement Factors (1)	II-49	Surface Clutter (2)
I-122	Correction & Improvement Factors (2)	II-50	Surface Clutter (3)
I-121	Detection Range for Fluctuating Targets	II-51	Two-Way Pattern Beamwidth
I-122	Example	II-52	Surface Clutter (4)
I-123	Defeating Radar by Low Observability	II-53	Backscatter From Extended Surfaces
I-124	Methods of RCS Reduction and Control	II-54	Backscatter From Extended Surfaces
I-125	Corner Reflector Reduction by Shaping	II-55	Clutter Spectrum (1)
I-126	RCS of Shaped Plates	II-56	Clutter Spectrum (2)
I-127	Application of Serrations to Reduce Edge Scattering	II-57	Clutter Spectrum (3)
I-128	Application of Serrations to Reduce Edge Scattering	II-58	Clutter Spectrum (4)
I-129	Traveling Waves	II-59	Clutter Spectrum (5)
I-130	Trailing Edge Resistive Strips	II-60	Clutter Spectrum (6)
I-131	Application of Reduction Methods	II-61	Clutter Spectrum (7)
I-132	Low Observable Platforms: F-117	II-62	Sea States
I-133	Low Observable Platforms: B-2	II-63	Sea Clutter
I-134	Low Observable Platforms: Sea Shadow	II-64	Example: AN/APS-200
II-1	Other Sources of Loss	II-65	Example: AN/APS-200
II-2	Atmospheric Attenuation	II-66	Example: AN/APS-200
II-3	Rain Attenuation	II-67	Delay Line Canceler (1)
II-4	Transmission Line Loss	II-68	Delay Line Canceler (2)
II-5	Antenna Beamshape Loss	II-69	Delay Line Canceler (3)
II-6	Collapsing Loss (Combining Loss)	II-70	Delay Line Canceler (4)
II-7	Noise Figure & Effective Temperature (1)	II-71	Staggered and Multiple PRFs (1)
II-8	Comments on Noise Figure & Temperature	II-72	Staggered and Multiple PRFs (2)
II-9	Noise in Cascaded Networks (1)	II-73	Staggered and Multiple PRFs (3)
II-10	Noise Figure & Effective Temperature (2)	II-74	Synchronous Detection (I and Q Channels)
II-11	Noise Figure From Loss	II-75	Analog vs Digital Processing for MTI
II-12	Examples (1)	II-76	Single Channel Receiver Block Diagram
II-13	Examples (2)	II-77	Synchronous Receiver Block Diagram
II-14	Examples (3)	II-78	SNR Advantage of Synchronous Detection (1)
II-15	Examples (4)	II-79	SNR Advantage of Synchronous Detection (2)
II-16	Examples (5)	II-80	Processing of a Coherent Pulse Train (1)
II-17	Examples (6)	II-81	Sampling Theorem (1)
II-18	Examples (7)	II-82	Sampling Theorem (2)
II-19	Doppler Frequency Shift (1)	II-83	Processing of a Coherent Pulse Train (2)
II-20	Doppler Frequency Shift (2)	II-84	Processing of a Coherent Pulse Train (3)
II-21	Doppler Frequency Shift (3)	II-85	Processing of a Coherent Pulse Train (4)
II-22	Doppler Filter Banks	II-86	Discrete Fourier Transform (DFT)
II-23	Example	II-87	Doppler Filtering Using the DFT (1)
II-24	Example	II-88	Doppler Filtering Using the DFT (2)
II-25	I and Q Representation	II-89	Pulse Doppler Receiver
II-26	Doppler Frequency Shift (4)	II-90	Sample Plot in Doppler-Range Space
II-27	CW Radar Problems (1)	II-91	Pulse Burst Mode
II-28	CW Radar Problems (2)	II-92	MTI Limitations (1)
II-29	CW Radar Problems (3)	II-93	MTI Limitations (2)
II-30	Frequency Modulated CW (FMCW)	II-94	MTI Canceler Improvement Factors
II-31	FMCW (2)	II-95	MTI Canceler Improvement Factors
II-32	FMCW (3)	II-96	Example
II-33	FMCW (4)	II-97	Coherent and Noncoherent Pulse Trains
II-34	FMCW Complications	II-98	Noncoherent Pulse Train Spectrum (1)
II-35	FMCW Complications	II-99	Noncoherent Pulse Train Spectrum (2)
II-36	MTI and Pulse Doppler Radar	II-100	Search Radar Equation (1)
II-37	MTI (1)	II-101	Search Radar Equation (2)
II-38	MTI (2)	II-102	Search Radar Equation (3)
II-39	MTI (3)	II-103	Search Radar Equation (4)
II-40	PD and MTI Problem: Eclipsing	II-104	Radar Tracking (1)
II-41	PD and MTI Problem: Range Ambiguities	II-105	Radar Tracking (2)
II-42	Range Ambiguities (2)	II-106	Radar Tracking (3)
II-43	Range Ambiguities (3)	II-107	Gain Control
II-44	Example	II-108	Example

II-109	Example	III-47	Parabolic Reflector Antenna Losses
II-110	Monopulse Tracking (1)	III-48	Other Reflector Configurations
II-111	Monopulse Tracking (2)	III-49	Example
II-112	Monopulse Tracking (3)	III-50	Example
II-113	Monopulse Tracking (4)	III-51	Radiation by a Line Source (1)
II-114	Monopulse Tracking (5)	III-52	Radiation by a Line Source (2)
II-115	Monopulse Tracking (6)	III-53	Array Antennas (1)
II-116	Monopulse Tracking (7)	III-54	Array Antennas (2)
II-117	Low Angle Tracking (1)	III-55	Visible Region
II-118	Low Angle Tracking (2)	III-56	Array Antennas (3)
II-119	Low Angle Tracking (3)	III-57	Array Antennas (4)
II-120	Low Angle Tracking (4)	III-58	Array Factor for 2D Arrays
II-121	Tracking Error Due to Multipath	III-59	Gain of Phased Arrays
II-122	Low Angle Tracking (5)	III-60	Array Elements and Ground Planes
II-123	Low Angle Tracking (6)	III-61	Array of Dipoles Above a Ground Plane
II-124	Atmospheric Refraction (1)	III-62	Series Fed Waveguide Slot Array
II-125	Atmospheric Refraction (2)	III-63	Low Probability of Intercept Radar (LPIR)
II-126	Atmospheric Refraction (3)	III-64	Low and Ultra Low Sidelobes
III-1	Noise Power Spectral Density	III-65	Antenna Pattern Control
III-2	Matched Filters (1)	III-66	Tapered Aperture Distributions
III-3	Matched Filters (2)	III-67	Calculation of Aperture Efficiency
III-4	Matched Filters (3)	III-68	Cosecant-Squared Antenna Pattern
III-5	Matched Filters (4)	III-69	Example
III-6	Matched Filters (5)	III-70	Array Example (1)
III-7	Matched Filters (6)	III-71	Array Example (2)
III-8	Matched Filters (7)	III-72	Array Example (3)
III-9	Complex Signals	III-73	Array Example (4)
III-10	Ambiguity Function (1)	III-74	Calculation of Antenna Temperature
III-11	Ambiguity Function (2)	III-75	Multiple Beam Antennas (1)
III-12	Ambiguity Function (3)	III-76	Multiple Beam Antennas (2)
III-13	Ambiguity Function (4)	III-77	Radiation Patterns of a Multiple Beam Array
III-14	Ambiguity Function (5)	III-78	Beam Coupling Losses for a 20 Element Array
III-15	Range Accuracy (1)	III-79	Active vs Passive Antennas
III-16	Range Accuracy (2)	III-80	SNR Calculation for a Lossless Feed Network
III-17	Range Accuracy (3)	III-81	SNR Calculation for a Lossless Feed Network
III-18	Range Accuracy (4)	III-82	Passive Two-Beam Array (1)
III-19	Velocity Accuracy	III-83	Passive Two-Beam Array (2)
III-20	Uncertainty Relation	III-84	Active Two-Beam Array (1)
III-21	Angular Accuracy	III-85	Active Two-Beam Array (2)
III-22	Pulse Compression	III-86	Comparison of SNR: Active vs Passive
III-23	Linear FM Pulse Compression (Chirp)	III-87	Example
III-24	Linear FM Pulse Compression (Chirp)	III-88	Active Array Radar Transmit/Receive Module
III-25	Linear FM Pulse Compression (Chirp)	III-89	Digital Phase Shifters
III-26	Linear FM Pulse Compression (Chirp)	III-90	Effect of Phase Shifter Roundoff Errors
III-27	Chirp Filter Output Waveform	III-91	Digital Phase Shifters
III-28	Range Resolution (1)	III-92	True Time Delay (TTD) Scanning
III-29	Range Resolution (2)	III-93	Time Delay vs Fixed Phase Scanning
III-30	Pulse Compression Example	III-94	Beam Squint Due to Frequency Change
III-31	Chirp Complications	III-95	Example of TTD vs. Phase Shifter
III-32	Digital Pulse Compression	III-96	Time Delay Networks
III-33	Barker Sequences	III-97	Time Delay Using Fiber Optics
III-34	Pulse Compressor/Expander	III-98	Digital Beamforming (1)
III-35	The Ideal Radar Antenna	III-99	Digital Beamforming (2)
III-36	Antenna Refresher (1)	III-100	Digital Beamforming (3)
III-37	Lens Antenna	III-101	Monopulse Difference Beams
III-38	Solid Angles and Steradians	III-102	Sum and Difference Beamforming
III-39	Antenna Far Field	III-103	Waveguide Monopulse Beamforming Network
III-40	Antenna Pattern Features	III-104	Antenna Radomes
III-41	Antenna Refresher (2)	III-105	Conformal Antennas & "Smart Skins"
III-42	Antenna Refresher (3)	III-106	Testing of Charred Space Shuttle Tile
III-43	Directivity Example	III-107	Antenna Imperfections (Errors)
III-44	Antenna Polarization Loss	III-108	Smart Antennas (1)
III-45	Reflector Antennas	III-109	Smart Antennas (2)
III-46	Parabolic Reflector Antenna	III-110	Transmission Line Refresher (1)

III-111	Transmission Line Refresher (2)	IV-29	Harmonic Radar (2)
III-112	Transmission Line Refresher (3)	IV-30	Harmonic Radar Tracking of Bees
III-113	Multiplexers	IV-31	Synthetic Aperture Radar (SAR)
III-114	Rotary Joints	IV-32	SAR (2)
III-115	Microwave Switches	IV-33	SAR (3)
III-116	Circulators	IV-34	Comparison of Array Factors
III-117	Waveguide Magic Tee	IV-35	Image Resolution
III-118	Filter Characteristics	IV-36	Unfocused SAR (1)
III-119	Mixers (1)	IV-37	Unfocused SAR (2)
III-120	Mixers (2)	IV-38	Focused SAR
III-121	Mixers (3)	IV-39	Example
III-122	Input-Output Transfer Characteristic	IV-40	Cross Range Processing (1)
III-123	Intermodulation Products	IV-41	Cross Range Processing (2)
III-124	Intermodulation Example	IV-42	Cross Range Processing (3)
III-125	Amplifiers	IV-43	Motion Compensation
III-126	Low-Noise Amplifier	IV-44	Radar Mapping
III-127	Intermodulation Products of Amplifiers	IV-45	SAR Image
III-128	Sample Microwave Amplifier Characteristic	IV-46	SAR Range Equation
III-129	Development of Sources	IV-47	SAR Problems (1)
III-130	Power Capabilities of Sources	IV-48	SAR Problems (2)
III-131	Transmitters (1)	IV-49	Inverse Synthetic Aperture Radar (ISAR)
III-132	Transmitters (2)	IV-50	ISAR (2)
III-133	Klystrons	IV-51	ISAR (3)
III-134	Klystron Operation	IV-52	ISAR (4)
III-135	Cavity Magnetron	IV-53	Spotlight SAR
III-136	Magnetron Operation	IV-54	HF Radars (1)
III-137	Eight Cavity Magnetron	IV-55	HF Radars (2)
III-138	Magnetron Basics (1)	IV-56	HF Radars (3)
III-139	Magnetron Basics (2)	IV-57	Typical HF OTH Radar Parameters
III-140	Free-Electron Laser (FEL) Operation	IV-58	Typical HF Clutter and Target Spectrum
III-141	Free-Electron Lasers	IV-58	HF Coastal Radar (CODAR)
III-142	Radar Waveform Parameter Measurements (1)	IV-60	Relocatable OTH Radar (ROTHR)
III-143	Radar Waveform Parameter Measurements (2)	IV-61	HF Radar Example (CONUS-B)
III-144	Radar Waveform Parameter Measurements (3)	IV-62	Stepped Frequency Radar (1)
III-145	Radar Waveform Parameter Measurements (4)	IV-63	Stepped Frequency Radar (2)
III-146	Radar Waveform Parameter Measurements (5)	IV-64	Stepped Frequency Radar (3)
IV-1	Special Radar Systems and Applications	IV-65	Stepped Frequency Radar (4)
IV-2	AN/TPQ-37 Firefinder Radar	IV-66	Stepped Frequency Radar (5)
IV-3	Firefinder Radar Antenna (1)	IV-67	Stepped Frequency Radar (6)
IV-4	Firefinder Radar Antenna (2)	IV-68	Imaging of Moving Targets
IV-5	AN/TPQ-37 Subarray	IV-69	Stepped Frequency Imaging (1)
IV-6	Firefinder Radar Antenna (3)	IV-70	Stepped Frequency Imaging (2)
IV-7	Patriot Air Defense Radar (1)	IV-71	Stepped Frequency Imaging (3)
IV-8	Patriot Air Defense Radar (2)	IV-72	Ultra-Wide Band Radar (1)
IV-9	SCR-270 Air Search Radar	IV-73	Ultra-Wide Band Radar (2)
IV-10	SCR-270-D Radar	IV-74	Ultra-Wide Band Radar (3)
IV-11	SPY-1 Shipboard Radar	IV-75	Ultra-Wide Band Radar (4)
IV-12	X-Band Search Radar (AN/SPS-64)	IV-76	Ultra-Wide Band Radar (5)
IV-13	AN/SPS-64	IV-77	Ultra-Wide Band Radar (6)
IV-14	C-Band Search Radar (AN/SPS-67)	IV-78	Ultra-Wide Band Radar (7)
IV-15	AN/SPS-67	IV-79	Ultra-Wide Band Radar (8)
IV-16	Combat Surveillance Radar (AN/PPS-6)	IV-80	RCS Considerations
IV-17	AN/PPS-6	IV-81	Time Domain Scattering
IV-18	Early Air Surveillance Radar (AN/APS-31)	IV-82	F-111 Resonant Frequencies
IV-19	AN/APS-31	IV-83	Currents on a F-111 at its First Resonance
IV-20	AN/APS-40	IV-84	Excitation of the First Resonance
IV-21	AN/APS-40	IV-85	Antenna Considerations
IV-22	Plan Position Indicator (PPI)	IV-86	Brown Bat Ultrasonic Radar (1)
IV-23	Radiometers (1)	IV-87	Brown Bat Ultrasonic Radar (2)
IV-24	Radiometers (2)	IV-88	Doppler Weather Radar (1)
IV-25	Radiometers (3)	IV-89	Doppler Weather Radar (2)
IV-26	Radiometers (4)	IV-90	Doppler Weather Radar (3)
IV-27	Radiometers (5)	IV-91	Doppler Weather Radar (4)
IV-28	Harmonic Radar (1)	IV-92	Doppler Weather Radar (5)

IV-93	Implementation and Interpretation of Data (1)	IV-157	Ground Penetrating Radar (6)
IV-94	Implementation and Interpretation of Data (2)	IV-158	Ground Penetrating Radar (7)
IV-95	Implementation and Interpretation of Data (3)	IV-159	Ground Penetrating Radar (8)
IV-96	Implementation and Interpretation of Data (4)		
IV-97	Implementation and Interpretation of Data (5)		
IV-98	Clear Air Echoes and Bragg Scattering		
IV-99	Weather Radar Example		
IV-100	Monolithic Microwave Integrated Circuits		
IV-101	Tile Concept		
IV-102	Module Concept		
IV-103	MMIC Single Chip Radar (1)		
IV-104	MMIC Single Chip Radar (2)		
IV-105	MMIC FMCW Single Chip Radar (1)		
IV-106	MMIC FMCW Single Chip Radar (2)		
IV-107	Defeating Radar Using Chaff		
IV-108	Chaff (1)		
IV-109	Chaff (2)		
IV-110	Chaff (3)		
IV-111	Chaff and Flares		
IV-112	Bistatic Radar (1)		
IV-113	Bistatic Radar (2)		
IV-114	Flight-Tracking Firm Takes Off		
IV-115	Bistatic Radar (3)		
IV-116	Bistatic Radar (4)		
IV-117	Bistatic Radar Example (1)		
IV-118	Bistatic Radar (5)		
IV-119	Bistatic Radar (6)		
IV-120	Bistatic Radar (7)		
IV-121	Bistatic Radar (8)		
IV-122	Bistatic Radar (9)		
IV-123	Bistatic Radar (10)		
IV-124	Bistatic Radar Example (2)		
IV-125	Line-of-Sight Constrained Coverage (1)		
IV-126	Line-of-Sight Constrained Coverage (2)		
IV-127	Bistatic Radar (11)		
IV-128	Bistatic Radar (12)		
IV-129	Bistatic Footprint and Clutter Area (1)		
IV-130	Bistatic Footprint and Clutter Area (2)		
IV-131	Bistatic Radar Cross Section (1)		
IV-132	Bistatic Radar Cross Section (2)		
IV-133	Bistatic Radar Cross Section (3)		
IV-134	Bistatic Radar Example Revisited		
IV-135	Cross Eye Jamming (1)		
IV-136	Cross Eye Jamming (2)		
IV-137	ECM for Conical Scanning		
IV-138	Ground Bounce ECM		
IV-139	Suppression of Sidelobe Jammers (1)		
IV-140	Suppression of Sidelobe Jammers (2)		
IV-141	CSLC Equations for an Array Antenna		
IV-142	CSLC Performance		
IV-143	Adaptive Antennas		
IV-144	Laser Radar (1)		
IV-145	Laser Radar (2)		
IV-146	Laser Radar (3)		
IV-147	Laser Radar (4)		
IV-148	Laser Radar (5)		
IV-149	Laser Radar (6)		
IV-150	Laser Radar (7)		
IV-151	Laser Radar (8)		
IV-152	Ground Penetrating Radar (1)		
IV-153	Ground Penetrating Radar (2)		
IV-154	Ground Penetrating Radar (3)		
IV-155	Ground Penetrating Radar (4)		
IV-156	Ground Penetrating Radar (5)		