“Get On The Air” – What Happens When Your Signal Leaves Your Radio

by Mark Kleine N5HZR

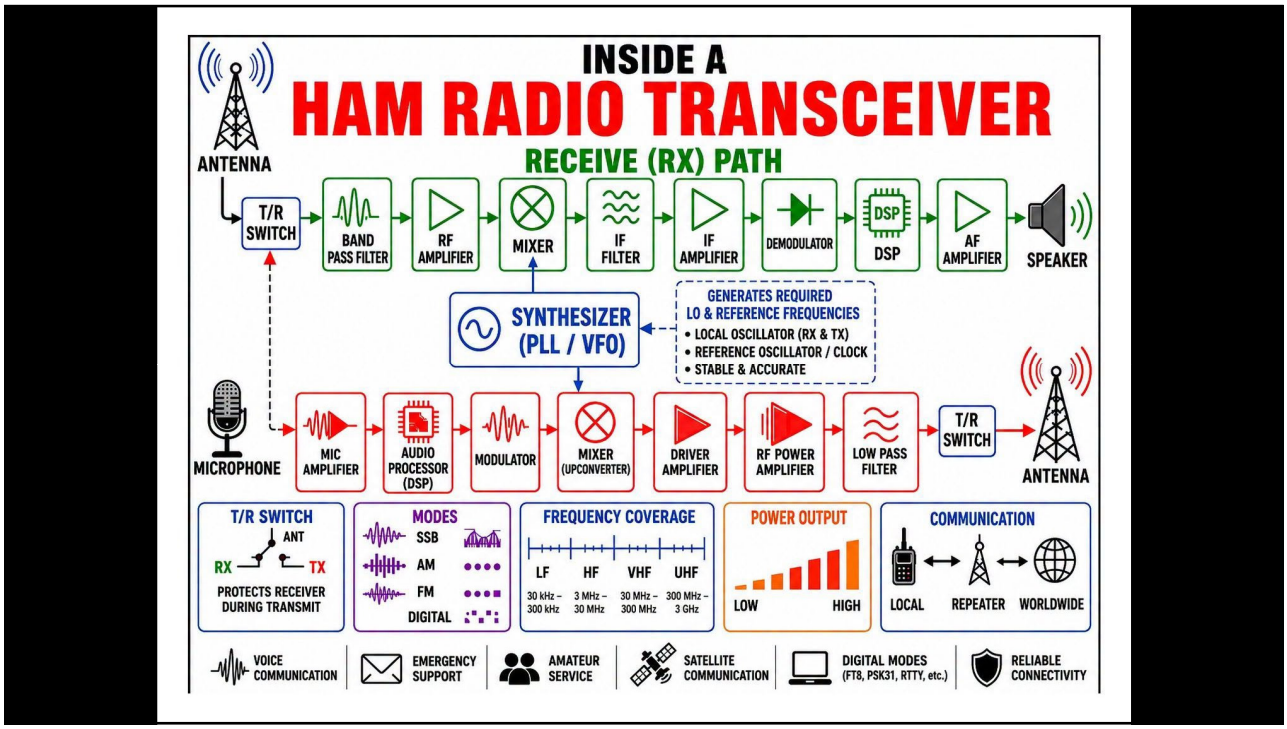
https://w5nor.org/antennas/

1

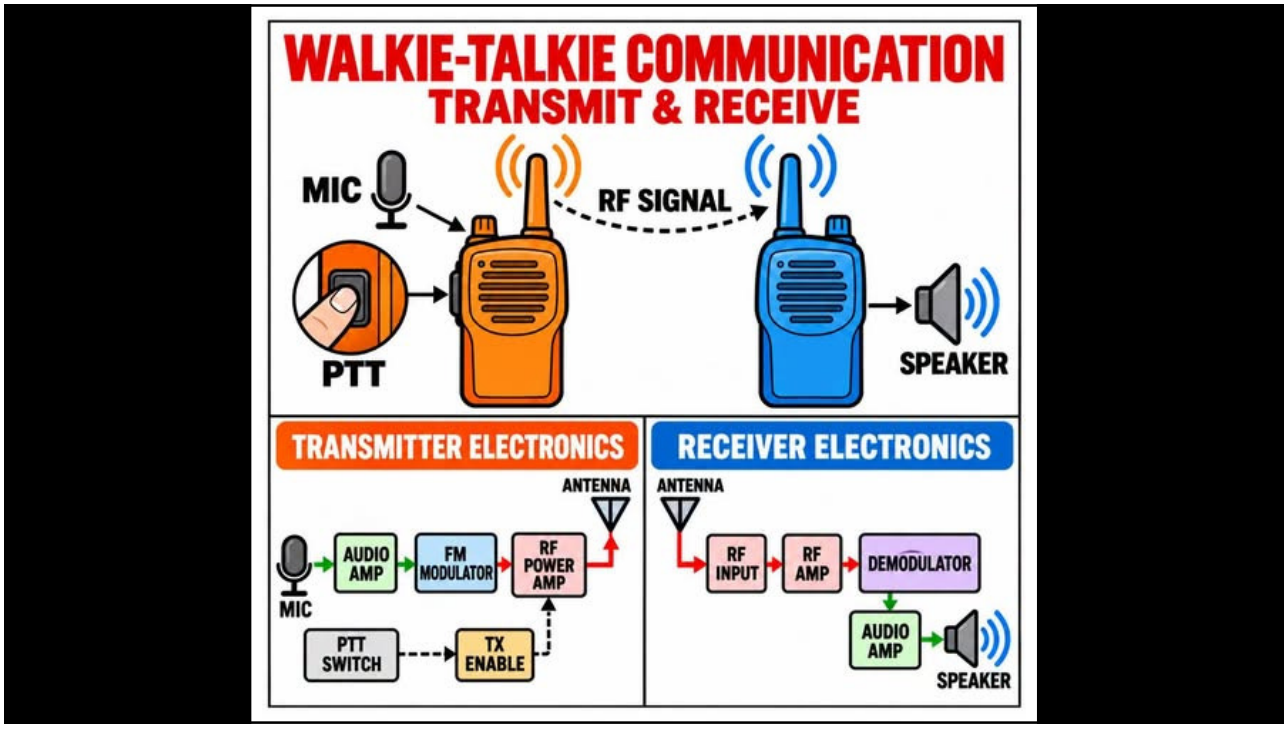
Station Setup

- Power Supply
- Radio
- Transmission Line
- Antenna

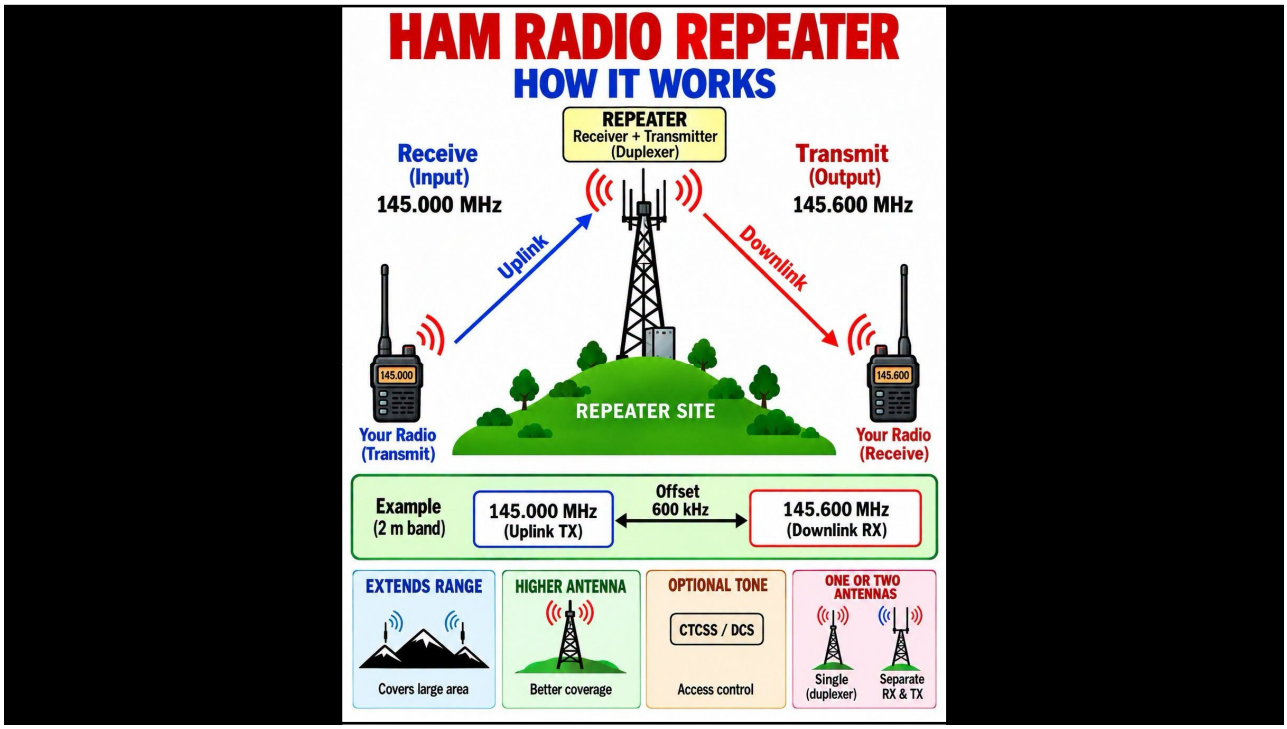
2


INSIDE A
HAM RADIO TRANSCEIVER
RECEIVE (RX) PATH
ANTENNA
T/R SWITCH
BAND PASS FILTER
RF AMPLIFIER
MIXER
IF FILTER
IF AMPLIFIER
DEMODULATOR
DSP
AF AMPLIFIER
SPEAKER
SYNTHESIZER (PLL / VFO)
GENERATES REQUIRED LO & REFERENCE FREQUENCIES
• LOCAL OSCILLATOR (RX & TX)
• REFERENCE OSCILLATOR / CLOCK
• STABLE & ACCURATE
MICROPHONE
MIC AMPLIFIER
AUDIO PROCESSOR (DSP)
MODULATOR
MIXER (UPCONVERTER)
DRIVER AMPLIFIER
RF POWER AMPLIFIER
LOW PASS FILTER
T/R SWITCH
ANTENNA
T/R SWITCH
ANT
RX
TX
PROTECTS RECEIVER DURING TRANSMIT
MODES
SSB
AM
FM
DIGITAL
FREQUENCY COVERAGE
LF
HF
VHF
UHF
30 kHz – 300 kHz
3 MHz – 30 MHz
30 MHz – 300 MHz
300 MHz – 3 GHz
POWER OUTPUT
LOW
HIGH
COMMUNICATION
LOCAL
REPEATER
WORLDWIDE
VOICE COMMUNICATION
EMERGENCY SUPPORT
AMATEUR SERVICE
SATELLITE COMMUNICATION
DIGITAL MODES (FT8, PSK31, RTTY, etc.)
RELIABLE CONNECTIVITY

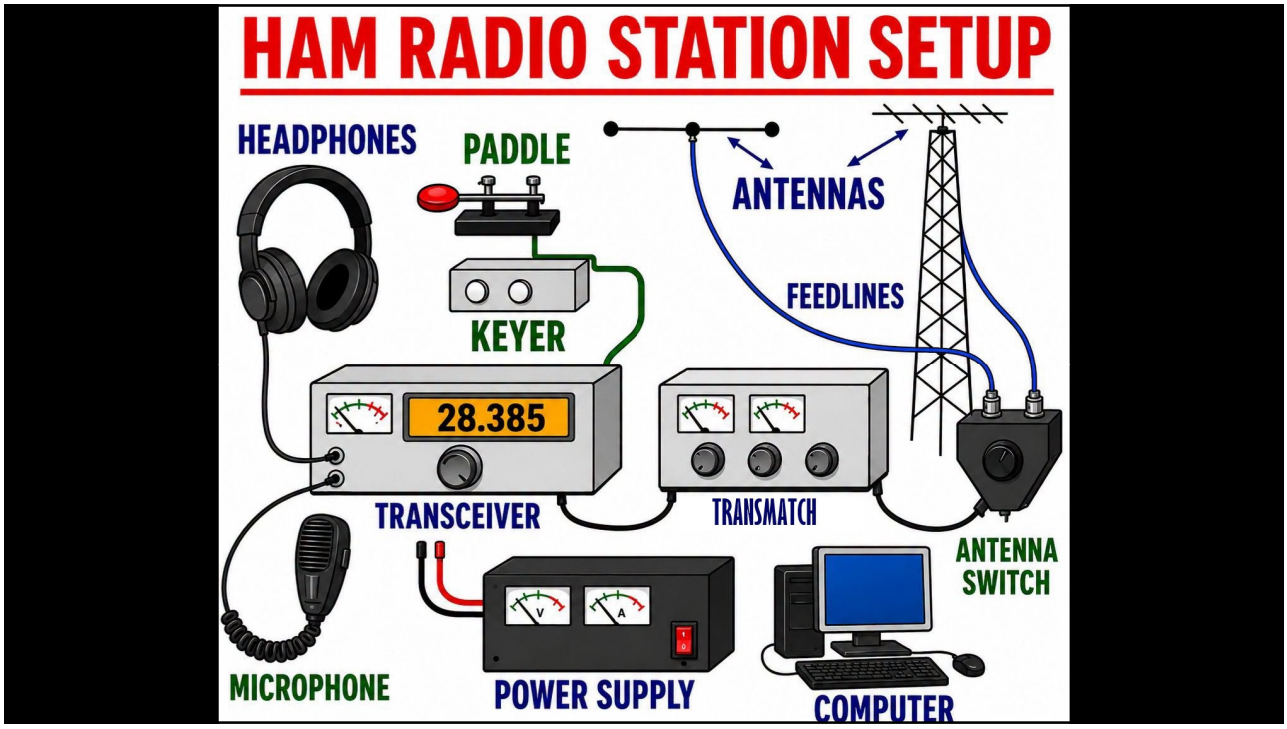
3


WALKIE-TALKIE COMMUNICATION
TRANSMIT & RECEIVE
MIC
RF SIGNAL
PTT
SPEAKER
TRANSMITTER ELECTRONICS
RECEIVER ELECTRONICS
ANTENNA
MIC
AUDIO AMP
FM MODULATOR
RF POWER AMP
PTT SWITCH
TX ENABLE
ANTENNA
RF INPUT
RF AMP
DEMODULATOR
AUDIO AMP
SPEAKER

4


HAM RADIO REPEATER
HOW IT WORKS
REPEATER
Receiver + Transmitter
(Duplexer)
Receive
(Input)
145.000 MHz
Transmit
(Output)
145.600 MHz
Uplink
Downlink
145.000
145.600
REPEATER SITE
Your Radio
(Transmit)
Your Radio
(Receive)
Example
(2 m band)
145.000 MHz
(Uplink TX)
Offset
600 kHz
145.600 MHz
(Downlink RX)
EXTENDS RANGE
Covers large area
HIGHER ANTENNA
Better coverage
OPTIONAL TONE
CTCSS / DCS
Access control
ONE OR TWO ANTENNAS
Single
(duplexer)
Separate
RX & TX

5


HAM RADIO STATION SETUP
HEADPHONES
PADDLE
ANTENNAS
FEEDLINES
KEYER
28.385
TRANSCEIVER
TRANSMATCH
ANTENNA
SWITCH
MICROPHONE
POWER SUPPLY
COMPUTER

6


WHY COAXIAL CABLES ARE HIGHLY INSULATED?
Outer Jacket
Braided Shield
Dielectric (Insulation)
Main Conductor
RG-6 COAXIAL CABLE
Foil Shield
COAXIAL CONNECTORS
Why highly insulated?
Keeps the signal inside, blocks external noise, reduces leakage, and maintains impedance.

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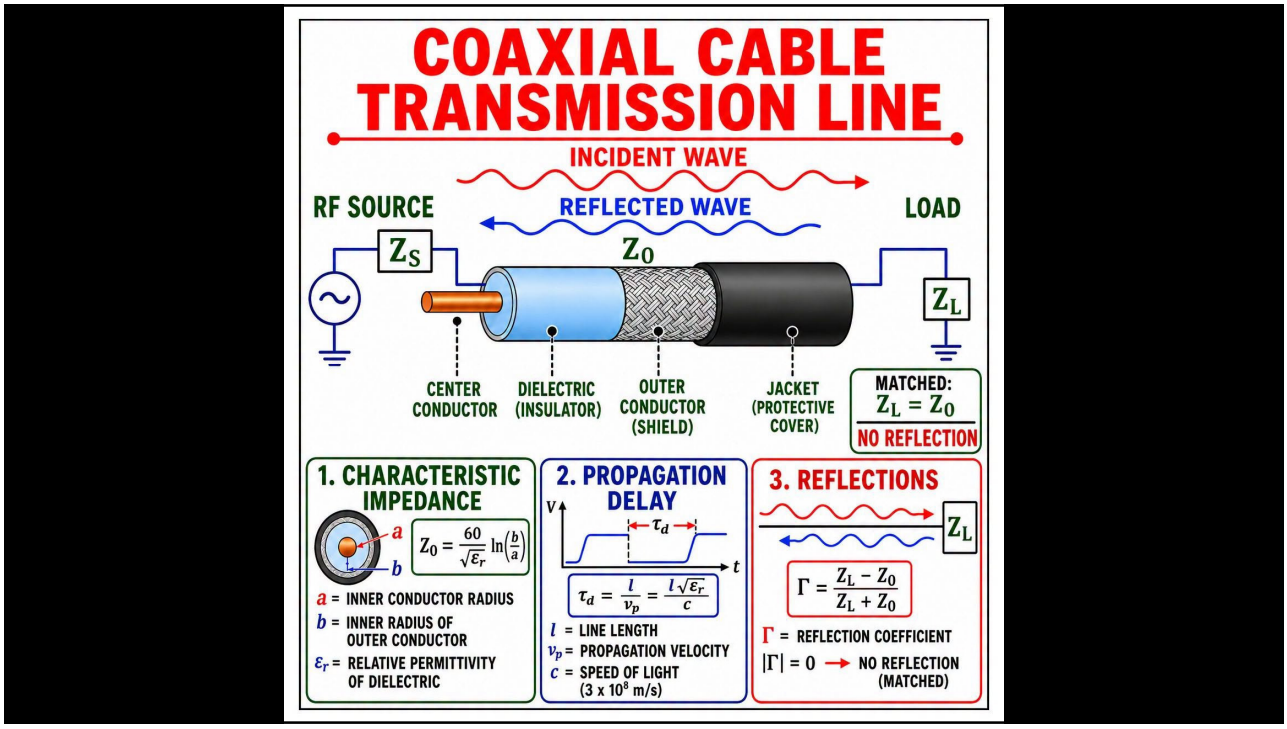
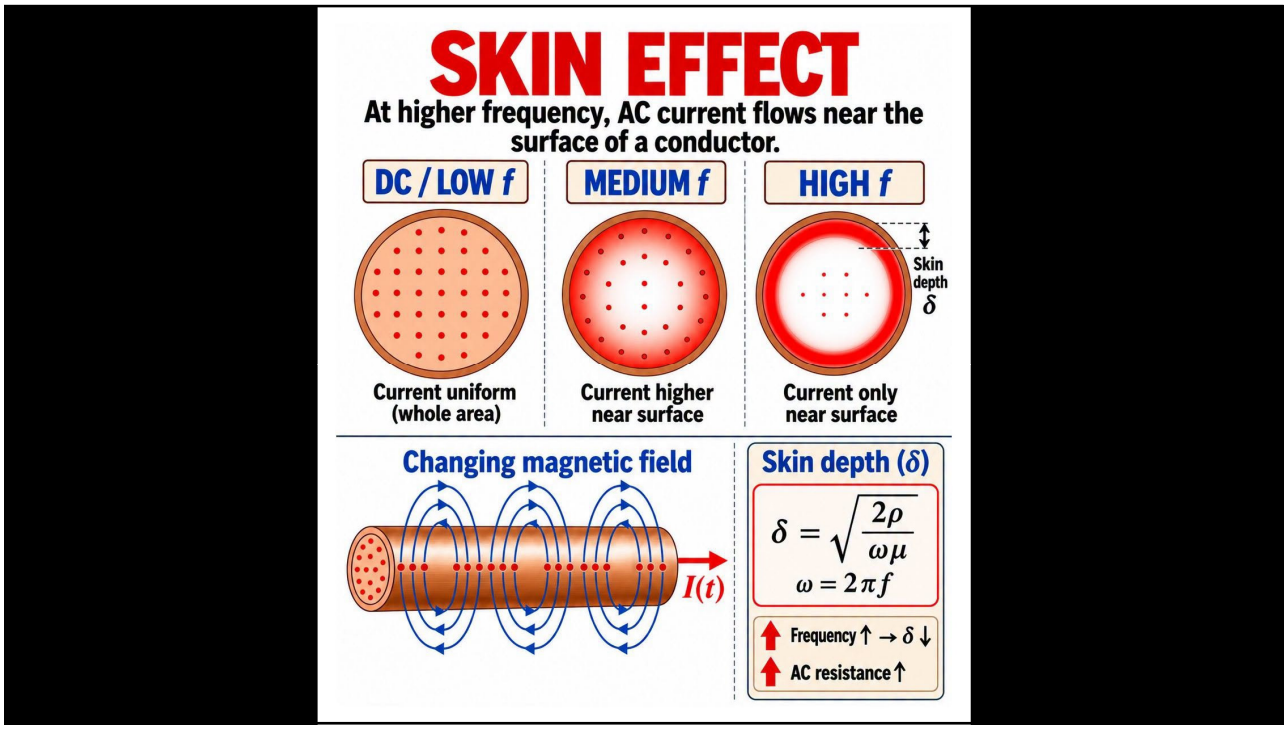

COAXIAL CABLE TRANSMISSION LINE
INCIDENT WAVE
REFLECTED WAVE
RF SOURCE
LOAD
Z_S
Z_0
Z_L
CENTER CONDUCTOR
DIELECTRIC (INSULATOR)
OUTER CONDUCTOR (SHIELD)
JACKET (PROTECTIVE COVER)
MATCHED: $Z_L = Z_0$
NO REFLECTION
1. CHARACTERISTIC IMPEDANCE
$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{b}{a}\right)$
a = INNER CONDUCTOR RADIUS
b = INNER RADIUS OF OUTER CONDUCTOR
ε_r = RELATIVE PERMITTIVITY OF DIELECTRIC
2. PROPAGATION DELAY
$\tau_d = \frac{l}{v_p} = \frac{l\sqrt{\varepsilon_r}}{c}$
l = LINE LENGTH
v_p = PROPAGATION VELOCITY
c = SPEED OF LIGHT (3×10^8 m/s)
3. REFLECTIONS
$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$
Γ = REFLECTION COEFFICIENT
$|\Gamma| = 0$ → NO REFLECTION (MATCHED)

8


SKIN EFFECT
At higher frequency, AC current flows near the surface of a conductor.
DC / LOW f
MEDIUM f
HIGH f
Skin depth δ
Current uniform (whole area)
Current higher near surface
Current only near surface
Changing magnetic field
I(t)
Skin depth (δ)
$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$
$\omega = 2\pi f$
Frequency ↑ → δ ↓
AC resistance ↑

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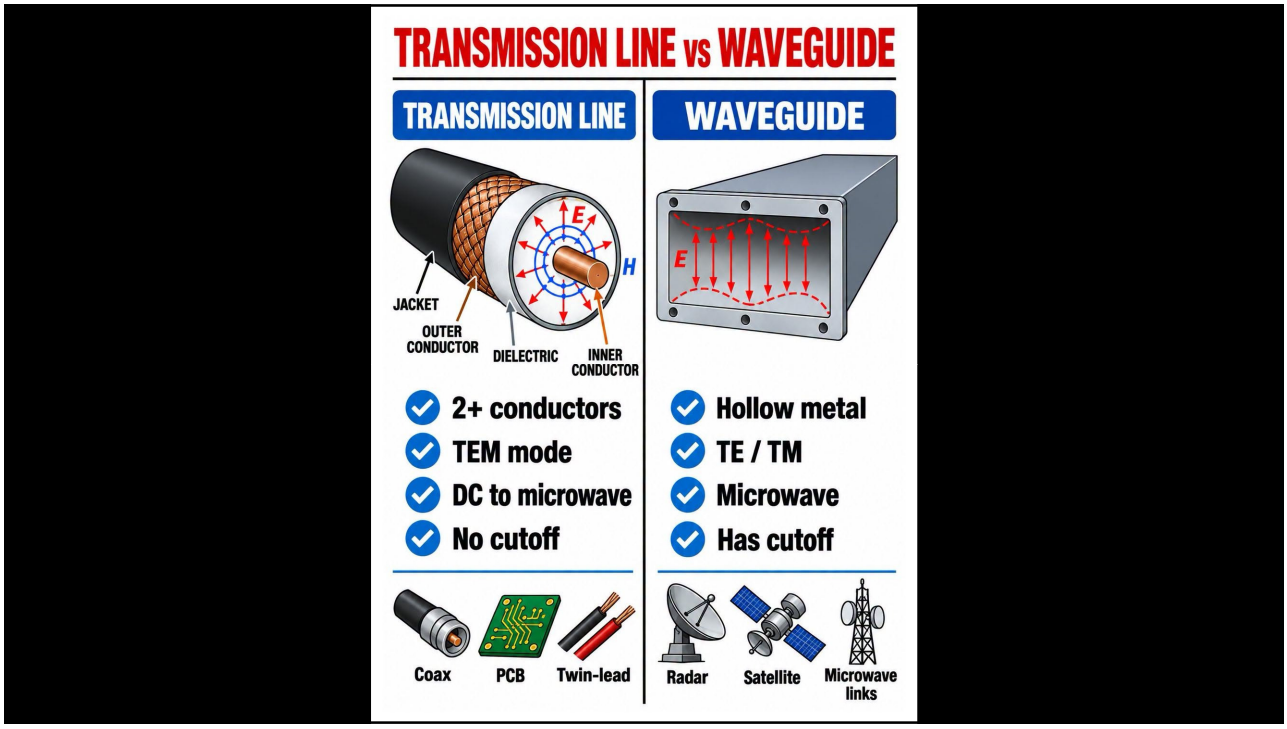
TRANSMISSION LINE vs WAVEGUIDE
TRANSMISSION LINE
WAVEGUIDE
E
H
JACKET
OUTER CONDUCTOR
DIELECTRIC
INNER CONDUCTOR
2+ conductors
TEM mode
DC to microwave
No cutoff
Hollow metal
TE / TM
Microwave
Has cutoff
Coax
PCB
Twin-lead
Radar
Satellite
Microwave links

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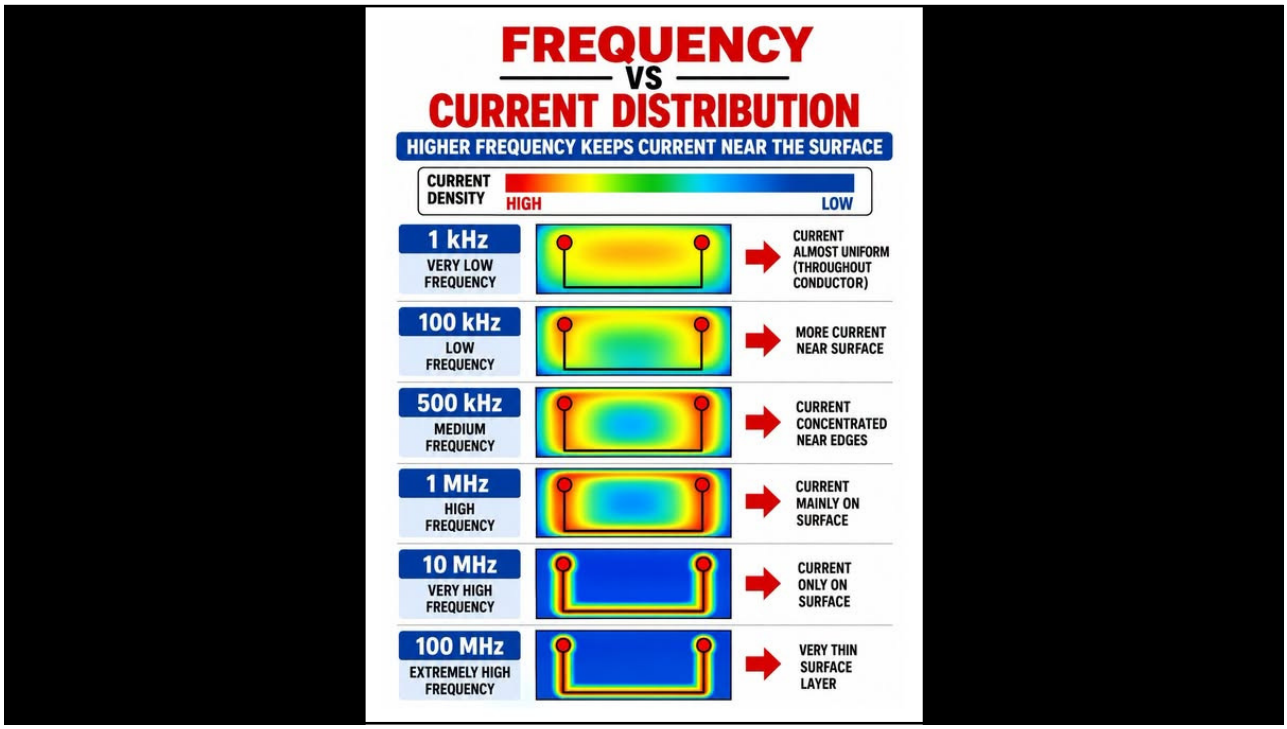
FREQUENCY
VS
CURRENT DISTRIBUTION
HIGHER FREQUENCY KEEPS CURRENT NEAR THE SURFACE
CURRENT DENSITY
HIGH
LOW
1 kHz
VERY LOW FREQUENCY
CURRENT ALMOST UNIFORM (THROUGHOUT CONDUCTOR)
100 kHz
LOW FREQUENCY
MORE CURRENT NEAR SURFACE
500 kHz
MEDIUM FREQUENCY
CURRENT CONCENTRATED NEAR EDGES
1 MHz
HIGH FREQUENCY
CURRENT MAINLY ON SURFACE
10 MHz
VERY HIGH FREQUENCY
CURRENT ONLY ON SURFACE
100 MHz
EXTREMELY HIGH FREQUENCY
VERY THIN SURFACE LAYER

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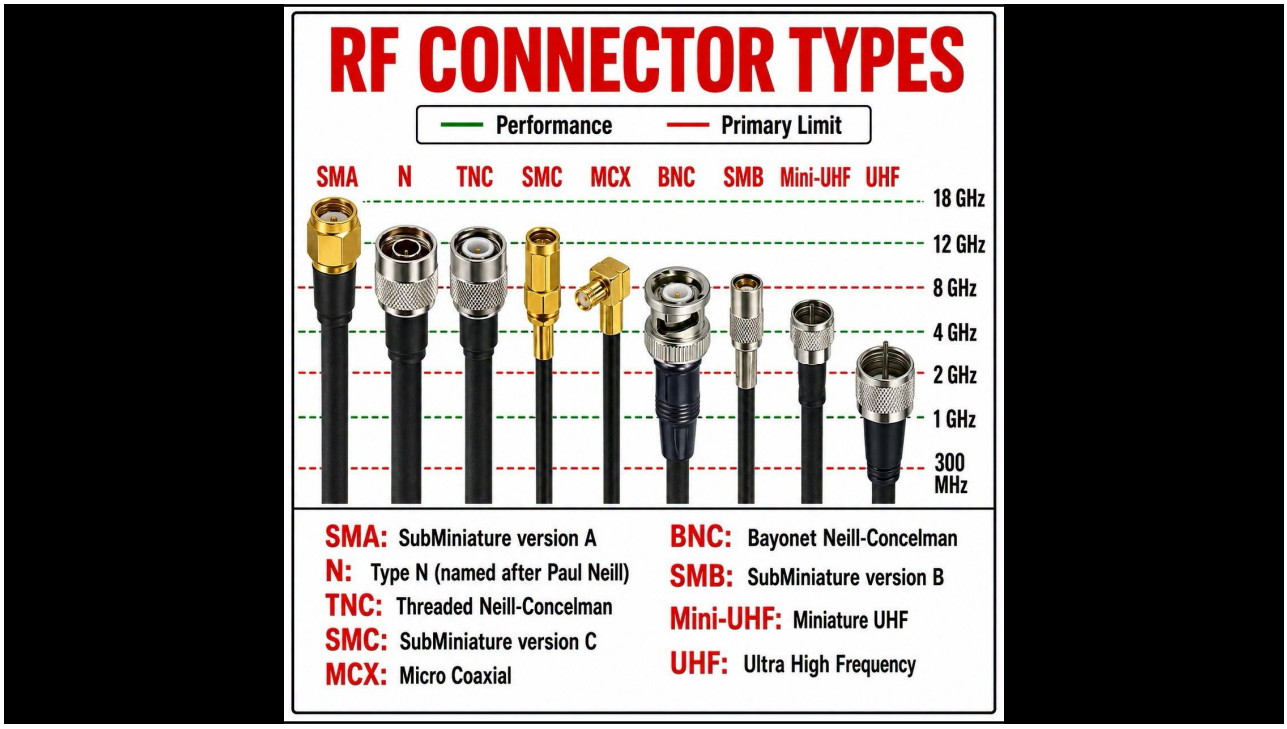
RF CONNECTOR TYPES
Performance
Primary Limit
SMA
N
TNC
SMC
MCX
BNC
SMB
Mini-UHF
UHF
18 GHz
12 GHz
8 GHz
4 GHz
2 GHz
1 GHz
300 MHz
SMA: SubMiniature version A
N: Type N (named after Paul Neill)
TNC: Threaded Neill-Concelman
SMC: SubMiniature version C
MCX: Micro Coaxial
BNC: Bayonet Neill-Concelman
SMB: SubMiniature version B
Mini-UHF: Miniature UHF
UHF: Ultra High Frequency

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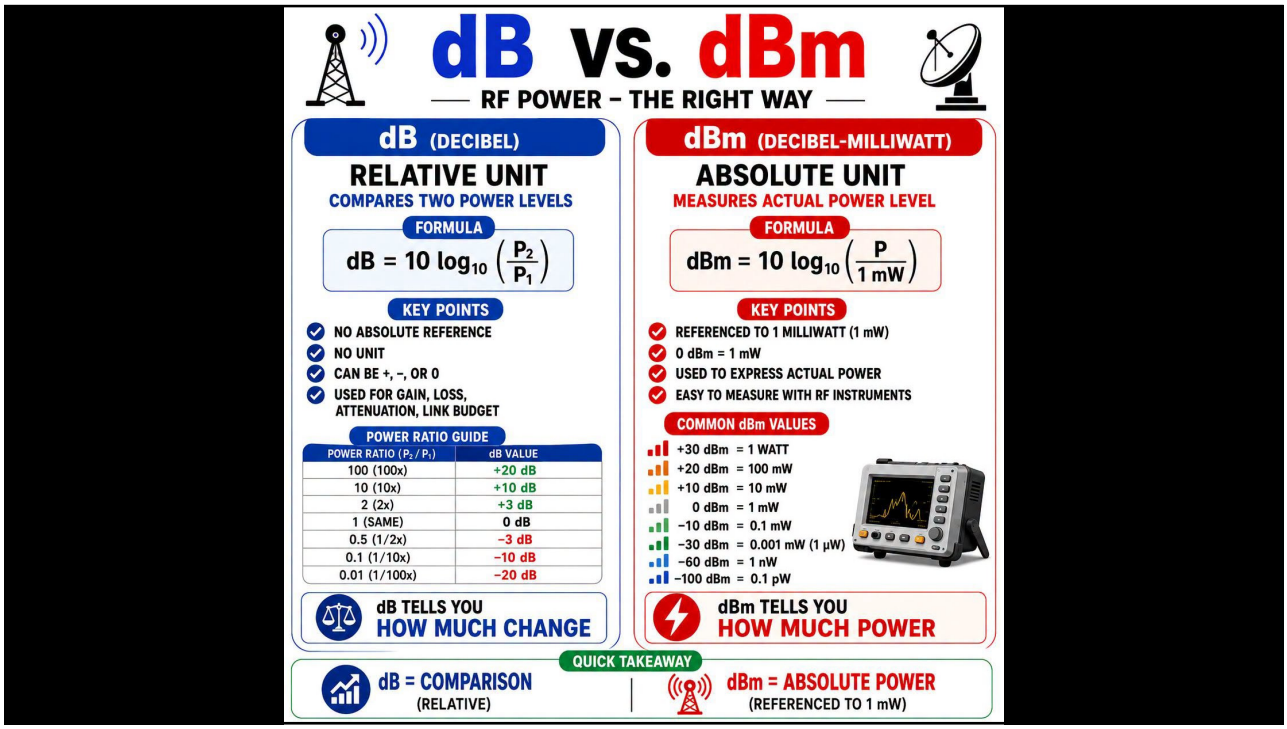
dB vs. dBm
RF POWER – THE RIGHT WAY
dB (DECIBEL)
RELATIVE UNIT
COMPARES TWO POWER LEVELS
FORMULA
$dB = 10 \log_{10}\left(\frac{P_2}{P_1}\right)$
KEY POINTS
NO ABSOLUTE REFERENCE
NO UNIT
CAN BE +, –, OR 0
USED FOR GAIN, LOSS, ATTENUATION, LINK BUDGET
POWER RATIO GUIDE
POWER RATIO (P_2 / P_1) | dB VALUE
100 (100x) | +20 dB
10 (10x) | +10 dB
2 (2x) | +3 dB
1 (SAME) | 0 dB
0.5 (1/2x) | –3 dB
0.1 (1/10x) | –10 dB
0.01 (1/100x) | –20 dB
dB TELLS YOU HOW MUCH CHANGE
dBm (DECIBEL-MILLIWATT)
ABSOLUTE UNIT
MEASURES ACTUAL POWER LEVEL
FORMULA
$dBm = 10 \log_{10}\left(\frac{P}{1\ mW}\right)$
KEY POINTS
REFERENCED TO 1 MILLIWATT (1 mW)
0 dBm = 1 mW
USED TO EXPRESS ACTUAL POWER
EASY TO MEASURE WITH RF INSTRUMENTS
COMMON dBm VALUES
+30 dBm = 1 WATT
+20 dBm = 100 mW
+10 dBm = 10 mW
0 dBm = 1 mW
–10 dBm = 0.1 mW
–30 dBm = 0.001 mW (1 µW)
–60 dBm = 1 nW
–100 dBm = 0.1 pW
dBm TELLS YOU HOW MUCH POWER
QUICK TAKEAWAY
dB = COMPARISON (RELATIVE)
dBm = ABSOLUTE POWER (REFERENCED TO 1 mW)

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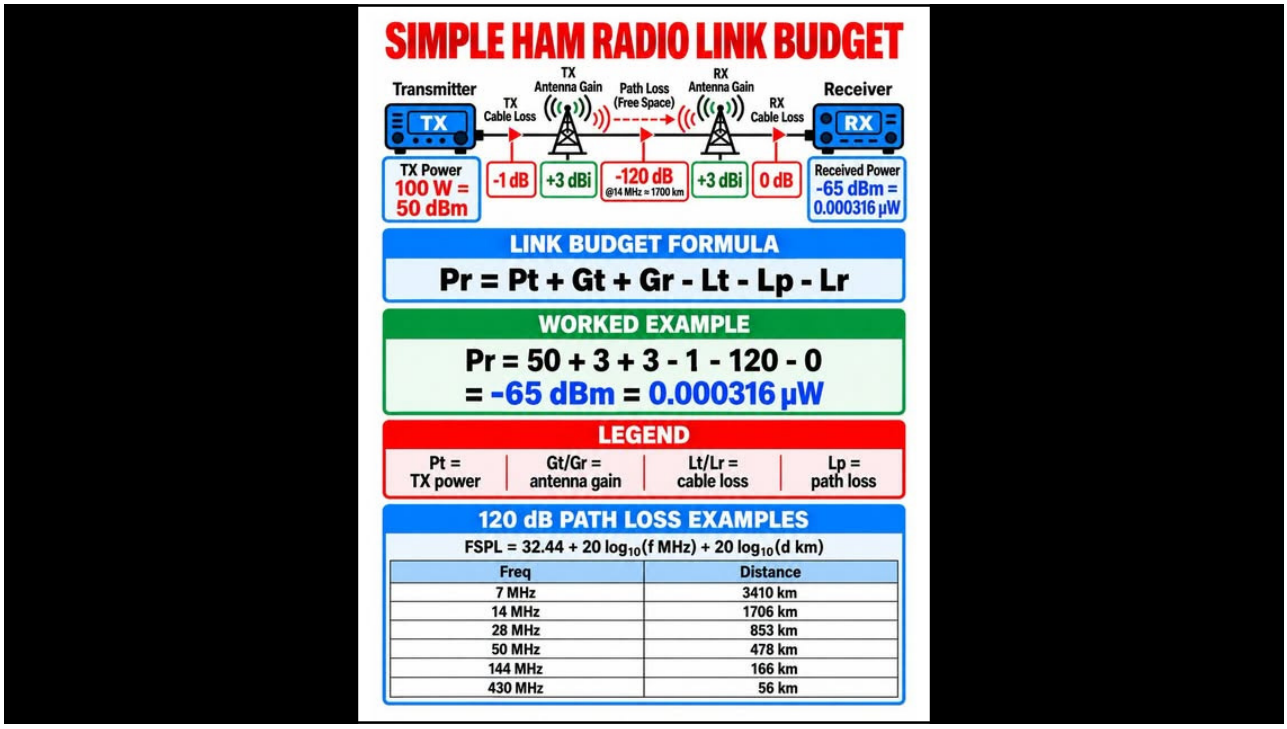
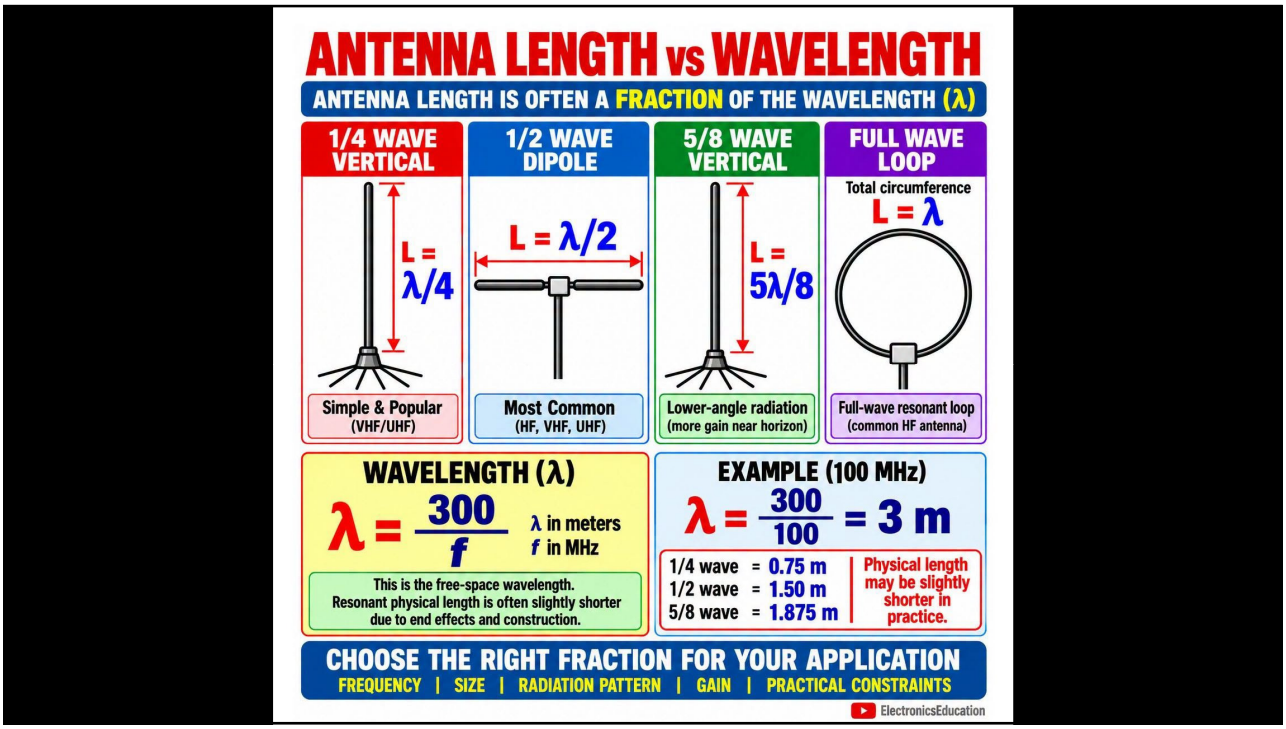

SIMPLE HAM RADIO LINK BUDGET
Transmitter
TX
TX Cable Loss
TX Antenna Gain
Path Loss (Free Space)
RX Antenna Gain
RX Cable Loss
Receiver
RX
TX Power 100 W = 50 dBm
-1 dB
+3 dBi
-120 dB @14 MHz = 1700 km
+3 dBi
0 dB
Received Power -65 dBm = 0.000316 µW
LINK BUDGET FORMULA
Pr = Pt + Gt + Gr - Lt - Lp - Lr
WORKED EXAMPLE
Pr = 50 + 3 + 3 - 1 - 120 - 0
= -65 dBm = 0.000316 µW
LEGEND
Pt = TX power
Gt/Gr = antenna gain
Lt/Lr = cable loss
Lp = path loss
120 dB PATH LOSS EXAMPLES
FSPL = 32.44 + 20 log10(f MHz) + 20 log10(d km)
Freq | Distance
7 MHz | 3410 km
14 MHz | 1706 km
28 MHz | 853 km
50 MHz | 478 km
144 MHz | 166 km
430 MHz | 56 km

14



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Antennas - Three Main Points

- All Antennas Work
- All Antennas Are a Compromise
- All Antennas Are a Dipole, Unless They Are a Loop

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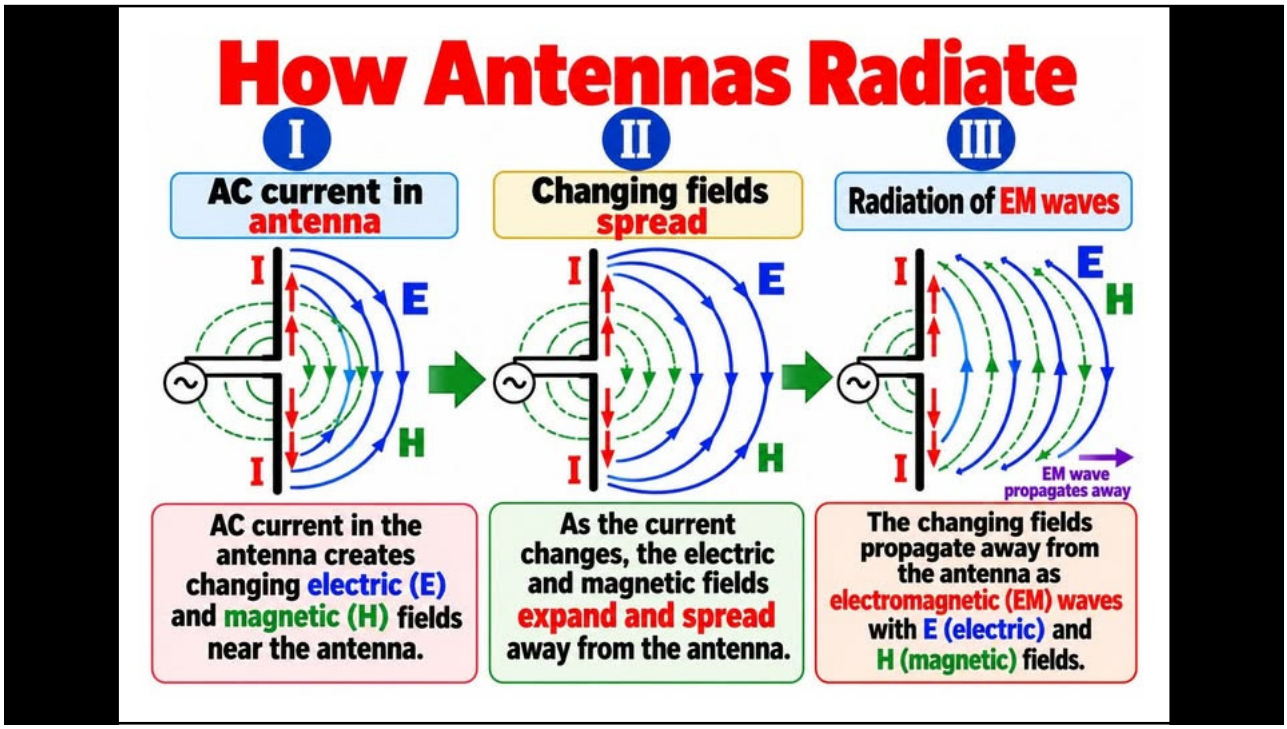
How Antennas Radiate
I
AC current in antenna
II
Changing fields spread
III
Radiation of EM waves
I
E
H
I
I
E
H
I
I
E
H
I
EM wave propagates away
AC current in the antenna creates changing electric (E) and magnetic (H) fields near the antenna.
As the current changes, the electric and magnetic fields expand and spread away from the antenna.
The changing fields propagate away from the antenna as electromagnetic (EM) waves with E (electric) and H (magnetic) fields.

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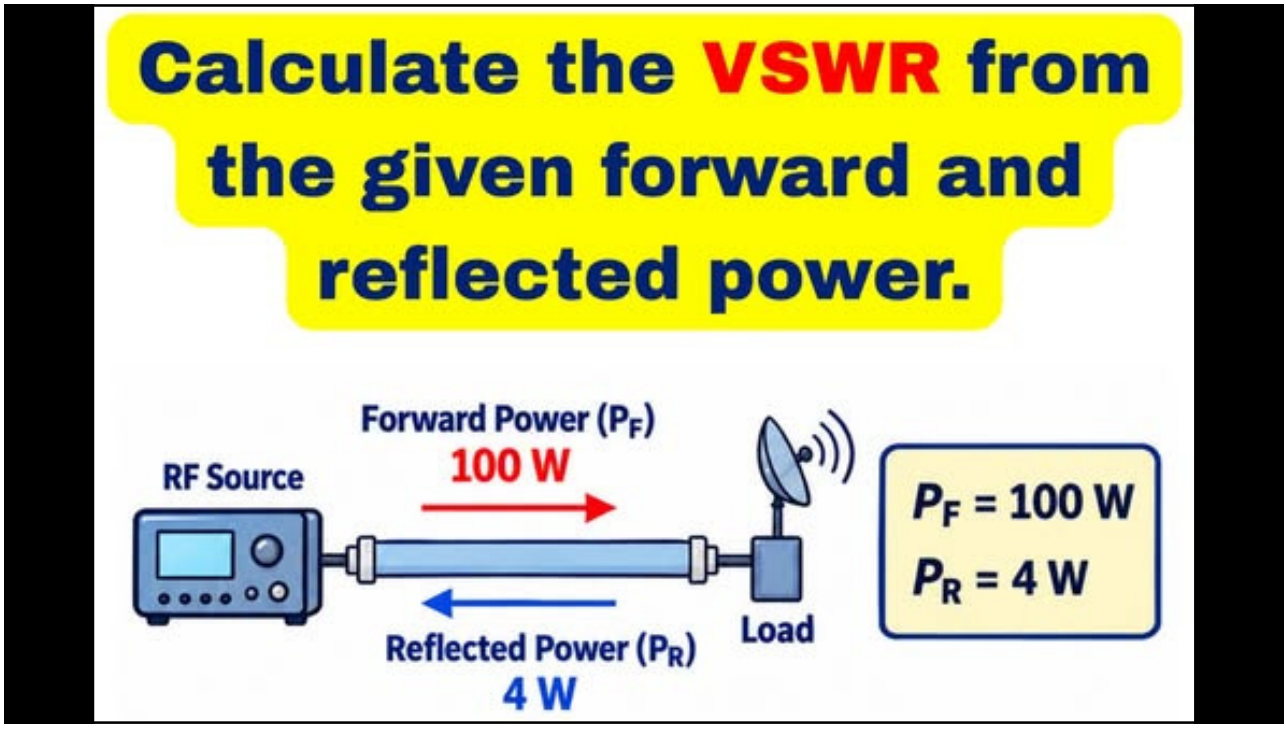
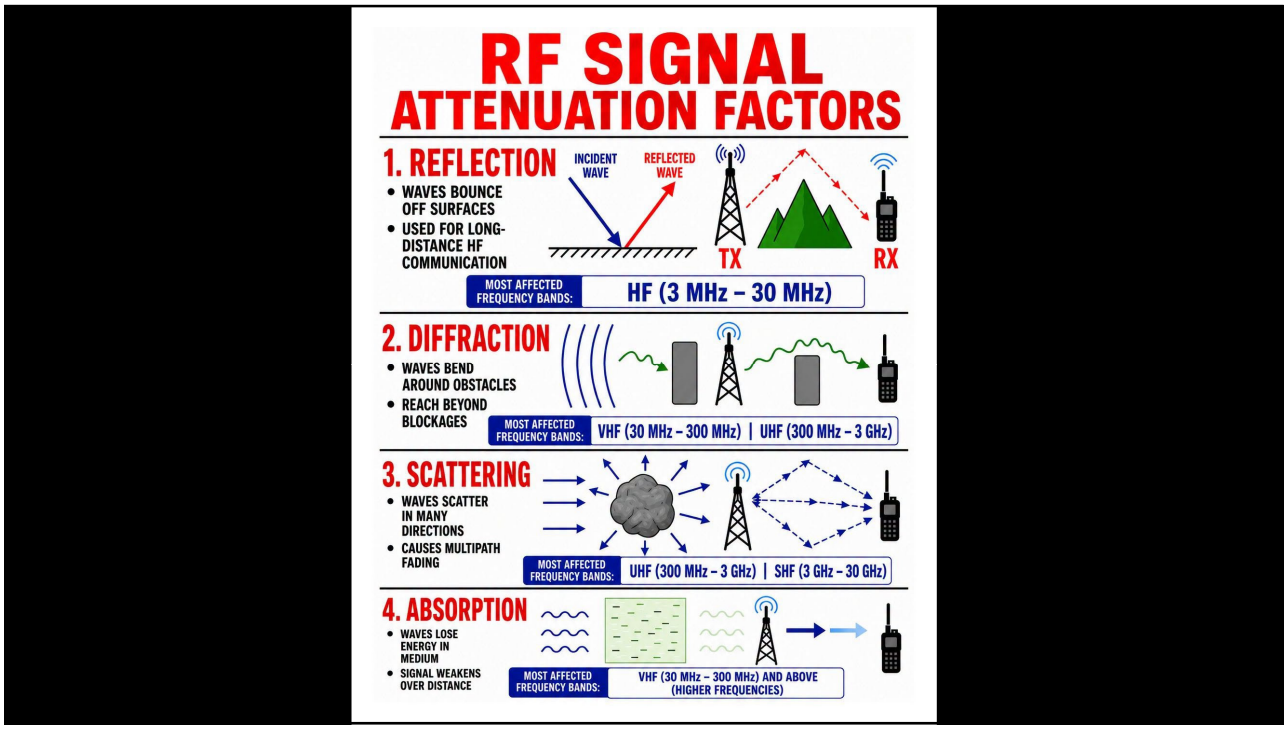

Calculate the VSWR from the given forward and reflected power.
Forward Power (P_F)
100 W
RF Source
Load
Reflected Power (P_R)
4 W
P_F = 100 W
P_R = 4 W

18


RF SIGNAL
ATTENUATION FACTORS
1. REFLECTION
• WAVES BOUNCE OFF SURFACES
• USED FOR LONG-DISTANCE HF COMMUNICATION
INCIDENT WAVE
REFLECTED WAVE
TX
RX
MOST AFFECTED FREQUENCY BANDS: HF (3 MHz – 30 MHz)
2. DIFFRACTION
• WAVES BEND AROUND OBSTACLES
• REACH BEYOND BLOCKAGES
MOST AFFECTED FREQUENCY BANDS: VHF (30 MHz – 300 MHz) | UHF (300 MHz – 3 GHz)
3. SCATTERING
• WAVES SCATTER IN MANY DIRECTIONS
• CAUSES MULTIPATH FADING
MOST AFFECTED FREQUENCY BANDS: UHF (300 MHz – 3 GHz) | SHF (3 GHz – 30 GHz)
4. ABSORPTION
• WAVES LOSE ENERGY IN MEDIUM
• SIGNAL WEAKENS OVER DISTANCE
MOST AFFECTED FREQUENCY BANDS: VHF (30 MHz – 300 MHz) AND ABOVE (HIGHER FREQUENCIES)

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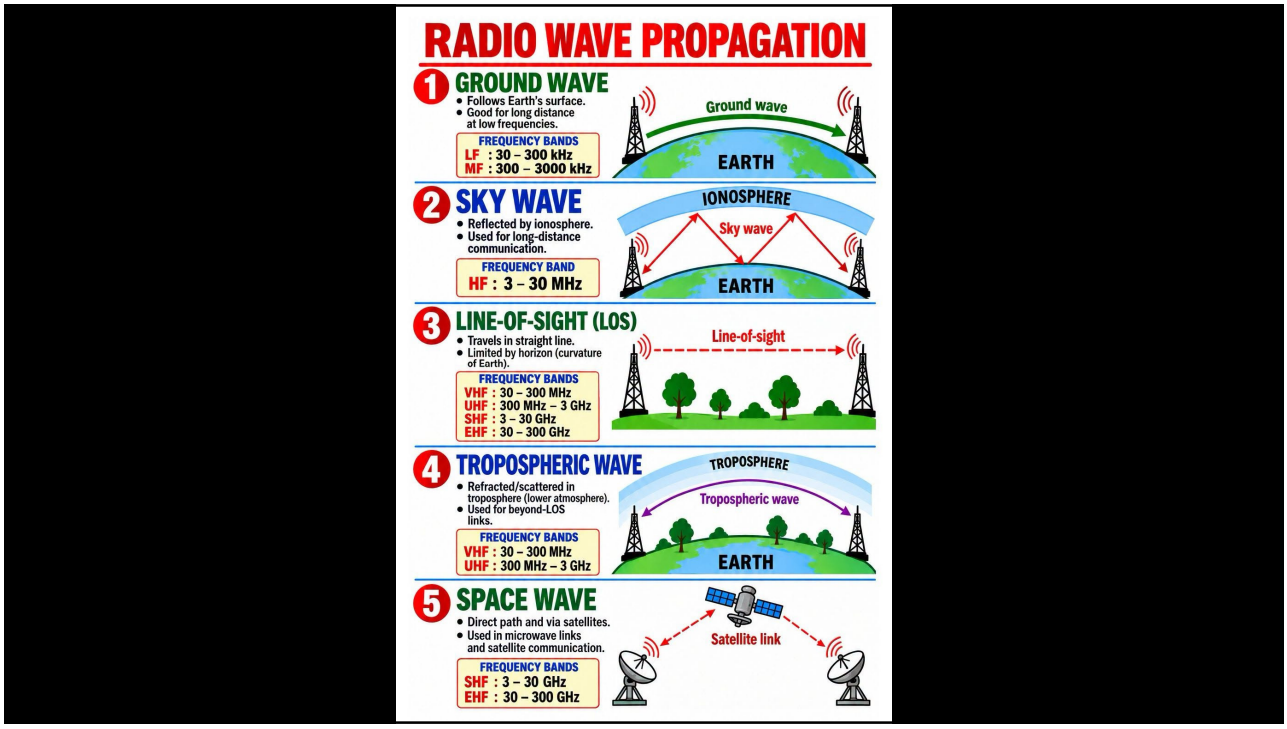
RADIO WAVE PROPAGATION
1 GROUND WAVE
• Follows Earth's surface.
• Good for long distance at low frequencies.
FREQUENCY BANDS
LF : 30 – 300 kHz
MF : 300 – 3000 kHz
Ground wave
EARTH
2 SKY WAVE
• Reflected by ionosphere.
• Used for long-distance communication.
FREQUENCY BAND
HF : 3 – 30 MHz
IONOSPHERE
Sky wave
EARTH
3 LINE-OF-SIGHT (LOS)
• Travels in straight line.
• Limited by horizon (curvature of Earth).
FREQUENCY BANDS
VHF : 30 – 300 MHz
UHF : 300 MHz – 3 GHz
SHF : 3 – 30 GHz
EHF : 30 – 300 GHz
Line-of-sight
4 TROPOSPHERIC WAVE
• Refracted/scattered in troposphere (lower atmosphere).
• Used for beyond-LOS links.
FREQUENCY BANDS
VHF : 30 – 300 MHz
UHF : 300 MHz – 3 GHz
TROPOSPHERE
Tropospheric wave
EARTH
5 SPACE WAVE
• Direct path and via satellites.
• Used in microwave links and satellite communication.
FREQUENCY BANDS
SHF : 3 – 30 GHz
EHF : 30 – 300 GHz
Satellite link

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RF Propagation – Listen to your reciever

- Band Fading
- Band Dropout
- Skip Zone
- Underwater sounds
- Hearing One End
- Others “Showing Up” on your Freq

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RF Propagation – Power

- Power Doesn’t Equal Distance
- Power Adds Signal
- 10 W ➔ 100 W is 10 dB
  - 10 dB is 1.6 S units on a receiver
- 100 W ➔ 1,500 W is 15 dB
  - 15 dB is 2.5 S units on a receiver

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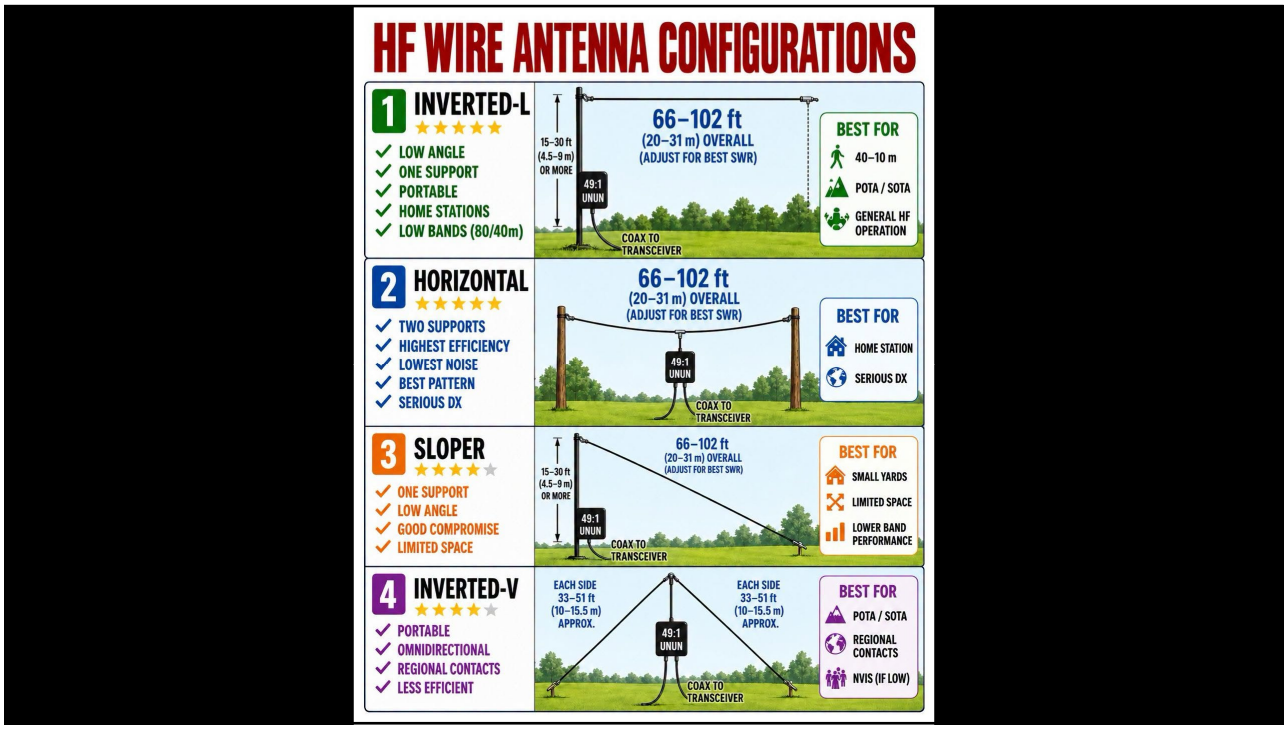
HF WIRE ANTENNA CONFIGURATIONS
1 INVERTED-L
LOW ANGLE
ONE SUPPORT
PORTABLE
HOME STATIONS
LOW BANDS (80/40m)
15–30 ft (4.5–9 m) OR MORE
66–102 ft
(20–31 m) OVERALL
(ADJUST FOR BEST SWR)
49:1 UNUN
COAX TO TRANSCEIVER
BEST FOR
40–10 m
POTA / SOTA
GENERAL HF OPERATION
2 HORIZONTAL
TWO SUPPORTS
HIGHEST EFFICIENCY
LOWEST NOISE
BEST PATTERN
SERIOUS DX
66–102 ft
(20–31 m) OVERALL
(ADJUST FOR BEST SWR)
49:1 UNUN
COAX TO TRANSCEIVER
BEST FOR
HOME STATION
SERIOUS DX
3 SLOPER
ONE SUPPORT
LOW ANGLE
GOOD COMPROMISE
LIMITED SPACE
15–30 ft (4.5–9 m) OR MORE
66–102 ft
(20–31 m) OVERALL
(ADJUST FOR BEST SWR)
49:1 UNUN
COAX TO TRANSCEIVER
BEST FOR
SMALL YARDS
LIMITED SPACE
LOWER BAND PERFORMANCE
4 INVERTED-V
PORTABLE
OMNIDIRECTIONAL
REGIONAL CONTACTS
LESS EFFICIENT
EACH SIDE 33–51 ft (10–15.5 m) APPROX.
EACH SIDE 33–51 ft (10–15.5 m) APPROX.
49:1 UNUN
COAX TO TRANSCEIVER
BEST FOR
POTA / SOTA
REGIONAL CONTACTS
NVIS (IF LOW)

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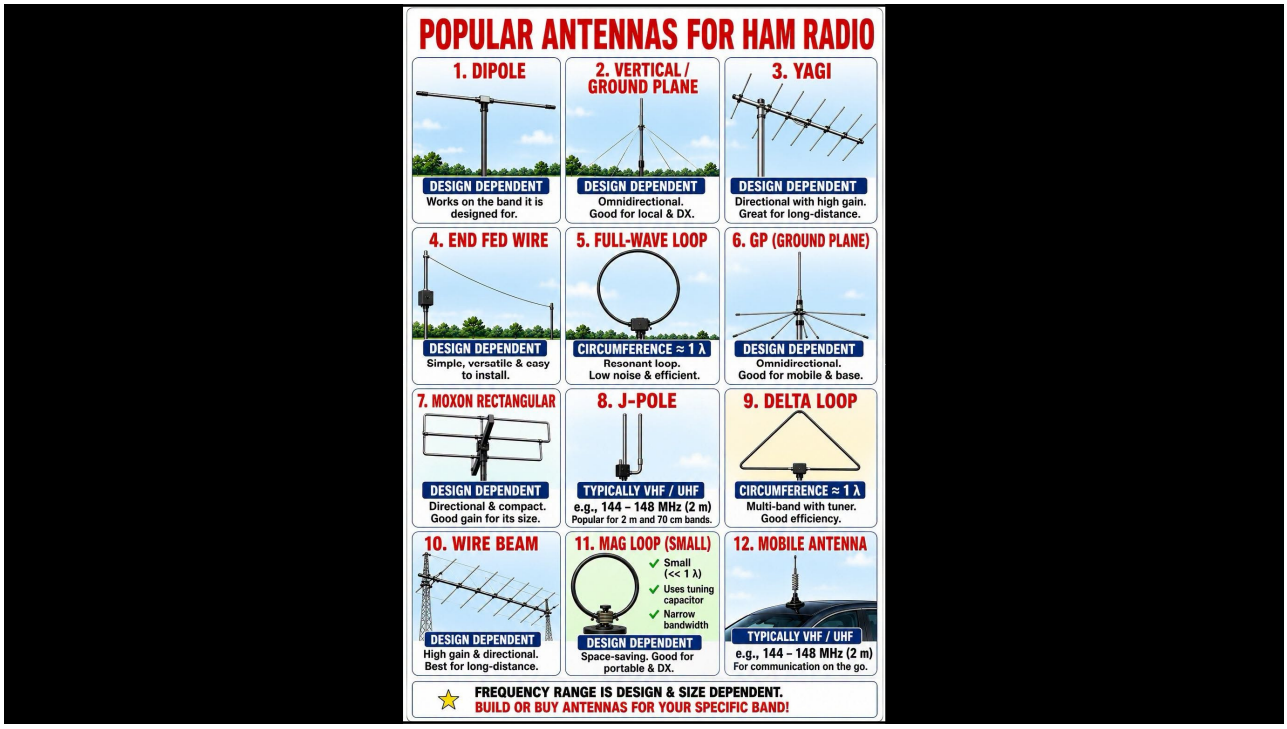
POPULAR ANTENNAS FOR HAM RADIO
1. DIPOLE
DESIGN DEPENDENT
Works on the band it is designed for.
2. VERTICAL / GROUND PLANE
DESIGN DEPENDENT
Omnidirectional.
Good for local & DX.
3. YAGI
DESIGN DEPENDENT
Directional with high gain.
Great for long-distance.
4. END FED WIRE
DESIGN DEPENDENT
Simple, versatile & easy to install.
5. FULL-WAVE LOOP
CIRCUMFERENCE ≈ 1 λ
Resonant loop.
Low noise & efficient.
6. GP (GROUND PLANE)
DESIGN DEPENDENT
Omnidirectional.
Good for mobile & base.
7. MOXON RECTANGULAR
DESIGN DEPENDENT
Directional & compact.
Good gain for its size.
8. J-POLE
TYPICALLY VHF / UHF
e.g., 144 – 148 MHz (2 m)
Popular for 2 m and 70 cm bands.
9. DELTA LOOP
CIRCUMFERENCE ≈ 1 λ
Multi-band with tuner.
Good efficiency.
10. WIRE BEAM
DESIGN DEPENDENT
High gain & directional.
Best for long-distance.
11. MAG LOOP (SMALL)
Small (<< 1 λ)
Uses tuning capacitor
Narrow bandwidth
DESIGN DEPENDENT
Space-saving. Good for portable & DX.
12. MOBILE ANTENNA
TYPICALLY VHF / UHF
e.g., 144 – 148 MHz (2 m)
For communication on the go.
FREQUENCY RANGE IS DESIGN & SIZE DEPENDENT.
BUILD OR BUY ANTENNAS FOR YOUR SPECIFIC BAND!

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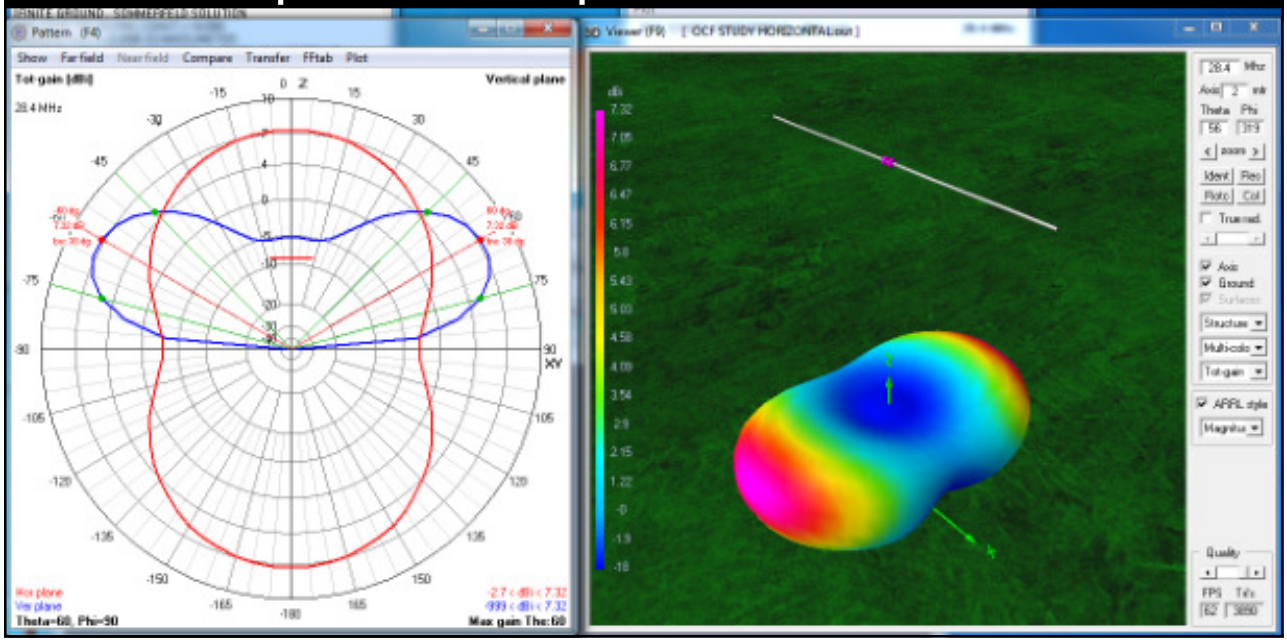
https://www.qsl.net/kk4obi/



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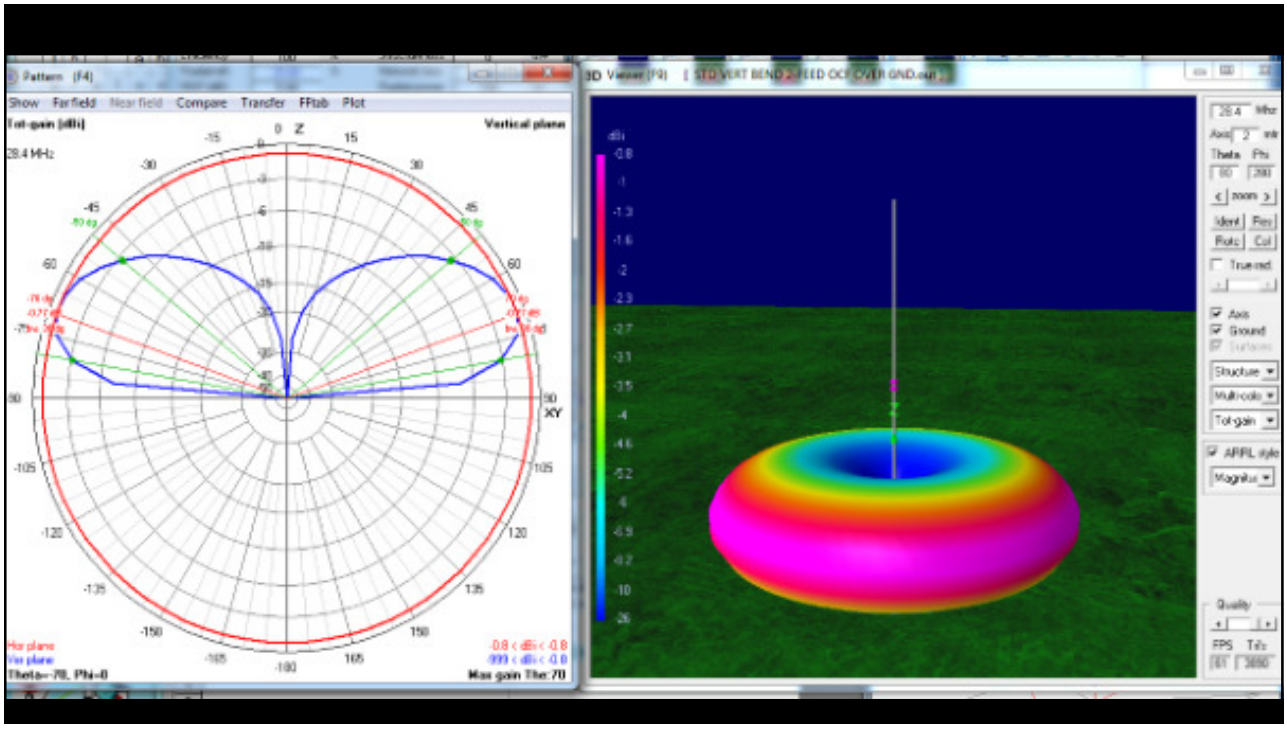

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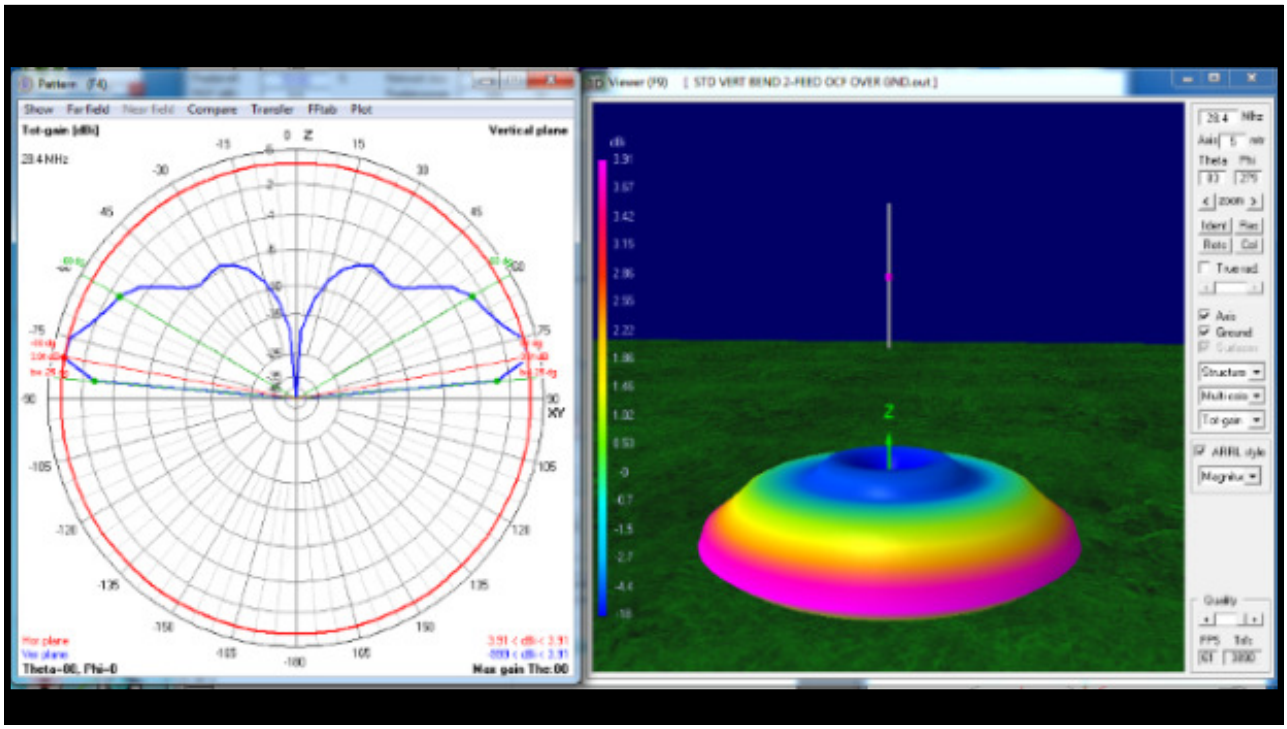

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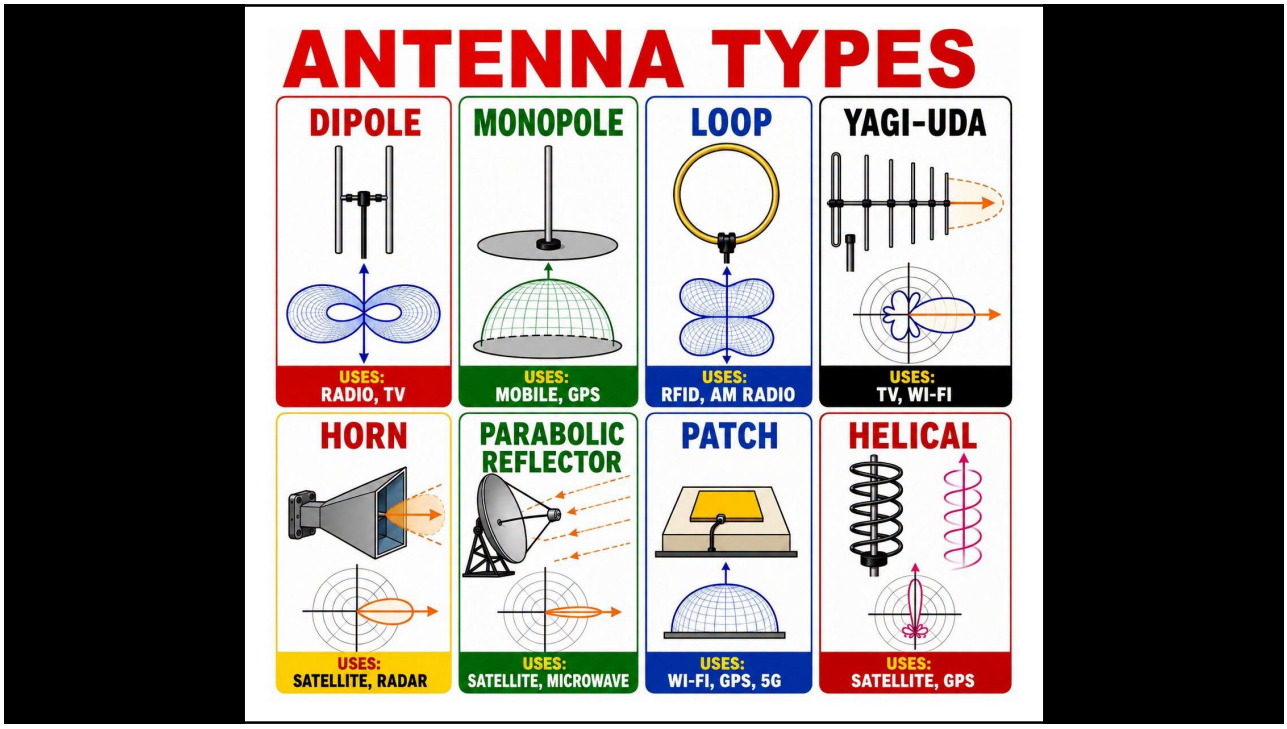
ANTENNA TYPES
DIPOLE
USES: RADIO, TV
MONOPOLE
USES: MOBILE, GPS
LOOP
USES: RFID, AM RADIO
YAGI-UDA
USES: TV, WI-FI
HORN
USES: SATELLITE, RADAR
PARABOLIC REFLECTOR
USES: SATELLITE, MICROWAVE
PATCH
USES: WI-FI, GPS, 5G
HELICAL
USES: SATELLITE, GPS

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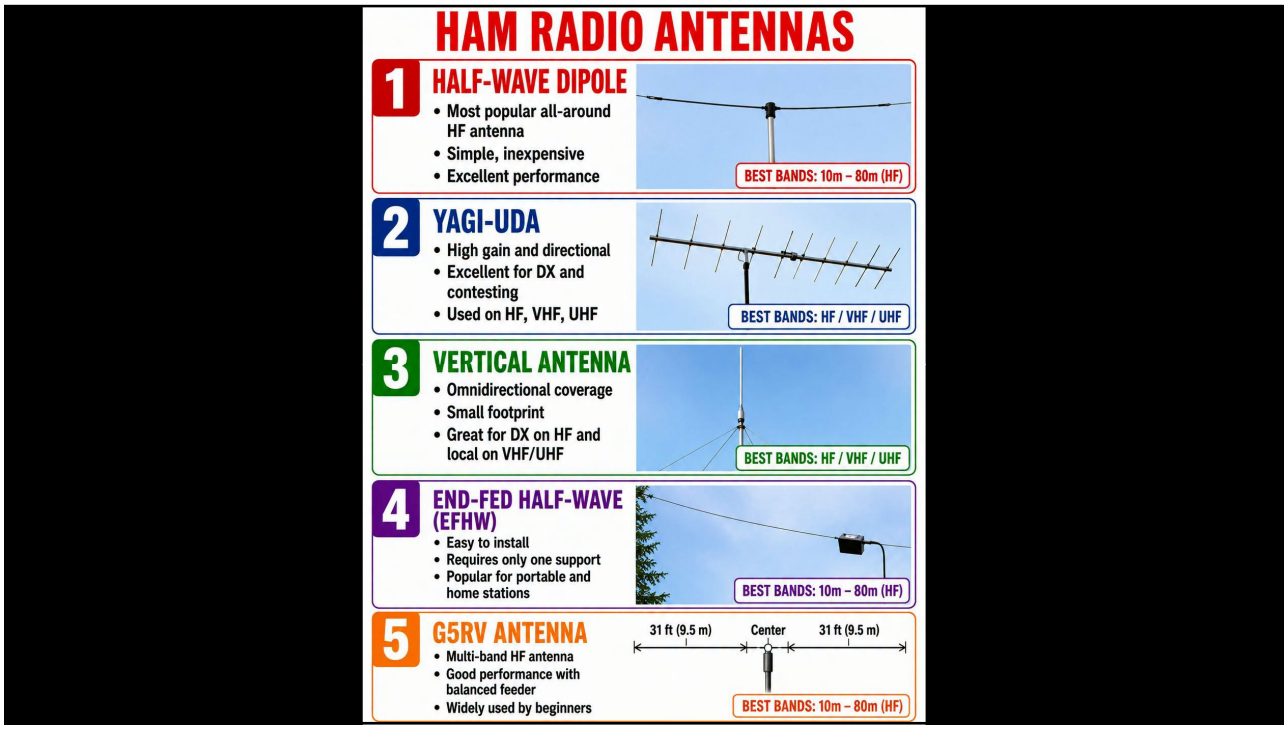
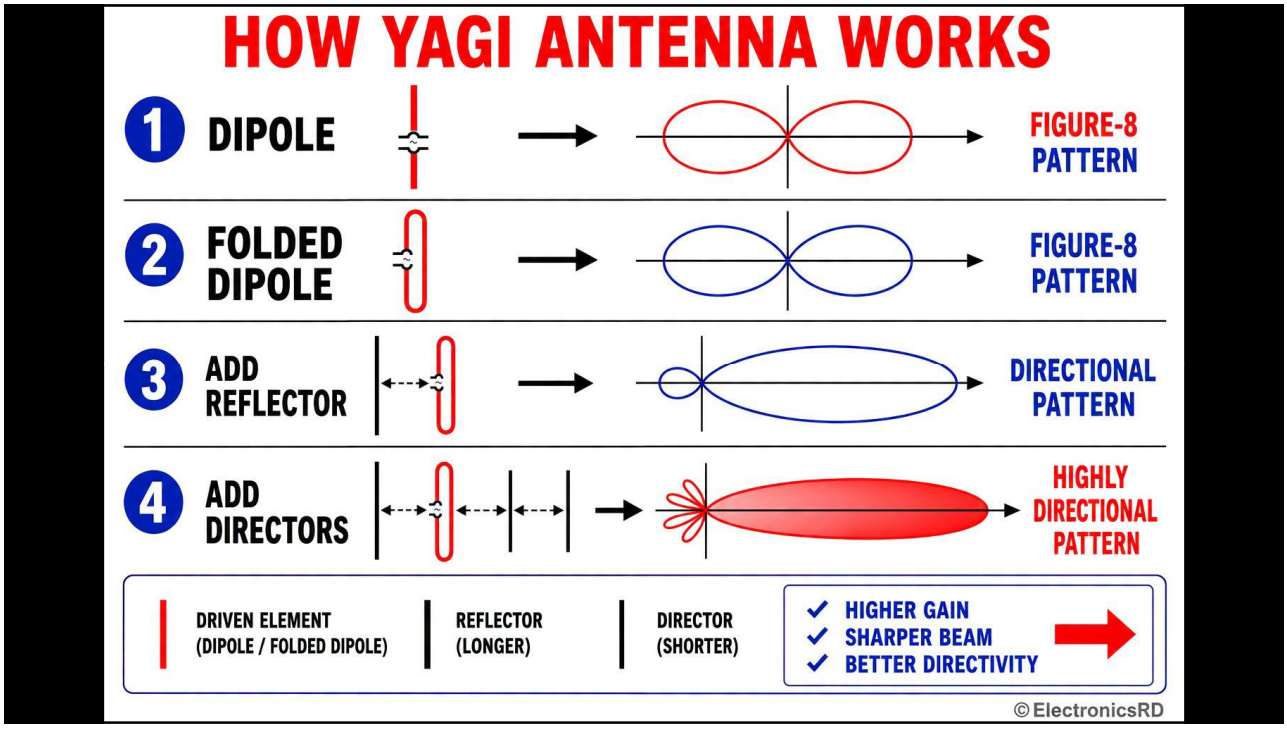
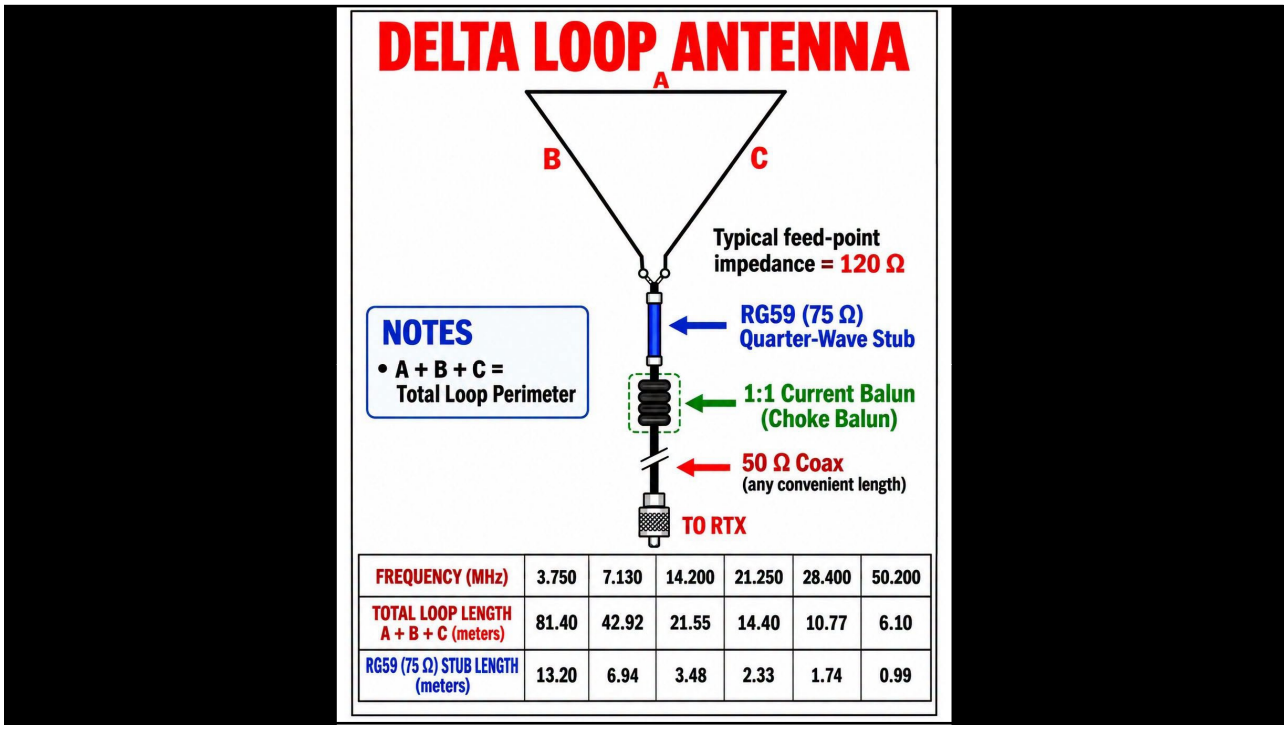

HAM RADIO ANTENNAS
1
HALF-WAVE DIPOLE
• Most popular all-around HF antenna
• Simple, inexpensive
• Excellent performance
BEST BANDS: 10m – 80m (HF)
2
YAGI-UDA
• High gain and directional
• Excellent for DX and contesting
• Used on HF, VHF, UHF
BEST BANDS: HF / VHF / UHF
3
VERTICAL ANTENNA
• Omnidirectional coverage
• Small footprint
• Great for DX on HF and local on VHF/UHF
BEST BANDS: HF / VHF / UHF
4
END-FED HALF-WAVE (EFHW)
• Easy to install
• Requires only one support
• Popular for portable and home stations
BEST BANDS: 10m – 80m (HF)
5
G5RV ANTENNA
• Multi-band HF antenna
• Good performance with balanced feeder
• Widely used by beginners
31 ft (9.5 m)
Center
31 ft (9.5 m)
BEST BANDS: 10m – 80m (HF)

29

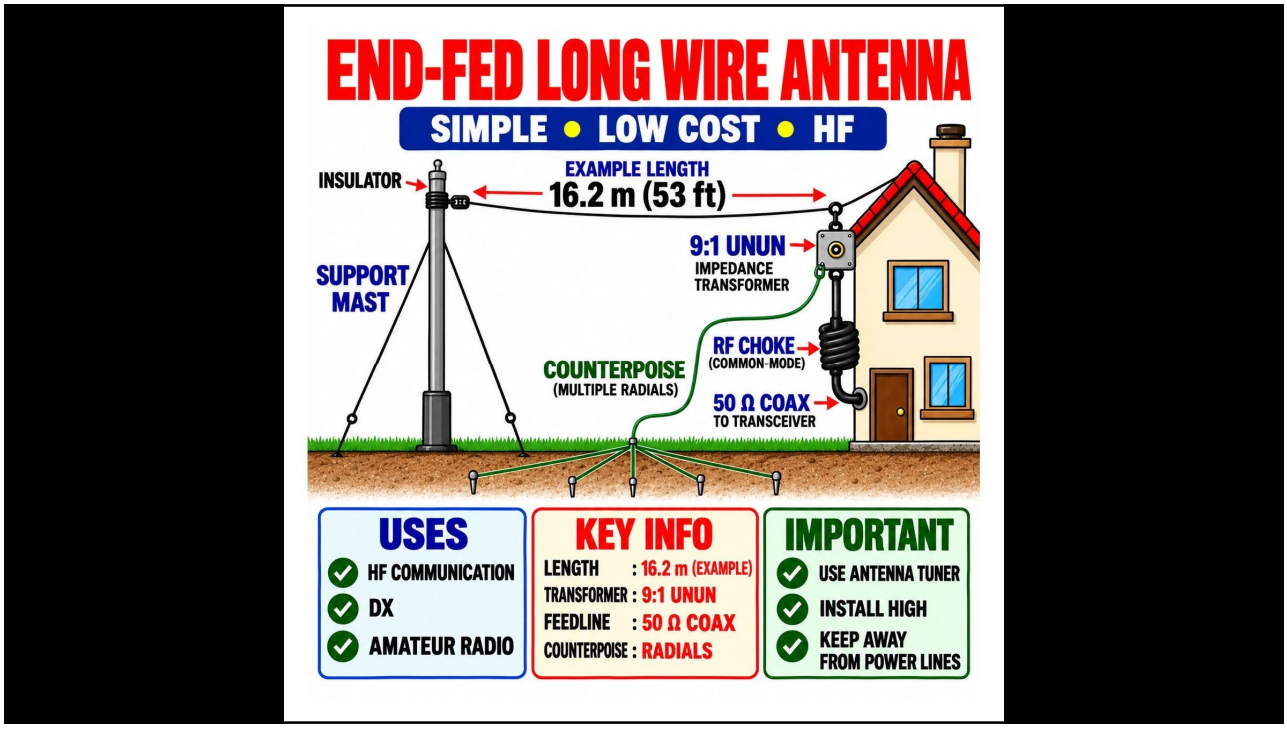

HOW YAGI ANTENNA WORKS
1
DIPOLE
FIGURE-8 PATTERN
2
FOLDED DIPOLE
FIGURE-8 PATTERN
3
ADD REFLECTOR
DIRECTIONAL PATTERN
4
ADD DIRECTORS
HIGHLY DIRECTIONAL PATTERN
DRIVEN ELEMENT (DIPOLE / FOLDED DIPOLE)
REFLECTOR (LONGER)
DIRECTOR (SHORTER)
✓ HIGHER GAIN
✓ SHARPER BEAM
✓ BETTER DIRECTIVITY
©ElectronicsRD

30

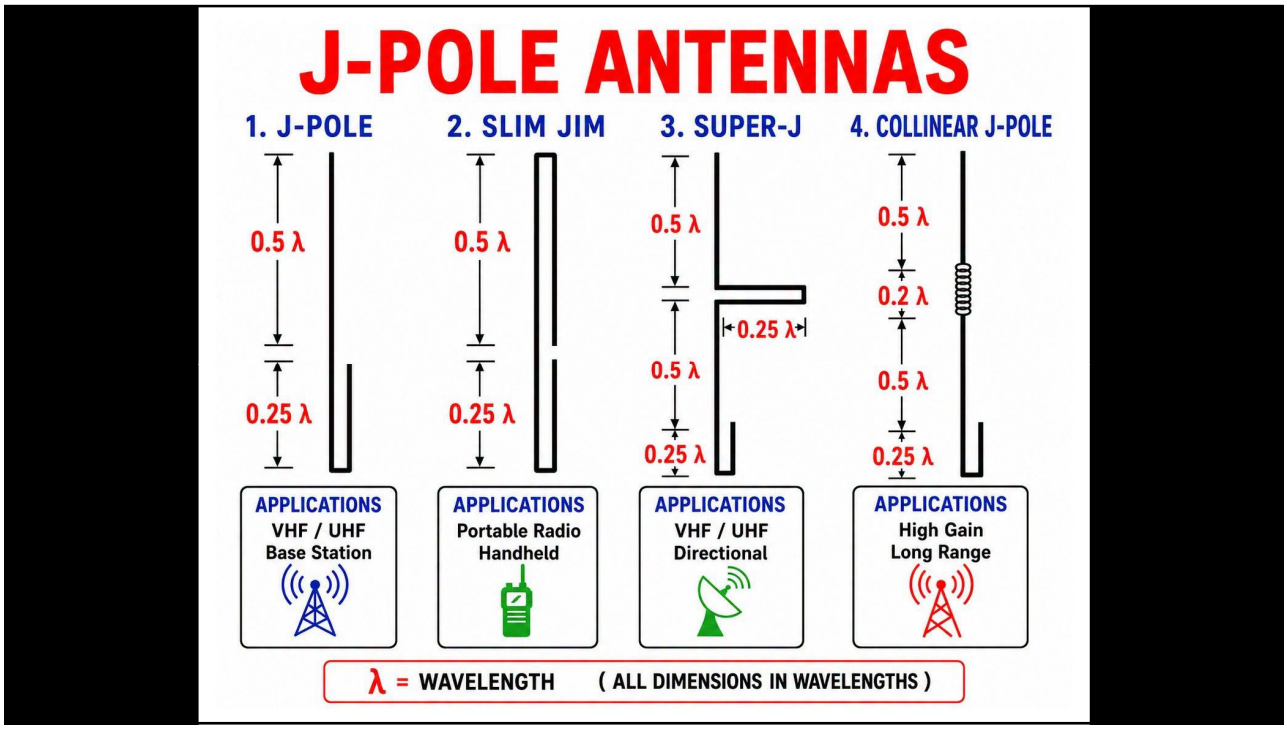


FREQUENCY (MHz)	3.750	7.130	14.200	21.250	28.400	50.200
TOTAL LOOP LENGTH A + B + C (meters)	81.40	42.92	21.55	14.40	10.77	6.10
RG59 (75 Ω) STUB LENGTH (meters)	13.20	6.94	3.48	2.33	1.74	0.99

31



32


J-POLE ANTENNAS
1. J-POLE
0.5 λ
0.25 λ
APPLICATIONS
VHF / UHF
Base Station
2. SLIM JIM
0.5 λ
0.25 λ
APPLICATIONS
Portable Radio
Handheld
3. SUPER-J
0.5 λ
0.25 λ
0.5 λ
0.25 λ
APPLICATIONS
VHF / UHF
Directional
4. COLLINEAR J-POLE
0.5 λ
0.2 λ
0.5 λ
0.25 λ
APPLICATIONS
High Gain
Long Range
λ = WAVELENGTH (ALL DIMENSIONS IN WAVELENGTHS)

33



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ttps://kk5jy.net/LoG/

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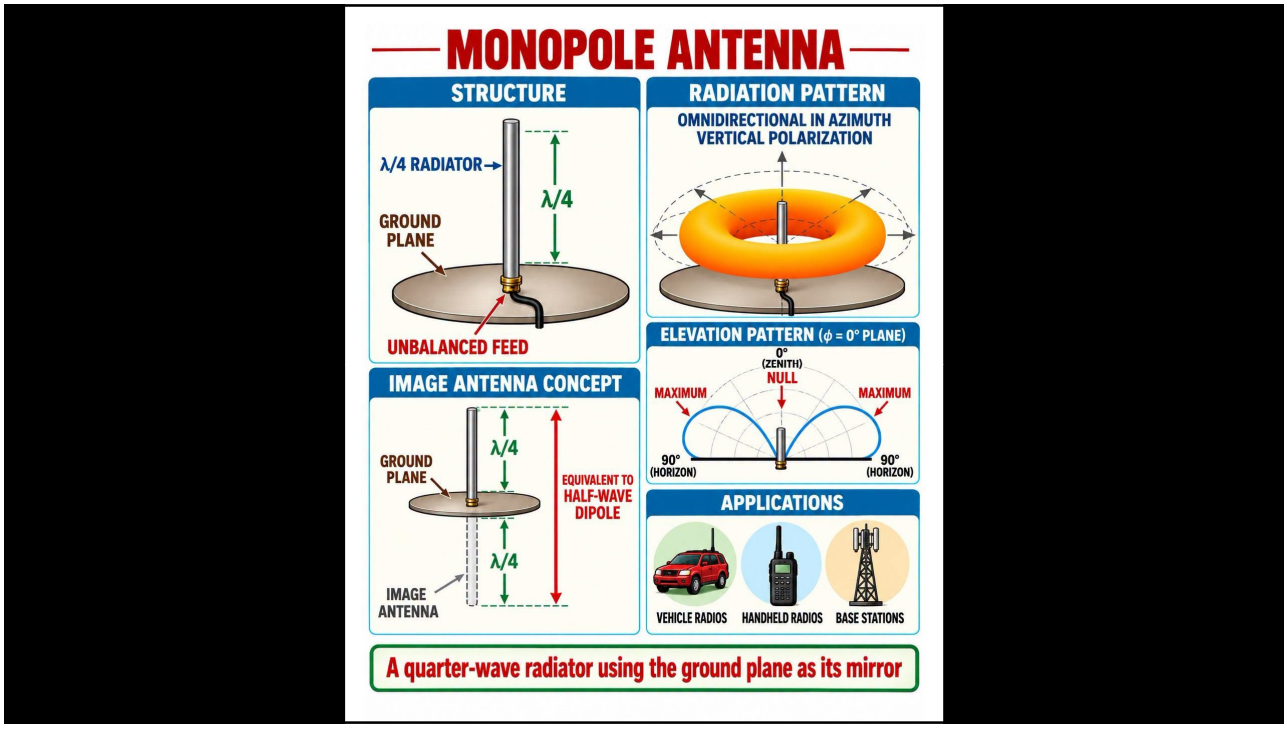
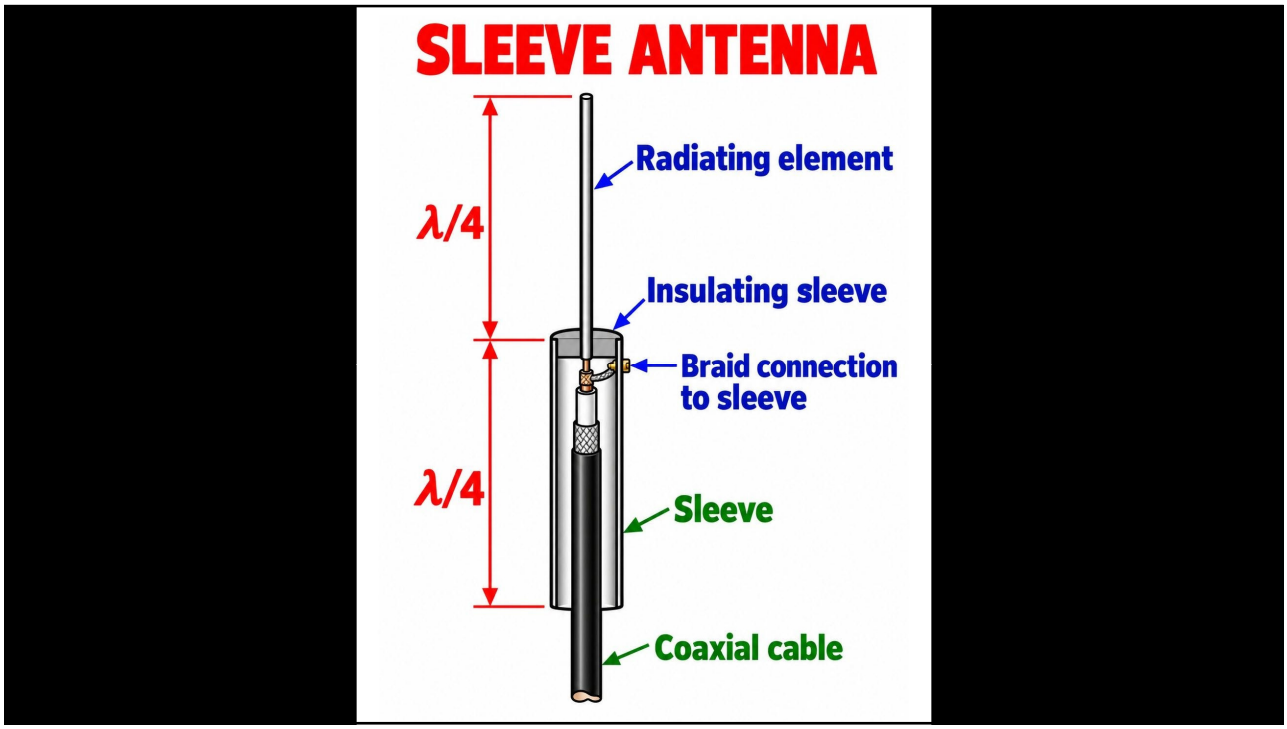
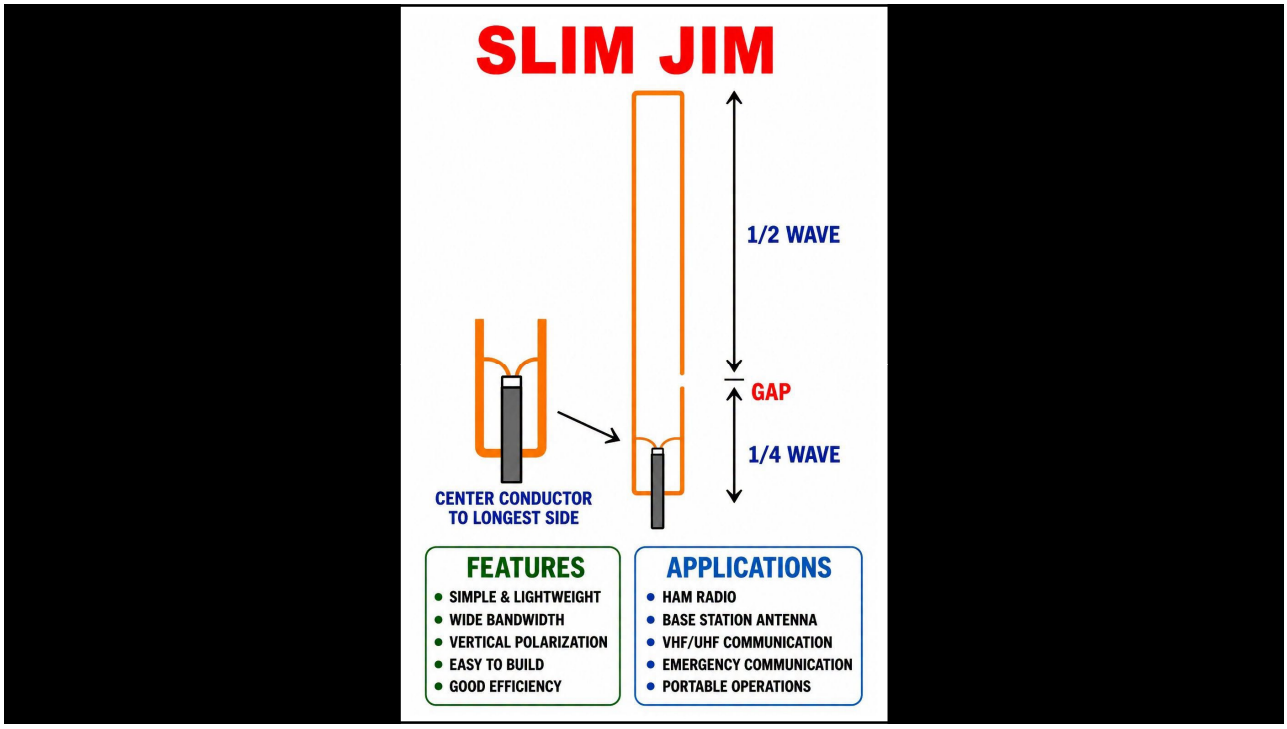

MONOPOLE ANTENNA
STRUCTURE
λ/4 RADIATOR
λ/4
GROUND PLANE
UNBALANCED FEED
RADIATION PATTERN
OMNIDIRECTIONAL IN AZIMUTH
VERTICAL POLARIZATION
ELEVATION PATTERN (ϕ = 0° PLANE)
0° (ZENITH)
NULL
MAXIMUM
MAXIMUM
90° (HORIZON)
90° (HORIZON)
IMAGE ANTENNA CONCEPT
GROUND PLANE
λ/4
λ/4
EQUIVALENT TO HALF-WAVE DIPOLE
IMAGE ANTENNA
APPLICATIONS
VEHICLE RADIOS
HANDHELD RADIOS
BASE STATIONS
A quarter-wave radiator using the ground plane as its mirror

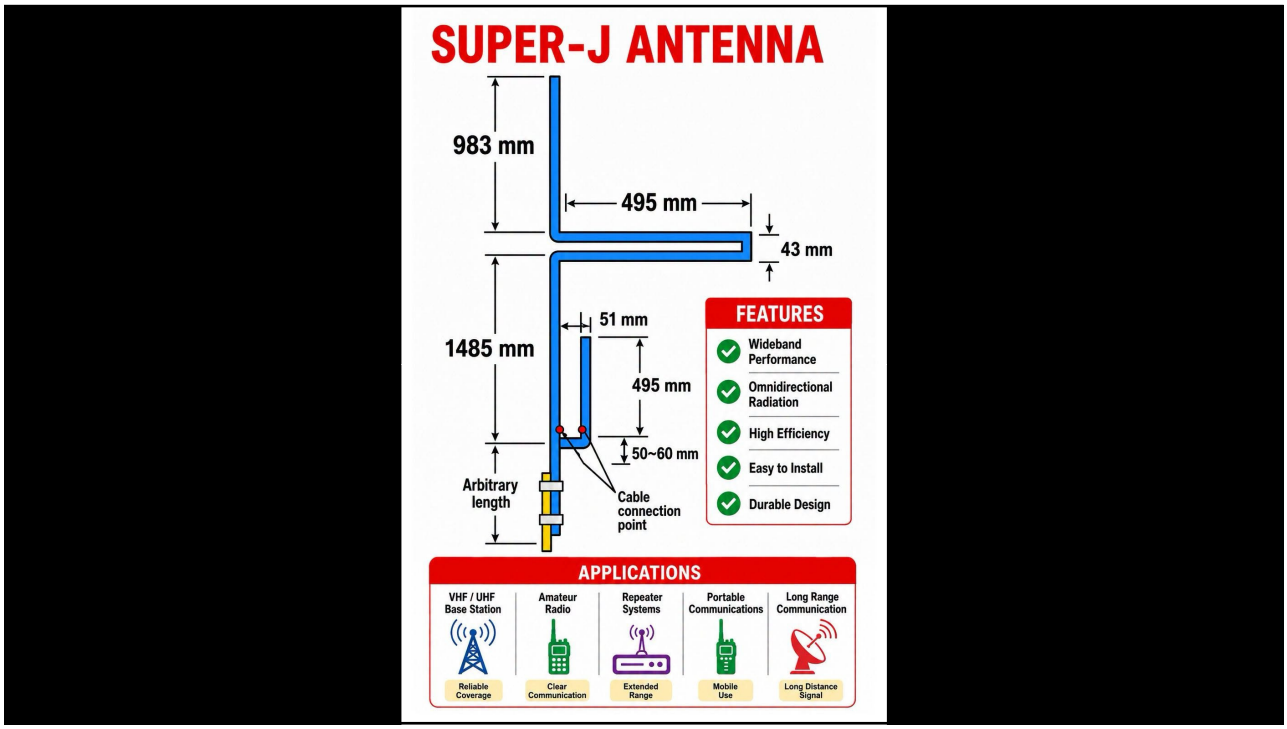
36


SLEEVE ANTENNA
λ/4
λ/4
Radiating element
Insulating sleeve
Braid connection to sleeve
Sleeve
Coaxial cable

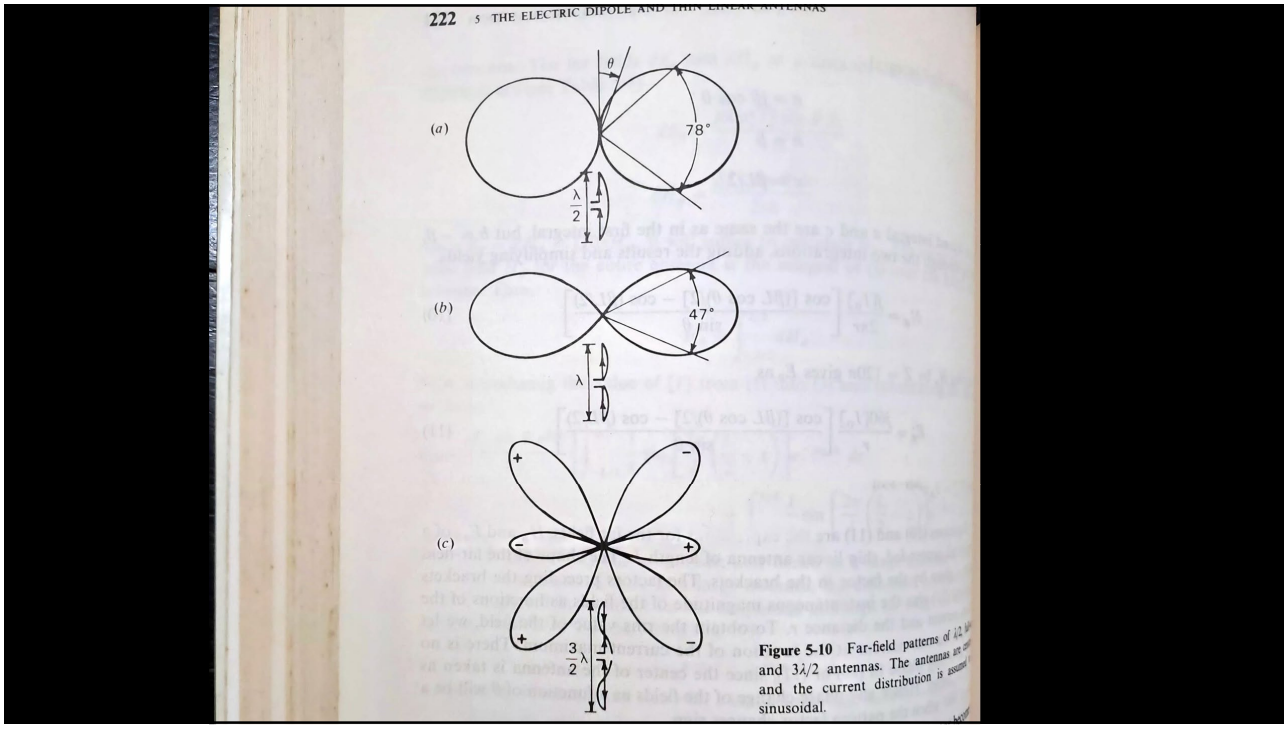
37


SLIM JIM
1/2 WAVE
GAP
1/4 WAVE
CENTER CONDUCTOR TO LONGEST SIDE
FEATURES
SIMPLE & LIGHTWEIGHT
WIDE BANDWIDTH
VERTICAL POLARIZATION
EASY TO BUILD
GOOD EFFICIENCY
APPLICATIONS
HAM RADIO
BASE STATION ANTENNA
VHF/UHF COMMUNICATION
EMERGENCY COMMUNICATION
PORTABLE OPERATIONS

38


SUPER-J ANTENNA
983 mm
495 mm
43 mm
1485 mm
51 mm
495 mm
50~60 mm
Arbitrary length
Cable connection point
FEATURES
Wideband Performance
Omnidirectional Radiation
High Efficiency
Easy to Install
Durable Design
APPLICATIONS
VHF / UHF Base Station
Amateur Radio
Repeater Systems
Portable Communications
Long Range Communication
Reliable Coverage
Clear Communication
Extended Range
Mobile Use
Long Distance Signal

39


222 5 THE ELECTRIC DIPOLE AND
θ
(a)
78°
λ/2
(b)
47°
λ
(c)
3λ/2
Figure 5-10 Far-field patterns of
and 3λ/2 antennas. The antennas
and the current distribution is
sinusoidal.

40