



CANADIAN BASIC AMATEUR RADIO EXAM PREPARATION

SECTION 6 D FEEDLINES & ANTENNA SYSTEMS





**THIS COURSE IS BEING TAUGHT TO THE JULY 15, 2025 UPDATE
OF THE CANADIAN BASIC AMATEUR RADIO EXAM QUESTIONS.**

SECTION 6 QUESTION CATEGORIES:

B-006-001: TRANSMISSION LINE FUNDAMENTALS

B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

B-006-003: PRACTICAL CONSIDERATIONS FOR TRANSMISSION LINES

B-006-004: TRANSMISSION LINE LOSSES AND PERFORMANCE

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

B-006-006: IMPEDANCE MATCHING AND ANTENNA TUNERS

SECTION 6 QUESTION CATEGORIES:

B-006-007: ANTENNA POLARIZATION AND BASIC PATTERNS

B-006-008: ANTENNA RESONANCE AND LENGTH ADJUSTMENTS

B-006-009: ANTENNA GAIN, DIRECTIVITY AND PARASITIC ELEMENTS

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B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

B-006-012: DIPOLE AND RELATED WIRE ANTENNAS

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)



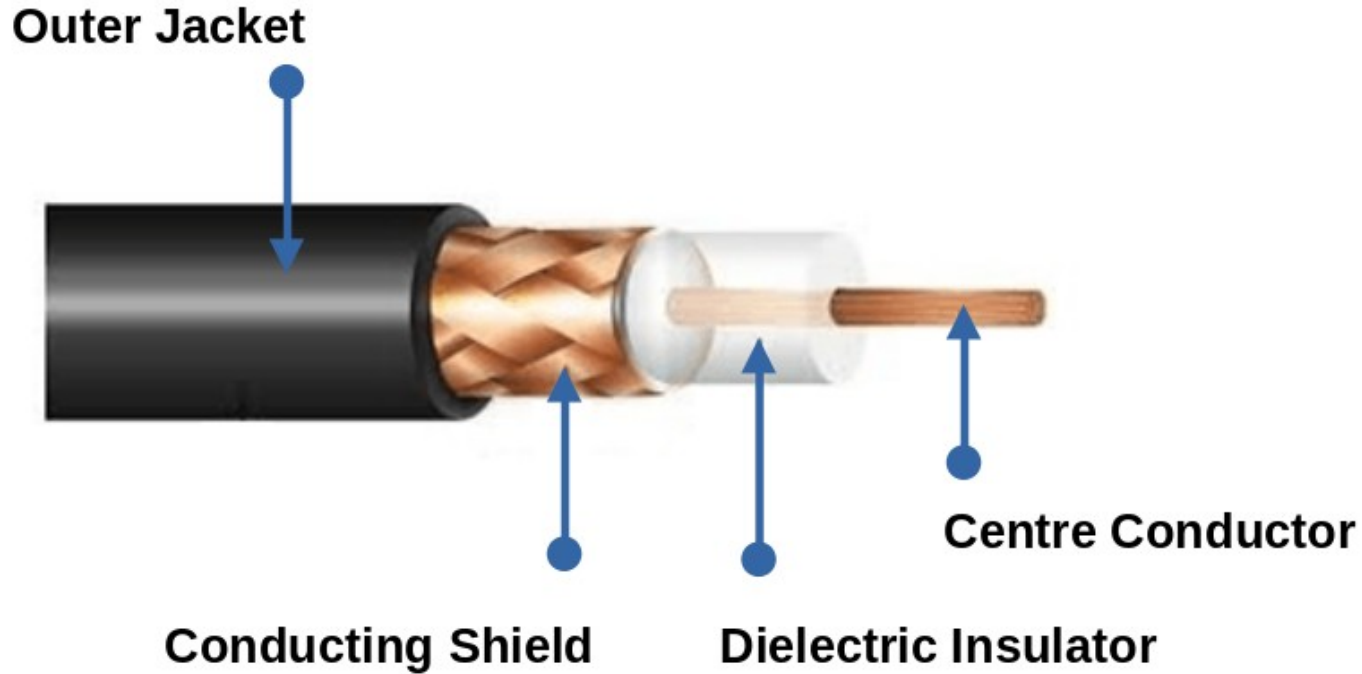
QUESTION SECTION B-006-001:

TRANSMISSION LINE FUNDAMENTALS

1. WHAT IS A TRANSMISSION LINE AND ITS BASIC ROLE?

- A **TRANSMISSION LINE** CONNECTS YOUR TRANSCEIVER (RADIO) TO THE ANTENNA.
- IT CARRIES RADIO FREQUENCY (RF) ENERGY FROM THE TRANSMITTER TO THE ANTENNA (AND RECEIVED SIGNALS BACK).
- COMMON TYPES INCLUDE **COAXIAL CABLE (COAX)** AND OPEN-WIRE / LADDER LINE.

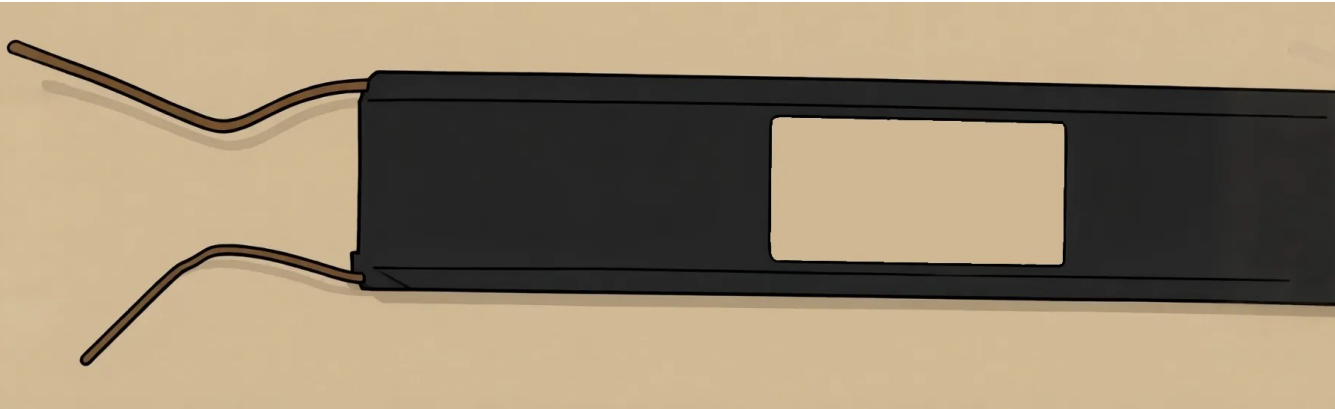
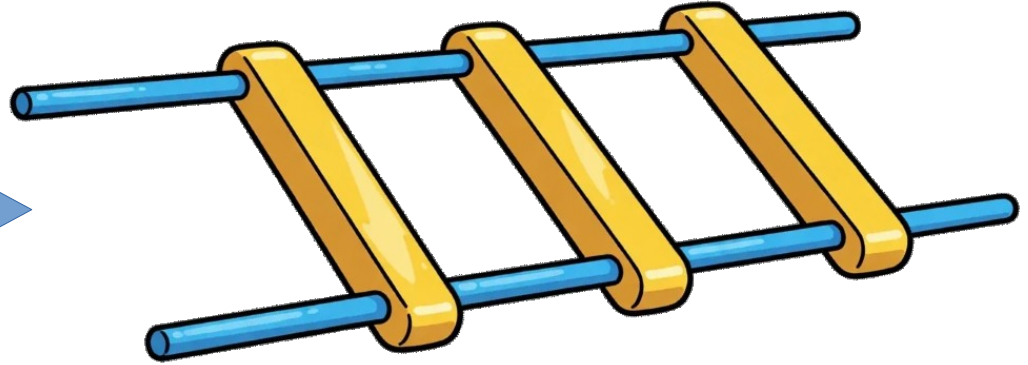
B-006-001: TRANSMISSION LINE FUNDAMENTALS



50 Ω Coaxial Cable

B-006-001: TRANSMISSION LINE FUNDAMENTALS

Open Wire Line
500–600 Ω



Window Line
450 Ω



CHARACTERISTIC IMPEDANCE – THE KEY PROPERTY



- **CHARACTERISTIC IMPEDANCE (Z_0)** IS LIKE THE "NATURAL RESISTANCE" THE LINE PRESENTS TO RF ENERGY. IT'S MEASURED IN OHMS.
- **EXAMPLES:** 50 Ω , 52 Ω , 75 Ω , 300 Ω , 450 Ω , 600 Ω .
- IT IS **NOT CHANGED BY LENGTH** — A 20 M PIECE OF 52 Ω LINE CUT TO 10M IS **STILL 52 OHMS**.
- **MATCHING IMPEDANCE BETWEEN RADIO, LINE, AND ANTENNA/LOAD MINIMIZES LOSSES AND REFLECTIONS (IMPORTANT FOR EFFICIENT POWER TRANSFER).**

CHARACTERISTIC IMPEDANCE – WHY THIS MATTERS

- **THE CONNECTOR ON THE BACK OF THE TRANSCEIVER IS EXPECTING 50Ω**
- RADIO STANDARDIZED ON 50Ω BECAUSE IT PROVIDES **THE BEST COMPROMISE** BETWEEN MAXIMUM POWER HANDLING (OPTIMAL AT 30Ω) AND LOWEST SIGNAL ATTENUATION (OPTIMAL AT 77Ω) FOR COAXIAL CABLES.

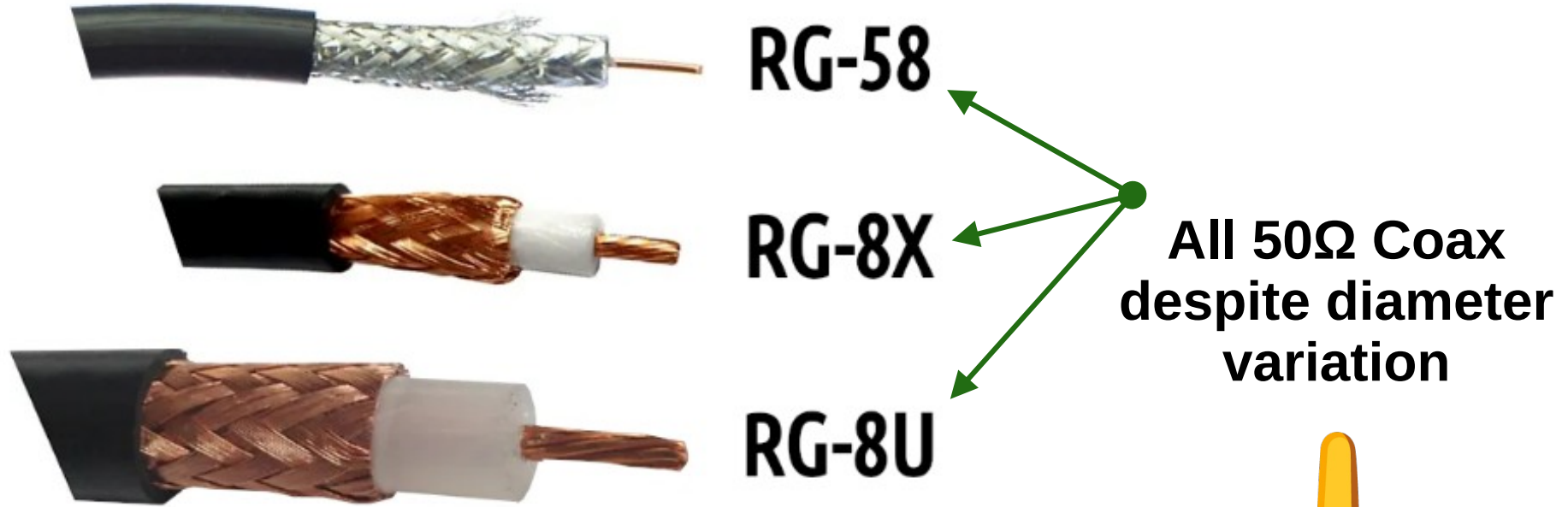


REGARDLESS OF
CONNECTION TYPE, IT'S
ALWAYS 50Ω AT THE RIG

WHAT DETERMINES CHARACTERISTIC IMPEDANCE?

- DEPENDS ON THE **PHYSICAL CONSTRUCTION** OF THE LINE — **NOT** ON LENGTH OR THE MATERIALS ALONE IN A SIMPLE WAY.
- FOR **COAXIAL CABLE (COAX)**:
 - DETERMINED BY THE RATIO OF THE DIAMETER OF THE OUTER SHIELD (CONDUCTOR) TO THE DIAMETER OF THE INNER CONDUCTOR.
 - → DIFFERENT DIAMETERS CAN YIELD THE SAME IMPEDANCE IF THE RATIO STAYS THE SAME (EXPLAINS WHY RG-58, RG-8, ETC., ARE OFTEN $\sim 50\Omega$ DESPITE SIZE DIFFERENCES).

B-006-001: TRANSMISSION LINE FUNDAMENTALS

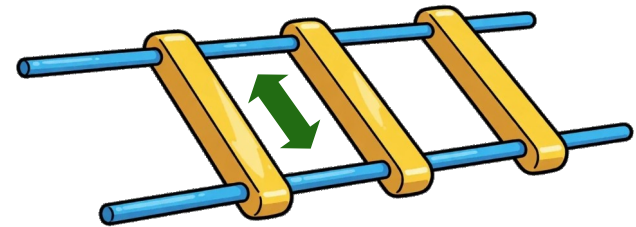


Coaxial Cable Types



WHAT DETERMINES CHARACTERISTIC IMPEDANCE?

- DEPENDS ON THE **PHYSICAL CONSTRUCTION** OF THE LINE — **NOT** ON LENGTH OR THE MATERIALS ALONE IN A SIMPLE WAY.
- FOR **OPEN-WIRE (PARALLEL CONDUCTOR, LADDER LINE, TWIN-LEAD)**:
 - DETERMINED BY: THE **SPACING** (DISTANCE) BETWEEN THE CENTRES OF THE TWO CONDUCTORS
 - THE **DIAMETER OF THE CONDUCTORS** → WIDER SPACING OR THINNER WIRES GENERALLY INCREASES IMPEDANCE.



PRACTICAL POINTS FOR HAMS

- **COAXIAL CABLE** IS COMMONLY USED AND **CAN BE BURIED DIRECTLY IN THE GROUND** FOR SOME DISTANCE WITHOUT MAJOR PROBLEMS (IT'S SHIELDED AND PROTECTED).
- FOR **MAXIMUM POWER TRANSFER** WITH NO REFLECTIONS (IDEAL CASE): IF THE TRANSMITTER SEES A **50Ω LINE**, THE LOAD (ANTENNA OR DUMMY LOAD) SHOULD ALSO BE **50Ω (PURELY RESISTIVE)**. THE LOAD THEN ABSORBS ALL THE RF ENERGY DELIVERED.

OTHER IMPORTANT INFLUENCES:

- **VELOCITY FACTOR** — HOW FAST RF TRAVELS IN THE CABLE COMPARED TO FREE SPACE (ALWAYS <1).
- THE MAJOR FACTOR IS THE **DIELECTRIC MATERIAL** (THE INSULATING MATERIAL BETWEEN CONDUCTORS). AIR HAS VF ≈ 1 ; POLYETHYLENE ≈ 0.66 ; FOAM ≈ 0.8 – 0.85 , ETC. THIS AFFECTS ELECTRICAL LENGTH AND PHASING.

WHAT HAPPENS WITH MISMATCH?

- IF THE LOAD IMPEDANCE (EX: ANTENNA) DIFFERS SIGNIFICANTLY FROM THE LINE'S CHARACTERISTIC IMPEDANCE (MISMATCH), THE INPUT IMPEDANCE SEEN AT THE RADIO END IS **NOT** SIMPLY THE LOAD VALUE.
- INSTEAD, IT'S A **COMPLEX VALUE** Reflected from the antenna INFLUENCED BY **THE LINE LENGTH** (PLUS FREQUENCY), LEADING TO STANDING WAVES, HIGHER LOSSES, POTENTIAL DAMAGE TO THE TRANSMITTER, ETC. → USE MATCHING OR TUNERS WHEN NEEDED.



QUESTION SECTION B-006-002:

TYPES OF TRANSMISSION LINES

AND BALUNS

B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

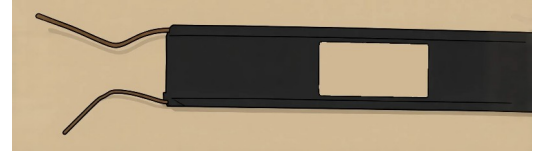
3 MAIN TYPES OF TRANSMISSION LINES USED IN HAM RADIO

- **COAXIAL CABLE**
- A CENTRE CONDUCTOR (WIRE) SURROUNDED BY INSULATING MATERIAL (DIELECTRIC), THEN COVERED BY A METAL SHIELD OR BRAID (OUTER CONDUCTOR), AND AN OUTER JACKET.
- IT'S **UNBALANCED** BECAUSE THE SHIELD IS TYPICALLY AT GROUND POTENTIAL.
- COMMON IN HAM SETUPS (EX: RG-58, RG-8, LMR-400) DUE TO SHIELDING AND EASE OF USE.



B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

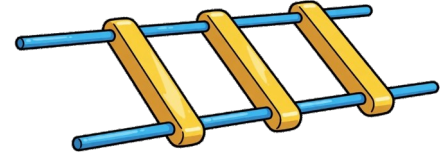
3 MAIN TYPES OF TRANSMISSION LINES USED IN HAM RADIO



- **WINDOW LINE** (ALSO CALLED LADDER LINE OR TWIN-LEAD):
- TWO PARALLEL WIRES EMBEDDED SIDE-BY-SIDE IN INSULATING MATERIAL (OFTEN WITH "WINDOWS" CUT OUT TO REDUCE WEIGHT AND DIELECTRIC LOSS).
- IT'S **BALANCED** — BOTH WIRES CARRY EQUAL BUT OPPOSITE RF CURRENTS, NO GROUND REFERENCE.

B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

3 MAIN TYPES OF TRANSMISSION LINES USED IN HAM RADIO



- **OPEN-WIRE LINE** (TRUE LADDER LINE OR OPEN-WIRE FEEDER):
- TWO CONDUCTORS (WIRES) HELD A CONSTANT DISTANCE APART BY INSULATED RODS OR SPREADERS (OFTEN HOMEMADE WITH PLASTIC OR CERAMIC SPACERS).
- ALSO **BALANCED**, WITH VERY LOW LOSS WHEN KEPT AWAY FROM METAL/GROUND. POPULAR FOR MULTI-BAND HF ANTENNAS.

BALANCED VS. UNBALANCED TRANSMISSION LINES

- A **BALANCED** TRANSMISSION LINE HAS TWO PARALLEL WIRES CARRYING EQUAL CURRENTS IN OPPOSITE DIRECTIONS (NO NET CURRENT TO GROUND).
- AN **UNBALANCED** LINE HAS ONE CONDUCTOR CONNECTED TO GROUND (THE SHIELD IN COAX).

WHAT IS A BALUN AND WHY DO WE NEED IT?

- **BALUN** = JUNCTION DEVICE (TRANSFORMER) BETWEEN **BALANCED** AND **UNBALANCED** SYSTEMS.
- **PURPOSE:** CONNECT BALANCED AND UNBALANCED SYSTEMS AND PREVENTING **COMMON-MODE CURRENTS** ON THE OUTSIDE OF COAX SHIELD, WHICH CAN CAUSE RFI, PATTERN DISTORTION, OR SHOCK HAZARDS.

B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

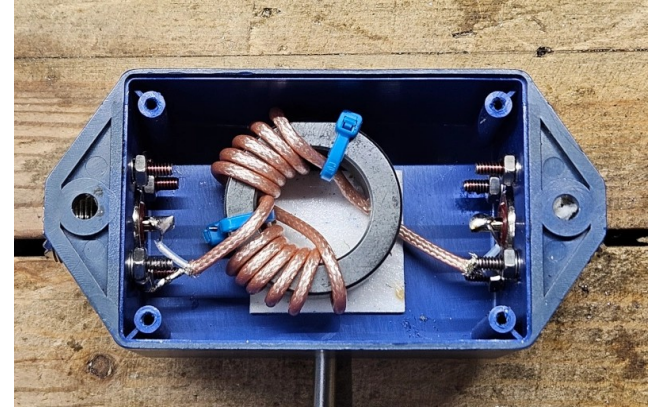
COMMON BALUN USES IN HAM RADIO:

- FEED A BALANCED ANTENNA (EX: DIPOLE, DOUBLET) WITH UNBALANCED COAX (50 Ω).
- INSTALL THE BALUN BETWEEN THE COAXIAL CABLE AND THE ANTENNA (OFTEN AT THE FEEDPOINT).
- A **1:1 CURRENT BALUN** (ALSO CALLED A **1:1 CHOKE**) IS TYPICAL HERE TO CHOKe COMMON-MODE CURRENTS.

B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

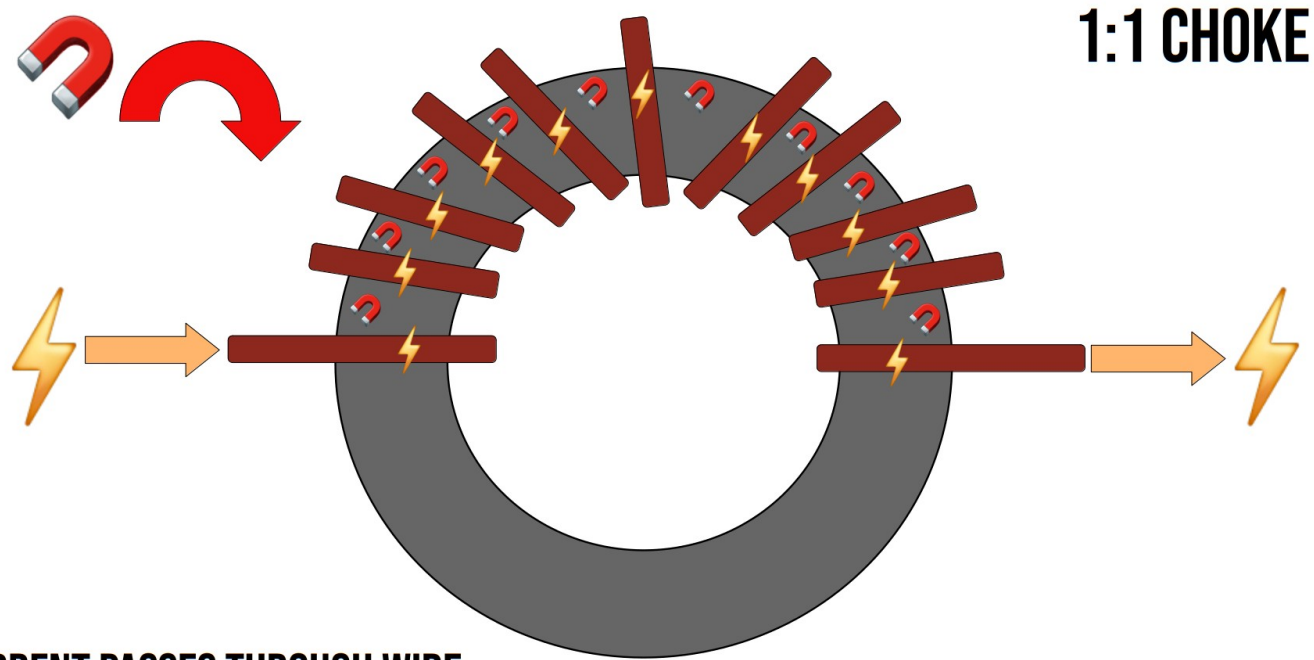
COMMON BALUN USES IN HAM RADIO:

- **EXAMPLES OF 1:1 CHOKES**
- **USES A FERRITE CORE**
- **TURNS OF COAX GO AROUND AND THROUGH THE CORE**



B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

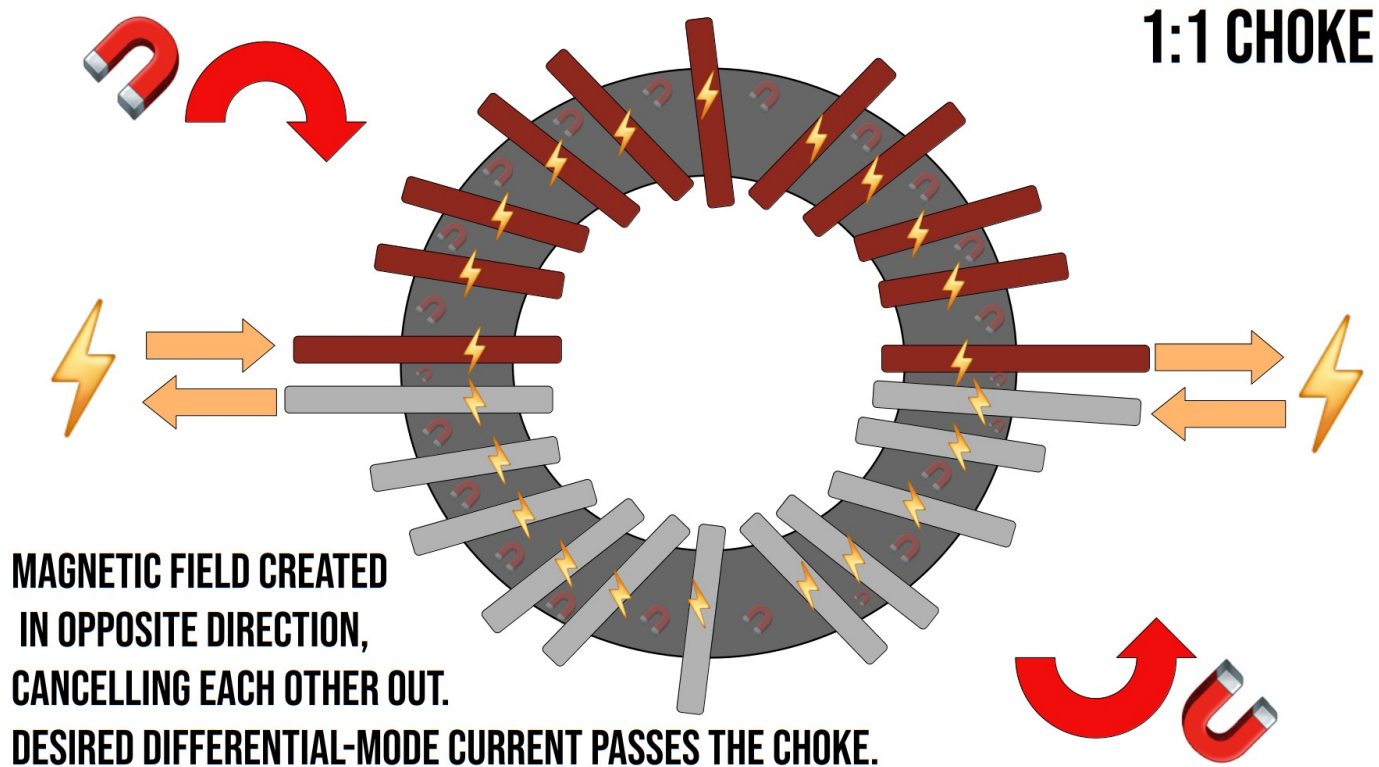
HOW DOES THE BALUN WORK:



**CURRENT PASSES THROUGH WIRE.
MAGNETIC FIELD CREATED IN CLOCK-WISE DIRECTION.**

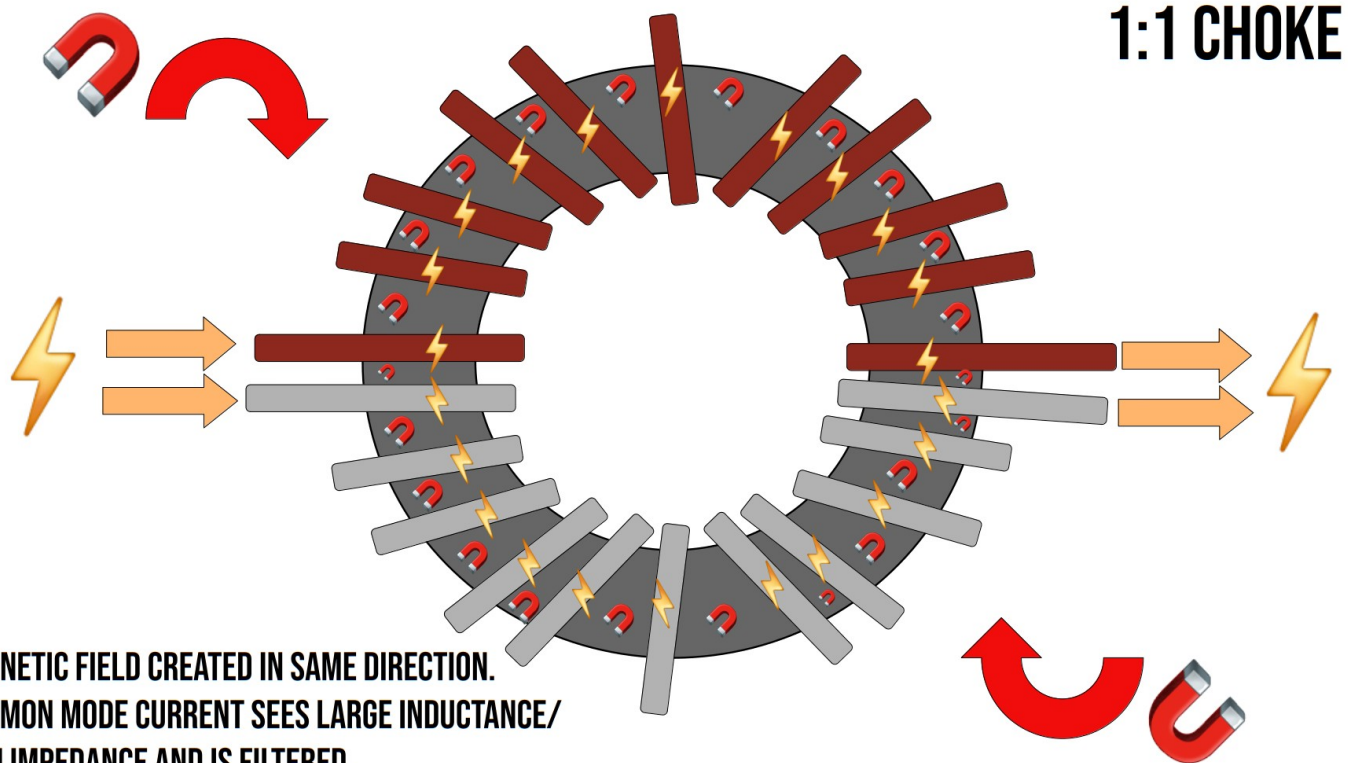
B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

HOW DOES THE BALUN WORK:



B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

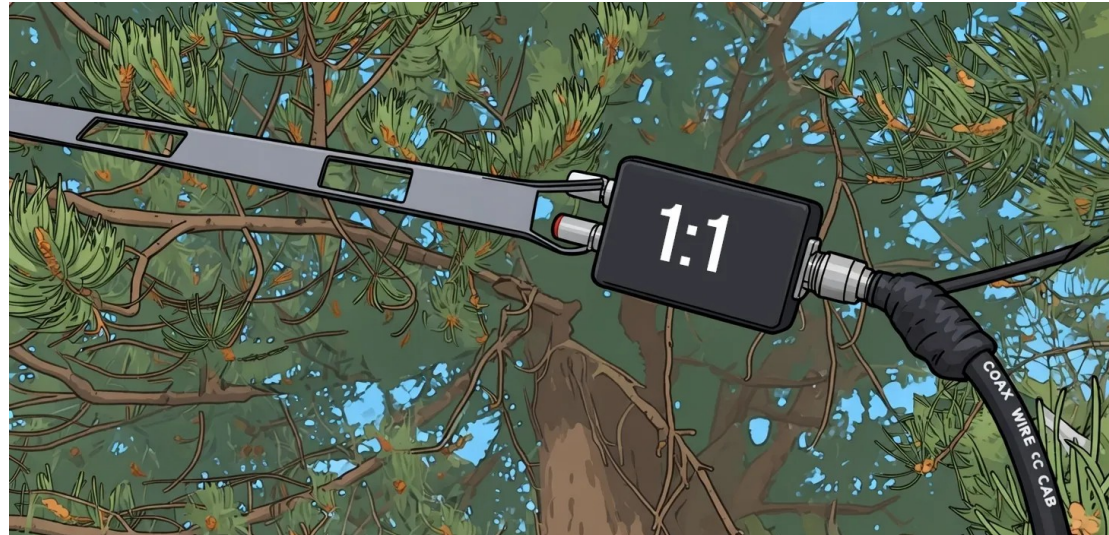
HOW DOES THE BALUN WORK:



B-006-002: TYPES OF TRANSMISSION LINES AND BALUNS

COMMON BALUN USES IN HAM RADIO:

- **CONNECT COAXIAL CABLE (UNBALANCED) TO WINDOW LINE OR OPEN-WIRE LINE (BALANCED).**
- **→ USE A BALUN AT THE JUNCTION.**





QUESTION SECTION B-006-003:
PRACTICAL CONSIDERATIONS FOR
TRANSMISSION LINES

B-006-003: PRACTICAL CONSIDERATIONS FOR TRANSMISSION LINES

COAXIAL CABLE IN REAL-WORLD HAM USE

- COAX IS **MORE USABLE IN A WIDE VARIETY OF SETTINGS** COMPARED TO OPEN-WIRE OR WINDOW LINE.
- KEY ADVANTAGES INCLUDE: EXCELLENT SHIELDING — BLOCKS EXTERNAL NOISE AND PREVENTS RF FROM RADIATING FROM THE FEEDLINE.
- **CAN RUN NEAR METAL OBJECTS** (EX: ATTACHED TO A METAL FENCE FOR SEVERAL METRES) **WITHOUT BEING ADVERSELY AFFECTED** (UNLIKE BALANCED LINES, WHICH SUFFER SEVERE IMBALANCE AND LOSSES NEAR CONDUCTORS OR GROUND).
- HANDLES HARSH WEATHER BETTER — IN LOCATIONS WITH FREQUENT **ICING CONDITIONS**, COAX IS THE MOST SUITABLE TRANSMISSION LINE (LESS ICE BUILDUP ISSUES, NO SPACERS TO ICE OVER).
- OVERALL RELIABILITY AND CONVENIENCE FOR MOST HF/VHF/UHF SETUPS.

COAX DIELECTRIC CHOICES: SOLID VS. FOAM

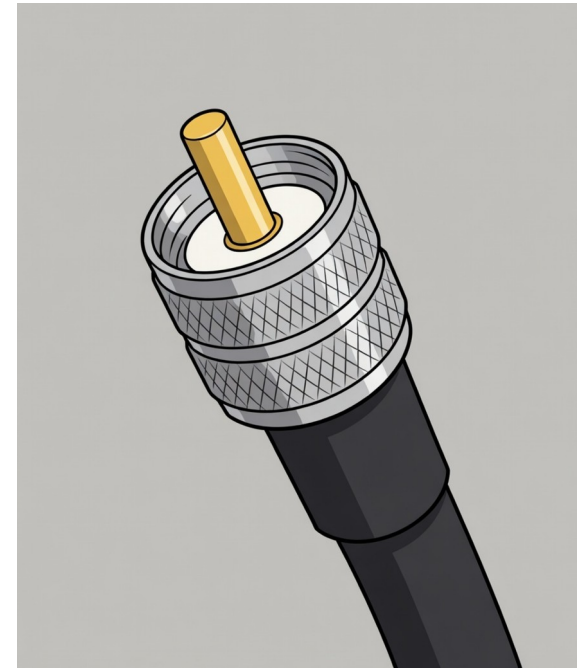
- **FOAM DIELECTRIC** (E.G., IN MANY MODERN LOW-LOSS CABLES LIKE LMR-400): PRIMARY ADVANTAGE IS LOWER LOSS (BETTER SIGNAL STRENGTH OVER LONG RUNS, ESPECIALLY AT HIGHER FREQUENCIES).
- **SOLID DIELECTRIC** (E.G., OLDER RG-58 OR RG-213 STYLES): PREFERRED WHEN MAKING A COMMON-MODE CURRENT CHOKE BY WINDING COAX ON A FERRITE TOROID — **LESS RISK OF A SHORT** BECAUSE THE CENTER CONDUCTOR CAN'T MOVE AND CONTACT THE SHIELD UNDER FLEXING OR TEMPERATURE CHANGES.

SHIELDING IN COAXIAL CABLE

- THE OUTER CONDUCTOR (SHIELD) PREVENTS RF LEAKAGE AND EXTERNAL INTERFERENCE.
- THE TYPE OFFERING THE **BEST SHIELDING** IS A **SOLID SHIELD** (EX: HARDLINE OR SOME PREMIUM CABLES WITH A SOLID COPPER TUBE) — PROVIDES NEAR-100% COVERAGE AND SUPERIOR REJECTION OF NOISE COMPARED TO BRAIDED OR FOIL + BRAID SHIELDS.

COMMON RF CONNECTORS IN HAM RADIO

- **PL-259** (UHF CONNECTOR): COMMONLY INSTALLED ON RG-213 (OR SIMILAR THICK COAX) FOR CONNECTION TO HF TRANSCEIVERS.
- **SO-239** (FEMALE)



COMMON RF CONNECTORS IN HAM RADIO

- **SMA CONNECTOR:** USUALLY JOINS A MODERN HAND-HELD TRANSCEIVER (HT) TO ITS ANTENNA — COMPACT AND COMMON ON VHF/UHF RIGS.



COMMON RF CONNECTORS IN HAM RADIO

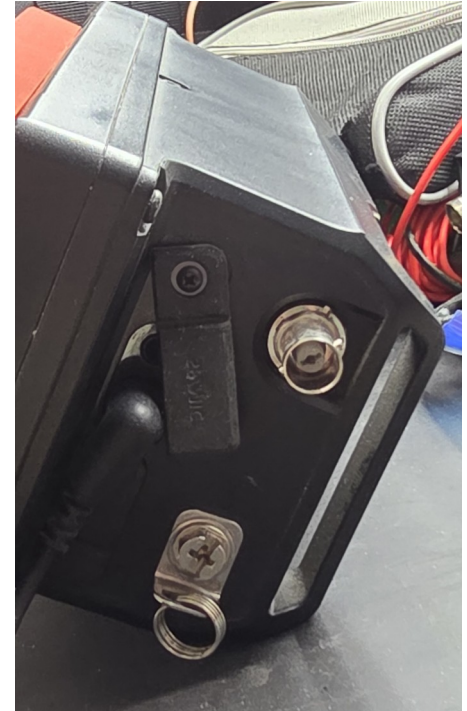
- **N CONNECTOR:** POPULAR RF CONNECTOR DESIGNED TO BE MOISTURE RESISTANT — THREADED, WEATHERPROOF WHEN PROPERLY INSTALLED (GREAT FOR OUTDOOR/BASE STATION USE).



B-006-003: PRACTICAL CONSIDERATIONS FOR TRANSMISSION LINES

COMMON RF CONNECTORS IN HAM RADIO

- **BNC CONNECTOR:** COMMONLY USED FOR LOW-POWER TRANSCEIVERS AND TEST INSTRUMENTS (QUICK TWIST-ON, GOOD UP TO ~GHZ).

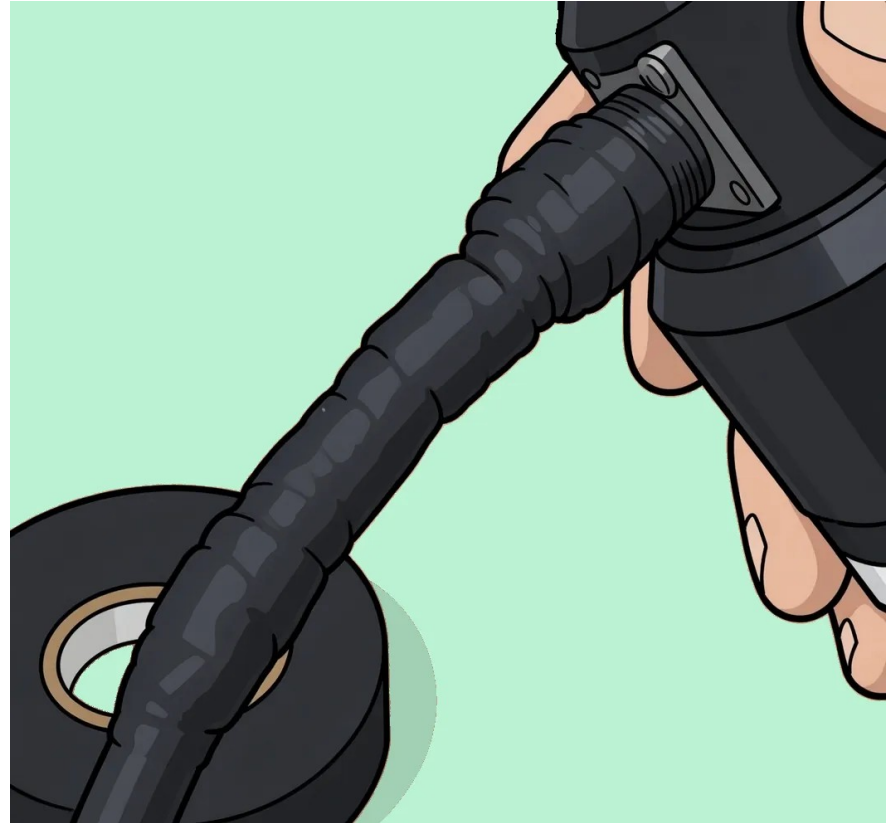


MAINTENANCE TIP: CONNECTOR CARE

- REGULARLY **CLEAN AND TIGHTEN** ALL ANTENNA CONNECTORS TO **KEEP CONTACT RESISTANCE AT A MINIMUM** — PREVENTS POWER LOSS, HEATING, INTERMITTENT CONNECTIONS, AND POTENTIAL DAMAGE FROM HIGH SWR.

PERMANENT OUTDOOR INSTALL:

- **WRAP IN SELF-AMALGAMATING TAPE, THEN SEAL WITH ELECTRICAL TAPE.**





QUESTION SECTION B-006-004:

TRANSMISSION LINE LOSSES AND

PERFORMANCE

TRANSMISSION LINE LOSSES

- RF ENERGY TRAVELLING THROUGH ANY TRANSMISSION LINE **LOSES SOME POWER** DUE TO RESISTANCE IN CONDUCTORS, DIELECTRIC HEATING, AND RADIATION/LEAKAGE.
- LOSSES ARE EXPRESSED IN **DECIBELS (dB) PER UNIT LENGTH** (EX: dB PER 100 METRES OR PER 100 FEET).
- HIGHER LOSS = LESS POWER REACHES THE ANTENNA → WEAKER TRANSMITTED SIGNAL AND POORER RECEIVED SIGNALS

KEY FACTORS THAT INCREASE LOSS

- **LENGTH**: SIGNAL LOSS INCREASES AS THE LENGTH INCREASES.
- **EX**: DOUBLING THE LENGTH FROM 20 M TO 40 M INCREASES LOSS BY 100% (IT'S ADDITIVE IN dB).
- **FREQUENCY**: LOSS INCREASES WITH INCREASING FREQUENCY DUE TO SKIN EFFECT (CURRENT FLOWS ONLY ON CONDUCTOR SURFACES) AND DIELECTRIC LOSSES. HIGHER BANDS (EX: 70 CM / 440 MHz) SUFFER MUCH MORE LOSS THAN HF (EX: 80 M / 3.5 MHz).

B-006-004: TRANSMISSION LINE LOSSES AND PERFORMANCE

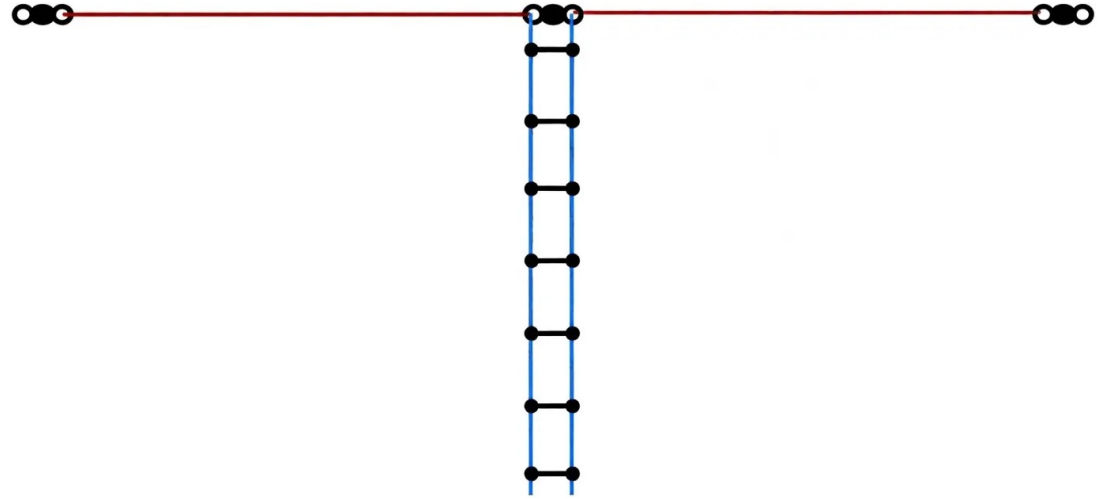
COMPARING COMMON CABLES: RG-58 VS. RG-213 VS. OPEN-WIRE

- SMALLER/THINNER CABLES LIKE RG-58 HAVE HIGHER LOSS DUE TO SMALLER CONDUCTORS AND SOLID DIELECTRIC.
- MAJOR ADVERSE CONSEQUENCE OF USING RG-58 ON THE 70 CM BAND (UHF): **EXCESS RF LOSS** IN THE LINE (OFTEN 15-20+ DB/100 M, WASTING MOST POWER).
- SWITCHING FROM THICKER RG-213 (LOWER LOSS) TO RG-58 (HIGHER LOSS): **LESS RF POWER IS RADIATED** FROM THE ANTENNA (EVEN WITH SAME TRANSMITTER POWER).
- **LOWEST LOSS TRANSMISSION LINE ON HF**: OPEN-WIRE LINE (VERY LOW DIELECTRIC LOSS, HIGH EFFICIENCY EVEN AT MISMATCH).

MAJOR ADVANTAGE OF OPEN-WIRE (OR LADDER) LINE

- IT CAN BE OPERATED AT **HIGH SWR** (STANDING WAVE RATIO) WITHOUT EXCESSIVE LOSS.

→ IDEAL FOR MULTI-BAND
ANTENNAS WITH TUNERS —
MISMATCHES CAUSE LESS
HEATING/POWER WASTE
COMPARED TO COAX.



B-006-004: TRANSMISSION LINE LOSSES AND PERFORMANCE

PRACTICAL TIPS TO MINIMIZE LOSS



- **KEEP FEEDLINES AS SHORT AS POSSIBLE.**
 - **EX: IF TRANSMITTER AND ANTENNA ARE ONLY 15 M APART BUT CONNECTED BY 60 M OF RG-58, SHORTEN THE EXCESS CABLE TO REDUCE UNNECESSARY LOSS.**
- **CHOOSE LOWER-LOSS CABLE FOR LONGER RUNS OR HIGHER FREQUENCIES (EX: RG-213, LMR-400, OR OPEN-WIRE ON HF).**
- **ON VHF/UHF, AVOID THIN COAX LIKE RG-58 FOR ANYTHING BEYOND SHORT JUMPS.**



QUESTION SECTION B-006-005:

STANDING WAVE RATIO (SWR)

AND MEASUREMENT

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

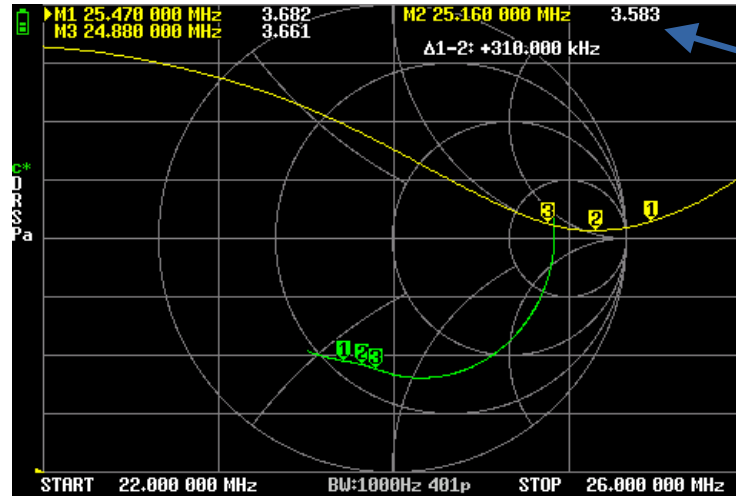
WHAT IS SWR AND WHAT DO READINGS MEAN?

- **SWR** (STANDING WAVE RATIO) MEASURES HOW WELL THE ANTENNA SYSTEM IS MATCHED TO THE TRANSMISSION LINE AND RADIO (IDEALLY 50 Ω). SOMETIMES THIS IS CALLED VSWR (VOLTAGE STANDING WAVE RATIO).
- IT COMPARES **FORWARD** POWER (FROM TRANSMITTER) TO **REFLECTED** POWER (BOUNCED BACK DUE TO MISMATCH). AN **SWR OF 1:1** MEANS **THE BEST IMPEDANCE MATCH HAS BEEN ATTAINED** — NO REFLECTIONS, MAXIMUM POWER TRANSFER TO THE ANTENNA.
- AN **SWR OF LESS THAN 1.5:1** MEANS A FAIRLY GOOD IMPEDANCE MATCH — ACCEPTABLE FOR MOST OPERATIONS WITH LOW LOSS. (IN THE REAL WORLD, THIS SWR IS JUST FINE).

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

HOW AN SWR METER WORKS

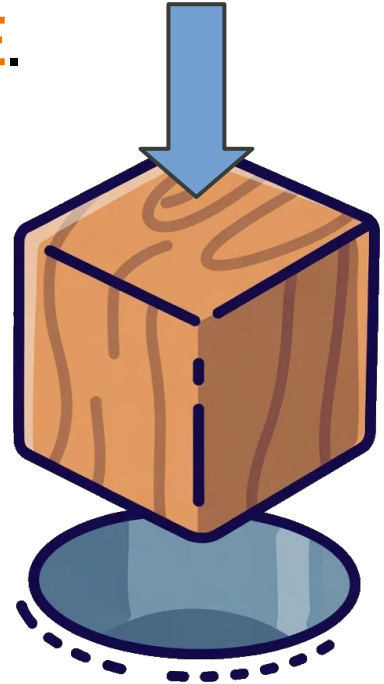
- AN SWR METER MEASURES **FORWARD AND REFLECTED VOLTAGE** (OR POWER) TO CALCULATE THE RATIO.
- IT SHOWS SWR ON A SCALE (EX: 1:1 IS PERFECT, HIGHER NUMBERS 2:1 OR 3:1 = WORSE MISMATCH).



B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

WHAT CAUSES STANDING WAVES?

- IF THE CHARACTERISTIC IMPEDANCE OF THE TRANSMISSION LINE DOES NOT MATCH THE ANTENNA INPUT IMPEDANCE, **STANDING WAVES ARE PRODUCED IN THE LINE.**
- EX: USING 75Ω COAX INSTEAD OF 50Ω TO FEED A 50Ω ANTENNA.
- IT'S LIKE TRYING TO FORCE A SQUARE PEG THROUGH A ROUND HOLE
- THE STUFF THAT DOESN'T FIT THROUGH THE HOLE REFLECTS BACK!



B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

EFFECTS OF HIGH SWR / STANDING WAVES

- PRESENCE OF STANDING WAVES RESULTS IN **REDUCED TRANSFER OF RF ENERGY TO THE ANTENNA**
- MAIN ADVERSE EFFECT OF OPERATING WITH HIGH SWR: **INCREASED TRANSMISSION LINE LOSS** (REFLECTED POWER HEATS THE LINE, ESPECIALLY IN COAX; LESS POWER RADIATES)
- EXCESSIVE SWR CAN ALSO DAMAGE THE FINALS IN YOUR TRANSCEIVER!

COMMON CAUSES OF HIGH OR ERRATIC SWR

- **AN OPEN OR SHORT CIRCUIT** IN THE ANTENNA SYSTEM (EX: BROKEN WIRE, WATER IN CONNECTOR)
- **INTERMITTENT CONNECTION** IN THE ANTENNA SYSTEM (LOOSE COAX, BAD SOLDER) — MOST LIKELY CAUSE OF **ERRATIC READINGS** ON AN SWR METER

EFFECT OF LINE LOSS ON SWR READINGS

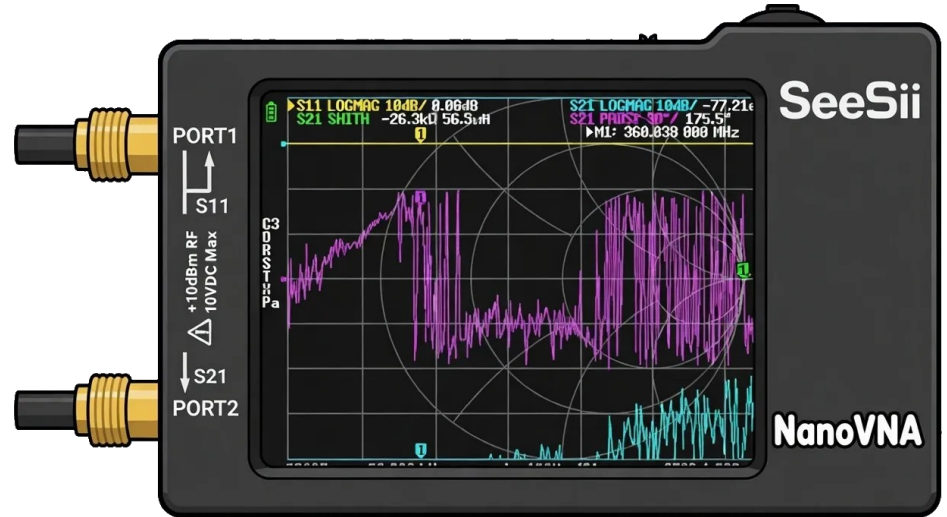
- **LINE LOSS (ATTENUATION IN THE CABLE) DECREASES THE SWR READING AT THE STATION** BECAUSE REFLECTED ENERGY IS ATTENUATED TWICE (TO THE ANTENNA AND BACK)
- → **HIGH-LOSS LINES CAN "MASK" A BAD MISMATCH — ALWAYS CHECK AT THE ANTENNA END IF POSSIBLE!**

TOOLS FOR TUNING AND DIAGNOSIS

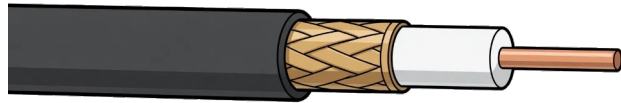
- **ANTENNA ANALYZER:** VERY USEFUL FOR ADJUSTING THE PHYSICAL LENGTH OF AN ANTENNA (TRIM FOR RESONANCE)
- PROVIDES DETAILED INFO: **SWR OF THE ANTENNA SYSTEM OVER A RANGE OF FREQUENCIES**, IMPEDANCE, RESONANCE POINTS, ETC.

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

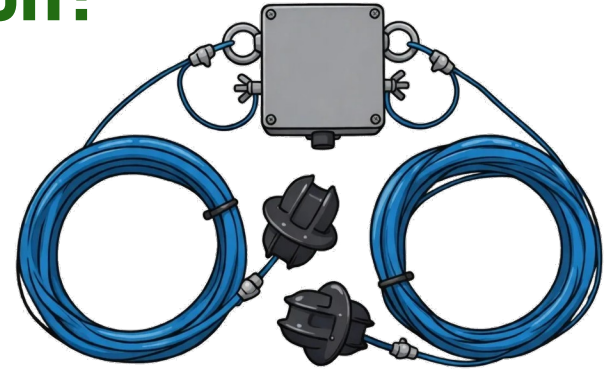
TOOLS FOR TUNING AND DIAGNOSIS



WHAT ACTUALLY HAPPENS WITH MISMATCH?



50Ω



72Ω

22Ω

'REAL' RESISTIVE DIFFERENCE

REFLECTION COEFFICIENT: Γ (GAMMA)

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \Gamma = \frac{72 - 50}{72 + 50} \quad \Gamma = \frac{22}{122} \quad \Gamma = 0.18$$

$Z_L = 72\Omega$ (LOAD IMPEDANCE)

$Z_0 = 50\Omega$ (CHARACTERISTIC IMPEDANCE)



VOLTAGE STANDING WAVE RATIO CALCULATION

$$VSWR = \frac{1 + \Gamma}{1 - \Gamma}$$

$$VSWR = \frac{1 + 0.18}{1 - 0.18} \quad VSWR = \frac{1.18}{0.82}$$



$$VSWR = 1.44$$

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

IMPEDANCE = RESISTANCE + REACTANCE

- A “RESONANT ANTENNA” MEANS NO REACTANCE (OPPOSITION TO AC CURRENT) – WHICH IS NEARLY IMPOSSIBLE. BUT WE CAN COME CLOSE!
- Z (IMPEDANCE) = R (RESISTANCE) + jX (REACTIVE COMPONENT)
- THIS IS FREQUENCY DEPENDANT. AS YOU CHANGE FREQUENCY, REACTANCE IS GOING TO CHANGE WHICH IS GOING TO AFFECT OUR IMPEDANCE WHICH WILL AFFECT SWR!
- WITH ANTENNAS: “EVERYTHING AFFECTS EVERYTHING!”



B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

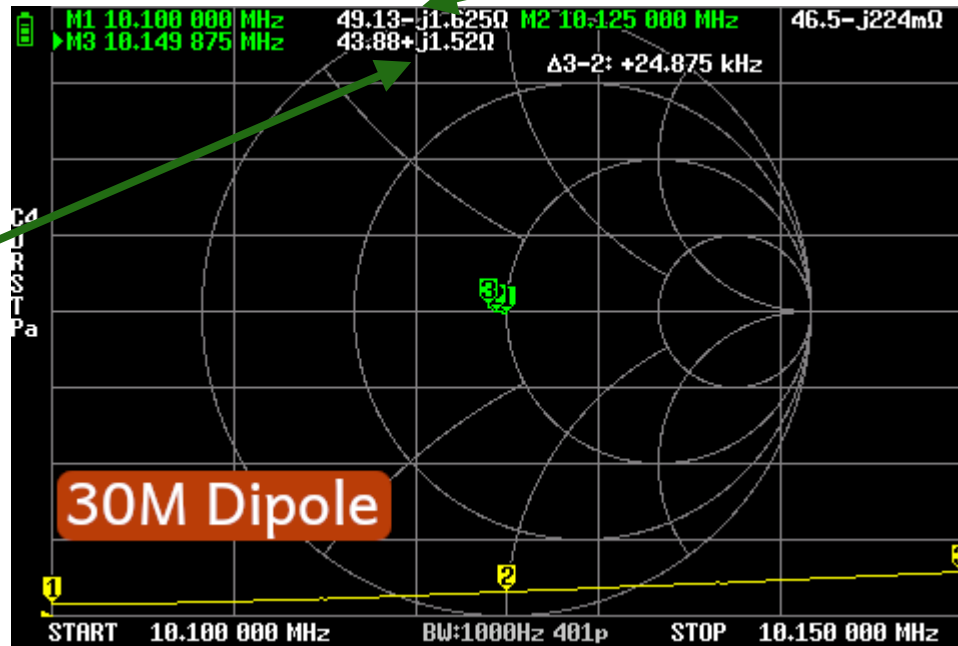
“COMPLEX IMPEDANCE”

- COMPLEX IMPEDANCE IS WRITTEN AS: $Z = R + jX$
- jX IS YOUR REACTIVE COMPONENT OF CAPACITIVE OR INDUCTIVE REACTANCE
- WHEN YOU SHORTEN AN ANTENNA, YOU ARE ADDING CAPACITANCE
- WHEN YOU LENGTHEN AN ANTENNA, YOU ARE ADDING INDUCTANCE
- THIS IS TRYING TO TUNE THE ANTENNA CIRCUIT TO FREQUENCY BY “CANCELLING OUT” jX



B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT

NANO VNA SMITH CHART



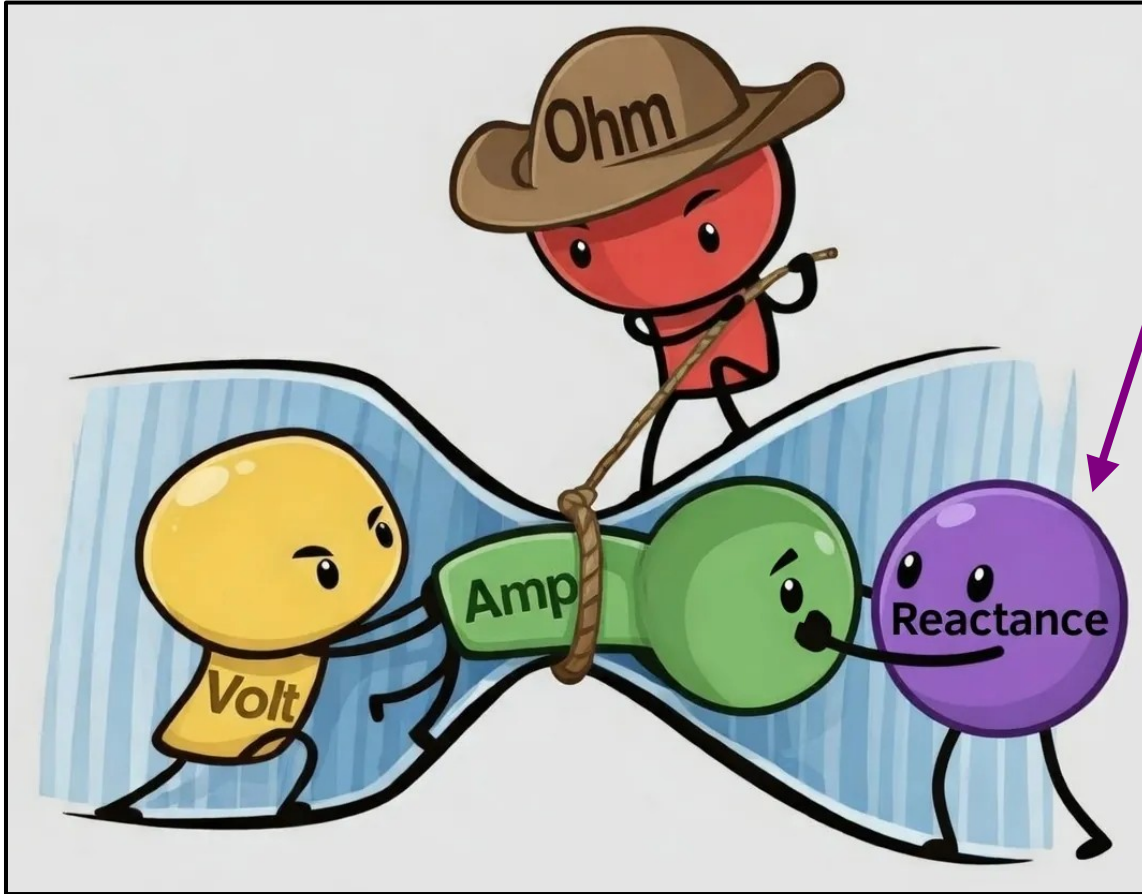
M3 43.88 + j1.52Ω

1.52 Ohms of
Inductive (+)
Reactance

M31 49.13 - j1.625Ω

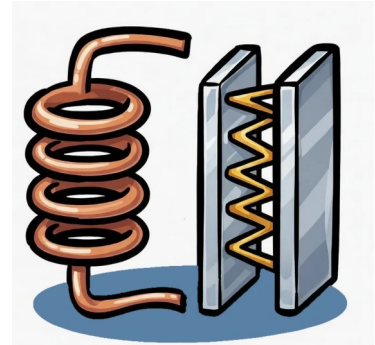
1.625 Ohms of
Capacitive (-)
Reactance

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT



THE CULPRIT!

- IN REAL LIFE, YOUR ANTENNA (LOAD) IS HARDLY EVER A PERFECTLY MATCHED 50Ω
- ANTENNA TUNERS OR MATCH-BOXES USE VARYING LEVELS OF **INDUCTANCE** AND **CAPACITANCE** TO MINIMIZE REACTANCE AS MUCH AS POSSIBLE.
- THIS HELPS MAKE YOUR ANTENNA, FEEDLINE AND RIG CLOSE TO PURELY RESISTIVE FOR MAXIMUM POWER TRANSFER.





QUESTION SECTION B-006-006:

IMPEDANCE MATCHING AND ANTENNA

TUNERS

WHY IMPEDANCE MATCHING MATTERS IN HAM RADIO

- MODERN SOLID-STATE HF TRANSCEIVERS ARE SENSITIVE TO MISMATCHES.
- AN **EXCESSIVE IMPEDANCE MISMATCH** BETWEEN THE TRANSCEIVER AND TRANSMISSION LINE WILL CAUSE THE RADIO TO **AUTOMATICALLY REDUCE POWER** (FOLDBACK PROTECTION TO PREVENT DAMAGE FROM HIGH REFLECTED POWER)
- GOAL: DELIVER MAXIMUM POWER FROM TRANSMITTER TO ANTENNA WITH MINIMAL LOSS AND NO DAMAGE.

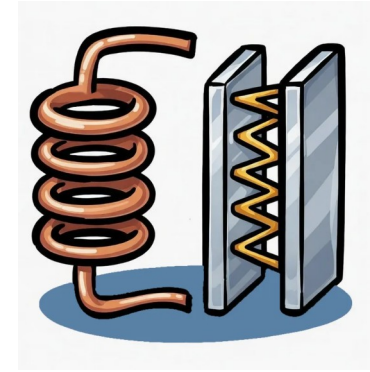
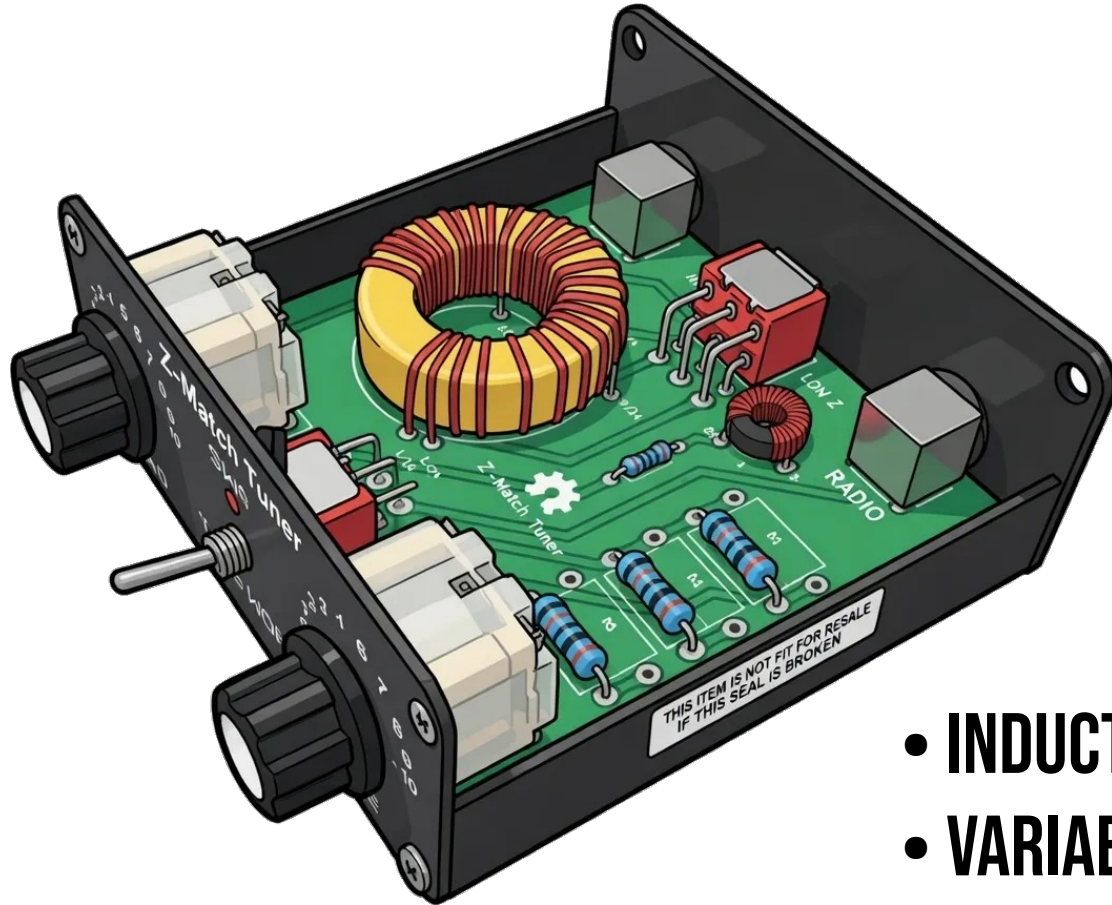
WHY IMPEDANCE MATCHING MATTERS IN HAM RADIO

- IF BOTH SOURCE (TRANSCEIVER) AND LOAD (ANTENNA) IMPEDANCES ARE PURELY RESISTIVE, **MAXIMUM POWER DELIVERY** OCCURS WHEN LOAD **IMPEDANCE EQUALS SOURCE IMPEDANCE**.
- AKA: THE SYSTEM IS WELL-MATCHED AND TUNED

WHAT AN ANTENNA TUNER DOES

- **“TUNER” IS A BIT OF A MISNOMER.**
- **AN ANTENNA TUNER (ALSO CALLED AN ANTENNA COUPLER OR MATCHING UNIT) MATCHES A TRANSCEIVER TO A MISMATCHED ANTENNA SYSTEM.**
- **IT DOES NOT CHANGE THE ANTENNA ITSELF — IT COMPENSATES BY ADDING CAPACITIVE OR INDUCTIVE REACTANCE TO CANCEL OUT THE MISMATCH.**
- **ENABLES THE TRANSCEIVER TO DELIVER RATED POWER TO A MISMATCHED ANTENNA SYSTEM WITHOUT TRIGGERING FOLDBACK**

B-006-005: STANDING WAVE RATIO (SWR) AND MEASUREMENT



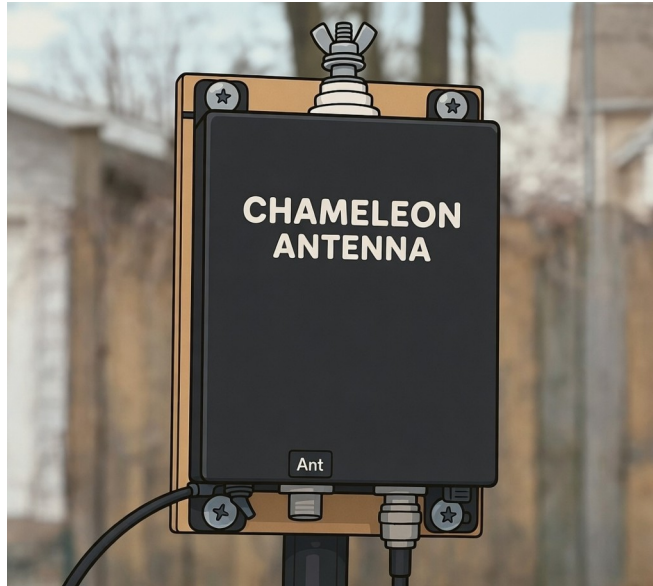
MANUAL TUNER

- INDUCTOR TAPS FOR INDUCTANCE
- VARIABLE CAPACITORS FOR CAPACITANCE

IDEAL PLACEMENT OF THE ANTENNA TUNER

- BEST PLACE TO MINIMIZE LOSSES IS AT **THE JUNCTION BETWEEN THE TRANSMISSION LINE AND ANTENNA** (REMOTE / REMOTE TUNER)
- ADVANTAGE OF LOCATING THE TUNER NEAR THE ANTENNA FEED POINT (VS. NEAR THE TRANSCEIVER): **LESS TRANSMISSION LINE LOSS** — THE TUNER MAKES THE LINE SEE A GOOD MATCH, SO REFLECTED POWER DOESN'T TRAVEL BACK THROUGH THE ENTIRE CABLE CAUSING EXTRA HEATING
- REMOTE TUNERS ARE IDEAL, BUT THEY ARE COSTLY!

B-006-006: IMPEDANCE MATCHING AND ANTENNA TUNERS



Remote Tuner
Outside at the
Antenna

Remote Tuner Head Unit
inside at the Rig



KEY RULE ABOUT MATCHED SYSTEMS

- IF THE ANTENNA IS **CORRECTLY MATCHED** TO THE TRANSMISSION LINE (SWR $\approx$ 1:1 AT THE FEED POINT), **THE LENGTH OF THE TRANSMISSION LINE WILL HAVE NO EFFECT ON THE MATCHING** — THE TRANSCEIVER SEES 50 OHMS REGARDLESS OF CABLE LENGTH

B-006-006: IMPEDANCE MATCHING AND ANTENNA TUNERS

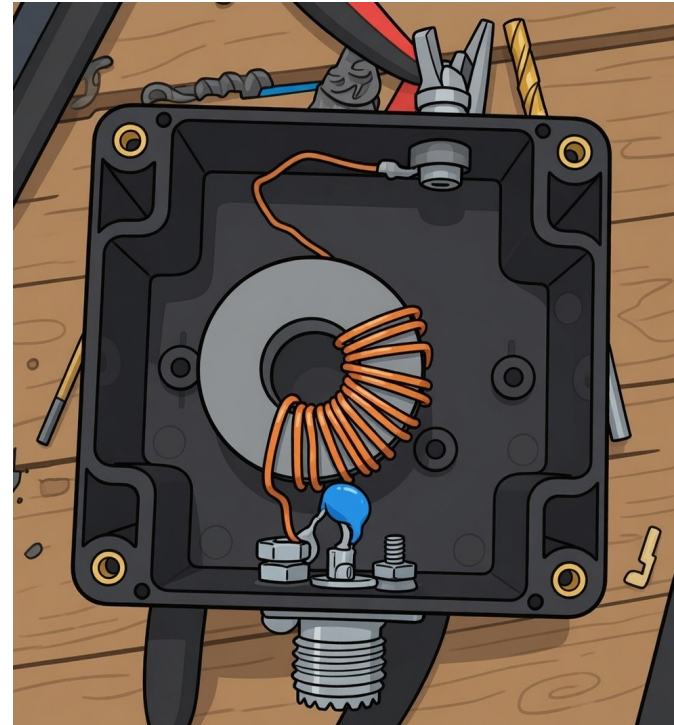
CONVENIENT PLACEMENT OF THE ANTENNA TUNER

- MOST HAMS HAVE A TUNER AT THE RIG INSTEAD OF A REMOTE TUNER BECAUSE THEY ARE CHEAPER AND MORE CONVENIENT.
- WITH THE TUNER AT THE RIG, IT ONLY MAKES THE TRANSMITTER SEE 50Ω (LOW SWR FROM TUNER BACK TO RADIO). BUT THE COAX BETWEEN TUNER AND ANTENNA STILL SEES POSSIBLY HIGH SWR (DEPENDING ON ANTENNA SETUP).
- COAX HAS HIGHER LOSS WHEN SWR IS HIGH (MORE CURRENT/VOLTAGE EXTREMES CAUSE EXTRA HEATING IN THE DIELECTRIC AND CONDUCTORS). THIS LOSS IS ADDITIONAL TO THE MATCHED-LINE LOSS
- EXAMPLE: RG-8X MIGHT BE 0.5 dB/100 FT AT 1:1 SWR BUT 2-4+ dB/100 FT OR MORE AT 10:1+ SWR, DEPENDING ON BAND AND LENGTH. RESULT: A NOTICEABLE FRACTION (SOMETIMES 20-50% OR MORE) OF YOUR TRANSMITTED POWER GETS DISSIPATED AS HEAT IN THE COAX INSTEAD OF RADIATED BY THE ANTENNA. RECEIVE SIGNALS ARE ALSO ATTENUATED THE SAME WAY (RECIPROCITY)!

HIGH IMPEDANCE ANTENNAS

- **END-FED HALF-WAVE (EFHW) ANTENNAS HAVE VERY HIGH FEED-POINT IMPEDANCE (~SEVERAL THOUSAND OHMS).**
- **TO MATCH TO 50-OHM COAXIAL CABLE, USE A TRANSFORMER GENERALLY 49:1 OR 64:1 UNUN – UNBALANCED TO UNBALANCED.**

HIGH IMPEDANCE ANTENNAS



HIGH IMPEDANCE ANTENNAS

- **EXAMPLE: A FOLDED DIPOLE HAS ~ 300 OHMS FEED-POINT IMPEDANCE, FED WITH 50-OHM COAX. REQUIRED TRANSFORMATION RATIO: 6:1 (SINCE $300 / 50 = 6$)**
- **ADVANTAGE OF TRANSFORMERS AT RADIO FREQUENCIES: CAN BE DESIGNED TO MATCH OVER A WIDE BANDWIDTH**



QUESTION SECTION B-006-007:

ANTENNA POLARIZATION AND BASIC PATTERNS

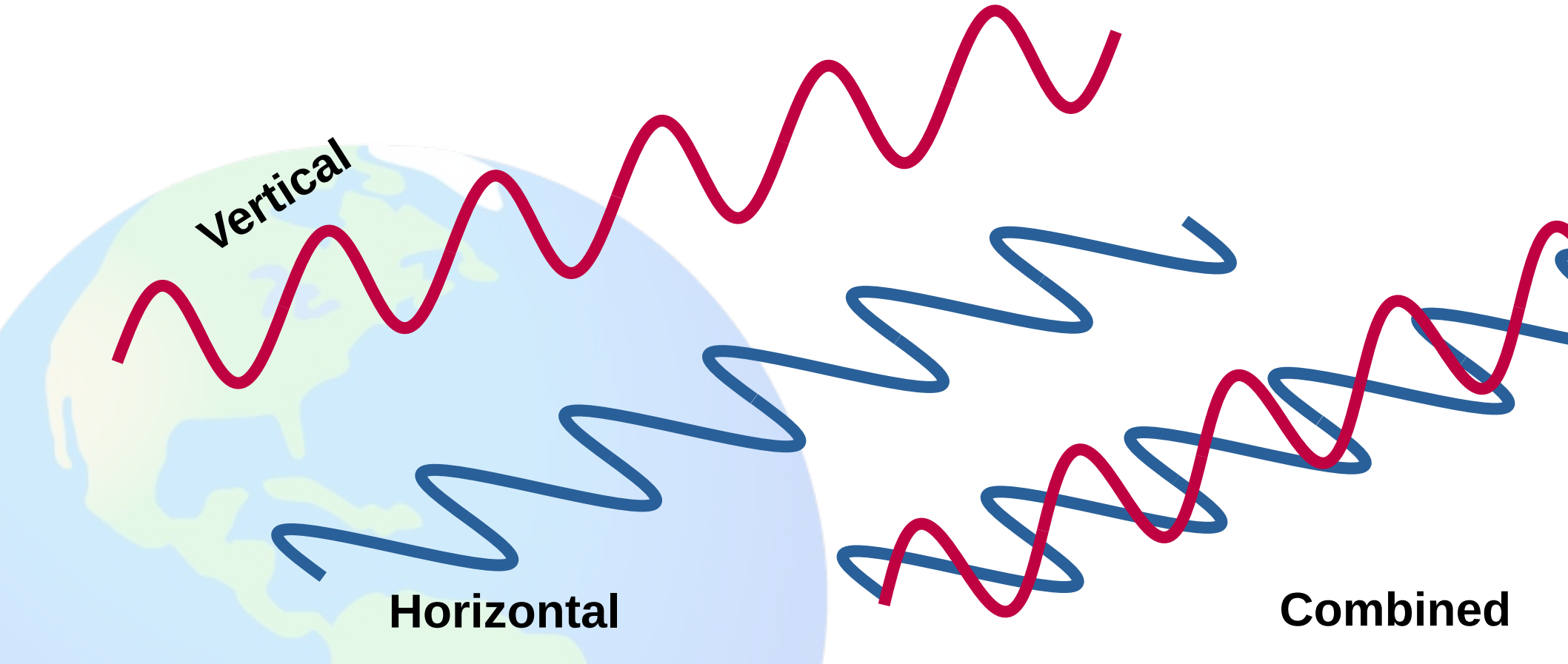
WHAT IS ANTENNA POLARIZATION?

- **POLARIZATION** REFERS TO THE ORIENTATION OF THE **ELECTRIC FIELD** (E-FIELD) OF THE ELECTROMAGNETIC WAVE RELATIVE TO THE EARTH'S SURFACE.
- IT DETERMINES HOW THE WAVE TRAVELS AND IS RECEIVED — MISMATCHED POLARIZATION CAN CAUSE SIGNIFICANT SIGNAL LOSS (UP TO 20+ dB IN EXTREME CASES).

WHAT IS ANTENNA POLARIZATION?

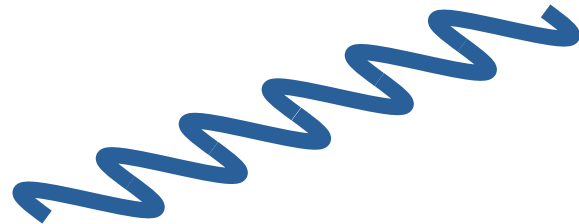
- **HORIZONTAL POLARIZATION:** THE ELECTRIC LINES OF FORCE ARE PARALLEL TO THE EARTH'S SURFACE
- **VERTICAL POLARIZATION:** THE ELECTRIC LINES OF FORCE ARE PERPENDICULAR TO THE EARTH'S SURFACE

WHAT IS ANTENNA POLARIZATION?



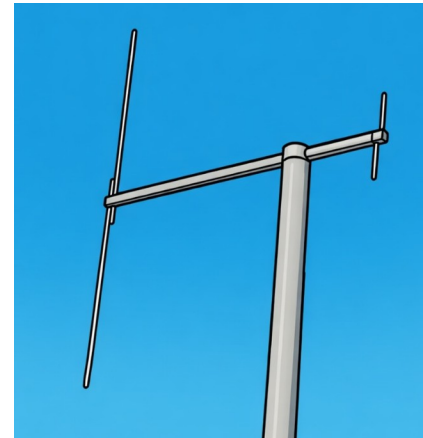
HOW ANTENNA ORIENTATION DETERMINES POLARIZATION

- THE POLARIZATION MATCHES THE ORIENTATION OF THE RADIATING ELEMENT (FOR LINEAR ANTENNAS LIKE DIPOLES OR YAGIS): A **YAGI ANTENNA** WITH ELEMENTS **PARALLEL** TO THE EARTH'S SURFACE PRODUCES HORIZONTAL POLARIZATION



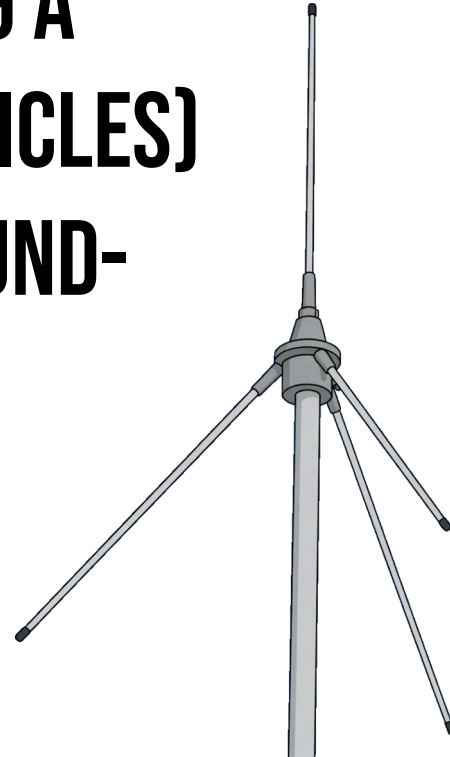
HOW ANTENNA ORIENTATION DETERMINES POLARIZATION

- A HALF-WAVELENGTH ANTENNA (EX: DIPOLE) MOUNTED **PERPENDICULAR** TO THE EARTH'S SURFACE – VERTICALLY – PRODUCES **VERTICAL** POLARIZATION



PRACTICAL RECEPTION AND COMPATIBILITY

- VHF SIGNALS FROM A MOBILE STATION USING A **VERTICAL** WHIP ANTENNA (COMMON ON VEHICLES) ARE BEST RECEIVED USING A **VERTICAL** GROUND-PLANE ANTENNA AT THE BASE STATION



B-006-007: ANTENNA POLARIZATION AND BASIC PATTERNS

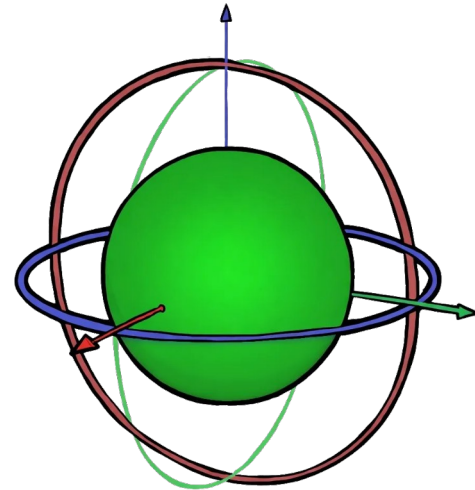
PRACTICAL RECEPTION AND COMPATIBILITY

- A **VERTICALLY POLARIZED WAVE** THAT TRAVELS VIA GROUND WAVE (COMMON ON LOWER HF BANDS) ARRIVES WITH **VERTICAL POLARIZATION** AT THE RECEIVING END
- COMPARED TO A HORIZONTAL ANTENNA, A **VERTICAL ANTENNA** WILL RECEIVE A VERTICALLY POLARIZED RADIO WAVE AT **HIGHER STRENGTH** (B-006-007-011).
- → ALWAYS TRY TO MATCH TRANSMIT AND RECEIVE POLARIZATIONS FOR MAXIMUM SIGNAL (CROSS-POLARIZATION LOSS IS A BIG DEAL IN WEAK-SIGNAL WORK)

B-006-007: ANTENNA POLARIZATION AND BASIC PATTERNS

THE ISOTROPIC RADIATOR – A THEORETICAL REFERENCE

- AN **ISOTROPIC ANTENNA** (OR ISOTROPIC RADIATOR) IS A HYPOTHETICAL POINT SOURCE THAT RADIATES EQUALLY IN ALL DIRECTIONS
- ITS THREE-DIMENSIONAL RADIATION PATTERN IS A PERFECT SPHERE (UNIFORM INTENSITY EVERYWHERE)
- REAL ANTENNAS (DIPOLES, YAGIS, ETC.) HAVE DIRECTIONAL PATTERNS — THE ISOTROPIC IS USED AS A REFERENCE TO CALCULATE GAIN





QUESTION SECTION B-006-008:

ANTENNA RESONANCE AND LENGTH

ADJUSTMENTS

RESONANCE AND LENGTH ADJUSTMENTS FOR WIRE DIPOLES

- A **HALF-WAVE DIPOLE** IS **RESONANT** AT A FREQUENCY WHERE ITS TOTAL LENGTH IS APPROXIMATELY HALF A WAVELENGTH ($\lambda/2$ IN FREE SPACE, ADJUSTED SLIGHTLY SHORTER DUE TO VELOCITY FACTOR/END EFFECTS).
- RESONANT FREQUENCY IS INVERSELY PROPORTIONAL TO LENGTH:
 - SHORTER ANTENNA → HIGHER FREQUENCY
 - LONGER ANTENNA → LOWER FREQUENCY.

B-006-008: ANTENNA RESONANCE AND LENGTH ADJUSTMENTS

RESONANCE AND LENGTH ADJUSTMENTS FOR WIRE DIPOLES

- **EXAMPLES:**
- A WIRE DIPOLE RESONANT AT **3900 kHz** (80 M BAND) CAN BE CHANGED TO **3600 kHz** BY MAKING IT LONGER
- A DIPOLE RESONANT AT **3600 kHz** CAN BE TUNED TO **3900 kHz** BY MAKING IT SHORTER
- TO **LOWER** THE RESONANT FREQUENCY, THE OPERATOR SHOULD **LENGTHEN THE ANTENNA**
- THE **RESONANT FREQUENCY** OF AN ANTENNA MAY **BE INCREASED** BY SHORTENING THE RADIATING ELEMENT

B-006-008: ANTENNA RESONANCE AND LENGTH ADJUSTMENTS

RESONANCE AND LENGTH ADJUSTMENTS FOR WIRE DIPOLE

“IF THE FREQUENCY IS TOO LOW, IT’S TOO LONG!”



B-006-008: ANTENNA RESONANCE AND LENGTH ADJUSTMENTS

ADDING REACTANCE TO CHANGE RESONANCE

ADDING A **SERIES INDUCTANCE** (LOADING COIL) TO AN ANTENNA WOULD **DECREASE THE RESONANT FREQUENCY** (EFFECTIVE ELECTRICAL LENGTHENING WITHOUT PHYSICALLY EXTENDING THE WIRE)



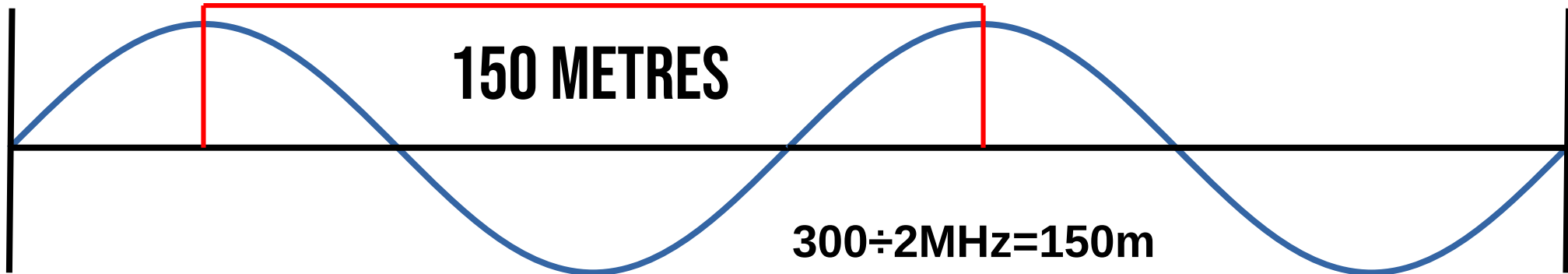
WAVELENGTH IN FREE SPACE

- THE SPEED OF A RADIO WAVE **IS THE SAME AS THE SPEED OF LIGHT.**
- LIGHTSPEED IS 300,000,000 M/S
- EASY FORMULA. WAVELENGTH:
$$\lambda (\textit{metres}) = \frac{300}{f (\textit{MHz})}$$

B-006-008: ANTENNA RESONANCE AND LENGTH ADJUSTMENTS

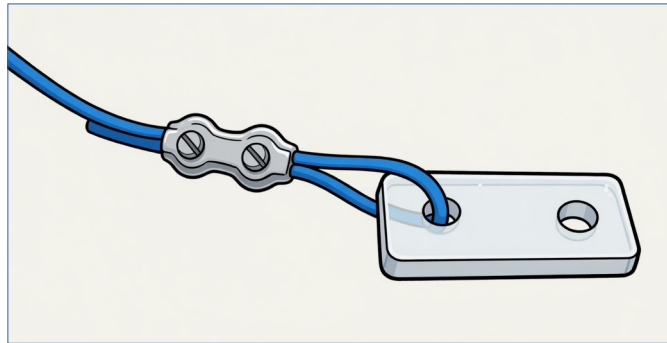
WAVELENGTH IN FREE SPACE

- **EXAMPLES:**
 - **A 25 MHz SIGNAL HAS A WAVELENGTH OF 12 METRES**
 - **A 2 MHz SIGNAL HAS A WAVELENGTH OF 150 METRES**



WHY USE INSULATORS AT ANTENNA ENDS?

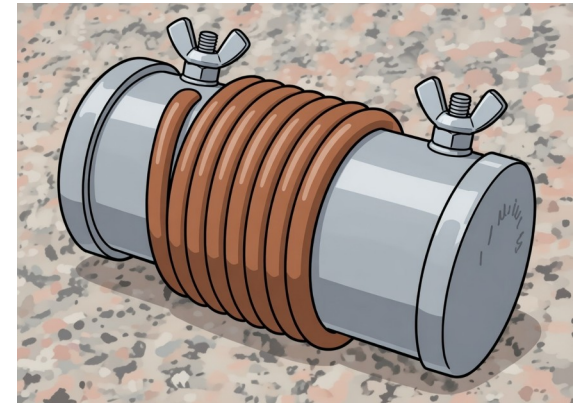
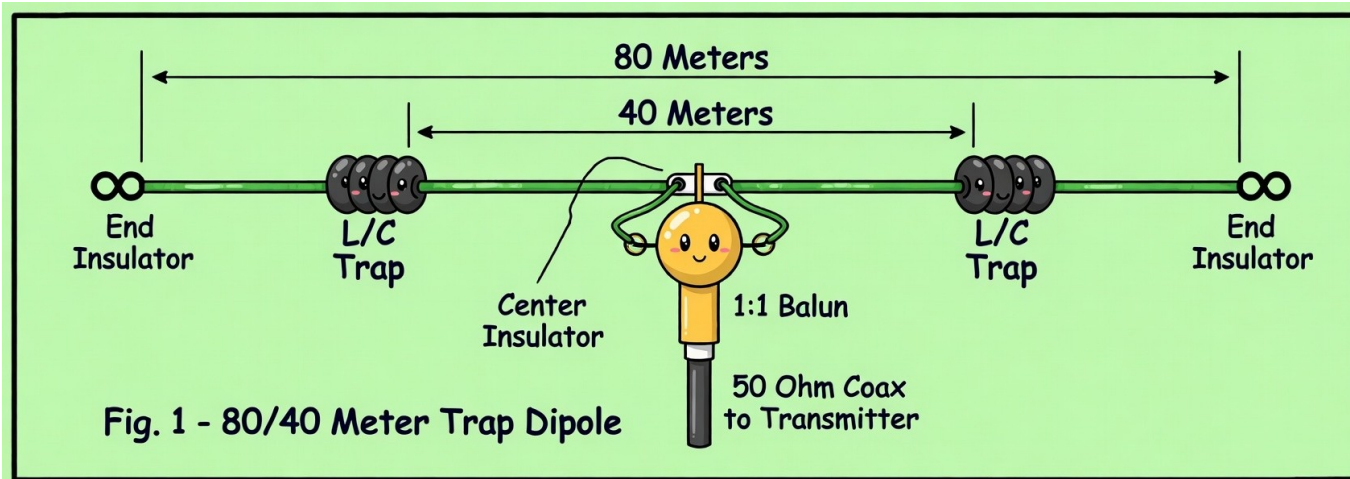
- **INSULATORS** ARE USED AT THE ENDS OF A SUSPENDED WIRE ANTENNA TO **LIMIT THE ELECTRICAL LENGTH** OF THE ANTENNA (PREVENT THE WIRE FROM "SHORTING" TO GROUND OR SUPPORTS, WHICH WOULD CHANGE RESONANCE OR CAUSE LOSSES)



B-006-008: ANTENNA RESONANCE AND LENGTH ADJUSTMENTS

MULTI-BAND ANTENNAS: TRAPS

- SOME ANTENNAS USE **TRAPS** TO OPERATE ON MULTIPLE BANDS.
- A TRAP IS **A COIL AND CAPACITOR IN PARALLEL** (PARALLEL LC CIRCUIT) THAT ACTS AS A HIGH-IMPEDANCE "BLOCK" AT ONE FREQUENCY (STOPPING CURRENT BEYOND THE TRAP) WHILE PASSING OTHERS





QUESTION SECTION B-006-009:

ANTENNA GAIN, DIRECTIVITY AND PARASITIC ELEMENTS

PARASITIC ELEMENTS – THE KEY TO DIRECTIONAL ANTENNAS

- A **PARASITIC ELEMENT** IS NOT DIRECTLY CONNECTED TO THE FEEDLINE. IT IS ENERGIZED BY **INDUCTION OR RADIATION** FROM THE DRIVEN ELEMENT (THE ONE CONNECTED TO THE TRANSMITTER)
- ADDING ONE OR MORE PARASITIC ELEMENTS TO A **HALF-WAVE DIPOLE** INCREASES ITS **DIRECTIVITY** (FOCUSES RADIATION IN A PREFERRED DIRECTION)

PARASITIC ELEMENTS – THE KEY TO DIRECTIONAL ANTENNAS



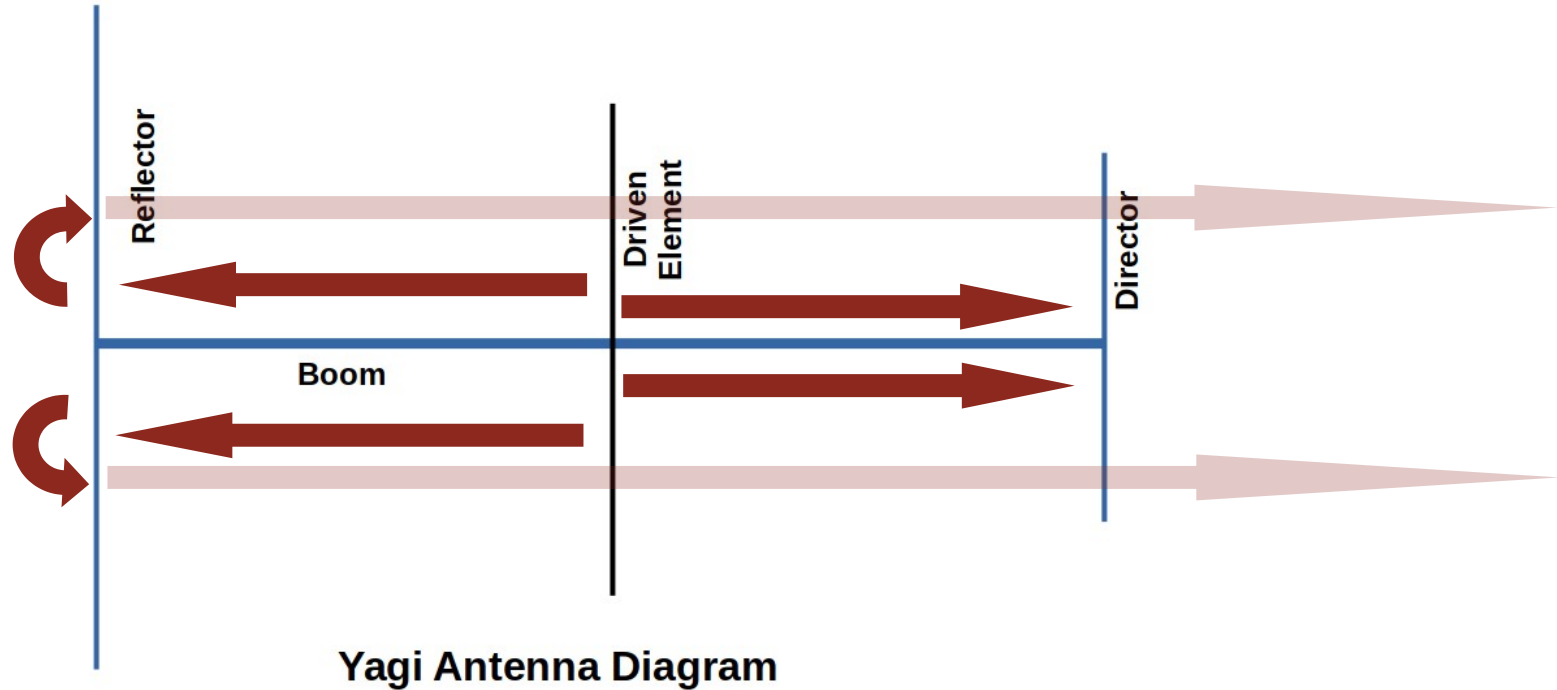
**YAGI-UDA
OR
“YAGI ANTENNA”
IS A
BEAM ANTENNA**

HOW PARASITIC ELEMENTS SHAPE THE PATTERN IN A YAGI

- ADDING A **SLIGHTLY SHORTER** PARASITIC ELEMENT (DIRECTOR) IN FRONT OF THE DRIVEN DIPOLE: RADIATION STRENGTH INCREASES FROM **THE DIPOLE TOWARDS THE NEW ELEMENT** (FORWARD DIRECTION).
- ADDING A **SLIGHTLY LONGER** PARASITIC ELEMENT (REFLECTOR) BEHIND THE DRIVEN DIPOLE: RADIATION STRENGTH INCREASES FROM **THE NEW ELEMENT TOWARDS THE DIPOLE** (ALSO FORWARD, AS THE REFLECTOR "PUSHES" ENERGY FORWARD).

B-006-009: ANTENNA GAIN, DIRECTIVITY AND PARASITIC ELEMENTS

HOW PARASITIC ELEMENTS SHAPE THE PATTERN IN A YAGI



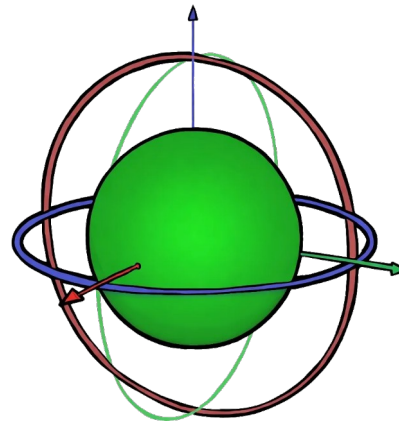
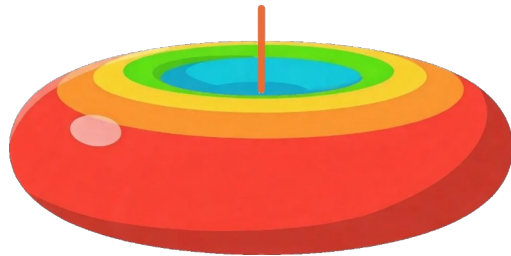
B-006-009: ANTENNA GAIN, DIRECTIVITY AND PARASITIC ELEMENTS

ANTENNA GAIN AND REFERENCES

- **ANTENNA GAIN** IS THE **RATIO OF THE RADIATED SIGNAL STRENGTH** OF AN ANTENNA TO THAT OF A REFERENCE ANTENNA (IN THE DIRECTION OF MAXIMUM RADIATION)
- GAIN CONCENTRATES POWER IN CERTAIN DIRECTIONS
- APPROXIMATE GAIN OF A HALF-WAVE DIPOLE IN FREE SPACE RELATIVE TO AN ISOTROPIC RADIATOR: 2.1 dB
- THE "i" IN dBi STANDS FOR **ISOTROPIC** (HYPOTHETICAL POINT SOURCE WITH SPHERICAL PATTERN)

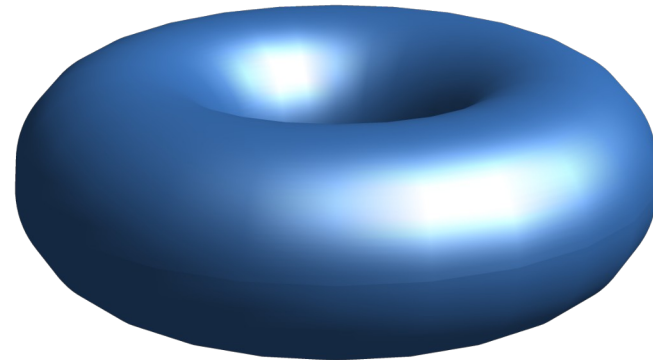
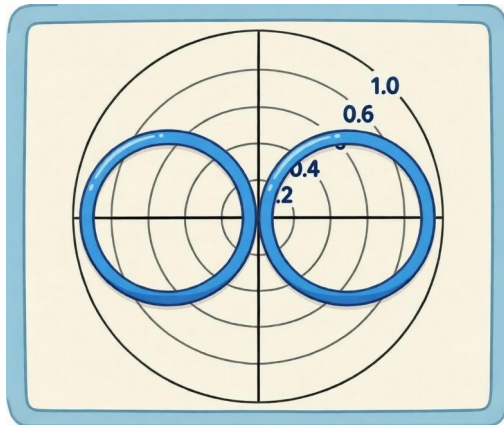
ANTENNA GAIN AND REFERENCES

- AN ANTENNA WITH 4.1 **dB*i*** GAIN HAS 2.0 dB GAIN OVER A HALF-WAVE DIPOLE (SINCE A DIPOLE IS ~2.1 dB*i* ; $4.1 - 2.1 = 2.0$ dB)



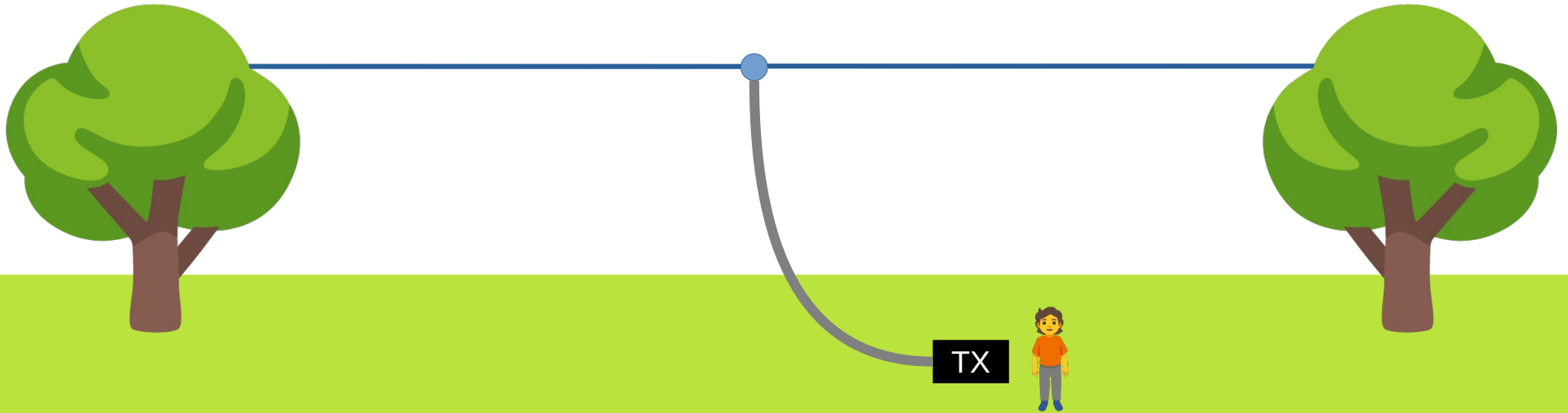
RADIATION PATTERN OF A HALF-WAVE DIPOLE

- IN FREE SPACE, A HALF-WAVE DIPOLE HAS **MAXIMUM RADIATION BROADSIDE (PERPENDICULAR)** TO THE ANTENNA WIRE — **FIGURE-8 PATTERN IN THE HORIZONTAL PLANE, DOUGHNUT-SHAPED IN 3D**



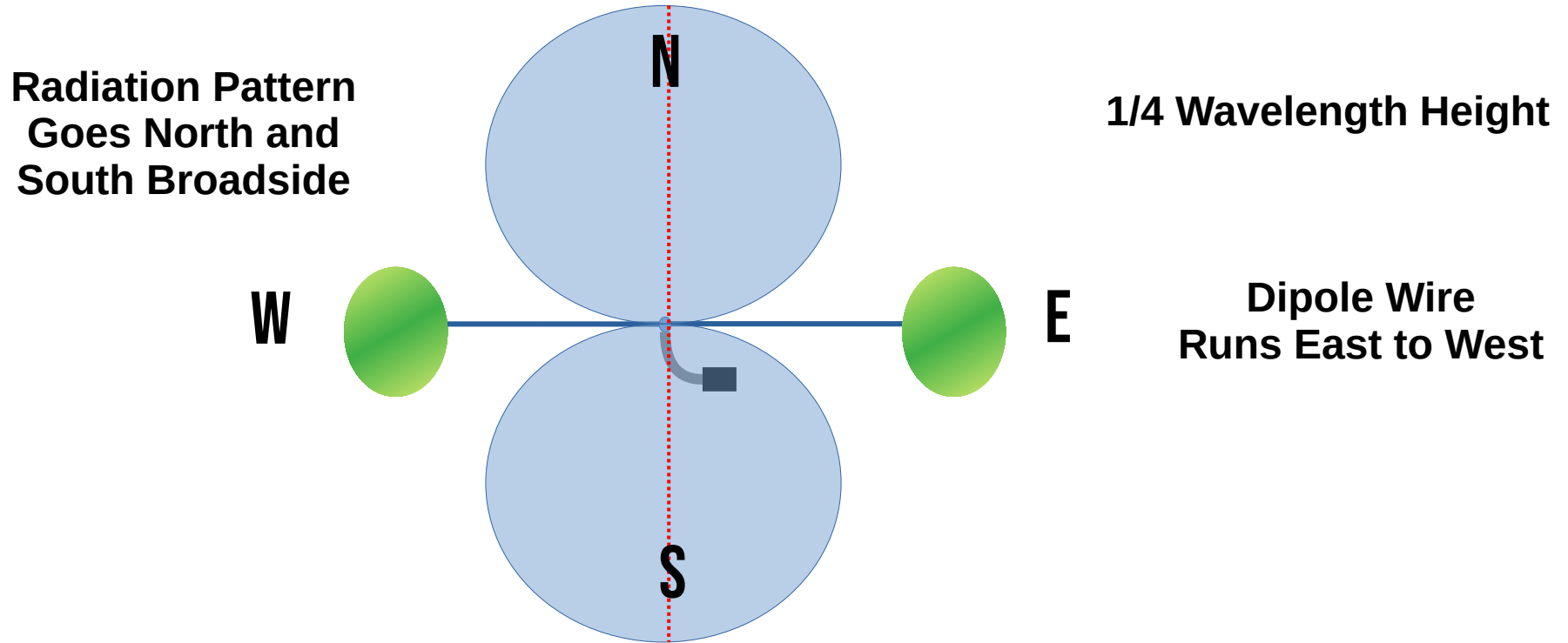
RADIATION PATTERN OF A HALF-WAVE DIPOLE

1/4 Wavelength Height



Side View, Broad Side the Antenna

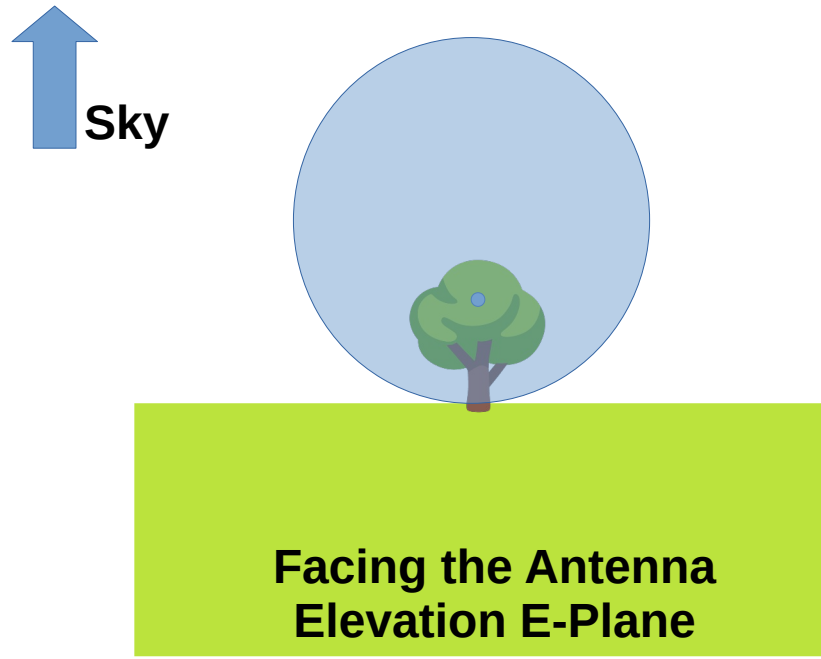
RADIATION PATTERN OF A HALF-WAVE DIPOLE



Top View looking Down on the Antenna
Horizontal H-Plane

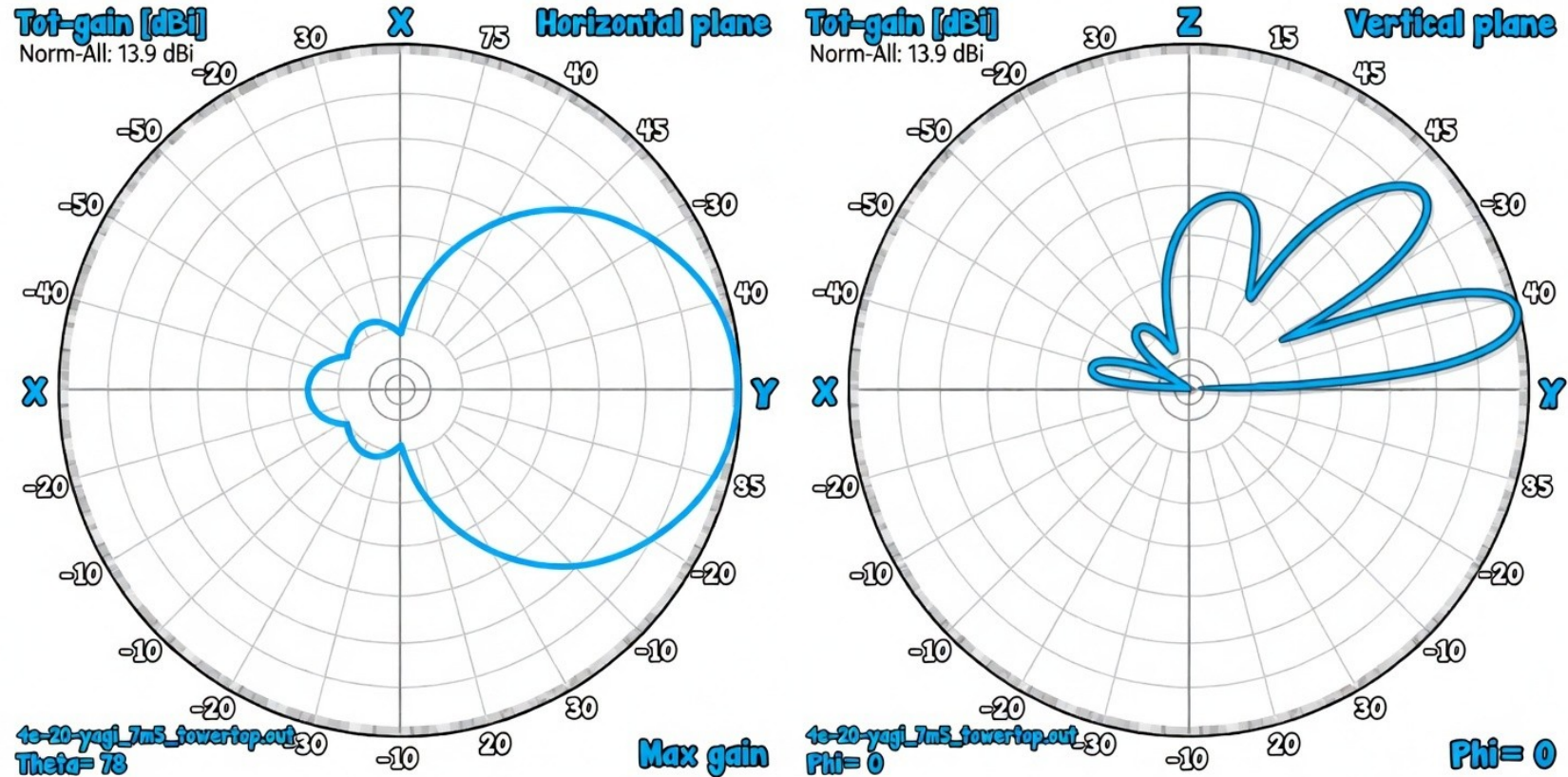
RADIATION PATTERN OF A HALF-WAVE DIPOLE

1/4 Wavelength Height



B-006-009: ANTENNA GAIN, DIRECTIVITY AND PARASITIC ELEMENTS

RADIATION PATTERN OF A BEAM ANTENNA





QUESTION SECTION B-006-010:

VERTICAL ANTENNAS AND GROUND

SYSTEMS

B-006-010: VERTICAL ANTENNAS AND GROUND SYSTEMS

CALCULATING QUARTER-WAVELENGTH ANTENNA LENGTH (FOR HF BELOW 30 MHz)

- A QUARTER-WAVELENGTH ($\lambda/4$) VERTICAL IS A POPULAR SIMPLE ANTENNA, ESPECIALLY FOR HF (BELOW 30 MHz). IT RADIATES OMNIDIRECTIONALLY IN THE HORIZONTAL PLANE WHEN PROPERLY INSTALLED.
- TO CALCULATE: **DIVIDE 71.3 BY THE OPERATING FREQUENCY IN MHz.**

WHERE DOES 71.3 COME FROM???

- TO FIND THE WAVELENGTH IN METRES WHEN THE FREQUENCY IS IN MEGAHERTZ WE USE OUR SAME FORMULA: $(\lambda) = 300/F \text{ (MHz)}$
- SINCE THIS IS A **QUARTER-WAVE $(1/4\lambda)$ DESIGN**, THE FREE-SPACE LENGTH MUST BE **DIVIDED BY 4**. $300/4 \times F = 75/F$
- WE APPLY THE **VELOCITY FACTOR** OF 0.95 TO ACCOUNT FOR THE WIRE ANTENNA'S IMPEDANCE. $75 \times 0.95 = 71.3$

B-006-010: VERTICAL ANTENNAS AND GROUND SYSTEMS

EXAMPLE CALCULATIONS FOR QUARTER-WAVE AND HALF-WAVE VERTICALS

- **QUESTION B-006-010-002: IF YOU MADE A QUARTER-WAVELENGTH VERTICAL ANTENNA FOR 21.125 MHZ, APPROXIMATELY HOW LONG WOULD IT BE? ANSWER: 3.37 METRES.**
- **CALCULATION:** $71.3 / 21.125 \approx 3.37$ M. THIS IS IN THE 15-METRE BAND — A COMPACT VERTICAL FOR HF.

B-006-010: VERTICAL ANTENNAS AND GROUND SYSTEMS

EXAMPLE CALCULATIONS FOR QUARTER-WAVE AND HALF-WAVE VERTICALS

- **QUESTION B-006-010-003: IF YOU MADE A HALF-WAVELENGTH VERTICAL ANTENNA FOR 223 MHz, APPROXIMATELY HOW LONG WOULD IT BE? ANSWER: 67 CM.**
- **HALF-WAVE IS TWICE THE QUARTER-WAVE LENGTH. AT VHF/UHF LIKE 1.25 M BAND, ANTENNAS ARE MUCH SHORTER.**
CALCULATION: $(300 / F) / 2 \approx 0.67 \text{ M OR } 67 \text{ CM.}$

B-006-010: VERTICAL ANTENNAS AND GROUND SYSTEMS

ADVANTAGES OF DIFFERENT VERTICAL LENGTHS - ESPECIALLY VHF/UHF MOBILE

- VERTICALS PERFORM DIFFERENTLY BASED ON ELECTRICAL LENGTH.
- A $5/8\lambda$ VERTICAL COMPRESSES THE RADIATION PATTERN TOWARD THE HORIZON, **PROVIDING MORE GAIN** — TYPICALLY 3 dB OR MORE OVER A $1/4\lambda$ — MAKING IT POPULAR FOR MOBILE VHF/UHF USE WHERE RANGE MATTERS.

RADIATION PATTERN OF A QUARTER-WAVE VERTICAL

- A $1/4\lambda$ VERTICAL HAS AN **OMNIDIRECTIONAL** PATTERN IN THE **HORIZONTAL PLANE**.
- THIS MAKES QUARTER-WAVE VERTICALS EXCELLENT FOR MOBILE OR BASE USE WHERE COVERAGE IN ALL DIRECTIONS IS NEEDED.

RADIATION PATTERN OF A QUARTER-WAVE VERTICAL

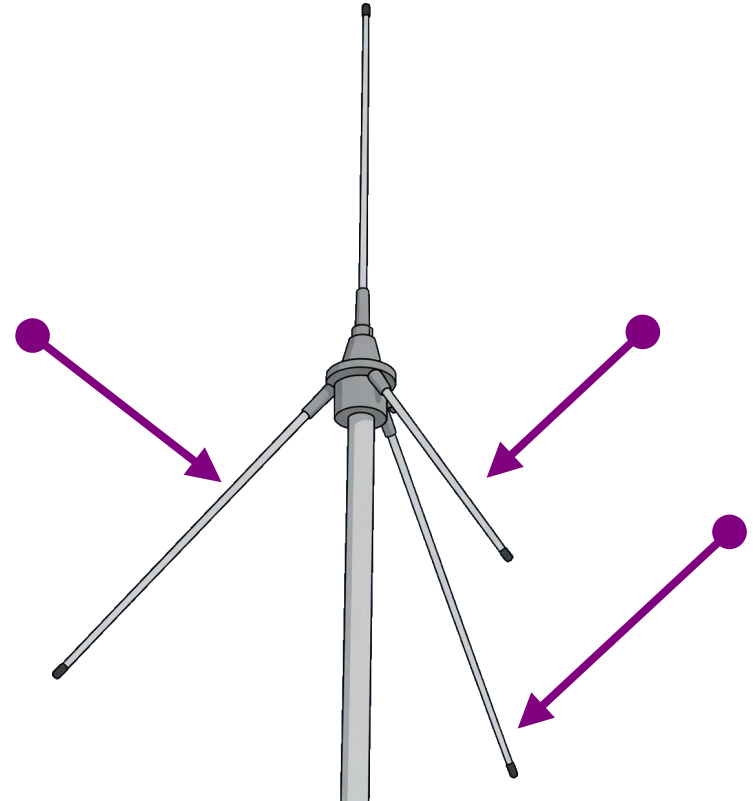


**RF GOES OUT EQUALLY WELL
IN ALL HORIZONTAL
DIRECTIONS.**

RADIAL SYSTEMS FOR GROUND PLANE / ELEVATED VERTICALS

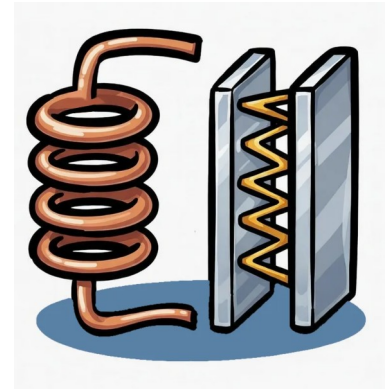
- **RADIALS** ARE ESSENTIAL FOR
A GOOD GROUND PLANE,
AFFECTING IMPEDANCE AND EFFICIENCY.

SLOPING RADIALS $\sim 30\text{--}45^\circ$ ADJUST THE
IMPEDANCE FROM $\sim 35\text{--}40$ OHMS (HORIZONTAL
RADIALS) TOWARD **50 OHMS**, IMPROVING MATCH
TO COMMON COAX.



PRACTICAL HF MOBILE VERTICALS: SHORT ANTENNAS AND LOADING

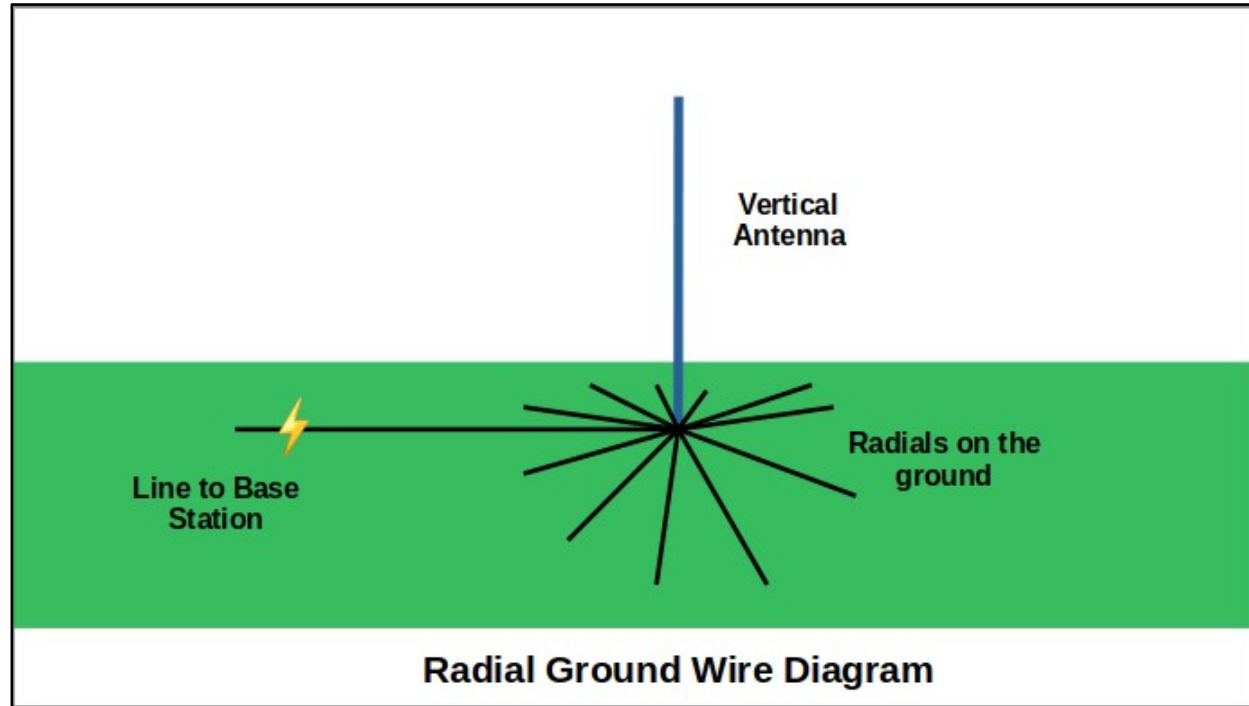
- HF MOBILE ANTENNAS ARE **PHYSICALLY SHORT** COMPARED TO **WAVELENGTH**, SO LOADING IS REQUIRED.
- **SHORT ANTENNAS** ARE **CAPACITIVE**
- THE COIL PROVIDES INDUCTIVE REACTANCE TO RESONATE THE SYSTEM.



B-006-010: VERTICAL ANTENNAS AND GROUND SYSTEMS

GROUND MOUNTED VERTICAL HF ANTENNAS

A **RADIAL FIELD** (EX: 16-60 WIRES, EACH $\sim \lambda/4$ LONG) CREATES AN EFFECTIVE RF GROUND, MINIMIZING LOSSES IN POOR SOIL AND IMPROVING EFFICIENCY.





QUESTION SECTION B-006-011:

YAGI ANTENNA DESIGN AND PERFORMANCE

MULTI-BAND YAGI DESIGN (TRAPS FOR HF BANDS)

- YAGI ANTENNAS ARE **DIRECTIONAL BEAMS** WITH HIGH GAIN, POPULAR ON HF FOR **FOCUSING POWER** IN ONE DIRECTION.
- **TRAPS** ARE PARALLEL LC CIRCUITS INSERTED IN ELEMENTS. THEY ACT AS INSULATORS AT HIGHER FREQUENCIES (ISOLATING OUTER SECTIONS) AND AS LOADING AT LOWER FREQUENCIES, ALLOWING ONE SET OF ELEMENTS TO RESONATE ON MULTIPLE BANDS LIKE 14 MHZ (20 M), 21 MHZ (15 M), AND 28 MHZ (10 M). THIS MAKES "TRIBAND" YAGIS PRACTICAL AND COMPACT.

MULTI-BAND YAGI DESIGN (TRAPS FOR HF BANDS)



APPROXIMATE ELEMENT LENGTHS FOR YAGI ANTENNAS

- YAGI ELEMENTS ARE BASED ON **HALF-WAVELENGTH DIPOLES**, WITH ADJUSTMENTS:
- **REFLECTOR** LONGER (5% LONGER),
- DRIVEN ELEMENT RESONANT,
- **DIRECTORS** SHORTER (5% SHORTER).

APPROXIMATE ELEMENT LENGTHS FOR YAGI ANTENNAS

- **DRIVEN ELEMENT:** $\sim 143 / F \text{ (MHz) METRES (OR CLOSE TO } 300 / F / 2 \text{ WITH VELOCITY FACTOR SHORTENING)}$.
- **REFLECTOR:** $\sim 152 / F \text{ METRES}$.
- **DIRECTOR:** $\sim 137 / F \text{ METRES}$.
- **THESE ARE PRACTICAL RULES-OF-THUMB FOR QUICK ESTIMATES FOR THE EXAM. REAL-LIFE DESIGNS VARY SLIGHTLY WITH ELEMENT DIAMETER, SPACING, AND BOOM EFFECTS.**

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

EXAMPLE CALCULATIONS FOR YAGI ELEMENTS

- **QUESTION B-006-011-002: WHAT IS THE APPROXIMATE LENGTH OF THE DRIVEN ELEMENT OF A YAGI ANTENNA FOR 14.0 MHz?**

ANSWER: 10.21 METRES.

- **CALCULATION:** $\sim 143 / 14 \approx 10.21 \text{ M.}$ THIS IS FOR THE 20-METRE BAND DRIVEN ELEMENT.

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

EXAMPLE CALCULATIONS FOR YAGI ELEMENTS

- **QUESTION B-006-011-003: WHAT IS THE APPROXIMATE LENGTH OF THE DIRECTOR ELEMENT OF A YAGI ANTENNA FOR 21.1 MHz?**

ANSWER: 6.44 METRES.

- **CALCULATION:** $\sim 137 / 21.1 \approx 6.49 \text{ M}$, CLOSE TO 6.44 M WITH TYPICAL SHORTENING FOR 15-METRE BAND DIRECTOR.

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

EXAMPLE CALCULATIONS FOR YAGI ELEMENTS

- **QUESTION B-006-011-004: WHAT IS THE APPROXIMATE LENGTH OF THE REFLECTOR ELEMENT OF A YAGI ANTENNA FOR 28.1 MHZ?**

ANSWER: 5.34 METRES.

- **CALCULATION:** $\sim 152 / 28.1 \approx 5.41 \text{ M}$, ADJUSTED TO $\sim 5.34 \text{ M}$ IN PRACTICE FOR 10-METRE BAND REFLECTOR.

IMPROVING GAIN IN YAGI ANTENNAS



- **ADDING ELEMENTS AND OPTIMIZING DESIGN BOOSTS DIRECTIVITY AND GAIN!**
- **LONGER BOOM + MORE DIRECTORS** NARROWS THE BEAM AND **INCREASES FORWARD GAIN** — TYPICALLY 1-2 dB PER ADDITIONAL DIRECTOR IN OPTIMIZED DESIGNS.
- **WIDER SPACING BETWEEN ELEMENTS** — ESPECIALLY DIRECTORS — ALLOWS BETTER CURRENT DISTRIBUTION AND PATTERN CONTROL, LEADING TO **HIGHER FORWARD GAIN**, THOUGH IT MAY NARROW BANDWIDTH OR AFFECT FRONT-TO-BACK RATIO.

WHY YAGIS ARE PRACTICAL ON HF (20-10 METRES)

- YAGIS SHINE ON HIGHER HF BANDS DUE TO **MANAGEABLE SIZE**.
- AT LOWER BANDS LIKE 40 M OR 80 M, ELEMENTS ARE VERY LONG (20-40+ M), MAKING ROTATION DIFFICULT/EXPENSIVE. ON 20-10 M, ELEMENTS ARE 5-10 M, SO ROTATABLE TOWERS/MASTS ARE PRACTICAL FOR POINTING THE BEAM TOWARD DESIRED CONTACTS.

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

KEY PERFORMANCE METRICS: FRONT-TO-BACK RATIO AND BANDWIDTH

- **FRONT-TO-BACK RATIO** IS HOW MUCH BETTER THE ANTENNA PERFORMS IN ITS MAIN FORWARD DIRECTION. THE "FRONT," (WHERE YOU WANT THE MAXIMUM SIGNAL TO GO) COMPARED TO THE OPPOSITE DIRECTION (THE "BACK," 180° AWAY).
- IT QUANTIFIES THE ANTENNA'S ABILITY TO **FOCUS ENERGY FORWARD** AND **REJECT OR MINIMIZE RADIATION/RECEPTION FROM BEHIND**.
- A HIGHER F/B RATIO MEANS THE ANTENNA IS MORE DIRECTIONAL — STRONGER FORWARD, WEAKER BACKWARD.

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

KEY PERFORMANCE METRICS: FRONT-TO-BACK RATIO AND BANDWIDTH

- **BANDWIDTH** DESCRIBES HOW "WIDE" A BAND OF FREQUENCIES THE ANTENNA CAN EFFECTIVELY TRANSMIT OR RECEIVE SIGNALS WITHOUT ITS PERFORMANCE DROPPING OFF TOO MUCH.
- A WIDER BANDWIDTH MEANS THE ANTENNA WORKS WELL ACROSS MORE FREQUENCIES (**BROADBAND**), WHILE A NARROW BANDWIDTH MEANS IT'S TUNED TIGHTLY TO A SPECIFIC FREQUENCY OR SMALL RANGE (**NARROWBAND**).
- THE TRADE OFF IS **CONVENIENCE** (WIDER RANGE OF OPERATING BANDWIDTH) VS. **GAIN** (NARROWER FREQUENCY = GREATER EFFICIENCY).
- **Q** (QUALITY FACTOR) - HOW EFFECTIVE A TUNED CIRCUIT WILL BE IN SELECTING ONLY A NARROW BAND OF FREQUENCIES.

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

KEY PERFORMANCE METRICS: FRONT-TO-BACK RATIO AND BANDWIDTH

- YOU CAN MAKE A YAGI HAVE GREATER BANDWIDTH BY USING THICKER ELEMENTS.
- THIS LOWERS Q-FACTOR, BROADENING RESONANCE AND SWR BANDWIDTH — USEFUL FOR COVERING FULL BANDS LIKE 10 M OR 15 M.
- THE BEST YAGI ELEMENT SPACING FOR A COMPROMISE BETWEEN GAIN AND FRONT-BACK RATIO IS 0.2λ
- SPACING BETWEEN DRIVEN/REFLECTOR AND DRIVEN/FIRST DIRECTOR OFFERS GOOD BALANCE: DECENT GAIN (7-8 dB) AND SOLID F/B (15-20 dB) WITHOUT EXCESSIVE BOOM LENGTH.)

B-006-011: YAGI ANTENNA DESIGN AND PERFORMANCE

STACKING YAGI ANTENNAS FOR EXTRA GAIN

- **STACKING** (VERTICAL OR HORIZONTAL) COMBINES MULTIPLE IDENTICAL YAGIS FOR **MORE GAIN**.
- QUESTION B-006-011-011: IF THE FORWARD GAIN OF A SIX-ELEMENT YAGI IS ABOUT 10 DBI, WHAT WOULD THE GAIN OF TWO OF THESE ANTENNAS BE IF THEY WERE "STACKED"? **ANSWER: 13 dBi.**
- PROPER STACKING OF TWO IDENTICAL ANTENNAS ADDS ≈ 3 dB GAIN DUE TO ARRAY FACTOR — POWER COMBINES COHERENTLY IN THE MAIN LOBE. THIS ASSUMES OPTIMAL SPACING, PHASING, AND FEED. REAL-WORLD MAY BE ~ 2.5 –3 dB.
- STACKING NARROWS VERTICAL BEAMWIDTH AND LOWERS TAKEOFF ANGLE, GREAT FOR DX.



QUESTION SECTION B-006-012:

DIPOLE AND RELATED WIRE ANTENNAS

HALF-WAVE DIPOLE LENGTH CALCULATIONS

- **THE HALF-WAVELENGTH** DIPOLE IS A FUNDAMENTAL, **BALANCED ANTENNA**.
- APPROXIMATE TOTAL LENGTH USES THE FORMULA:

$$\text{LENGTH (METRES)} = 143 / \text{FREQUENCY (MHz)}.$$

- $300/2 = 150$. 150×0.95 (VELOCITY FACTOR) = 143

HALF-WAVE DIPOLE LENGTH CALCULATIONS

- **QUESTION B-006-012-001: IF YOU MADE A HALF-WAVELENGTH DIPOLE ANTENNA FOR 28.150 MHZ, APPROXIMATELY HOW LONG WOULD IT BE? ANSWER: 5.08 METRES.**
- **CALCULATION: $143 / 28.150 = 5.08$ M. THIS IS FOR THE 10-METRE BAND**

HALF-WAVE DIPOLE LENGTH CALCULATIONS

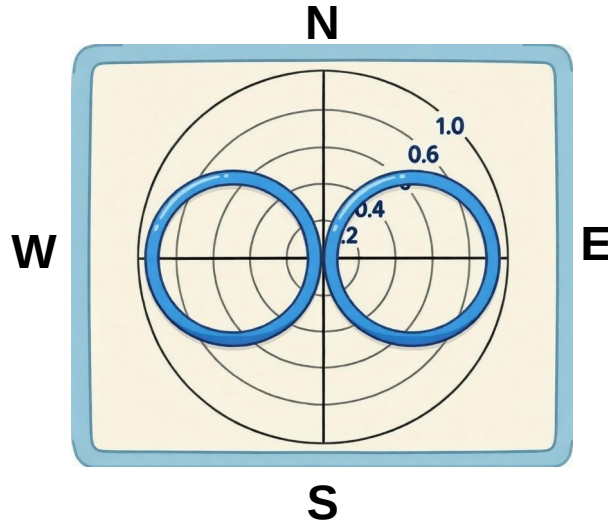
- **QUESTION B-006-012-009: IF YOU WERE TO CUT A HALF-WAVE DIPOLE FOR 3.75 MHZ, WHAT WOULD BE ITS APPROXIMATE LENGTH?**
ANSWER: 38.13 METRES.
- **CALCULATION:** $143 / 3.75 \approx 38.13 \text{ M.}$ THIS IS FOR THE 80-METRE BAND.

RADIATION PATTERN AND DIRECTIONAL CHARACTERISTICS

- IN FREE SPACE (IGNORING GROUND), A HALF-WAVE DIPOLE HAS A CLASSIC PATTERN; HEIGHT AND ORIENTATION AFFECT REAL-WORLD PERFORMANCE.
- MAXIMUM RADIATION IS **BROADSIDE/PERPENDICULAR** TO THE WIRE; MINIMUM OFF THE ENDS. THE 3D SHAPE RESEMBLES A **DOUGHNUT** (TORUS) WITH THE DIPOLE THROUGH THE HOLE.

RADIATION PATTERN AND DIRECTIONAL CHARACTERISTICS

- **BROADSIDE RADIATION:** MAXIMUM SIGNAL **PERPENDICULAR** TO THE WIRE. IF ENDS ARE NORTH/SOUTH, THE LOBES GO EAST/WEST.



FEED POINT IMPEDANCE

- **IMPEDANCE MATCHING IS KEY FOR LOW SWR AND EFFICIENT POWER TRANSFER.**
- **THEORETICAL VALUE IN FREE SPACE IS ABOUT 73 OHMS.**
- **IN PRACTICE, NEAR GROUND IT DROPS TO ~50-70 OHMS DEPENDING ON HEIGHT; EASY MATCH TO 50-OHM COAX WITH A 1:1 BALUN OR SLIGHT TRIMMING TO RESONANCE.**

DISADVANTAGES OF RANDOM WIRE ANTENNAS

- **RANDOM WIRES ARE SIMPLE BUT HAVE PRACTICAL ISSUES.**
- **NON-RESONANT LENGTHS CAUSE HIGH SWR AND COMMON-MODE CURRENTS ON THE FEED LINE, LEADING TO RF IN THE SHACK — DISTORTED AUDIO, HOT MICS, OR EQUIPMENT ISSUES.**
- **USE A GOOD TUNER AND COMMON-MODE CHOKE/1:1 BALUN TO MITIGATE.**

END-FED HALF-WAVE (EFHW) ANTENNAS

- EFHWs ARE POPULAR FOR SIMPLICITY AND MULTI-BAND CAPABILITY.
- WHEN FED AT THE END, AN EFHW IS RESONANT ON ITS FUNDAMENTAL AND ODD HARMONICS (EX: 40 M EFHW WORKS ON 15 M, 10 M TOO). WITH A 49:1 OR 64:1 UNUN/TRANSFORMER.)
- IT MATCHES WELL TO 50-OHM COAX FOR **MULTI-BAND OPERATION.**

TRAP ANTENNAS: ADVANTAGES AND DISADVANTAGES

- **TRAPS** ALLOW MULTI-BAND OPERATION ON A SINGLE WIRE OR BEAM.
- TRAPS ISOLATE SECTIONS AT HIGHER FREQUENCIES, LETTING ONE ANTENNA COVER **MULTIPLE BANDS** EFFICIENTLY. COMMON IN DIPOLES FOR 80/40/20 M OR TRIBAND YAGIS.
- TRAPS CAN CREATE ADDITIONAL RESONANCES OR ACT AS LOADING COILS, POTENTIALLY INCREASING **HARMONIC RADIATION** IF NOT DESIGNED CAREFULLY. USE LOW-PASS FILTERS OR CAREFUL TUNING TO REDUCE THIS.



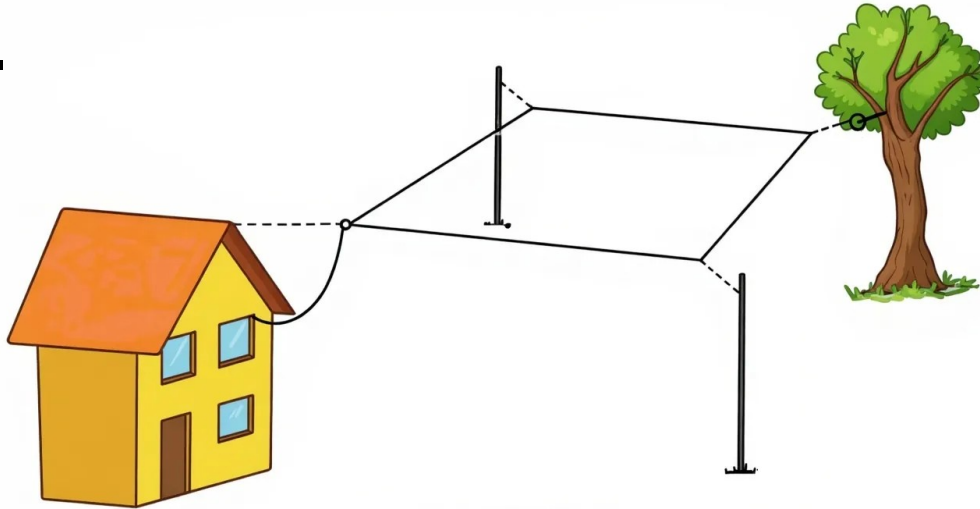
QUESTION SECTION B-006-013:

LOOP ANTENNAS (QUAD AND DELTA)

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

WHAT ARE LOOP ANTENNAS? (QUAD AND DELTA LOOP DEFINITIONS)

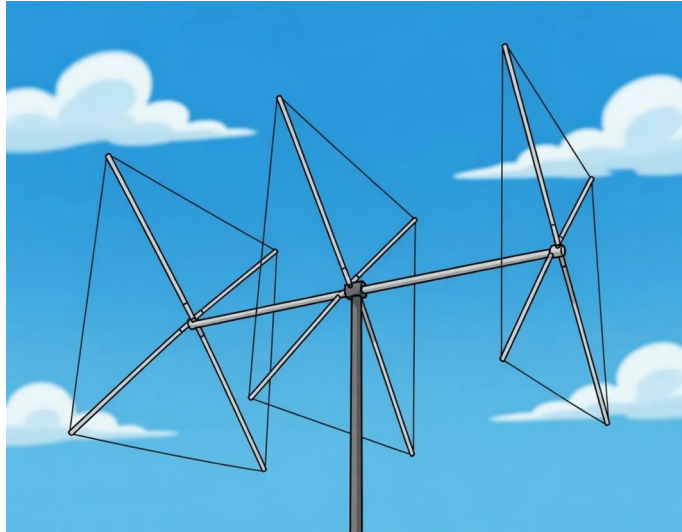
- **LOOP ANTENNAS** USE CLOSED WIRE LOOPS APPROXIMATELY **ONE FULL WAVELENGTH** IN CIRCUMFERENCE, OFFERING DIFFERENT RADIATION CHARACTERISTICS FROM DIPOLES OR YAGIS (OFTEN LOWER TAKEOFF ANGLE, QUIETER RECEIVE).



B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

WHAT ARE LOOP ANTENNAS? (QUAD AND DELTA LOOP DEFINITIONS)

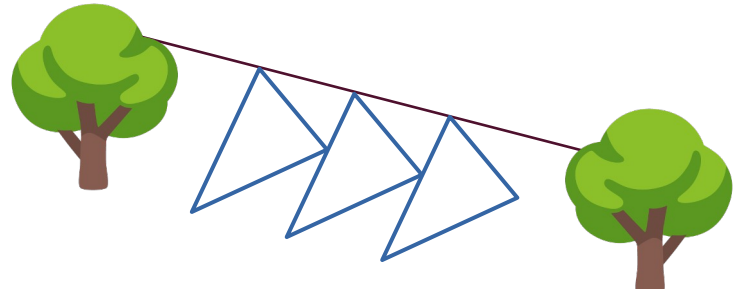
- A CLASSIC "**CUBICAL QUAD**" HAS A DRIVEN SQUARE LOOP PLUS PARASITIC REFLECTOR/DIRECTOR LOOPS ON A BOOM — SIMILAR TO A YAGI BUT WITH LOOPS INSTEAD OF LINEAR ELEMENTS. PROVIDES GOOD GAIN AND FRONT-TO-BACK RATIO.)



B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

WHAT ARE LOOP ANTENNAS? (QUAD AND DELTA LOOP DEFINITIONS)

- A **DELTA LOOP** ANTENNA IS A FULL WAVELENGTH LOOP IN THE SHAPE OF A TRIANGLE. IT'S NAMED AFTER THE GREEK LETTER DELTA (Δ) DUE TO THE TRIANGULAR SHAPE.
- IF YOU STACK THEM WITH ADDED PARASITIC DELTAS, IT BECOMES A DIRECTIONAL ARRAY LIKE A BEAM. SINGLE DELTA LOOPS ARE SIMPLE AND OFTEN HUNG VERTICALLY OR SLOPED.



APPROXIMATE LENGTH CALCULATIONS FOR LOOP ANTENNAS

- USE THE SAME FORMULA:

$$\lambda (\textit{metres}) = \frac{300}{f (\textit{MHz})}$$

- THEN MULTIPLY THE RESULT BY 1.02
- THIS IS AN ADJUSTMENT FOR VELOCITY FACTOR THAT THEY USE IN THE EXAM

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

APPROXIMATE LENGTH CALCULATIONS FOR LOOP ANTENNAS

- **QUESTION B-006-013-003: WHAT IS THE APPROXIMATE LENGTH OF THE DRIVEN ELEMENT OF A QUAD ANTENNA DESIGNED FOR 21.4 MHz? ANSWER: 14.30 METRES.**
- **CALCULATION: $300 / 21.4 = 14.02 \text{ M}$. $14.02 \times 1.02 = 14.30 \text{ M}$**

APPROXIMATE LENGTH CALCULATIONS FOR LOOP ANTENNAS

- QUESTION B-006-013-005: WHAT IS THE APPROXIMATE LENGTH OF A DELTA LOOP ANTENNA DESIGNED FOR 28.7 MHZ? **ANSWER: 10.66 METRES.**
- **CALCULATION:** $300 / 28.7 = 10.45 \text{ M.} \times 1.02 = 10.66 \text{ M}$ FOR 10-METRE BAND DELTA LOOP.

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

APPROXIMATE LENGTH CALCULATIONS FOR LOOP ANTENNAS

- QUESTION B-006-013-009: WHAT IS THE APPROXIMATE LENGTH OF THE WIRE FOR A HORIZONTAL LOOP TUNED AT 7.15 MHZ? **ANSWER: 42.80 METRES.**
- **CALCULATION:** $300 / 7.15 = 41.96 \text{ M.} \times 1.02 = 42.80 \text{ M.}$
- THIS IS OFTEN CALLED A "SKYLOOP" OR FULL-WAVE HORIZONTAL LOOP FOR 40M. MULTI-BAND CAPABLE WITH A TUNER.

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

POLARIZATION AND FEED POINT LOCATION

- POLARIZATION DEPENDS ON ORIENTATION AND FEED POINT — CRITICAL FOR MATCHING THE DESIRED RADIATION (HORIZONTAL FOR DX, VERTICAL FOR LOCAL/NVIS).
- QUESTION B-006-013-007: YOU ARE CONSTRUCTING AN HF DELTA LOOP ANTENNA. IT IS ORIENTED WITH THE BOTTOM ELEMENT PARALLEL TO THE GROUND. WHERE SHOULD YOU LOCATE THE FEED POINT FOR HORIZONTAL POLARIZATION? **ANSWER: IN THE CENTRE OF THE BOTTOM ELEMENT.**
- FEEDING AT THE CENTER OF THE HORIZONTAL SIDE EXCITES HORIZONTAL CURRENTS ACROSS THE LOOP, PRODUCING HORIZONTAL POLARIZATION

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

POLARIZATION AND FEED POINT LOCATION

- QUESTION B-006-013-008: MOVING THE FEED POINT OF A QUAD ANTENNA FROM A SIDE PARALLEL TO THE GROUND TO A SIDE PERPENDICULAR TO THE GROUND WILL HAVE WHAT EFFECT? **ANSWER: IT WILL CHANGE THE ANTENNA POLARIZATION FROM HORIZONTAL TO VERTICAL.**
- FEEDING A VERTICAL SIDE EXCITES VERTICAL CURRENTS, SWITCHING TO VERTICAL POLARIZATION — USEFUL FOR LOCAL OR GROUND-WAVE CONTACTS, BUT MAY RAISE TAKEOFF ANGLE.

B-006-013: LOOP ANTENNAS (QUAD AND DELTA)

ADVANTAGES AND DISADVANTAGES OF QUAD ANTENNAS

- **COMPARE TO YAGIS — QUADS OFFER SOME PERFORMANCE EDGES BUT PRACTICAL TRADE-OFFS.**
- **QUESTION B-006-013-006: WHAT IS A MAJOR DISADVANTAGE OF A QUAD ANTENNA, AS COMPARED TO A YAGI ANTENNA WITH THE SAME NUMBER OF ELEMENTS AND BOOM LENGTH? ANSWER: MORE SUSCEPTIBLE TO WEATHER DAMAGE.**
- **QUAD LOOPS USE MORE WIRE/SPREADER ARMS; ICE, WIND, OR BIRDS CAN DAMAGE THE STRUCTURE MORE EASILY THAN LINEAR YAGI ELEMENTS. QUADS ARE OFTEN LIGHTER AND HAVE SLIGHTLY HIGHER GAIN/BETTER F/B IN SOME DESIGNS, BUT MECHANICAL RELIABILITY IS A KEY DRAWBACK.**



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