

A DIY GUIDE BUILD YOUR OWN COMPACT MULTIBAND HF ANTENNA

A **DIY GUIDE BUILD YOUR OWN COMPACT MULTIBAND HF ANTENNA** OFFERS AMATEUR RADIO ENTHUSIASTS AND COMMUNICATIONS PROFESSIONALS A PRACTICAL AND COST-EFFECTIVE WAY TO ENHANCE THEIR HF OPERATIONS. THIS COMPREHENSIVE ARTICLE EXPLORES THE ESSENTIAL STEPS, MATERIALS, AND DESIGN CONSIDERATIONS NEEDED TO CONSTRUCT A VERSATILE AND COMPACT ANTENNA CAPABLE OF OPERATING ACROSS MULTIPLE HF BANDS. BY FOLLOWING THIS GUIDE, READERS WILL GAIN INSIGHTS INTO ANTENNA THEORY, COMPONENT SELECTION, AND ASSEMBLY TECHNIQUES THAT MAXIMIZE PERFORMANCE WHILE MINIMIZING SIZE. WHETHER FOR LIMITED SPACE ENVIRONMENTS OR PORTABLE USE, A WELL-DESIGNED MULTIBAND HF ANTENNA CAN SIGNIFICANTLY IMPROVE SIGNAL QUALITY AND RANGE. THE ARTICLE ALSO ADDRESSES COMMON CHALLENGES AND TROUBLESHOOTING TIPS TO ENSURE SUCCESSFUL IMPLEMENTATION. BELOW IS A DETAILED TABLE OF CONTENTS OUTLINING THE KEY SECTIONS OF THIS GUIDE.

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UNDERSTANDING MULTIBAND HF ANTENNAS

A MULTIBAND HF ANTENNA IS DESIGNED TO OPERATE EFFICIENTLY ACROSS SEVERAL HIGH-FREQUENCY AMATEUR RADIO BANDS. THESE ANTENNAS ENABLE COMMUNICATION OVER VARIOUS FREQUENCIES WITHOUT THE NEED FOR MULTIPLE ANTENNAS, WHICH IS ESPECIALLY ADVANTAGEOUS IN COMPACT OR SPACE-CONSTRAINED SETTINGS. UNDERSTANDING THE FUNDAMENTAL PRINCIPLES BEHIND MULTIBAND OPERATION, SUCH AS RESONANCE, IMPEDANCE MATCHING, AND BANDWIDTH, IS CRUCIAL FOR BUILDING AN EFFECTIVE ANTENNA. COMMON TYPES OF MULTIBAND ANTENNAS INCLUDE DIPOLES WITH TRAPS, FAN DIPOLES, AND END-FED DESIGNS, EACH WITH UNIQUE CHARACTERISTICS SUITED FOR DIFFERENT APPLICATIONS.

PRINCIPLES OF HF ANTENNA OPERATION

HF ANTENNAS FUNCTION BY CONVERTING RADIO FREQUENCY ELECTRICAL SIGNALS INTO ELECTROMAGNETIC WAVES AND VICE VERSA. KEY PARAMETERS INFLUENCING ANTENNA PERFORMANCE INCLUDE LENGTH, HEIGHT ABOVE GROUND, AND ELEMENT CONFIGURATION. RESONANCE OCCURS WHEN THE ANTENNA LENGTH CORRESPONDS TO A SPECIFIC FRACTION OF THE WAVELENGTH, ENSURING MAXIMUM ENERGY TRANSFER AND MINIMAL SIGNAL REFLECTION. IN MULTIBAND ANTENNAS, DESIGNERS MANIPULATE THESE PARAMETERS TO ACHIEVE RESONANCE ON MULTIPLE BANDS, OFTEN USING TRAPS OR PARALLEL ELEMENTS TO ISOLATE DIFFERENT FREQUENCY SEGMENTS.

ADVANTAGES OF A COMPACT DESIGN

COMPACT MULTIBAND HF ANTENNAS ARE PARTICULARLY BENEFICIAL FOR OPERATORS WITH LIMITED SPACE, SUCH AS URBAN LOCATIONS OR PORTABLE SETUPS. A REDUCED PHYSICAL FOOTPRINT MINIMIZES VISUAL IMPACT AND INSTALLATION COMPLEXITY, WHILE MAINTAINING OPERATIONAL FLEXIBILITY. A COMPACT DESIGN OFTEN REQUIRES INNOVATIVE ELEMENT ARRANGEMENTS AND EFFICIENT USE OF MATERIALS TO MAINTAIN PERFORMANCE WITHOUT EXCESSIVE SIZE OR WEIGHT.

PLANNING YOUR COMPACT MULTIBAND HF ANTENNA

EFFECTIVE PLANNING IS THE FOUNDATION OF A SUCCESSFUL DIY ANTENNA PROJECT. THIS PHASE INVOLVES SELECTING THE APPROPRIATE ANTENNA TYPE, DETERMINING FREQUENCY COVERAGE, AND CONSIDERING ENVIRONMENTAL FACTORS SUCH AS AVAILABLE SPACE AND MOUNTING OPTIONS. ESTABLISHING CLEAR PERFORMANCE GOALS AND CONSTRAINTS HELPS GUIDE DESIGN CHOICES AND MATERIAL PROCUREMENT.

CHOOSING THE RIGHT ANTENNA TYPE

SELECTING THE PROPER ANTENNA CONFIGURATION DEPENDS ON OPERATIONAL NEEDS AND PHYSICAL LIMITATIONS. POPULAR COMPACT MULTIBAND OPTIONS INCLUDE:

- **TRAP DIPOLES:** INCORPORATE INDUCTIVE TRAPS TO ISOLATE SECTIONS OF THE ANTENNA FOR DIFFERENT FREQUENCIES.
- **FAN DIPOLES:** UTILIZE MULTIPLE DIPOLE ELEMENTS CONNECTED TO A SINGLE FEED POINT, EACH CUT FOR A SPECIFIC BAND.
- **END-FED ANTENNAS:** EMPLOY A SINGLE WIRE FED AT ONE END, OFTEN WITH MATCHING UNITS TO COVER MULTIPLE BANDS.

UNDERSTANDING THE TRADE-OFFS OF EACH DESIGN, SUCH AS BANDWIDTH, COMPLEXITY, AND EASE OF CONSTRUCTION, IS ESSENTIAL FOR OPTIMAL SELECTION.

DETERMINING FREQUENCY BANDS

IDENTIFY THE HF BANDS YOU INTEND TO OPERATE ON, COMMONLY INCLUDING 80M, 40M, 20M, 15M, AND 10M AMATEUR BANDS. ACCURATE CALCULATION OF ELEMENT LENGTHS FOR EACH FREQUENCY BAND ENSURES EFFICIENT RESONANCE AND SIGNAL TRANSMISSION. USING FORMULAS BASED ON WAVELENGTH, ANTENNA DIMENSIONS ARE TAILORED TO TARGET FREQUENCIES, BALANCING SIZE AND PERFORMANCE.

MATERIALS AND TOOLS REQUIRED

GATHERING QUALITY MATERIALS AND PROPER TOOLS IS CRITICAL FOR BUILDING A DURABLE AND EFFICIENT COMPACT MULTIBAND HF ANTENNA. THE SELECTION OF COMPONENTS AFFECTS BOTH THE ANTENNA'S ELECTRICAL PROPERTIES AND ITS LONGEVITY IN OUTDOOR ENVIRONMENTS.

ESSENTIAL MATERIALS

THE FOLLOWING MATERIALS ARE COMMONLY REQUIRED:

- **CONDUCTIVE WIRE:** COPPER OR COPPER-CLAD STEEL WIRE, TYPICALLY 14 TO 18 GAUGE, FOR ANTENNA ELEMENTS.
- **INSULATORS:** DURABLE PLASTIC OR CERAMIC INSULATORS TO SUPPORT WIRE ENDS AND PREVENT ELECTRICAL SHORTS.
- **COILS OR TRAPS:** INDUCTORS MADE FROM ENAMELED WIRE AND PVC FORMS, USED IN TRAP DIPOLE DESIGNS.
- **FEEDLINE:** 50-OHM COAXIAL CABLE FOR CONNECTING THE ANTENNA TO THE TRANSCEIVER.
- **BALUN OR UNUN:** TRANSFORMERS TO MATCH IMPEDANCE AND REDUCE FEEDLINE RADIATION.
- **CONNECTORS AND HARDWARE:** WEATHER-RESISTANT CONNECTORS, CLAMPS, AND MOUNTING BRACKETS.

REQUIRED TOOLS

ESSENTIAL TOOLS INCLUDE WIRE CUTTERS, SOLDERING IRON, MULTIMETER OR ANTENNA ANALYZER, MEASURING TAPE, AND HAND TOOLS SUCH AS PLIERS AND SCREWDRIVERS. HAVING A LADDER OR SUITABLE CLIMBING EQUIPMENT MAY BE NECESSARY FOR INSTALLATION AT HEIGHT.

STEP-BY-STEP CONSTRUCTION PROCESS

THE CONSTRUCTION PHASE TRANSLATES PLANNING INTO A PHYSICAL ANTENNA. PRECISION AND ATTENTION TO DETAIL DURING THIS STAGE ENSURE OPTIMAL FUNCTIONALITY AND DURABILITY.

MEASURING AND CUTTING ELEMENTS

CALCULATE THE LENGTH OF EACH ANTENNA ELEMENT BASED ON TARGET FREQUENCIES USING THE FORMULA: $\text{LENGTH (FEET)} = 468 / \text{FREQUENCY (MHz)}$. CUT WIRES ACCURATELY AND ALLOW FOR TRIMMING DURING TUNING. LABEL ELEMENTS CLEARLY TO AVOID CONFUSION DURING ASSEMBLY.

ASSEMBLING TRAPS OR MULTIPLE ELEMENTS

FOR TRAP DIPOLES, WIND INDUCTIVE COILS WITH SPECIFIED TURNS AND DIAMETER ON NON-CONDUCTIVE FORMS. SECURE TRAPS FIRMLY AND CONNECT THEM IN SERIES WITH ANTENNA ELEMENTS. FOR FAN DIPOLES, ATTACH MULTIPLE DIPOLE ELEMENTS TO A COMMON FEED POINT USING A STURDY TERMINAL BLOCK OR RING CONNECTOR.

INSTALLING INSULATORS AND FEEDLINE

ATTACH INSULATORS AT WIRE ENDS AND APPROPRIATE POINTS ALONG THE ANTENNA TO MAINTAIN SPACING AND PREVENT SHORTS. CONNECT THE FEEDLINE TO THE ANTENNA USING A BALUN OR UNUN TO ENSURE IMPEDANCE MATCHING AND REDUCE COMMON-MODE CURRENTS. WEATHERPROOF ALL CONNECTIONS WITH APPROPRIATE SEALANTS OR TAPE.

TUNING AND TESTING YOUR ANTENNA

PROPER TUNING AND TESTING MAXIMIZE ANTENNA PERFORMANCE AND ENSURE SAFE OPERATION. THIS STEP INVOLVES MEASURING RESONANCE, ADJUSTING ELEMENT LENGTHS, AND VERIFYING FEEDLINE INTEGRITY.

USING AN ANTENNA ANALYZER

AN ANTENNA ANALYZER MEASURES THE STANDING WAVE RATIO (SWR) AND IMPEDANCE ACROSS FREQUENCIES. CONNECT THE ANALYZER AT THE FEEDPOINT AND SWEEP THROUGH THE DESIRED BANDS TO IDENTIFY RESONANCE POINTS. ADJUST ELEMENT LENGTHS BY TRIMMING OR EXTENDING WIRES TO ACHIEVE MINIMUM SWR NEAR TARGET FREQUENCIES.

COMMON TROUBLESHOOTING TIPS

ISSUES SUCH AS HIGH SWR, POOR RADIATION PATTERNS, OR UNEXPECTED RESONANCE CAN ARISE. VERIFY ALL CONNECTIONS ARE SECURE AND FREE FROM CORROSION. CHECK FOR NEARBY CONDUCTIVE OBJECTS THAT MAY DETUNE THE ANTENNA. RE-EXAMINE ELEMENT LENGTHS AND ENSURE TRAPS OR COILS ARE CORRECTLY CONSTRUCTED AND POSITIONED.

INSTALLATION AND MAINTENANCE TIPS

PROPER INSTALLATION AND ROUTINE MAINTENANCE EXTEND THE LIFE AND PERFORMANCE OF A COMPACT MULTIBAND HF ANTENNA. CONSIDER ENVIRONMENTAL FACTORS AND SAFETY DURING SETUP.

OPTIMAL MOUNTING TECHNIQUES

INSTALL THE ANTENNA AT AN APPROPRIATE HEIGHT AND ORIENTATION TO MAXIMIZE SIGNAL PROPAGATION. USE NON-CONDUCTIVE SUPPORTS SUCH AS FIBERGLASS POLES OR INSULATED ROPES. ENSURE THE ANTENNA IS CLEAR OF OBSTRUCTIONS LIKE TREES, BUILDINGS, AND POWER LINES TO MINIMIZE SIGNAL DEGRADATION AND SAFETY HAZARDS.

ROUTINE INSPECTION AND CARE

PERIODICALLY INSPECT THE ANTENNA FOR SIGNS OF WEAR, CORROSION, OR MECHANICAL DAMAGE. TIGHTEN LOOSE CONNECTIONS AND REPLACE WEATHERED COMPONENTS AS NEEDED. CLEAN INSULATORS AND CONNECTORS TO MAINTAIN ELECTRICAL INTEGRITY. PROPER CARE ENSURES CONSISTENT MULTIBAND PERFORMANCE OVER TIME.

FREQUENTLY ASKED QUESTIONS

WHAT MATERIALS DO I NEED TO BUILD A COMPACT MULTIBAND HF ANTENNA?

TO BUILD A COMPACT MULTIBAND HF ANTENNA, YOU TYPICALLY NEED INSULATED COPPER WIRE, A SUITABLE ANTENNA TUNER OR MATCHING NETWORK, A BALUN (1:1 OR 4:1 DEPENDING ON DESIGN), INSULATORS, COAXIAL CABLE (LIKE RG-58 OR RG-8), CONNECTORS (SUCH AS PL-259), MOUNTING HARDWARE, AND TOOLS LIKE A SOLDERING IRON, WIRE CUTTERS, AND A MEASURING TAPE.

HOW CAN I ENSURE MY DIY MULTIBAND HF ANTENNA COVERS MULTIPLE BANDS EFFECTIVELY?

USING AN ANTENNA DESIGN LIKE A FAN DIPOLE, TRAP DIPOLE, OR AN END-FED MULTIBAND ANTENNA WITH TRAPS OR LOADING COILS ALLOWS EFFICIENT OPERATION ON MULTIPLE HF BANDS. PROPERLY CALCULATING AND ADJUSTING THE LENGTHS OF EACH ELEMENT FOR SPECIFIC FREQUENCIES AND INCORPORATING AN ANTENNA TUNER CAN HELP ACHIEVE GOOD PERFORMANCE ACROSS BANDS.

WHAT IS THE BEST COMPACT DESIGN FOR A MULTIBAND HF ANTENNA FOR LIMITED SPACE?

A POPULAR COMPACT DESIGN FOR LIMITED SPACE IS THE TRAPPED DIPOLE OR AN END-FED HALF-WAVE ANTENNA COMBINED WITH A SUITABLE MATCHING NETWORK. VERTICAL OR INVERTED-V CONFIGURATIONS CAN ALSO SAVE SPACE. ADDITIONALLY, USING LOADING COILS OR TRAPS HELPS REDUCE THE OVERALL PHYSICAL LENGTH WHILE MAINTAINING RESONANCE ON MULTIPLE BANDS.

HOW DO I TUNE MY HOMEMADE MULTIBAND HF ANTENNA FOR OPTIMAL PERFORMANCE?

YOU CAN TUNE YOUR ANTENNA BY MEASURING THE STANDING WAVE RATIO (SWR) ON EACH DESIRED BAND USING AN SWR METER OR ANTENNA ANALYZER. ADJUST THE ELEMENT LENGTHS OR TRAP POSITIONS AS NEEDED TO MINIMIZE SWR. USING AN ANTENNA TUNER CAN FURTHER HELP MATCH THE ANTENNA IMPEDANCE TO YOUR TRANSCEIVER FOR OPTIMAL POWER TRANSFER.

CAN I USE HOUSEHOLD MATERIALS FOR BUILDING A COMPACT MULTIBAND HF ANTENNA?

YES, MANY HOUSEHOLD MATERIALS CAN BE REPURPOSED, SUCH AS INSULATED COPPER WIRE FROM OLD CABLES, PVC PIPES FOR

SUPPORT STRUCTURES, AND PLASTIC INSULATORS. HOWEVER, IT'S IMPORTANT TO ENSURE THE MATERIALS HAVE GOOD ELECTRICAL PROPERTIES AND WEATHER RESISTANCE TO MAINTAIN ANTENNA PERFORMANCE AND DURABILITY.

How do traps work in a multiband HF antenna?

TRAPS ARE PARALLEL LC CIRCUITS (INDUCTORS AND CAPACITORS) INSERTED INTO ANTENNA ELEMENTS. THEY ACT AS FREQUENCY-SELECTIVE FILTERS, ALLOWING THE ANTENNA TO BEHAVE LIKE DIFFERENT LENGTHS AT DIFFERENT FREQUENCIES. THIS ENABLES A SINGLE ANTENNA ELEMENT TO RESONATE ON MULTIPLE BANDS, MAKING THE ANTENNA MULTIBAND WHILE KEEPING IT COMPACT.

What are common mistakes to avoid when building a DIY compact multiband HF antenna?

COMMON MISTAKES INCLUDE INACCURATE ELEMENT LENGTH MEASUREMENTS, POOR SOLDERING OR CONNECTIONS CAUSING LOSSES, INSUFFICIENT INSULATION LEADING TO WEATHER DAMAGE, NOT USING A PROPER BALUN RESULTING IN FEEDLINE RADIATION, AND NEGLECTING TO CHECK SWR AND TUNE THE ANTENNA WHICH CAN CAUSE INEFFICIENT OPERATION OR DAMAGE TO THE TRANSMITTER.

How can I mount my compact multiband HF antenna for best performance?

MOUNT THE ANTENNA AS HIGH AND CLEAR OF OBSTRUCTIONS AS POSSIBLE, USING NON-CONDUCTIVE SUPPORTS LIKE PVC POLES OR FIBERGLASS MASTS. ENSURE THE FEEDLINE IS ROUTED AWAY FROM METAL OBJECTS AND KEEP THE ANTENNA ELEMENTS PROPERLY TENSIONED AND INSULATED. AN INVERTED-V CONFIGURATION CAN HELP REDUCE REQUIRED HEIGHT AND IMPROVE STABILITY IN LIMITED SPACES.

Additional Resources

1. *DIY Multiband HF Antennas: A Practical Guide for Amateur Radio Enthusiasts*

THIS BOOK OFFERS STEP-BY-STEP INSTRUCTIONS ON BUILDING COMPACT MULTIBAND HF ANTENNAS TAILORED FOR AMATEUR RADIO OPERATORS. IT COVERS ESSENTIAL MATERIALS, DESIGN PRINCIPLES, AND TUNING TECHNIQUES TO OPTIMIZE ANTENNA PERFORMANCE ACROSS MULTIPLE HF BANDS. READERS WILL FIND DETAILED DIAGRAMS AND TROUBLESHOOTING TIPS TO ENSURE SUCCESSFUL ANTENNA CONSTRUCTION AND OPERATION.

2. *Compact HF Antenna Designs: Building Efficient Multiband Solutions*

FOCUSED ON SPACE-SAVING ANTENNA DESIGNS, THIS GUIDE EXPLORES VARIOUS COMPACT MULTIBAND HF ANTENNAS SUITABLE FOR LIMITED OUTDOOR AREAS. IT PROVIDES INSIGHTS INTO ANTENNA THEORY, CONSTRUCTION METHODS, AND INSTALLATION STRATEGIES TO MAXIMIZE SIGNAL STRENGTH AND MINIMIZE INTERFERENCE. THE BOOK ALSO INCLUDES REAL-WORLD EXAMPLES AND PERFORMANCE COMPARISONS.

3. *The Ham Radio Operator's Guide to DIY Multiband HF Antennas*

AIMED AT HAM RADIO OPERATORS, THIS COMPREHENSIVE MANUAL EXPLAINS HOW TO DESIGN AND BUILD YOUR OWN MULTIBAND HF ANTENNAS WITH COMPACT FOOTPRINTS. IT DISCUSSES DIFFERENT ANTENNA TYPES, FEEDLINE OPTIONS, AND GROUNDING TECHNIQUES TO ENHANCE TRANSMISSION QUALITY. THE GUIDE ALSO HIGHLIGHTS COST-EFFECTIVE MATERIALS AND TOOLS FOR BUDGET-CONSCIOUS BUILDERS.

4. *Building Your Own Compact HF Antenna: Multiband Techniques for Beginners*

PERFECT FOR BEGINNERS, THIS BOOK BREAKS DOWN COMPLEX ANTENNA CONCEPTS INTO SIMPLE, UNDERSTANDABLE STEPS. IT FOCUSES ON CONSTRUCTING COMPACT MULTIBAND HF ANTENNAS USING READILY AVAILABLE MATERIALS, EMPHASIZING SAFETY AND EASE OF ASSEMBLY. READERS WILL APPRECIATE THE PRACTICAL ADVICE AND ILLUSTRATED INSTRUCTIONS THAT MAKE ANTENNA BUILDING ACCESSIBLE.

5. *Multiband HF Antennas for Small Spaces: DIY Projects and Plans*

THIS BOOK TARGETS RADIO ENTHUSIASTS WITH LIMITED INSTALLATION SPACE, OFFERING MULTIPLE DIY PROJECTS FOR COMPACT MULTIBAND HF ANTENNAS. EACH PROJECT INCLUDES DETAILED PLANS, MATERIAL LISTS, AND PERFORMANCE EXPECTATIONS. THE AUTHOR ALSO SHARES TIPS ON OPTIMIZING ANTENNA PLACEMENT AND MINIMIZING ENVIRONMENTAL IMPACTS.

6. EFFICIENT COMPACT MULTIBAND HF ANTENNAS: DESIGN, BUILD, AND OPTIMIZE

DELVING INTO THE SCIENCE OF ANTENNA EFFICIENCY, THIS GUIDE HELPS READERS DESIGN AND BUILD COMPACT MULTIBAND HF ANTENNAS THAT DELIVER SUPERIOR PERFORMANCE. IT COVERS ADVANCED TUNING METHODS, IMPEDANCE MATCHING, AND THE USE OF BALUNS AND TRAPS. THE BOOK IS IDEAL FOR THOSE SEEKING TO ENHANCE THEIR ANTENNA'S CAPABILITY THROUGH CAREFUL OPTIMIZATION.

7. PORTABLE MULTIBAND HF ANTENNAS: DIY BUILDS FOR FIELD OPERATIONS

FOCUSED ON PORTABILITY, THIS BOOK INSTRUCTS HOW TO CREATE LIGHTWEIGHT, COMPACT MULTIBAND HF ANTENNAS FOR FIELD AND EMERGENCY USE. IT INCLUDES CONSTRUCTION TECHNIQUES THAT FACILITATE QUICK ASSEMBLY AND DISASSEMBLY WITHOUT SACRIFICING PERFORMANCE. THE GUIDE ALSO DISCUSSES MATERIALS THAT WITHSTAND OUTDOOR CONDITIONS AND PROVIDE RELIABLE SIGNAL TRANSMISSION.

8. HANDS-ON GUIDE TO BUILDING COMPACT HF MULTIBAND ANTENNAS

THIS PRACTICAL HANDBOOK EMPHASIZES HANDS-ON LEARNING WITH NUMEROUS DIY ANTENNA BUILDING PROJECTS SUITABLE FOR VARIOUS HF BANDS. IT OFFERS CLEAR INSTRUCTIONS, PHOTOS, AND TROUBLESHOOTING ADVICE TO HELP READERS BUILD EFFECTIVE COMPACT ANTENNAS. THE BOOK IS SUITABLE FOR HOBBYISTS SEEKING TO IMPROVE THEIR TECHNICAL SKILLS AND ANTENNA SETUP.

9. SMART ANTENNA SOLUTIONS: DIY COMPACT MULTIBAND HF ANTENNAS FOR MODERN HAM RADIO

ADDRESSING MODERN HAM RADIO NEEDS, THIS BOOK PRESENTS SMART DESIGN SOLUTIONS FOR COMPACT MULTIBAND HF ANTENNAS USING INNOVATIVE MATERIALS AND TECHNIQUES. IT EXPLORES INTEGRATING ANTENNA TUNERS, AUTOMATED MATCHING SYSTEMS, AND SPACE-EFFICIENT LAYOUTS. READERS WILL FIND GUIDANCE ON BUILDING ANTENNAS THAT MEET CONTEMPORARY OPERATIONAL DEMANDS WITH MINIMAL FOOTPRINT.

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