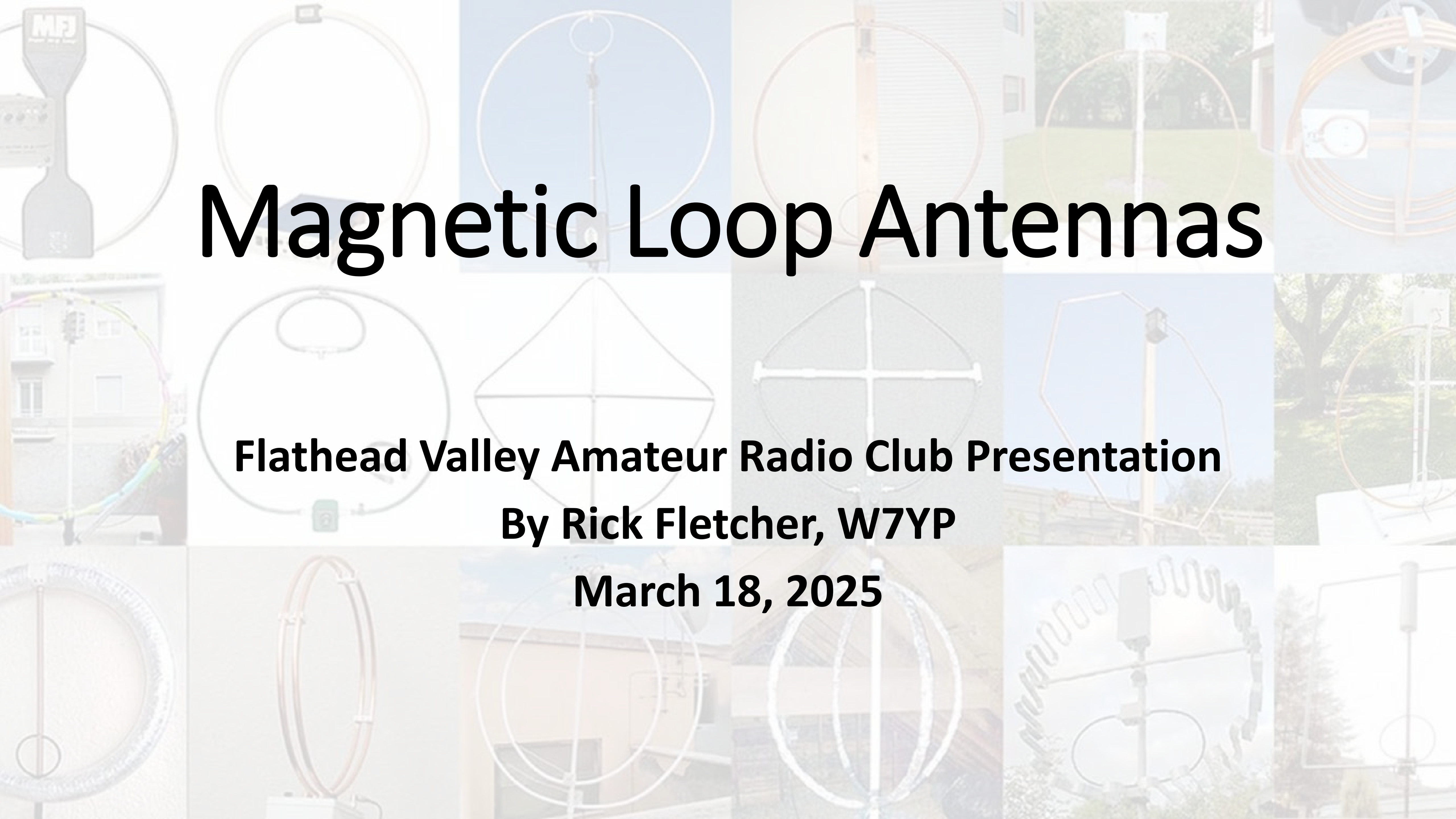

Magnetic Loop Antennas

Flathead Valley Amateur Radio Club Presentation

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March 18, 2025

Topics

- What is a Magnetic Loop Antenna?
- When Might You Use a Magnetic Loop Antenna?
- Theory of Operation
- Loop Radiation Characteristics
- Receiving Properties
- Design Considerations
- Optimization
- Commercial Offerings
- Q&A

NOTE: This presentation will only be discussing vertically-oriented small loop antennas

What is a Magnetic Loop Antenna?

- A RX-only or RX/TX antenna which uses a metallic conductive loop which is typically much smaller than half the operating wavelength
  - Circumference is typically somewhere between 1/8th and 1/3rd λ
    - When it has roughly uniform current distribution, it behaves like a lumped inductance
  - Primarily ‘senses’ the H-field, rather than the E-field
    - ‘Converts’ the magnetic field to an electrical signal
- A small HF antenna which, if properly designed and tuned, can perform quite well when compared to a large HF antenna
  - Difference in signal strength can be reduced to 1 or 2 S-units
  - A properly designed loop of 1m diameter will outperform any antenna type except a triband beam on 10m/15m/20m
    - Will be within an S-unit (6 dB) of a 3-element monobander at ½ λ above ground
- Sounds good, so what’s the catch?
  - Physics will not be mocked – the one unavoidable price for using an electrically-small antenna is narrow bandwidth
  - Narrow instantaneous bandwidth, rather than poor efficiency, is the fundamental trade-off with small loops

Typical Construction

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

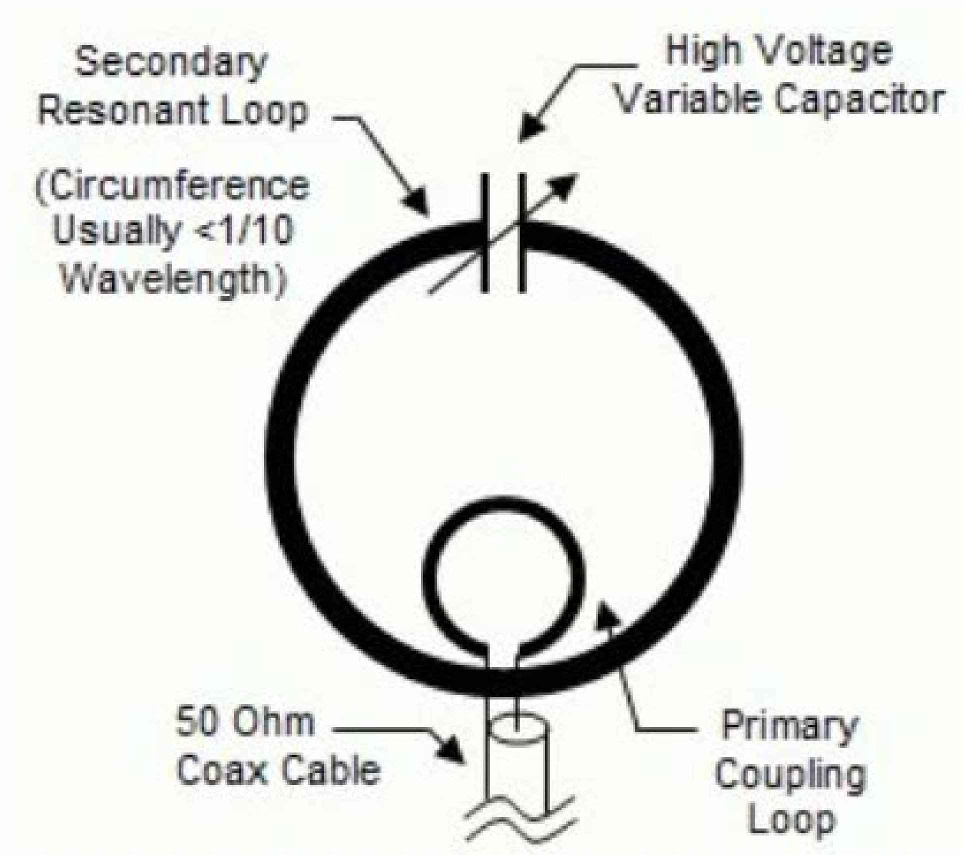
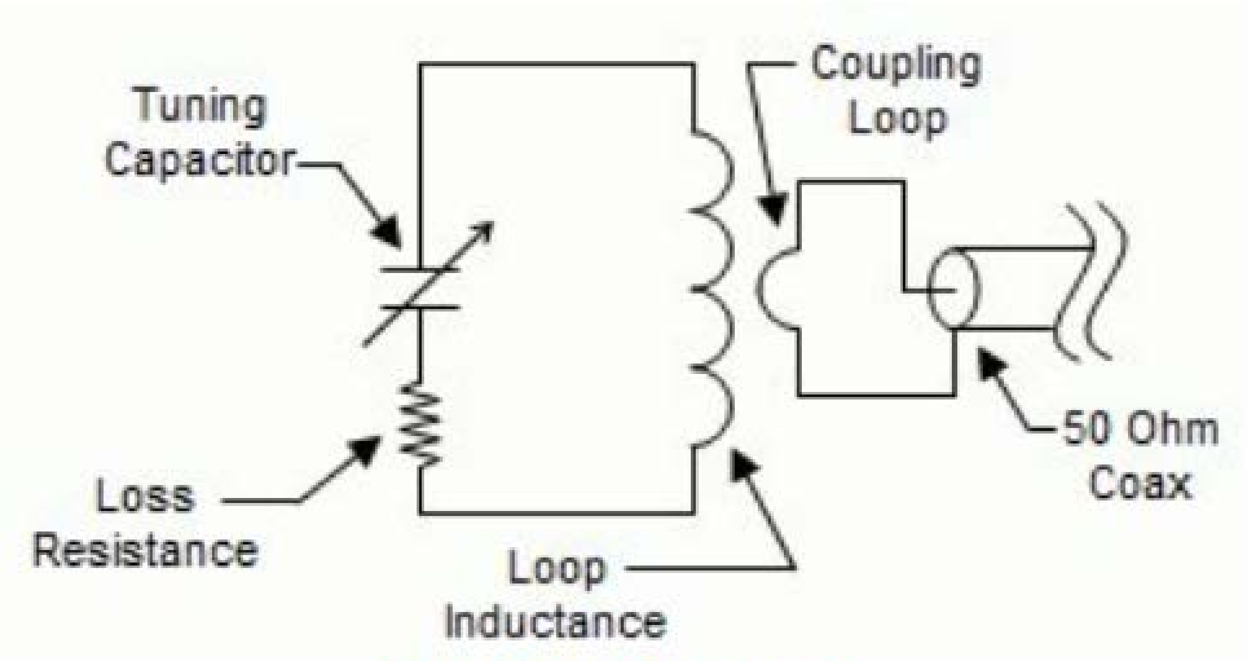


Diagram of a Small Loop Antenna



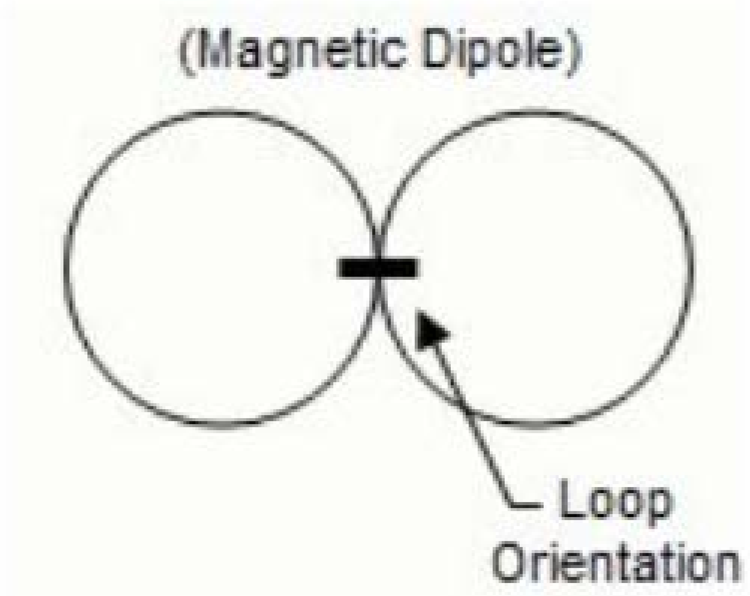
Equivalent Circuit

NOTE-1: The circumference of the coupling loop is typically 1/5th that of the resonant loop

NOTE-2: Gamma matches are sometimes used instead of a coupling loop

Radiation Pattern of a Balanced Loop

- “Balanced” means the currents are balanced across the loop
- View is from above the vertically-oriented loop
- Additional lobes will be present if current isn’t balanced along the loop

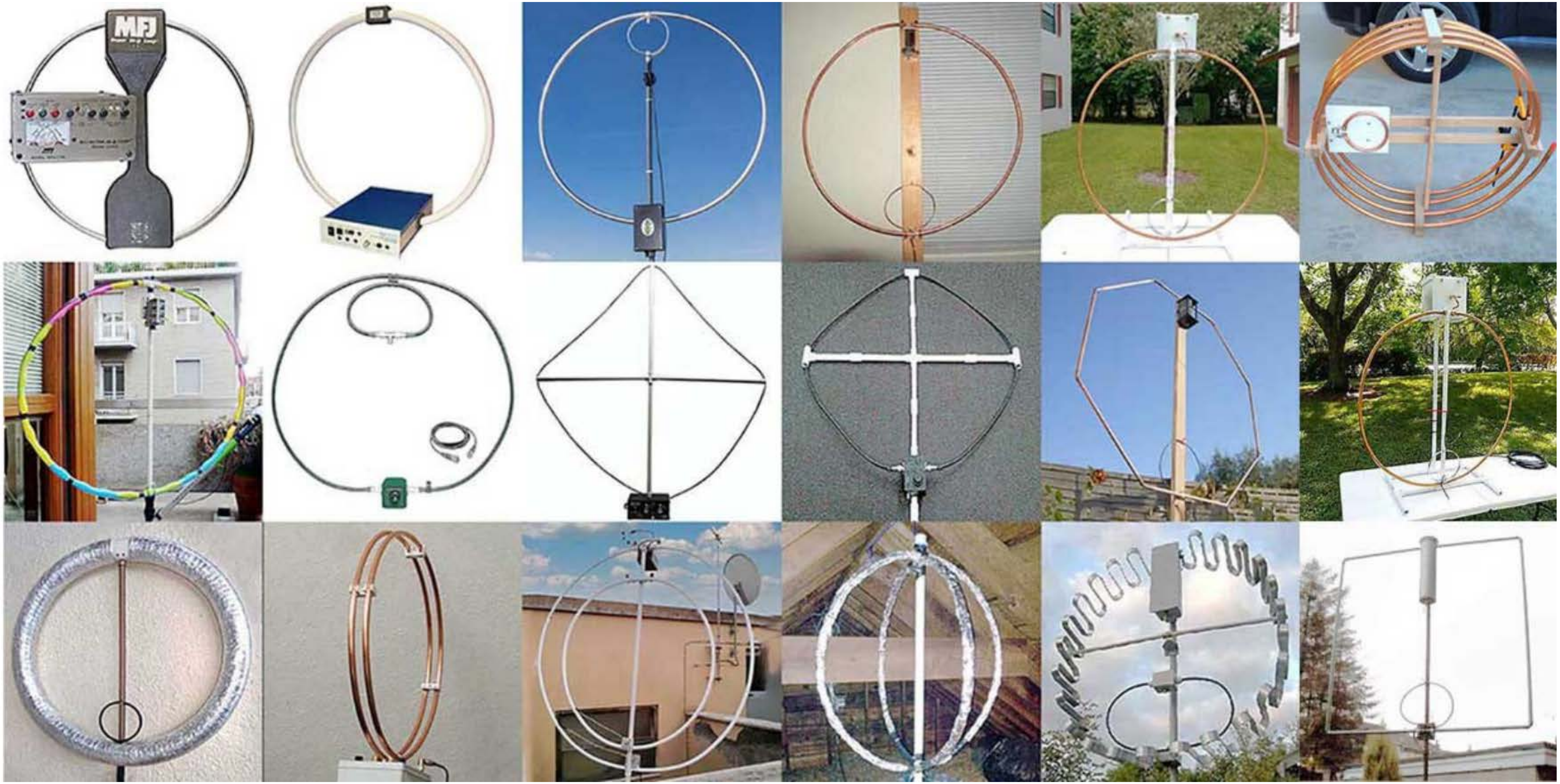


Magnetic Loop Antenna Pattern

Other Geometries

- Home built loops are often built as squares, hexagons or octagons
  - Squares have fewer solder joints to deal with when using copper pipe
- This is due to the difficulty of turning 1” or 2” copper plumbing pipe into a nice loop geometry
  - Heliax (“hardline”) can be fairly easily manipulated into a nice loop
  - Definitely more expensive per foot than copper plumbing pipe
- True circular loops are about 10% more efficient
  - Increasing the circumference and/or the diameter of the pipe can compensate for that

Examples of Magnetic Loop Antennas

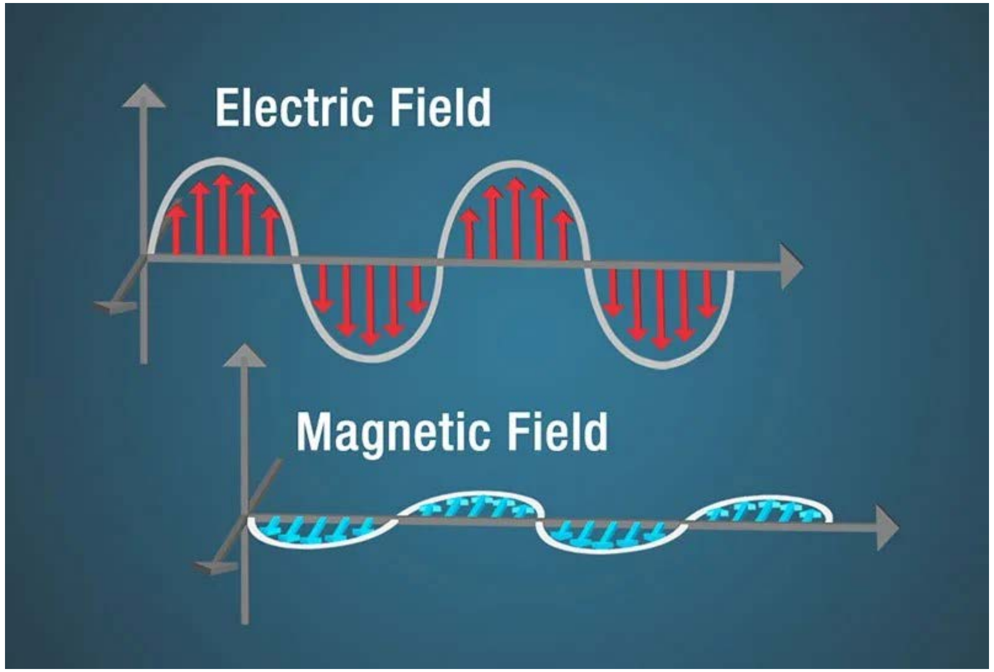


When Might You Use a Magnetic Loop?

- Radio direction finding
- Restricted operating space
- HOA restrictions
- Height above ground limitations
- HF antenna and tower cost considerations
- High noise operating environment
  - Loop can deliver a 10-20 dB greater SNR versus a dipole in a noisy urban setting
  - Even greater SNR improvement compared to a vertical antenna
- Portable operation
- Because a single small loop can replace both a horizontal dipole and a vertical antenna
  - Can provide good local and regional coverage and match or outperform a tall, ¼ λ vertical antenna for DX
- Because they're fun to build and use!

Theory of Operation

- Antenna design allows you to choose any two of these three characteristics:
  - Small size, in terms of wavelength
  - Efficiency
  - Broad bandwidth
- The small loop permits achieving the first two
- Antenna theory treats the small loop as the electrical conjugate of the dipole
  - The loop is a “magnetic dipole”, while the ordinary dipole is an “electric dipole”
  - Primarily responds to the magnetic field (H-field) component of electromagnetic waves, converting the changing magnetic flux into a voltage (Faraday’s Law)
  - Conventional antennas primarily couple to the electric field (E-field)
  - The H-field is perpendicular to the E-field, but both are intimately linked
    - The changing E-field generates the H-field, and vice versa

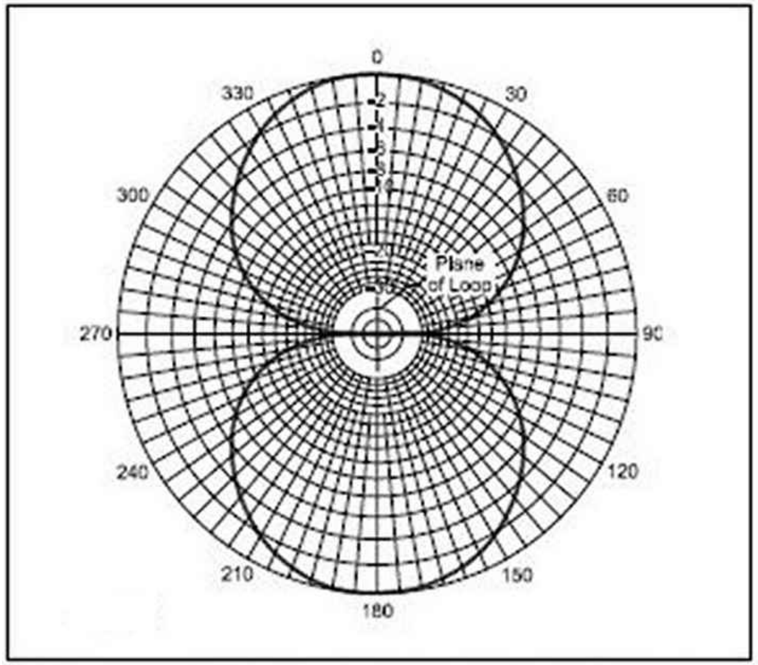


Theory of Operation (cont.)

- A well-constructed small loop acts as a resonant circuit (LC circuit)
  - The metal loop acts as an inductor
  - The variable capacitor allows the resonant frequency to be adjusted
  - Together, they create a high-Q parallel tuned circuit
- Its high Q tells us:
  - The loop isn’t lossy
  - It also isn’t inefficient
    - All of the power applied to the loop will be radiated except the portion absorbed in the lumped I^2R conductor + capacitor losses, which is released as heat
    - Proper design can make these series equivalent circuit losses negligible, especially when compared to the loop’s radiation resistance
    - High radiation efficiency can thus be achieved

Loop Radiation Characteristics

- Small loops have 2 simultaneously excited radiation modes
  - Magnetic
  - Electric folded dipole
- Adjusted to equal strength, radiation pattern asymmetry results, producing a front-to-back ratio of approximately 6 dB
- With its doughnut shaped pattern, it typically provides a gain of 1.5 dbi over average ground, and 5 dBi over conductive ground
  - Radials of a length twice that of the loop’s diameter can be used over suboptimal ground
  - A ½ λ horizontal dipole, ¼ λ above the ground, has a gain of 5.12 dBi
  - A ¼ λ vertical with 120 ¼ λ radials, has a gain of 2 dBi
- Front-to-side ratio of a balanced loop is typically 20-25 dB



Azimuth Pattern for 1/10th WL Loop

Loop Radiation Characteristics (cont.)

- One unique advantage of the small loop: When vertically oriented, maximum gain occurs at *both* low and high angles!
  - It radiates equally well at all elevation angles in the plane of the loop
  - A single small loop can replace both a horizontal dipole and a Vertical
  - Particularly beneficial on 160m, 80m and 40m
    - Great performance for local/regional coverage
    - Good DX performance which can outperform a very tall ¼ λ Vertical
- Energy radiated is vertically polarized on the horizon and horizontally polarized overhead (zenith)
- Loop positioning needs to be no more than 1 loop diameter above ground
  - Increase mounting height only if necessary to get above objects nearby
  - Mounting on a short mast on an elevated roof ground plane yields excellent results

Receiving Properties

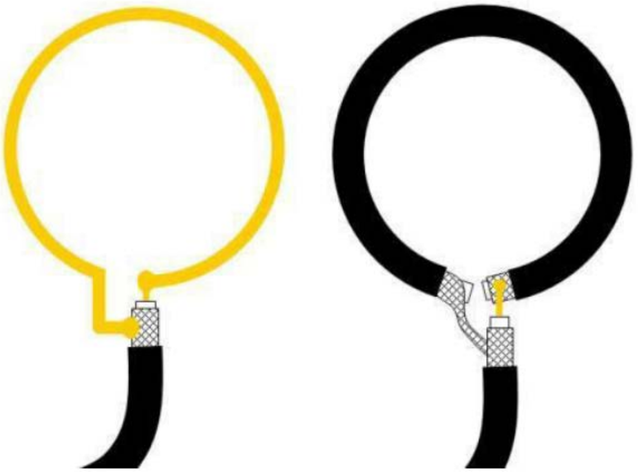
- A balanced magnetic loop will virtually always hear more than a big HF beam
  - The magnitude of the electric vector is 120π (26 dB) greater than that of the magnetic vector (E/H is known as the "wave impedance")
    - Due to the intrinsic impedance of free space (377 Ω)
    - The induction fields of man-made noise have E-field components many times greater than normal radio waves
  - Conventional antennas pickup far more of this noise than an H-coupled loop
  - A small loop will typically produce a SNR 10 to 20 dB greater than a dipole in a noisy urban environment
    - The improvement in SNR is even greater compared to a Vertical, because most man-made noise is vertically polarized
    - When receiving, SNR is everything
- The high-Q resonator (small loop) acts as a very narrowband bandpass filter ahead of the RX front-end
  - This incidental preselector feature improves receiver performance on the congested lower HF bands
  - Helps to eliminate or reduce broadcast station interference
  - Eliminates or reduces lightning and atmospheric electrical discharge noise
  - In TX mode, this filter action helps to attenuate transmitter harmonics

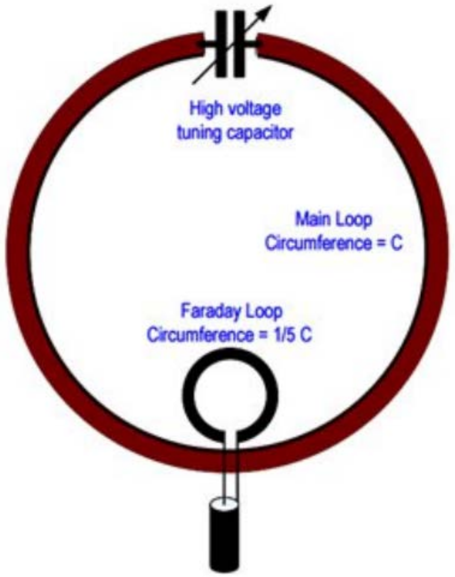
Receiving Properties (cont.)

- MYTH: a vertically-oriented loop antenna exhibits a bidirectional pattern with maximum reception occurring in the plane of the loop
  - True for ground-wave signals and for sky-wave signals arriving at very low elevation angles (< 10^o)
  - NOT true for sky-wave signals arriving at greater than 30^o angles of elevation, whose polarization usually rotates from vertical to horizontal at random rates
    - “Faraday Rotation”
    - At angles exceeding 45^o, the loop’s response favors horizontal polarization arriving at an azimuth angle of 90^o to the plane of the loop
      - For short range communications (< 300 miles), best reception will usually occur with the loop rotated 90^o (Its plane perpendicular to the azimuthal arrival angle)
  - At frequencies below 7 MHz, it’s not easy to predict what azimuthal bearing will provide the best nighttime reception over paths less than 300 miles
    - The prevalence of both sky-wave and ground-wave signals, which can randomly combine to produce significant fading
  - Generally, at distances exceeding 300-600 miles, the best orientation is with the plain of the loop in the direction of the arriving signal

Design Considerations

- Loop balance
  - Very important for rejecting local E-field noise
  - Essential for a ‘perfect’ figure-8 pattern with deep side nulls
  - Best achieved with a fully balanced Faraday transformer-coupled , broadband impedance matching loop with a 5:1 diameter ratio
    - Typically sits at the bottom feedpoint of the loop
  - Gamma matches result in inherent loop imbalance
    - This may result in common-mode currents on the feedine
      - Imparts E-field sensitivity, which may result in local noise pickup
      - This slight trade-off is not an issue in TX mode

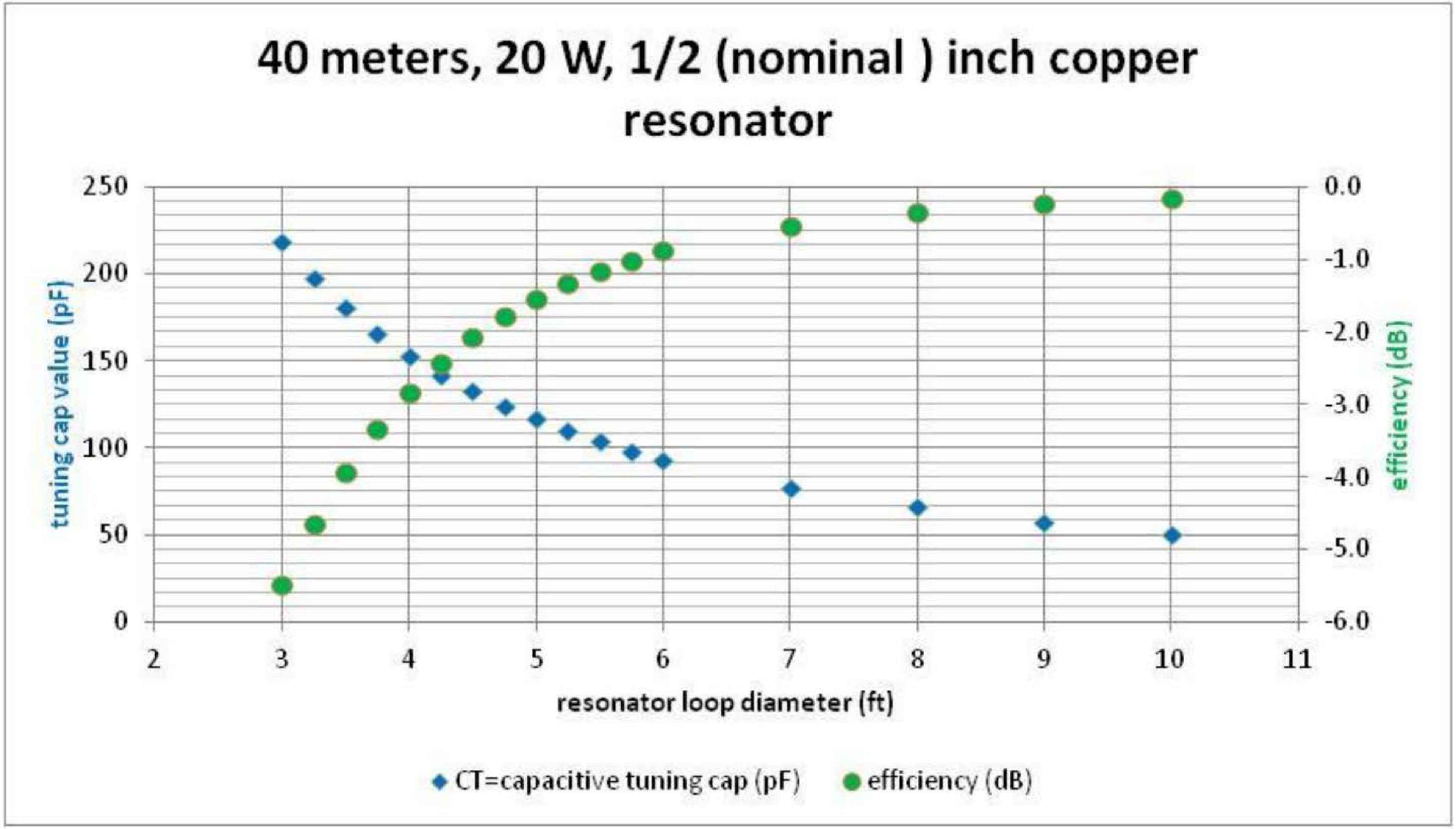




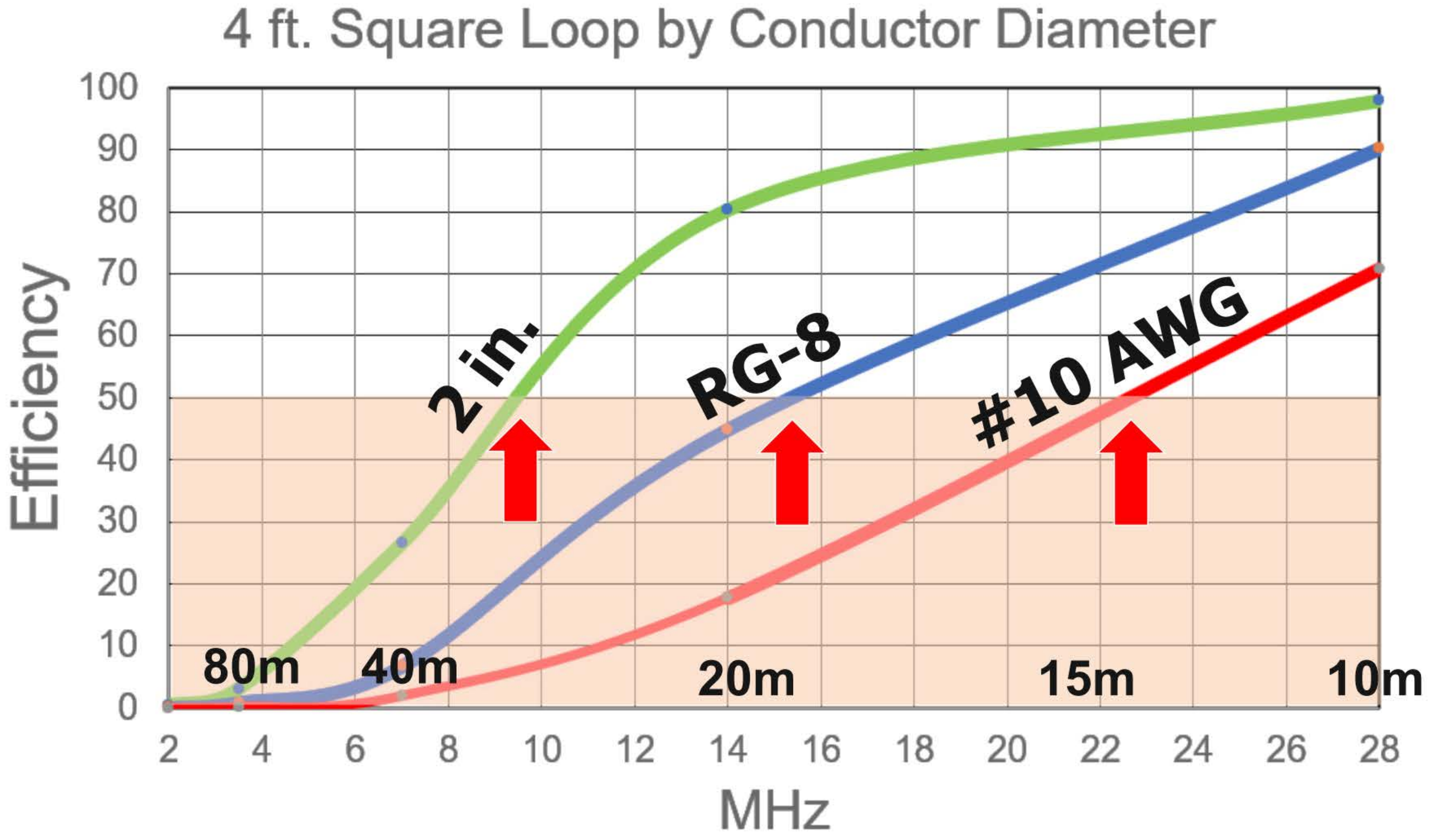
Magnetic Loop Optimization

- Satisfactory performance depends upon attention to these considerations
  - Loop shape
    - Circle is the best shape, but a somewhat bigger square can perform nearly as well
  - Loop size
    - The bigger the loop's diameter, the broader its bandwidth at the tuned frequency
    - Achievable bandwidth is roughly proportional to loop size/diameter
  - Construction material
    - Copper tubing conducts better than aluminum
      - Can provide up to a 10% boost in efficiency, given the same diameter material
  - Conductor diameter
    - The bigger the diameter, the better the efficiency curve, as you minimize losses due to skin effect
    - Q is inversely proportional to loop diameter
  - Matching mechanism
    - Use a Faraday coupler for the best current balance in the loop
  - Tuning capacitor
  - Siting

Main loop size is the primary determiner in best efficiency and capacitor value

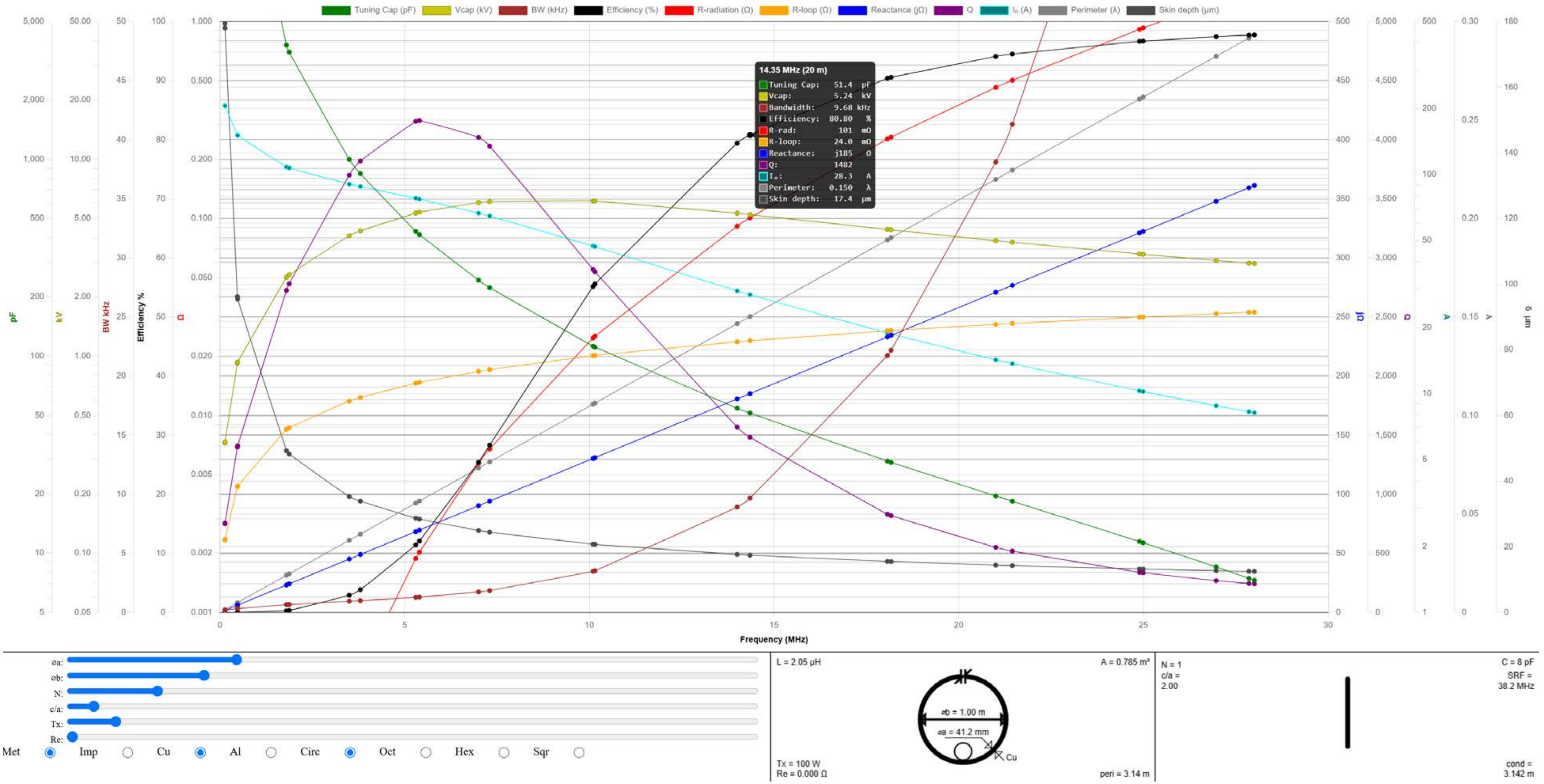


Efficiency:



4 ft. Square Loop by Conductor Diameter
Efficiency
MHz
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
2 in.
RG-8
#10 AWG
80m
40m
20m
15m
10m

Performance Plot for 1m Diameter Loop of LDF7-50a Heliax

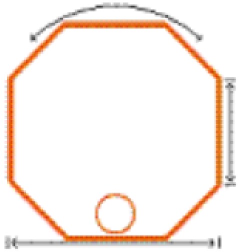


Octagonal 100W Loop – 66Pacific Calculator

Antenna efficiency: 75% (-1.2 dB below 100%)
Antenna bandwidth: 5.50 kHz
Tuning Capacitance: 80 pF

Capacitor voltage: 6,018 volts RMS
Resonant circulating current: 21.6 A
Radiation resistance: 0.080 ohms
Loss Resistance: 0.027 ohms
Inductance: 6.20 microhenrys
Inductive Reactance: 279 ohms
Quality Factor (Q): 1,300
Distributed capacity: 16 pF

Antenna "circumference": 20 feet



Side length: 2.50 feet

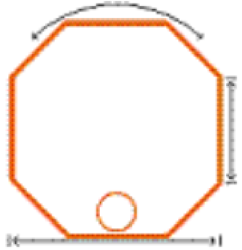
Antenna diameter: 6.0 feet

7.150 MHz

Antenna efficiency: 97% (-0.1 dB below 100%)
Antenna bandwidth: 65.9 kHz
Tuning Capacitance: 20 pF

Capacitor voltage: 3,448 volts RMS
Resonant circulating current: 6.24 A
Radiation resistance: 1.25 ohms
Loss Resistance: 0.038 ohms
Inductance: 6.20 microhenrys
Inductive Reactance: 553 ohms
Quality Factor (Q): 215
Distributed capacity: 16 pF

Antenna "circumference": 20 feet



Side length: 2.50 feet

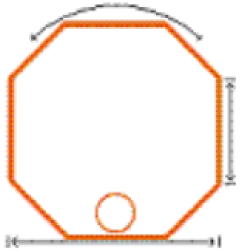
Antenna diameter: 6.0 feet

14.185 MHz

Antenna efficiency: 100% (0.0 dB below 100%)
Antenna bandwidth: 1,098 kHz
Tuning Capacitance: 5 pF

Capacitor voltage: 1,719 volts RMS
Resonant circulating current: 1.53 A
Radiation resistance: 21.3 ohms
Loss Resistance: 0.053 ohms
Inductance: 6.20 microhenrys
Inductive Reactance: 1,124 ohms
Quality Factor (Q): 26.3
Distributed capacity: 16 pF

Antenna "circumference": 20 feet



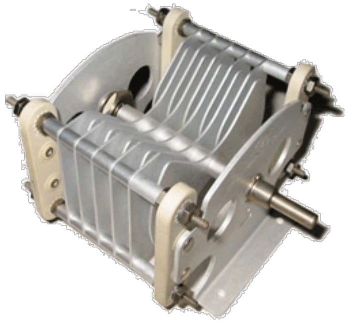
Side length: 2.50 feet

Antenna diameter: 6.0 feet

28.85 MHz

Tuning Capacitor

- WARNING: In TX operation, the voltages present across the tuning capacitor can reach **several thousand volts**!
  - The voltage can be over 1 kV with as little as 10W of transmit power
- Capacitor selection is critical to achieving desired loop performance
  - It sets the maximum tuning range of the loop
  - Its peak operating voltage will determine the maximum TX power
  - Minimize capacitor loss by not using capacitors with rotating contacts
- Butterfly capacitors are relatively inexpensive, but harder to tune
  - Typically have lower peak operating voltages
- Vacuum capacitors offer the lowest loss, but can be quite expensive
- Limit conduction losses by using welds or silver solder
  - Every additional milliohm caused by poor contact can cost you 1% or more in efficiency
- Try to keep the conduction path to the capacitor as large as the tubing of the loop
- Keep these considerations in mind when evaluating a commercial offering you might wish to purchase



Siting

- When the loop is mounted over a perfectly conducting ground plane reflector or copper radial wire mat, an electrical image is created that increases the effective loop area
  - This substantially increases the loop's radiation resistance
- Over average ground, the radiation resistance still increases, but a reflective loss resistance is also introduced
  - Due to transformer effect coupling near-field energy into the lossy ground
- When ferrous/iron material is too close, the magnetic near-field of the loop will induce a voltage across the RF resistance of the material, causing a current flow and associated I^2R power loss
  - This loss can be minimized by orienting the loop at right angles to the offending metal
- Another source of loss is capacitive coupling between the loop and ground
  - Minimize this by keeping the loop at least half a loop diameter or more above the ground

Do Loops Made of Coax Work Well?

- Define the word "well"
  - If you're going to be doing CW or digital modes, the answer is "well enough"
  - If you want to TX/RX SSB voice, especially at low power, prepare to be disappointed
- Coax itself has inherent losses, which significantly lowers its efficiency in a small loop application
  - The vast majority of commercial "portable" magnetic loops use LMR400 for the loop
    - Change that out for LMR600, and you'll see a noticeable improvement
    - Replace that with 1" hardline, and you'll see a BIG improvement

Commercial Offerings

- DX Engineering
  - https://www.dxengineering.com/
  - Offers several different brands, many of which it now owns
- Chameleon
  - https://chameleonantenna.com/collections/loop-antennas
- Alpha Antenna
  - https://www.alphaantenna.com/
- Precise RF
  - https://preciserf.com/product-category/antenna/

Commercial Offerings (cont.)

- Ciro Mazzoni MIDI Automatic Magnetic Loop ($2480)
  - 80-20m
  - Auto or manual tune
  - 300W 3.5-7.9 MHz; 800W 8-14.5 MHz
  - DX Engineering is their exclusive distributor in the U.S.
- Ciro Mazzoni STEALTH-A ($1800)
  - 40-10m
  - Auto or manual tune
  - 125W

References

- VK3CPU Magnetic Loop Calculator:
  - https://miguelvaca.github.io/vk3cpu/magloop.html?loop_diameter=1&conductor_diameter=41.2&loop_turns=1&loop_spacing=2&transmit_power=100&external_losses=0&unit=metric&metal=Cu&shape=circle
- IW5EDI Magnetic Loop Antenna Calculator:
  - https://www.iw5edi.com/software/magnetic-loop-calculator
- 66Pacific's Octagon Magnetic Loop Calculator:
  - https://www.66pacific.com/calculators/small-transmitting-loop-antenna-calculator.aspx
- One More:
  - https://www.changpuak.ch/electronics/Loop-Antenna-Calculator.php