

# Tuned Magnetic Loop Antennas

ver 1.7

5/28/2018

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KE7UAE

Extra, W.A.S

# Legal stuff

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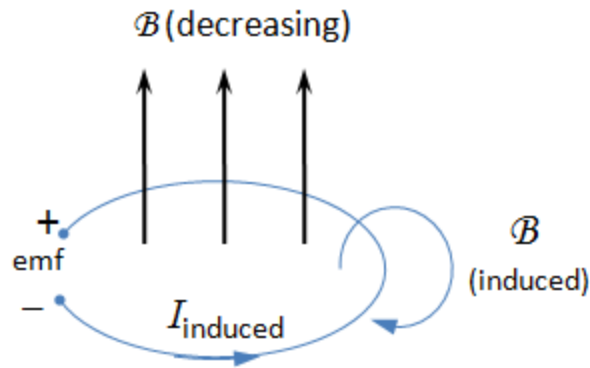
# \*\*\*\*\* Safety \*\*\*\*\*

- My 5.5 ft diameter loop antenna generates approximately 2 kV at the tuning capacitor operating at 10W, more for higher powers. Consult ARRL Antenna Handbook and other literature for electrical safety and RF safety based on your power level and location.
- Masts and guying need proper attention as well.

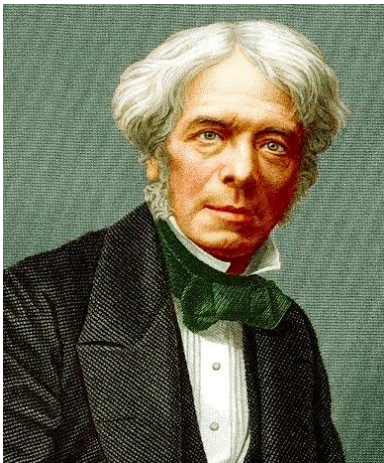
# agenda

- This is not a step-by-step process description and design but an archipelago of steps, you must launch the boat and paddle it 😊 Please see and use “References”
- I will provide some math and formulae for enrichment and reference but no calculus will be used.
- Why tuned magnetic loops?
  - Smaller size than dipoles, easier to hide in a house or attic, possibly or hopefully small enough to avoid provoking the neighbors/HOA.
  - Directional gain
  - No radials, not sensitive to height above ground. Narrow bandwidth, noise resistant

# Our benefactors: Michael Faraday and James Clerk Maxwell



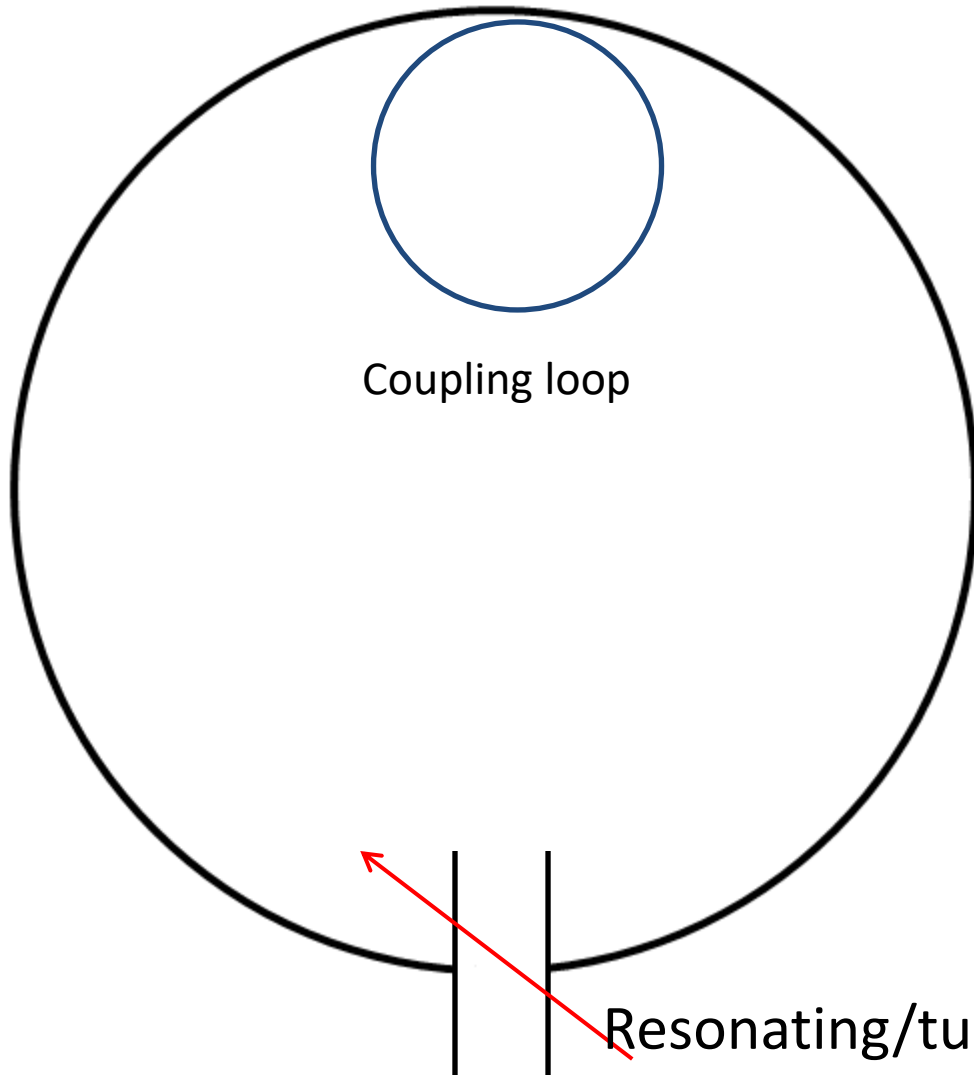
$$emf = -\frac{d}{dt} \int_s \vec{B} \cdot \vec{ds}$$



Nothing electrical like ac power  
, electric motors, radios,  
, cell phones, computers, etc that  
we have exists without  
this equation and three others,  
Together they are known as  
Maxwell's Equations



# Basic design concept



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

Resonating loop "L"

Resonating/tuning capacitor "C"

# Design options

- Capacitors
  - Twisted-pair cap for inexpensive proof of concept (I QSOed Sumatra with one )
  - Butterfly cap: less expensive than vacuum caps, harder to tune
  - Vacuum cap: lowest loss, most expensive
  - Don't use caps with rotating contact points – lossy
  - Understand your power-determined capacitor voltage rating need. Keep cap symmetrically located opposite coupling loop and limit conduction losses by keeping copper path as large as the tubing of the loop.

# Design options

- Copper
  - The larger pipe sizes have lower loss but are heavier, more expensive, harder to bend
  - If you can bend copper (annealing is recommended) you can avoid the small conductivity loss in soldered joints
  - Silver-soldering 45-degree elbows with attention to clean joints, fluxing and burnishing with steel wool has worked well for me
  - $\frac{3}{4}$  inch or even  $\frac{1}{2}$  inch pipe seems a reasonable trade-off to larger more expensive sizes, run the calculations of W5QJR's formulae in spreadsheet
  - Don't use stranded wire, RF loss is greater than for copper tubing – very long discussion on skin depth is relevant.



Instead of trying to see what you can get away with, try to see how well you can do. This is a design philosophy that I think more often leads to success.

# Basic equations

per W5QJR, "Small, High-Efficiency Loop Antennas" June QST 1986

Radiation resistance,  $R_R$ ,

$$= 3.38 \times 10^{-8} (F^2 A)^2 \quad (\text{Eq 1})$$

Loss resistance,  $R_L$ ,

$$= 9.96 \times 10^{-4} \sqrt{F \frac{S}{D}} \quad (\text{Eq 5})$$

$$\text{Efficiency, } \eta, = \frac{R_R}{R_R + R_L} \quad (\text{Eq 3})$$

Inductance,  $L$ ,  $= 1.9 \times 10^{-8}$

$$S(7.353 \log_{10} \frac{96S}{\pi D} - 6.386) \quad (\text{Eq 4})$$

Inductive reactance,  $X_L$ ,

$$= 2\pi FL \times 10^6 \quad (\text{Eq 5})$$

Tuning capacitor,  $C_T$ ,

$$= \frac{1}{2\pi FX_L \times 10^6} \quad (\text{Eq 6})$$

Quality factor,  $Q$ ,

$$= \frac{F}{\Delta F} = \frac{X_L}{2(R_R + R_L)} \quad (\text{Eq 7})$$

$$\text{Bandwidth, } \Delta F, = \frac{F}{Q} \quad (\text{Eq 8})$$

Distributed capacitance,  $C_D$ ,  $= 0.82 S$

$$\text{Capacitor voltage, } V_C, = \sqrt{PX_L Q} \quad (\text{Eq 9})$$

where

$A$  = area of loop (sq ft)

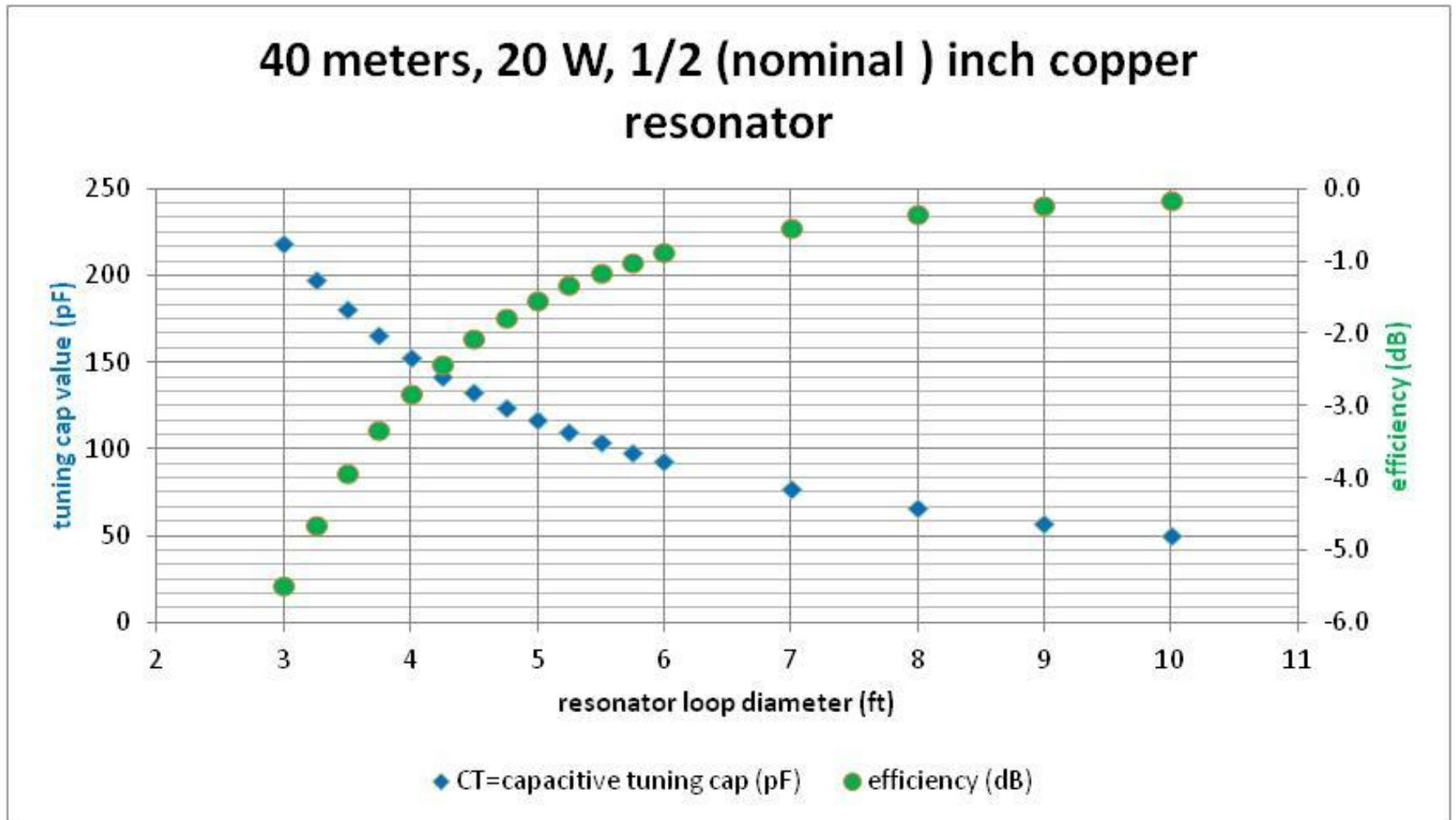
$S$  = length of conductor (ft)

$F$  = operating frequency (MHz)

$D$  = diameter of conductor (in)

$P$  = transmitter power (W)

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



# My digital rig

- Yaesu FT-450D, Tigertronics Signalink USB with factory cable and “personality module” , cross-needle SWR/power meter
- Home-made drive for tuning motor (tuning in the shack is highly-desirable for this antenna)
- Laptop running Ubuntu 18.04 Linux (and ONLY Linux)
  - It is highly frustrating to see computing delays in your screen when operating a time-sensitive program like WSJT-X. Linux has never done that to me.
  - Ubuntu includes a firewall, browser to go to pskreporter and utility to synchronize time via the Web
- WSJT-X – Joe Taylor is a genius 😊



Band Activity					Rx Frequency				
UTC	dB	DT	Freq	Message	UTC	dB	DT	Freq	Message
2219	-12	-2.3	2340	# CQ W4NQP EM80	2217	-10	-1.0	1241	# CQ DX CT1APP IM67
2221	-13	-0.8	2084	# KE7UAE DL2MIJ -20	2218	Tx		1241	# CT1APP KE7UAE CN85
2221	-13	-0.2	387	# OM6OU W6NWS -01	2219	-13	-1.3	2086	# CQ DX DL2MIJ JN58
2221	-23	0.2	625	# VE6TL RN6AM RR73	2220	Tx		2086	# DL2MIJ KE7UAE CN85
2221	-22	0.1	1486	# LU4JHF KC1GWX FN42	2221	-13	-0.8	2084	# KE7UAE DL2MIJ -20
2221	-12	0.1	1668	# EA1AHP AG7R DM13	2222	Tx		2086	# DL2MIJ KE7UAE -13
2221	-1	0.1	1819	# M6POB K1ROA DM13	2223	-12	-0.8	2084	# KE7UAE DL2MIJ RR73
2221	-11	-1.8	2201	# CQ W4NQP EM80	2224	Tx		2086	# DL2MIJ KE7UAE 73
2221	-1	0.8	2286	# AE5JH K3HSK FN11					
2221	-18	0.0	1578	# G4UGB WQ0G EM28					
2221	-15	0.2	1949	# UN1O KF0QR EN35					
2221	-17	0.0	2285	# AE5JH KB4OLM 73					
2223	-12	-0.8	2084	# KE7UAE DL2MIJ RR73					
2223	-12	-0.2	386	# OM6OU W6NWS RRR					
2223	-17	0.1	1485	# LU4JHF KC1GWX FN42					
2223	-11	0.0	1578	# G4UGB NZ5X DM96					
2223	-5	0.1	1665	# EA1AHP AG7R DM13					
2223	-12	0.1	1949	# UN1O KA1AF EL98					
2223	-4	0.8	2286	# AE5JH K3HSK R-17					
2223	-17	0.8	1949	# UN1O K0JUH EN35					
2223	-10	-1.8	2200	# F4EFZ W4NQP -15					

Log QSO Stop Monitor Erase Decode **Enable Tx** Halt Tx Tune

20m ● **14.076 000**

**2017 Aug 30 22:24:23**

Dx Call: DL2MIJ | Dx Grid: JN58

Az: 29 | 8676 km

Lookup Add

Report -13

Generate Std Msgs

Next	Now	Pwr
DL2MIJ KE7UAE CN85	<input type="radio"/>	Tx 1
DL2MIJ KE7UAE -13	<input type="radio"/>	Tx 2
DL2MIJ KE7UAE R-13	<input type="radio"/>	Tx 3
DL2MIJ KE7UAE RRR	<input type="radio"/>	Tx 4
DL2MIJ KE7UAE 73	<input checked="" type="radio"/>	Tx 5
CQ KE7UAE CN85	<input type="radio"/>	Tx 6

Tx: DL2MIJ KE7UAE 73 | JT9+JT65 | Last Tx: DL2MIJ KE7UAE 73 | 23/60 | WD: 19m

Germany on 10 W !



# 2017 QSO across USA with 10W and JT-65 (I am presently using FT8)

The screenshot displays the WSJT-X v1.7.0 interface. The top window shows two columns of log data: 'Band Activity' and 'Rx Frequency'. The 'Band Activity' column lists UTC, dB, DT, Freq, and Message. The 'Rx Frequency' column lists UTC, dB, DT, Freq, and Message. Below the logs are control buttons for 'Log QSO', 'Stop', 'Monitor', 'Erase', 'Decode', 'Enable Tx', 'Halt Tx', and 'Tune'. The center panel shows a frequency display of 14.076 000, a signal strength indicator, and a call sign 'KB3LNM' with 'FM19' and 'JT9+JT65' modes. The bottom panel shows a date and time display '2017 Aug 29 17:22:04' and a list of generated standard messages for transmission.

Band Activity					Rx Frequency				
UTC	dB	DT	Freq	Message	UTC	dB	DT	Freq	Message
1717	-17	0.1	1144	# YU1FW KM4ZLB EN37	1714	-10	0.2	314	# CQ N2ADV FN23
1717	-20	-0.6	1292	# CQ KB3LNM FM19	1716	-13	0.3	320	# CQ N2ADV FN23
1717	-18	0.1	1643	# KE8ERH K7JIZ -14	1717	-20	-0.6	1292	# CQ KB3LNM FM19
1717	-18	-0.0	2308	# LZ2RR N2JNZ 73	1718	Tx		1292	# KB3LNM KE7UAE CN85
1717	-22	0.1	1134	# N4LHY AC8SW EN82	1719	-19	-0.6	1292	# KE7UAE KB3LNM -13
1717	-11	-0.0	1396	# CQ DX W7REJ DM41	1719	-19	0.5	1298	# BD7TBP EA3VM R-17
1717	-22	-0.7	1742	# CQ KK6YYF CM98	1720	Tx		1292	# KB3LNM KE7UAE -20
1719	-20	0.0	328	# N2ADV AEODM DM59	1721	-20	-0.7	1293	# KE7UAE KB3LNM RRR
1719	-13	0.2	1084	# W3BS GM3PIL IO87	1722	Tx		1292	# KB3LNM KE7UAE 73
1719	-16	0.1	1136	# N4LHY AC8SW R-13					
1719	-5	-0.0	1398	# CQ DX W7REJ DM41					
1719	-10	0.1	1646	# KE8ERH K7JIZ RRR					
1719	-19	-0.6	1292	# KE7UAE KB3LNM -13					
1719	-19	0.5	1298	# BD7TBP EA3VM R-17					
1721	-19	0.0	329	# N2ADV AEODM R-09					
1721	-19	0.1	1085	# W3BS W4DEP EL89					
1721	-20	0.1	1137	# N4LHY AC8SW R-13					
1721	-7	-0.0	1400	# CQ DX W7REJ DM41					
1721	-10	0.1	1647	# KE8ERH K7JIZ 73					
1721	-20	-0.7	1293	# KE7UAE KB3LNM RRR					
1721	-16	0.1	1594	# N7AEG GM3PIL IO87					

# Zoom in ...

1717	-20	-0.6	1292	#	CQ	KB3LNM	FM19
1718	Tx		1292	#	KB3LNM	KE7UAE	CN85
1719	-19	-0.6	1292	#	KE7UAE	KB3LNM	-13
1719	-19	0.5	1298	#	BD7TBP	EA3VM	R-17
1720	Tx		1292	#	KB3LNM	KE7UAE	-20
1721	-20	-0.7	1293	#	KE7UAE	KB3LNM	RRR
1722	Tx		1292	#	KB3LNM	KE7UAE	73

He calls CQ with grid square

I answer with grid square

He sends my signal report

Pile-up

I send him signal report

Both say goodbye



# Signals from across USA using JT-65 and a tuned magnetic loop

The screenshot displays the WSJT-X v1.7.0 interface. The 'Band Activity' window shows a list of received signals with columns for UTC, dB, DT, Freq, and Message. The 'Rx Frequency' window shows a list of received signals with columns for UTC, dB, DT, Freq, and Message. The 'Enable Tx' button is highlighted in red. The 'Generate Stx Msgs' window shows a list of messages to be transmitted, including 'AB5VY KE7UAE CN85'. The 'Tx' status bar shows 'Tx: AB5VY KE7UAE CN85' and 'JT9+JT65'. The 'JTAlex 2.9.3 KE7UAE' window shows a list of active stations, including 'AB5VY - CO'.

UTC	dB	DT	Freq	Message
2125	-15	0.7	2194	# EB1DWF K9ZJ -05
2125	-16	-0.6	1690	# VA3TTB AB8WW EM88
2126	-22	0.2	432	# CQ CF3LLZ FN03
2126	-20	0.1	1243	# W4BN K4DXX R-17
2126	-19	1.8	1304	# PY7KG KG4ZGZ R-15
2126	-15	0.1	2441	# IU3BXP N2JK R-11
2127	-18	-1.5	794	# NC8I AG7EK DM43
2128	-21	0.2	1243	# W4BN K4DXX 73
2128	-23	1.8	1304	# KG4ZGZ TNX 73
2128	-19	0.2	1691	# W5VMA VA3TTB RRR
2128	-22	0.6	1992	# CQ K9ZJ EN53
2128	-14	0.1	2441	# IU3BXP N2JK 73
2129	-1	-0.6	432	# CF3LLZ N6VNI DM13
2129	-15	-1.6	794	# NC8I AG7EK R-15
2129	-24	-0.5	997	# AC2NW NC4RY -08
2129	-17	0.1	1304	# CT1EJC K4DAJ EM64
2129	-15	0.1	1544	# CQ AB5VY DN70
2129	-16	-0.6	1596	# LW2DQC WB4RA EM76
2129	-14	0.1	1690	# VA3TTB W5VMA 73
2129	-18	-1.1	1305	# CT1EJC K2PAA EL98
2129	-21	0.2	1434	# DG9MGU WB2MJG -02

UTC	dB	DT	Freq	Message
2038	-10	-0.5	1490	# CQ KJ4LTA EM71
2129	-15	0.1	1544	# CQ AB5VY DN70
2130	Tx		1544	# AB5VY KE7UAE CN85

20m 14.076 000

DX Call: AB5VY, DX Grid: DN70, Tx: 1544 Hz, Rx: 1544 Hz

2017 Aug 27 21:30:05

Tx: AB5VY KE7UAE CN85 JT9+JT65 Last Tx: AB5VY KE7UAE CN85

JTAlex 2.9.3 KE7UAE [20m,NO Log,#1] (Updates!) | Alerts | Settings | View | Sound ON | ? |

Station	State
N6VNI	CA
AG7EK	AZ
NC4RY	NC
K4DAJ	AL
K2PAA	FL
WB2MJG	NH
AB5VY	CO
WB4RA	TN
W5VMA	MS

California,  
Arizona  
North Carolina  
Alabama  
Florida  
New Hampshire  
Colorado  
Tennessee  
Mississippi

# directionality

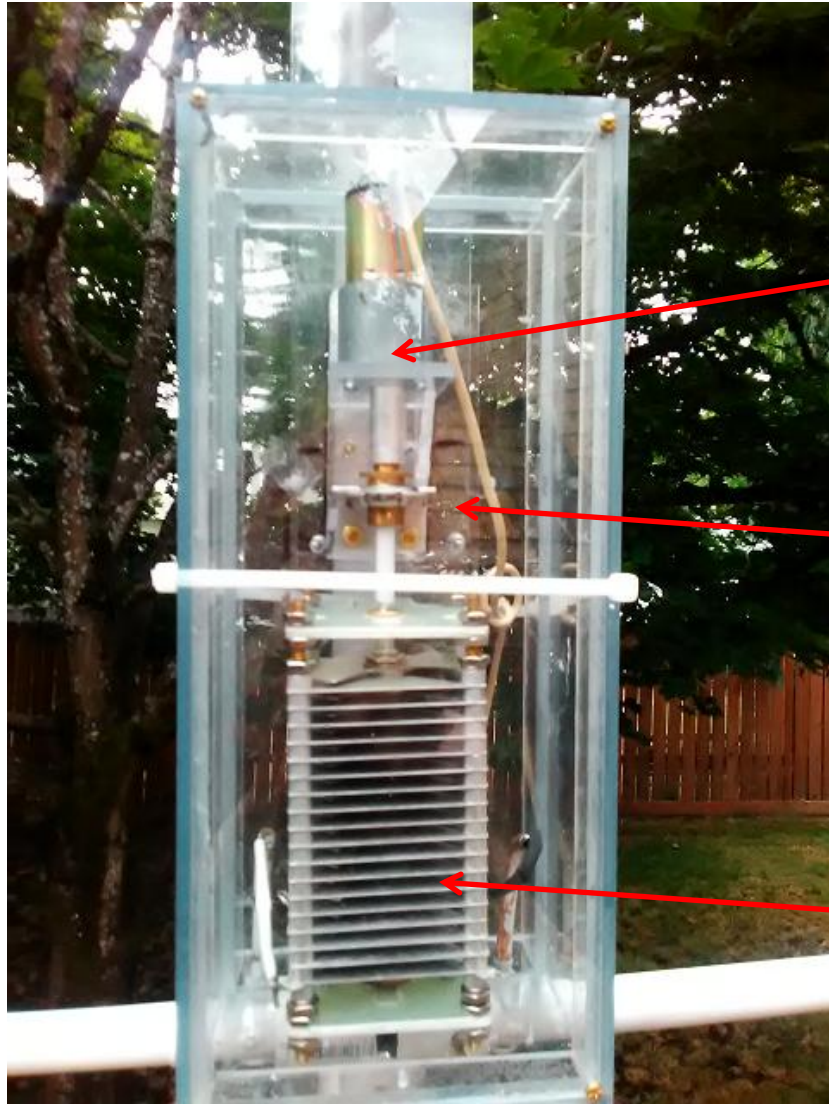
- The antenna receives and transmits best in the same direction as the plane of the resonating loop is oriented, though it will perform well off-axis as well.
- More in “backups”

# My antenna for 20 meters



QSO with Sumatra over JT-65 with this antenna at 20 W

# Tuning arrangements with butterfly caps



Geared motor –  $\sim 2$  rpm

6:1 planetary ball drive

MFJ-19 butterfly capacitor

# 40-meters , my present antenna, mast down for servicing



Primary advantage is likely to be the ability to erect this antenna in a small space. Mast is a Max Gain Systems telescoping model, the base is a cast iron table or umbrella support I picked up used .

# Fabrication

- Copper tubing, 45 degree elbows- propane torch and silver solder. Keep it clean, polish with steel wool, paint to avoid corrosion. RF current flows at the surface within a few skin depths of the top. See “backups”
- Table saw: nice for making neat enclosures but not essential
- Hand tools
- Capacitance meter, antenna analyzer (very great help, much easier than using your TX)

# Tuning challenge

- 2:1 VSWR BW of my 20-m antenna is about 20-30 kHz. Moving the butterfly capacitor through only 90 degrees goes from max to min capacitance and vice-versa
- Conservative approach:
  - Choose a variable cap value that takes your antenna from max frequency in one band to min frequency in that band. Use a fixed capacitor to move your chosen antenna size to near the top of the band, adding capacitance with the butterfly cap lowers the resonant frequency.
  - Limiting to one band allows selection of coupling loop that gives best match for that band
  - Some authors report multiband use but necessity to change the coupling loop for each band to achieve good match

# Suggested Tuning Hardware

- 2 rpm motor (via reduction transmission ) from Amazon [6-24VDC Gearhead Motor](#)  
Sold by: [Skycraft Parts & Electronic Surplus](#)
- 6:1 planetary drive from <http://www.orenelliottproducts.com/planetary-reduction-drives>
- Pulse-Width Modulated power supply from Amazon [RioRand \(TM\) 12V-40V 10A PWM DC Motor Speed Controller w/ Knob](#)
- Switch box with momentary contact switch to jog input power to PWM source and DPDT switch to change output polarity to motor
- Lowest loss (and more expensive ) is achieved using vacuum capacitors, I used Max Signal Systems as supplier



# Coupling loop, how big and where?

- Some trial-and-error here, antenna analyzer is highly convenient.
  - Tune for resonance at your frequency of greatest interest using the antenna analyzer
  - 1/5 the diameter of the main loop, vary location with respect to main resonator loop.
  - Published authors and projects vary somewhat on this
  - I have used ¼ in copper, ½ inch copper and coaxial line to make coupling loops as have others.

# Process

- Read all the articles in “References” and think for a while:
  - What frequency, power and size
  - Run the formulae in W5QJR QST article in a spreadsheet and get a feel for tradeoffs of size, power and frequency as they effect efficiency and tuning capacitor size.
  - You don’t need to invest in a tuning cap for the first iteration – a piece of twisted pair with high-voltage wire will make a capacitor that works, trim it with wire cutters (I did 😊 )
  - MFJ-19 or MFJ-26 can tune these antenna, use the spreadsheet to explore values that will work.
  - If you feel adventurous you can build your own fixed plate capacitors and butterfly capacitor, get the plates tig-welded to adjacent ones
  - Butterfly caps have low-to-no contact resistance hence are low loss and promote high Q and efficiency.
  - Vacuum capacitors are very good but quite expensive

# references

- ARRL Antenna Handbook
- “Small, High-Efficiency Loop Antennas”, W5QJR, QST magazine, June 1986s
- KK5JY.net
- “You Can Build a Compact Loop Antenna for 30 through 12 Meters”, WA3ULH, QST magazine , May 1994
- “An Overview of the Underestimated Magnetic Loop HF Antenna”, Leigh Turner, VK5KLT. This is an **outstanding** source on materials and construction.

<https://www.nonstopsystems.com/radio/pdf-ant/article-antenna-mag-loop-2.pdf>

- “A Ham moves to Linux”, Todd C. Williams, <https://just.plain.cool/post/2017-01-05-ham-to-linux/> was quite invaluable and very informative
- Google it and watch many tests of commercially available loops on YouTube and reports of experimenters and build-it-yourself’ers.

# Acknowledgements

- My Elmers: KK7B Rick Campbell, W7ZOI Wes Hayward
- Leigh Turner, VK5KLT who advised me patiently over email from Australia
- Others in my References slide

# Backup

# Conductor size and skin depth “ $\delta$ ”

Skin depth is the thickness of a conducting material that reduces EM wave penetration by  $1/e$  or “ $\delta$ ”. For copper at 7 MHz this equals 0.0007 inches.

$$\delta = \sqrt{\frac{2}{\omega \mu \sigma}} \quad *$$

skin depths	starting value	remainder	dB
1	1.00	0.63	-2.01
2	0.63	0.40	-4.01
3	0.40	0.25	-6.02
4	0.25	0.16	-8.03
5	0.16	0.10	-10.03

$$\omega = 2\pi f = 2\pi(7.0 \times 10^6 \text{ cycles / sec})$$

$$\mu = 1.257 \times 10^6 \text{ H / m}$$

$$\sigma = 5.8 \times 10^7 \text{ Siemens / m}$$

\* “Introduction to Electromagnetic Fields”, C.R. Paul and S.A. Naser

## Skin depth calculations and cross-sectional area for conduction

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{2}{2\pi(7 \times 10^6 \text{ rad / sec})(1.257 \times 10^{-6} \text{ H/m})(5.8 \times 10^7 \text{ S/m})}}$$

$$\delta = 1.76 \times 10^{-5} \text{ meters} = 0.0007 \text{ inches}$$

# Directivity (aka: gain)

- Heuristic argument for directional gain, not a calculation.
- Examination of Faradays law and the vector dot product indicates that the most emf will be generated when the propagating signal has a magnetic component perpendicular to the plane of the loop.