Tuned Magnetic Loop Antennas

ver 1.7
5/28/2018

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Extra, W.A.S

Legal stuff

- All trademarks are properties of their respective owners

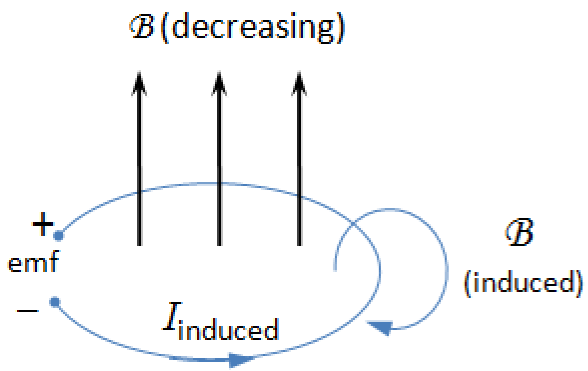
********* Safety **********

- 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.

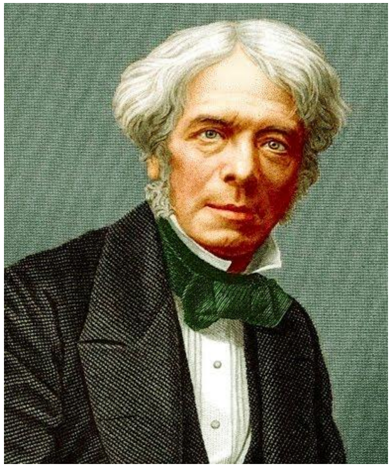
agenda

- 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

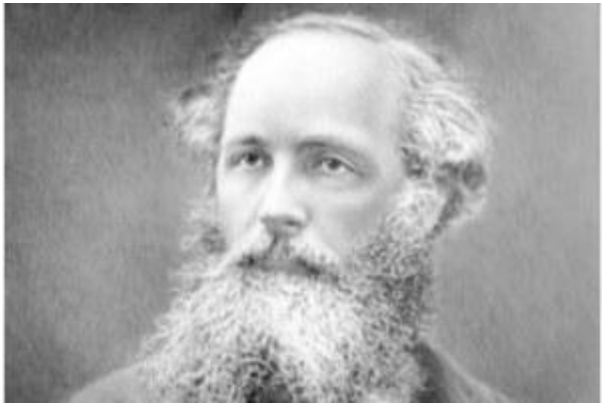
Our benefactors:
Michael Faraday and James Clerk Maxwell



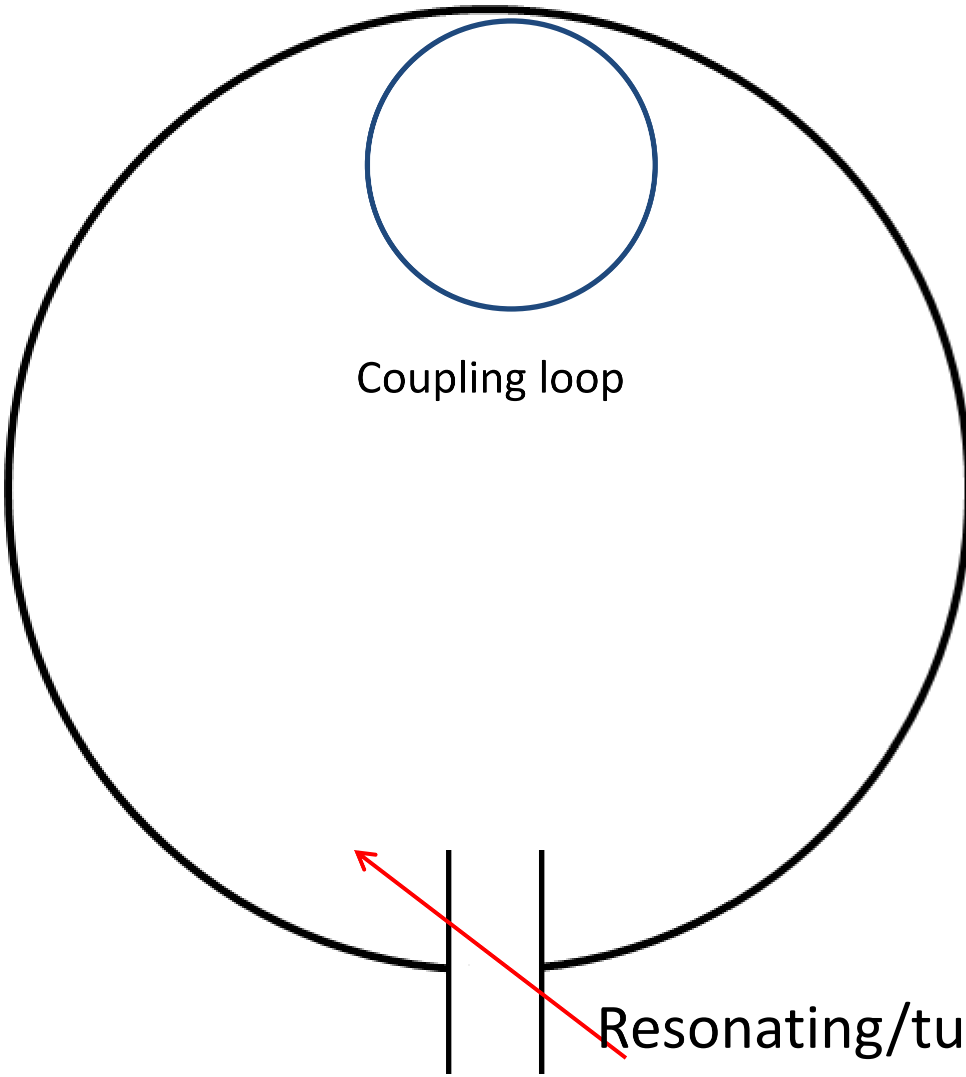
$$emf = -\frac{d}{dt}\int_{s} \vec{B} \cdot \vec{ds}$$



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



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

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
  - ¾ inch or even ½ 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,

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

Loss resistance, R_L,

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

Efficiency, η, $= \dfrac{R_R}{R_R + R_L}$ (Eq 3)

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

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

Inductive reactance, X_L,

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

Tuning capacitor, CT,

$$= \frac{1}{2\pi F X_L \times 10^6} \qquad \text{(Eq 6)}$$

Quality factor, Q,

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

Bandwidth, ΔF, $= \dfrac{F}{Q}$ (Eq 8)

Distributed capacitance, C_D, $= 0.82$ S

Capacitor voltage, V_C, $= \sqrt{P X_L Q}$ (Eq 9)

where

A = area of loop (sq ft)

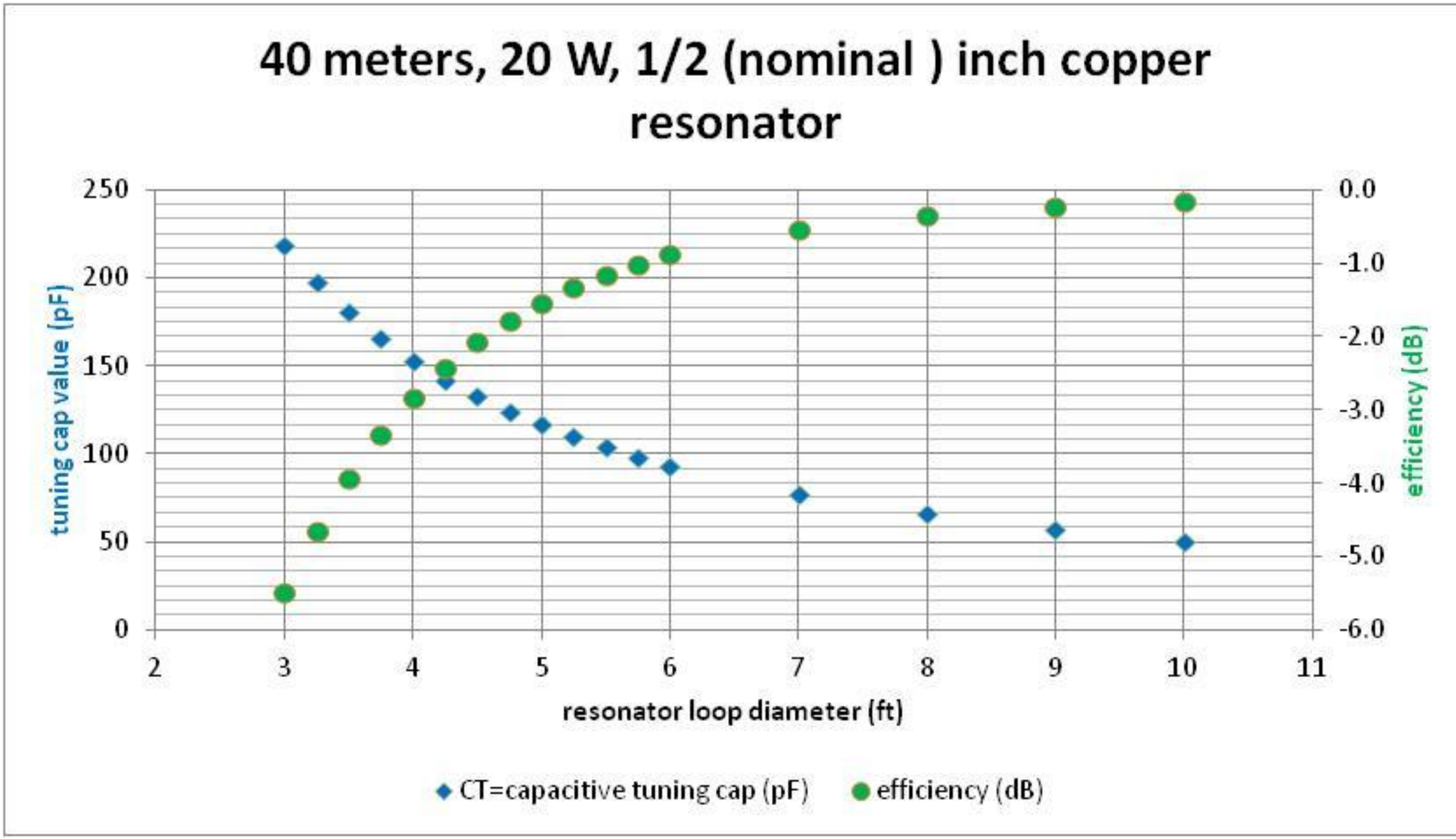
S = length of conductor (ft)

F = operating frequency (MHz)

D = diameter of conductor (in)

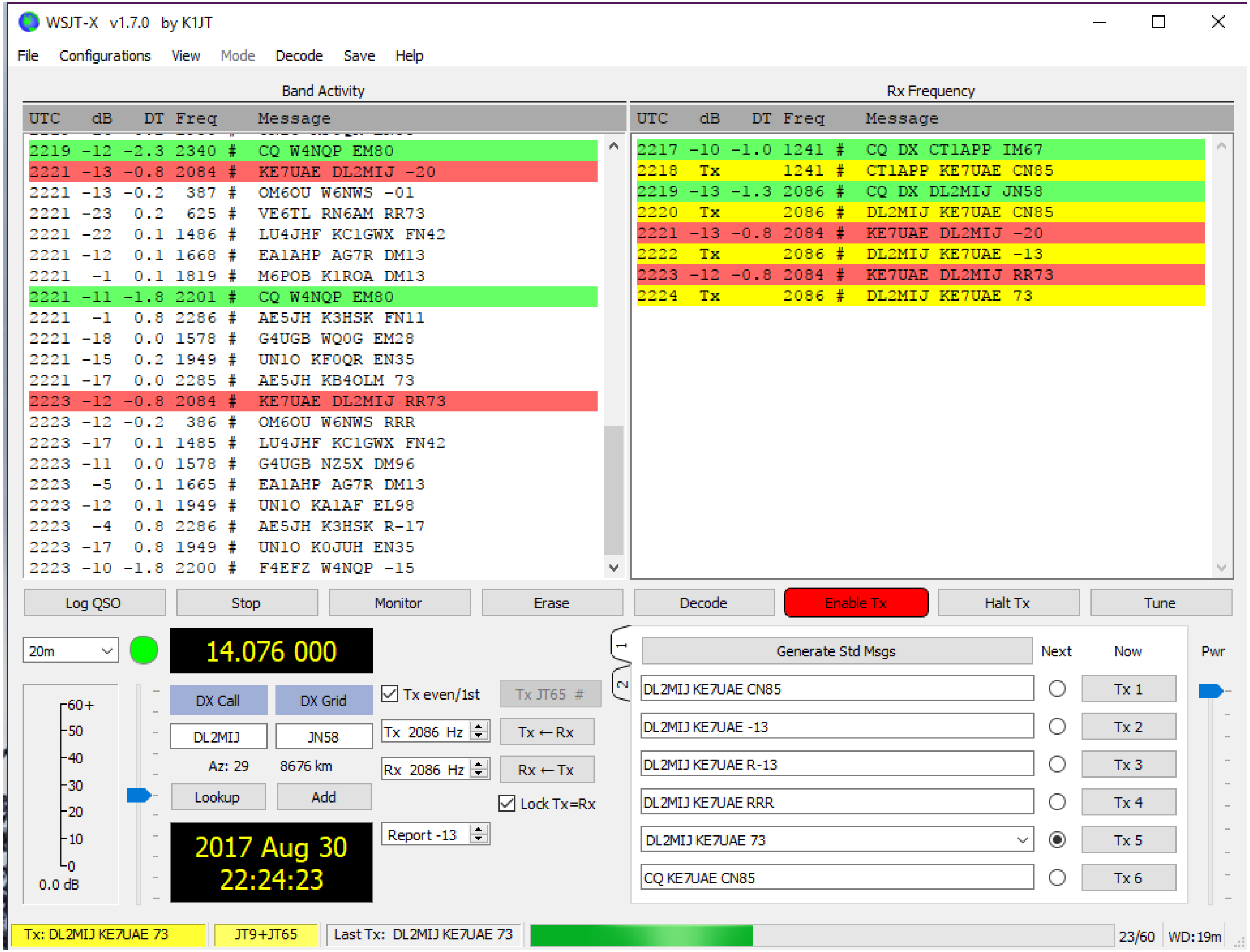
P = transmitter power (W)

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 ☺

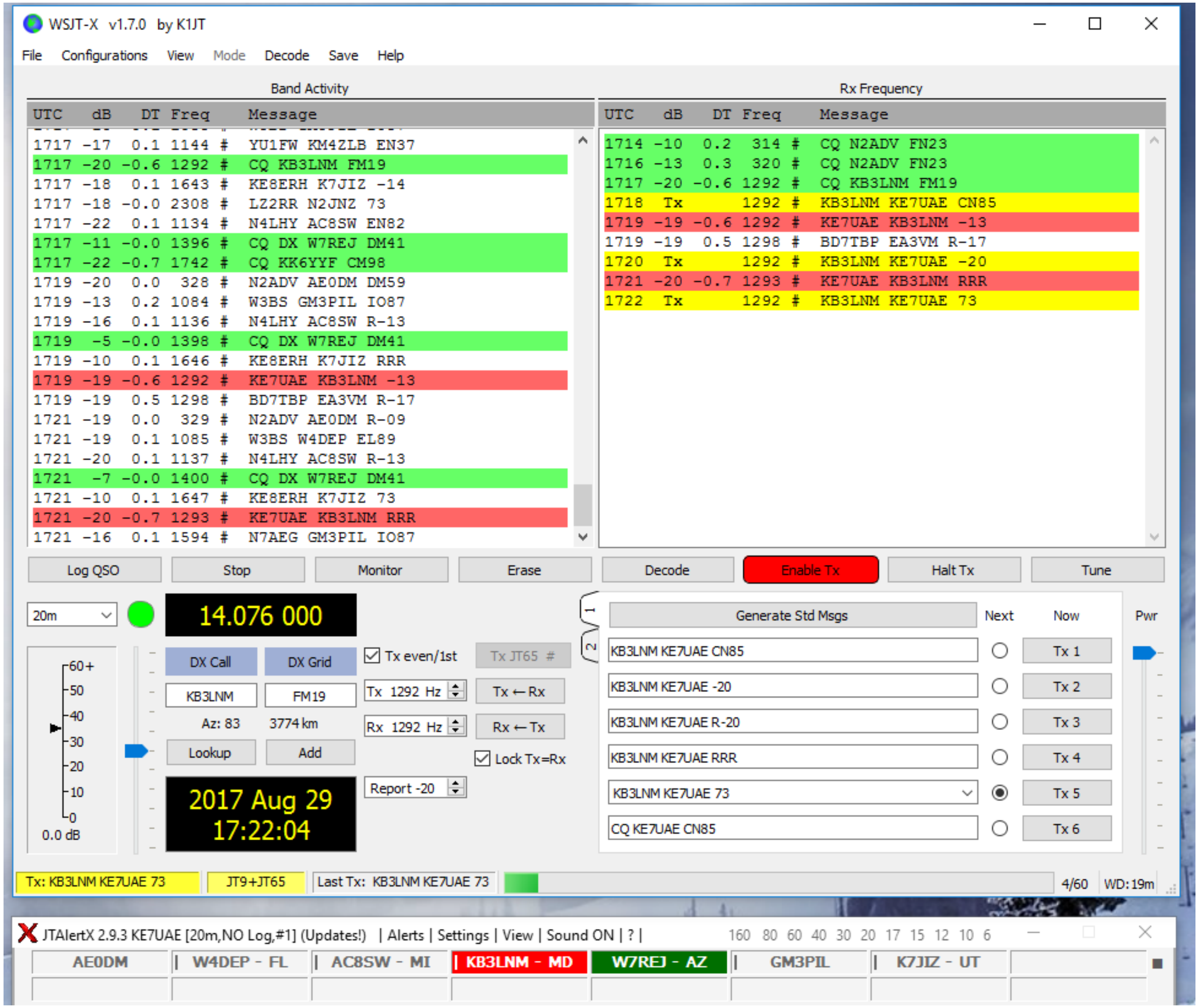


Germany on 10 W !


Dortmund
Essen
Antwerp
Cologne
Germany
Leipzig
Dresden
russels
Belgium
Frankfurt
Prague
Luxembourg
Mannheim
Nuremberg
Czechia
Grid Square JN58
Karlsruhe
Stuttgart
Strasbourg
Augsburg
Munich
Salzburg
Zürich
Austria
Graz

2017 QSO across USA with 10W and JT-65

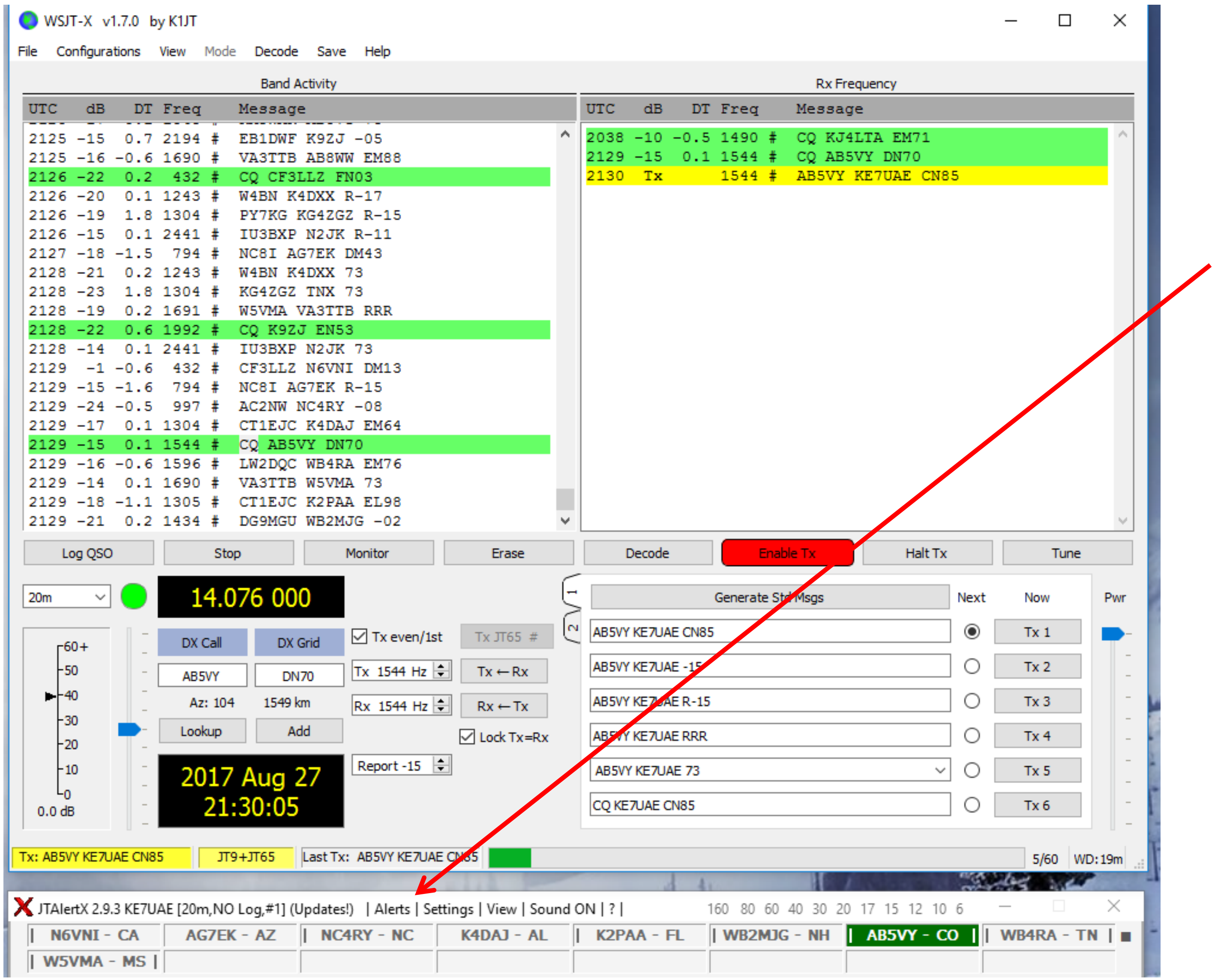
(I am presently using FT8)



Zoom in …

1717	-20	-0.6	1292	#	CQ	KB3LNM	FM19	He calls CQ with grid square
1718	Tx		1292	#	KB3LNM	KE7UAE	CN85	I answer with grid square
1719	-19	-0.6	1292	#	KE7UAE	KB3LNM	-13	He sends my signal report
1719	-19	0.5	1298	#	BD7TBP	EA3VM	R-17	Pile-up
1720	Tx		1292	#	KB3LNM	KE7UAE	-20	I send him signal report
1721	-20	-0.7	1293	#	KE7UAE	KB3LNM	RRR	
1722	Tx		1292	#	KB3LNM	KE7UAE	73	Both say goodbye

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



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

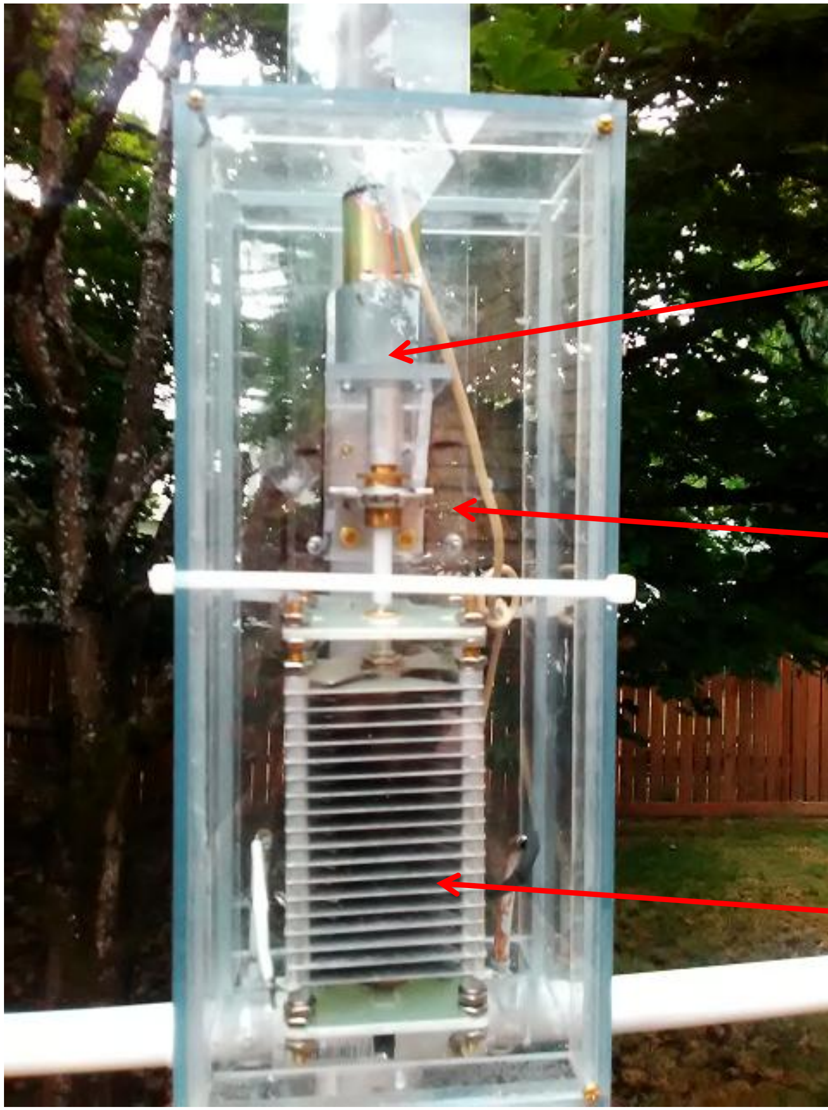
directionality

- 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 – ~ 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 “δ”

Skin depth is the thickness of a conducting material that reduces EM wave penetration by 1/e or “δ”. 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

$$\omega = 2\pi f = 2\pi(7.0\times10^{6}\, cycles/\sec)$$

$$\mu = 1.257\times10^{6}\, H/m$$

$$\sigma = 5.8\times10^{7}\, Siemens/m$$

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

Skin depth calculations and cross-sectional area for conduction

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{2}{2\pi(7\times10^{6}\,rad/\sec)(1.257\times10^{-6}\,H/m)(5.8\times10^{7}\,S/m)}}$$

$$\delta = 1.76\times10^{-5}\,meters = 0.0007\,inches$$

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.