

A Home-Brew Loop Tuning Capacitor

If you're itching to build a loop antenna and haven't found a suitable tuning capacitor that handles high voltage, your search has ended!

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(Photos by the author)

Judging from a number of recent on-the-air contacts, interest in small-diameter HF loop antennas is on the rise. Enterprising hams are discovering that a 3-foot-diameter circle of copper tubing can be used to work the world, even when mounted a mere foot or two off the ground.

Ted Hart, W5QJR, showed us how to design and construct highly efficient, small loop antennas.¹ His simple equations make it easy to lay out a loop to suit virtually any need. Hart's work is required reading for anyone interested in such an antenna.

The Difficult Part

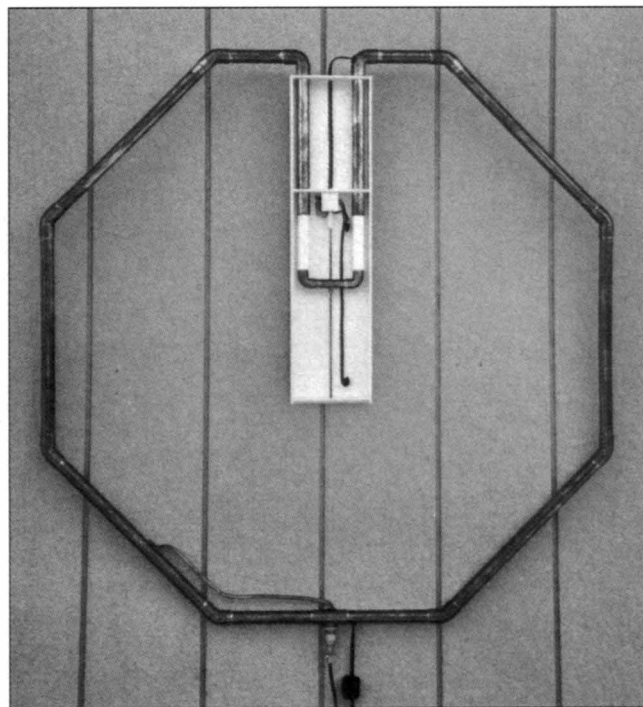
A common stumbling block in building a small transmitting loop is finding a suitable tuning capacitor. Most junk-box air-dielectric variable capacitors are unsuitable for use with loop antennas because they are lossy. A loop capacitor's stator and rotor plates must be securely fixed—soldered or welded, not merely clamped—to their respective supports to keep resistance to a minimum. Mechanical wiper contacts are undesirable for the same reason. Hart overcame this problem by using a split-stator capacitor. Each end of the loop is connected to one of the two stators, and the rotor acts as a coupler between the sections.

Feeding a small loop antenna with 100 W produces a kilovolt-level potential across the capacitor. To withstand such high voltages, wide capacitor-plate spacing is needed. Considering the effects of humidity and environmental pollutants, 1/4-inch spacing between the plates of an air-dielectric variable capacitor is desirable.

A Different Approach

The home-brew tuning capacitor shown in Figure 1 and the accompanying photographs is a low-cost alternative to commercial units. You can easily construct this ca-

The KD7S loop-tuning capacitor used with a 3-foot-diameter loop antenna. The antenna tunes from 10 through 20 meters and is rated for 100 W input.



pacitor in a day or two using simple hand tools. As a bonus, the need for an extremely low-speed tuning motor is offset by using a simplified drive mechanism.

Mechanically, the capacitor consists of two lengths of 1/2-inch-ID copper pipe that telescope in and out of two pieces of 3/4-inch-ID pipe. The larger-diameter pipes are analogous to the stators of a conventional split-stator capacitor; the smaller-diameter pipes are the rotors.²

In my capacitor, the center-to-center spacing between the two larger pipes is 3 3/4 inches. The smaller pipes have a 1/16-inch layer of Teflon plastic sheet wrapped around the outside to form a high-voltage insulator. The dielectric constant of Teflon also serves to increase the overall capacitance. This entire assembly is mounted on a 1/4-inch-thick piece of ABS plastic. An 1/8-inch plastic cover completes the enclosure.

A 180-rpm gear-head motor turns a length of #8-32 threaded brass rod soldered to the crossbar that holds together the smaller pipes. Depending on the rotational direction of the motor, the smaller pipes are either pulled into, or pushed out of, the larger pipes. The larger pipes are soldered directly to the loop. This construction results in an extremely low-loss capacitor capable of withstanding very high voltages.

You can construct the capacitor to provide virtually any desired capacitance range. The formula for calculating the capacitance³ is

$$C = \frac{0.224KA}{d}(n-1) \quad (\text{Eq 1})$$

where:

C = capacitance in picofarads (pF)

n = number of plates

K = dielectric constant,

A = area of one plate (in square inches)

d = spacing between plates

To calculate the surface area of the smaller tubes, multiply pi by the outside tube diameter times the length. A 1/2-inch-ID type M copper pipe has an OD of 0.625 inches. Substituting the values in the formula, we have $A = 3.14159 \times 0.625 \times 1 = 1.9635 \text{ in}^2$ for a 1-inch length of pipe.

As mentioned earlier, the Teflon insulation increases the capacitance as a result of its dielectric constant (2.1). The spacing, d, between the inner pipe and outer pipe is 1/16 inch, or 0.0625 inch. We calculate the capacitance of a 1-inch length of tubing using the following values: n = 2; K = 2.1; A = 1.9635, and d = 0.0625

$$C = \frac{0.224 \times 2.1 \times 1.9635}{0.0625}(2-1) \quad (\text{Eq 2})$$

Equation 2 yields a value of 14.778 pF. This value is for a single capacitor section. Because the sections are connected in series, the value is halved, to 7.389 pF per inch. Measurements show approximately 5 pF of stray capacitance for a 10-inch-long capacitor. This stray capacitance must be added to the overall value. Therefore, with a 1-inch section of capacitor, the actual value is about 12 pF. As the pipes telescope, the capaci-

¹Notes appear on page 32.

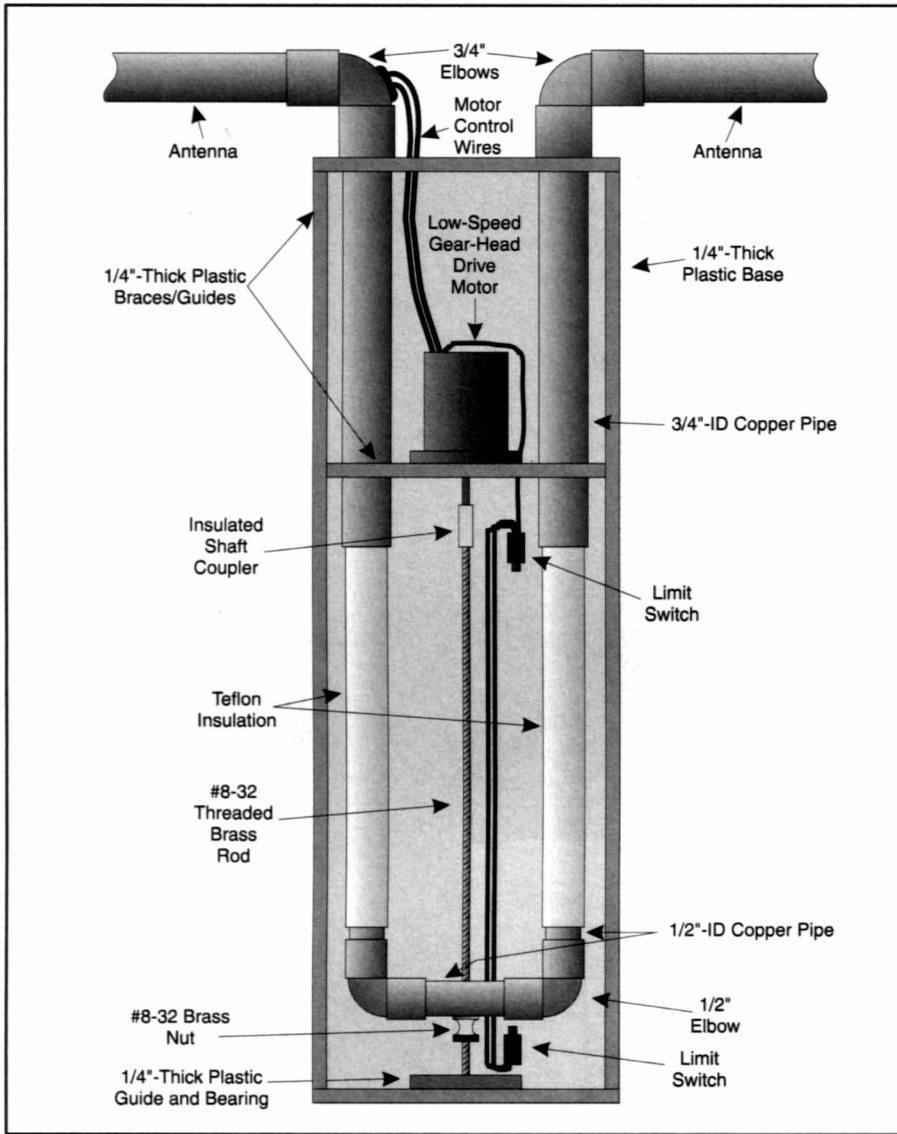


Figure 1—Mechanical drawing of the KD7S loop-tuning capacitor.

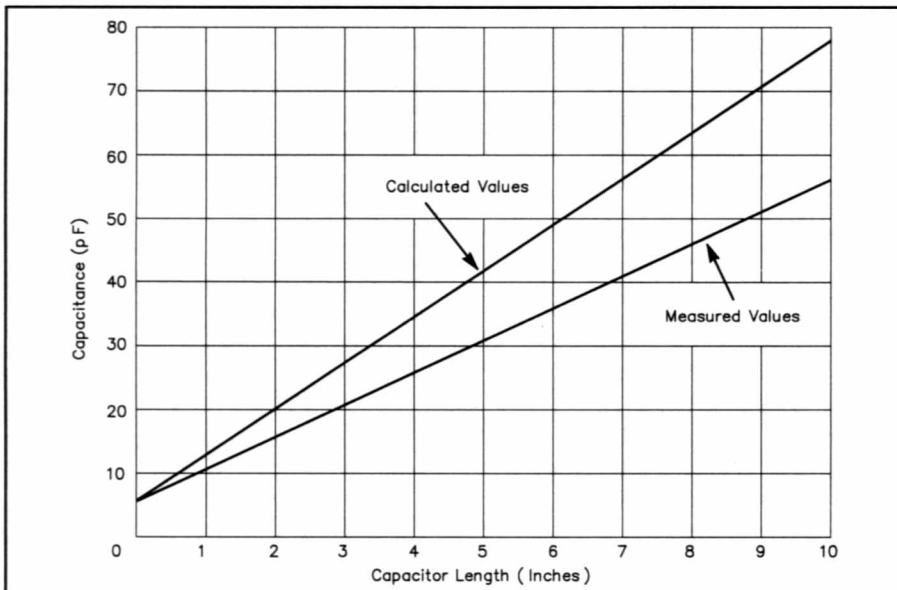


Figure 2—Comparison of the calculated versus measured values of capacitance using Equation 1. Stray capacitance must also be taken into account (see text).

tance increases linearly. For a 2-inch capacitor, the capacitance would be just under 20 pF, and so on.

Capacitance Variation

After I built the first capacitor, I discovered the measured capacitance to be somewhat less than the calculated value. These differences are shown by the graph in Figure 2. The actual value of capacitance was about 5.25 pF per inch instead of 7.389 pF per inch. I suspect the difference is due to the dielectric constant of the Teflon used for the insulation (see Note 2).

Voltage-Handling Capabilities

If you're concerned about the voltage-handling capabilities of a capacitor with a spacing of only $\frac{1}{16}$ inch between the inner and outer plates, don't be. According to the *Handbook*,⁴ the puncture voltage of Teflon insulation is 1 to 2 kV per mil (0.001 inch). This capacitor's voltage rating is well within limits for a typical 100-W transmitter.

Tuning Mechanism

Capacitor tuning is accomplished by turning the threaded brass rod with a low-speed gear-head motor. A short piece of plastic tubing connects the rod to the motor. The tubing acts as an insulator and a flexible coupling to smooth out minor shaft-alignment errors. The other end of the rod is threaded into a brass nut soldered to the crossbar holding the $\frac{1}{2}$ -inch pipes together. I used a 12-V motor rated at 180 rpm, but it has sufficient torque to work with as little as 4 V applied.

Instead of a sophisticated variable duty-cycle speed control circuit, I used an LM317 adjustable voltage regulator to vary the motor-control voltage from 4 to 12 V. Tuning speeds range from 11 seconds per inch at 12 V to 40 seconds per inch at 4 V. The higher speed is necessary to jump from band to band in a reasonable amount of time. The lower speed makes it easy to fine-tune the capacitor to any desired frequency within a particular band.

Construction Pointers

I've intentionally omitted step-by-step construction details from this article because of differences in drive motors, tubing sizes and available materials. However, by studying the photos and drawings, you should have no problem building your own capacitor. Table 1 contains a list of the parts I used in constructing my capacitors.

When building the capacitor, keep in mind that the smaller tubes must telescope in and out of the larger tubes with silky smoothness. Any binding will cause erratic tuning. For the same reason, the #8-32 brass threaded rod must be straight and properly aligned with the brass nut. *Take your time with this part of the project.*

If you can't locate a source of Teflon sheet for the insulation, use clear polyethylene. Your capacitor will, however, have a slightly higher overall capacitance because of the difference in the polyethylene's dielectric constant compared to that of Teflon. You may

Table 1

KD7S Loop-Tuning Capacitor Parts List for a 50-pF Capacitor

Qty	Description
2	10-inch length of 3/4-inch-ID type M copper pipe
2	10-inch length of 1/2-inch-ID type M copper pipe
1	3-inch length of 1/2-inch-ID type M copper pipe
2	1/2-inch, 90° copper elbows
2	3/4-inch, 90° copper elbows
2	10x22-inch pieces of 0.005-inch-thick Teflon or polyethylene sheet plastic
1	12-inch length of #8-32 threaded brass rod
1	#8-32 brass shoulder nut
2	22x5 1/2 x 1/4-inch ABS plastic sheet (top and bottom covers)
3	1x5 1/2 x 1/4-inch ABS plastic sheet (end pieces and center brace/guide)
2	1x22-x 1/4-inch ABS plastic sheet (side rails)
1	50 to 200-rpm gear-head dc motor
1	DPDT center-off toggle switch (up/down control)
2	SPDT microswitches (limit switches)
50 ft	3-conductor antenna rotator control cable
1	Enclosure (switch housing)

Misc: 4 to 12-V, 400-mA variable-output power supply, motor-mounting hardware, rubber grommets, hook-up wire, adhesive.

also find polyethylene is a little more difficult to work with than Teflon. The high-voltage-handling capabilities are about the same for either plastic.

Perhaps the easiest way to form the insulation is to pre-cut a length of plastic sheet the proper size. Place a lengthwise strip of double-sided tape on the tube to secure one end of the plastic. Begin wrapping the plastic around the tube while keeping it as tight as possible. *Don't allow any wrinkles or ridges to form.* Secure the other end of the plastic with another piece of tape. Once both tubes are covered, ensure they are just short of being a snug fit inside the larger tubes. Confirm that the insulation completely overlaps the open end of the small tubes. If not, the capacitor is certain to arc internally with more than a few watts applied to it. To protect the insulation, you can brush on a light coat of epoxy resin. Make sure the added thickness of epoxy doesn't interfere with the movement of the tubing.

Route the drive motor wiring *inside* the antenna pipes to minimize the amount of metal within the field of the antenna. Bring the wires out of the bottom next to the coaxial connector. As shown in Figure 3, a 3-wire

system allows the use of limit switches to restrict the movement of the "rotors."

Be sure to solder together all metal parts of the capacitor. Use a small propane torch, a good quality flux and 50/50 solid solder.

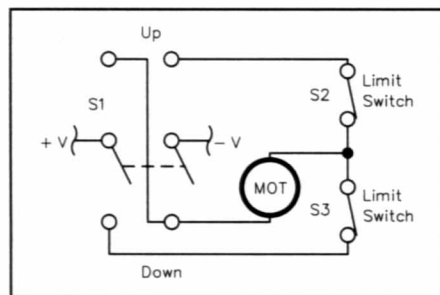


Figure 3—Schematic of the capacitor's tuning control circuit. S2 and S3 are microswitches used to limit the travel of the telescoping tubes (see Figure 1).

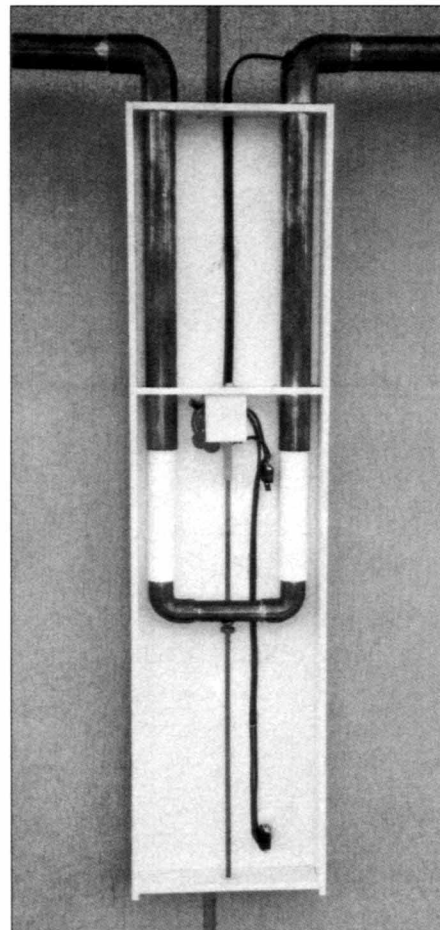


Figure 4—Close-up view of the KD7S loop-tuning capacitor and drive mechanism.

Never use acid-core solder on an electrical project! Clean all parts to be joined with steel wool prior to coating them with flux. Heat the joints to the point where the solder flows on its own. Very little solder is needed to make a strong, low-resistance joint. Be extremely safety conscious while soldering. No one wants to play host to the fire department or paramedic team when you could be working DX on 20 meters instead.

Test Results

Several of these home-brew capacitors have been tested on a 10-foot circumference (3-ft diameter) loop made of 3/4-inch copper pipe. The antenna is mounted within 4 feet of the ground and has been fed with power levels ranging from 5 to 100 W. I've made contacts on 10, 15, 17 and 20 meters with this arrangement. There's been no sign of capacitor heating or breakdown. Tuning is smooth and precise. During Field Day 1994, dozens of stations were worked, coast to coast, with good signal reports. DX contacts have included stations in South America, Europe, Japan and the South Pacific. In a nutshell, the antenna and capacitor combination works quite well!

I welcome your questions, comments and suggestions on this project. I'll reply to correspondents who supply a business-size SASE.

Acknowledgment

A special thank you goes to my wife, Merleigh Jones, who put up with my numerous weekends of "radio therapy" in the garage. Without her understanding and support, this project would never have become a reality.

Notes

- ¹T. Hart, "Small, High Efficiency Loop Antennas," *QST*, Jun 1986, pp 33-36.
- ²See J. Rusgrove, "The Trombone Trimmer—Build Your Own Variable Capacitors," *QST*, Nov 1975, pp 22-23 and 34. The calculated capacitance achieved using Rusgrove's equation amounts to about 2 pF per inch more than that found by using Equation 1 of this text. Note also (on pages 23 and 34 of the referent) the reasons given for a rather large discrepancy between the calculated and measured capacitance of The Trombone Trimmer.—*N1FB*
- ³*The ARRL Handbook*, 1994 edition, p 2-14.
- ⁴*The ARRL Handbook*, 1994 edition, p 2-13.

First licensed at age 13, Bill Jones wasn't satisfied with the restricted operating privileges his Novice ticket allowed, so he upgraded to General three months later. He's held an Extra Class license since they first became available.

High-speed CW, QRP and building his own equipment from scratch are Bill's primary Amateur Radio interests. According to Bill, his junk box looks like part of the freebie box from every hamfest ever held.

A Systems Analyst for the City of Fresno, California, Bill deals strictly with personal computers and is part of a team responsible for supporting several hundred city employees with hardware and software expertise. Mostly self-taught, he professes to be a graduate of McGraw-Hill, SAMS and TAB Universities...

