Distributed Capacity Folded Loop

This ceiling-mount mobile antenna will really go to your head!

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If you own a Fiberglas™ pickup shell, motorhome, or boat, this compact 40-meter mobile loop will compare favorably with a mobile whip antenna. What's better, it's invisible from the outside of the vehicle.

Over the years, the ham community has ignored small transmitting loops for the HF bands. Today, however, we live in a shrinking world. Everything is smaller: our rigs, our cars, even our QTHs.

I was curious. Would a loop work well there? Could it compete with a conventional HF whip antenna?

To answer this question, we need to get back to basics, to understand the fundamental strengths and weaknesses of both types of antenna.

Key principles

Compact transmitting loops and mobile HF whips are usually considered small antennas. Their total size is less than roughly 1/4-wavelength. How well each performs depends heavily on three key issues: (1) radiation resistance; (2) coupling field size (my term); and (3) antenna height.

In a full-sized antenna like a dipole, radiation resistance is comparatively high—about 73 ohms. In a compact loop or a mobile whip, the radiation resistance is much lower. Here are the formulas for the radiation resistance for a small loop and a short vertical whip (without loading coil or capacitive hat):

Loop

$$Rr = 19500 \times (D/WL)^4$$

where
Rr = Radiation resistance in ohms
D = Diameter of loop in meters
WL = Wavelength in meters

Whip

$$Rr = 392 \times (L/WL)^2$$

where
Rr = Radiation resistance in ohms
L = Length of whip in meters
WL = Wavelength in meters

To illustrate, **Table 1** translates the loop formula into real numbers. Notice how rapidly radiation resistance decreases with size. Why is this important? In the theoretical world, it isn't. An antenna with low radiation resistance, like a loop or a mobile whip, can radiate just as well as an antenna with high radiation resistance, like a dipole. The only difference will be the voltage and current in each antenna.

In the real world, however, antennas also have conductor resistance. The metal in an antenna is not perfect. All

Loop Diameter (Feet)	Rr (Ω)	Cr (Ω)	Efficiency (%)
10	0.49	0.089	85
9	0.32	0.080	80
8	0.20	0.071	74
7	0.12	0.062	67
6	0.064	0.053	55
5	0.031	0.044	41
4.5	*0.020*	*0.040*	*33*
4	0.013	0.035	27
3	0.004	0.027	12
2	0.0008	0.018	4
1	0.0000	0.00089	0.05

***Table 1.** Radiation resistance (Rr), conductor resistance (Cr), and efficiency of loops made of 3/4-inch (0.9-in. OD) copper pipe at 7 MHz.*

metals exhibit resistance. The problem is that it's in series with the radiation resistance. Transmitter power gets divided between the two. The part that goes to conductor resistance is wasted as heat. The portion that gets to the radiation resistance is the useful part. It becomes radio waves.

The real culprit is skin effect, the well-known tendency of RF current to flow only on the surface of a conductor. Here is that formula:

$$R = 0.00096 \times \sqrt{(F/D)}$$

where
R = Conductor resistance in ohms/ft
F = Frequency in MHz
D = Conductor diameter in inches

Again, I'll give this equation some real numbers. For example, let's take a large conductor, 3/4-inch (0.9-inch OD) copper water pipe. At 7 MHz, conductor resistance is 0.0028 ohms per foot. That's not much, you say. Take a look at the third and fourth columns of **Table 1**. Even with a conductor this large, for loops smaller than five feet the conductor resistance is actually greater than the radiation resistance. Instead of being a minor problem, skin effect eats us alive in compact loops.

Two additional concerns

What's more, even the type of metal we use to build a loop is important.

Silver	0.94
Copper	1.0
Gold	1.4
Aluminum	1.6
Chromium	1.8
Zinc	3.4
Brass	3.7 – 4.9
Tin	6.7
Steel	7.6 – 12.7
Lead	12.8

***Table 2.** Relative resistivity of common metals, compared to copper.*

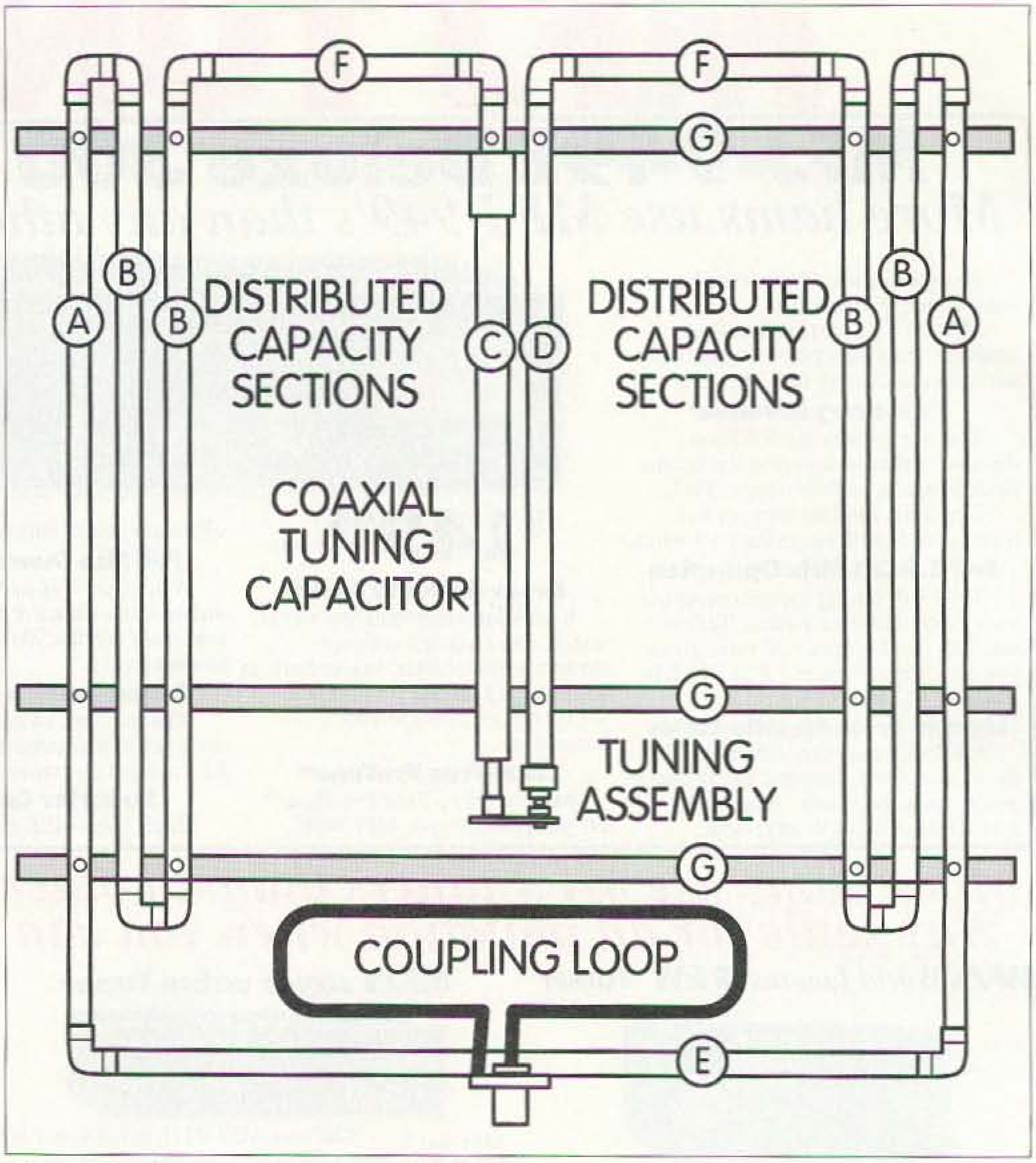

***Fig. 1.** The distributed capacity folded loop.*

I've listed the relative resistivities of some common metals in **Table 2**. I've included silver and gold for curiosity more than practicality. Gold is interesting, however. You might think that it would be the best conductor. Surprisingly, both silver and copper are better. We use gold on connectors not because of superior conductivity, but because it resists corrosion.

Copper is really the only choice for a loop. Even aluminum, which is suitable for larger antennas, has 60% more resistance. We can't afford this when we are fighting skin effect in a loop. Other metals are worse.

Perhaps you are thinking about silverplating. It's a good idea at much higher frequencies, but at 7 MHz the skin depth is too thick. Plating does not become practical until we are operating at UHF frequencies.

Also, the shape of the conductor is important. Round is best. A flat strap, for example, suffers much more from skin effect than a round conductor. Not only does the RF current move outward, it also moves to the edges.

For most small loops, 3/4-inch household copper water pipe is the most reasonable choice. It has moderately low conductor resistance and it's inexpensive.

A mobile whip

Whips don't suffer as badly from conductor resistance loss. In the equations above, you'll notice that the radiation resistance of a loop decreases in proportion to the fourth power of diameter. For a whip, it's only the second power of length. The radiation resistance and the efficiency of a typical 40-meter mobile whip are much higher than for a comparable loop. Does that make a whip better than a loop for mobile? Not necessarily.

In theory, a 1/4-wavelength mobile whip antenna is not a complete antenna. It is physically only half a dipole. It's often called a monopole. The missing half of the antenna exists, but it's a mirror image of the real half of the dipole in the ground plane under the monopole. Without it, the monopole would not function. The coupling field from the real half of the antenna becomes RF currents in the ground plane to complete the electrical circuit of the antenna.

If the ground plane under the antenna is a perfect conductor, the monopole will radiate just as well as if the other side of the dipole were actually present. In the typical mobile situation, however, the ground plane is terrible.

At HF frequencies, the vehicle's body is much too small to be the entire ground plane. The coupling field even for a short whip is many meters in diameter at 7 MHz. Contrast this with VHF, where the coupling field is only roughly a meter in diameter. Here the car body can provide the complete ground plane.

Soil makes up most of the ground plane at HF. Compared to a metal car body, soil is a poor conductor. It varies with location, but soil resistance is always at least 10 ohms, even in the best case.

Like conductor resistance, the soil resistance is in series with the radiation resistance, and the power again gets divided. At HF, most of the transmitter's power only heats up worms.

A mobile loop

In contrast, a mobile loop does not suffer in the same way. First, it isn't half an antenna like a mobile whip. The coupling field can make a complete circuit in space. Part of it does not have to become currents in the soil. The other half of the antenna is physically present.

The second reason is the size of the coupling field of a loop compared with a whip. Because the ends are folded back in a loop, the coupling field is mostly confined to the center of the loop. This makes it much smaller than the coupling field of a whip. Without going into the math, my loop's coupling field is roughly the same as a tiny 12-inch dipole's. The loop's energy becomes a radio wave long before it ever reaches the soil.

Does this mean that a loop is better for mobile operation? Again, not necessarily. There is more to the story. Here's where we get to antenna height.

Like any antenna, a loop works best in free space, far away from surrounding objects. Anything that you place near an antenna induces losses and lowers its efficiency.

Because of its very small coupling field, the electric and magnetic fields of a loop are more intense than for a whip. In free space this would not be a problem. Due to its shape, however, we normally have to mount a loop close to the metal body of the car.

For the whip, the metal body is an asset—it improves the ground plane. But for the loop, it is a disadvantage. Near the metal body of the car, losses induced by the loop's intense magnetic field are unfortunately quite high.

It is just easier to get a whip higher in the air than a loop. Notice the photo of my truck. The whip on average is several feet higher than the loop, so it is less of a "grounded" antenna.

What can we conclude, then? Is one antenna the clear winner for mobile operation? Frankly, no. A whip is easier to get higher in the air, and it suffers less from conductor resistance loss. However, it suffers badly from soil resistance loss. Also, it's ugly.

A loop does not suffer from soil resistance loss and is aesthetically much more attractive, at least from the outside of the vehicle. It, however, suffers badly from magnetic loss in the car's body. Therefore, both antennas are very highly compromised by the

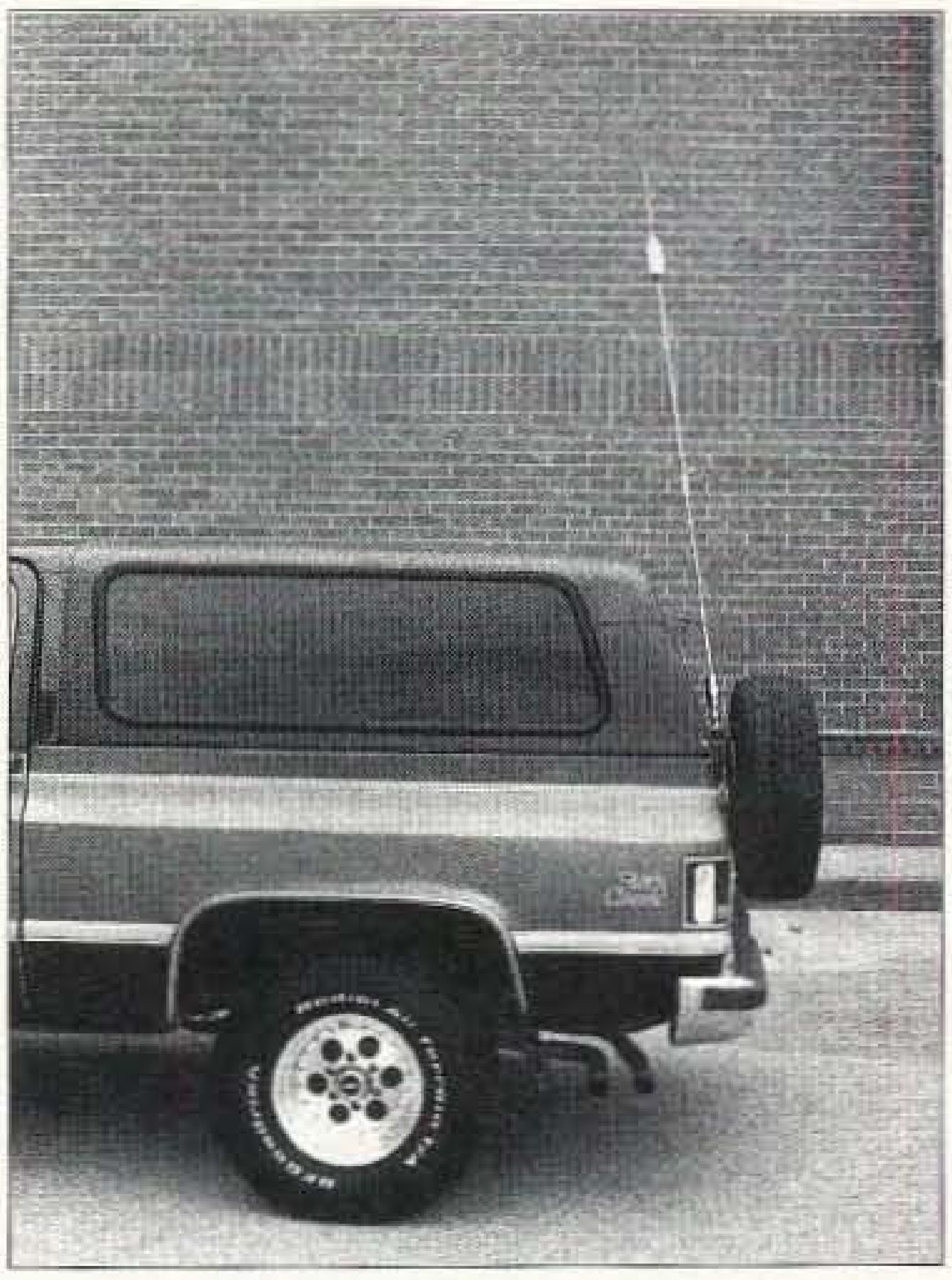

***Photo A.** Truck with 40-meter Hustler mobile whip. Loop not visible, inside.*

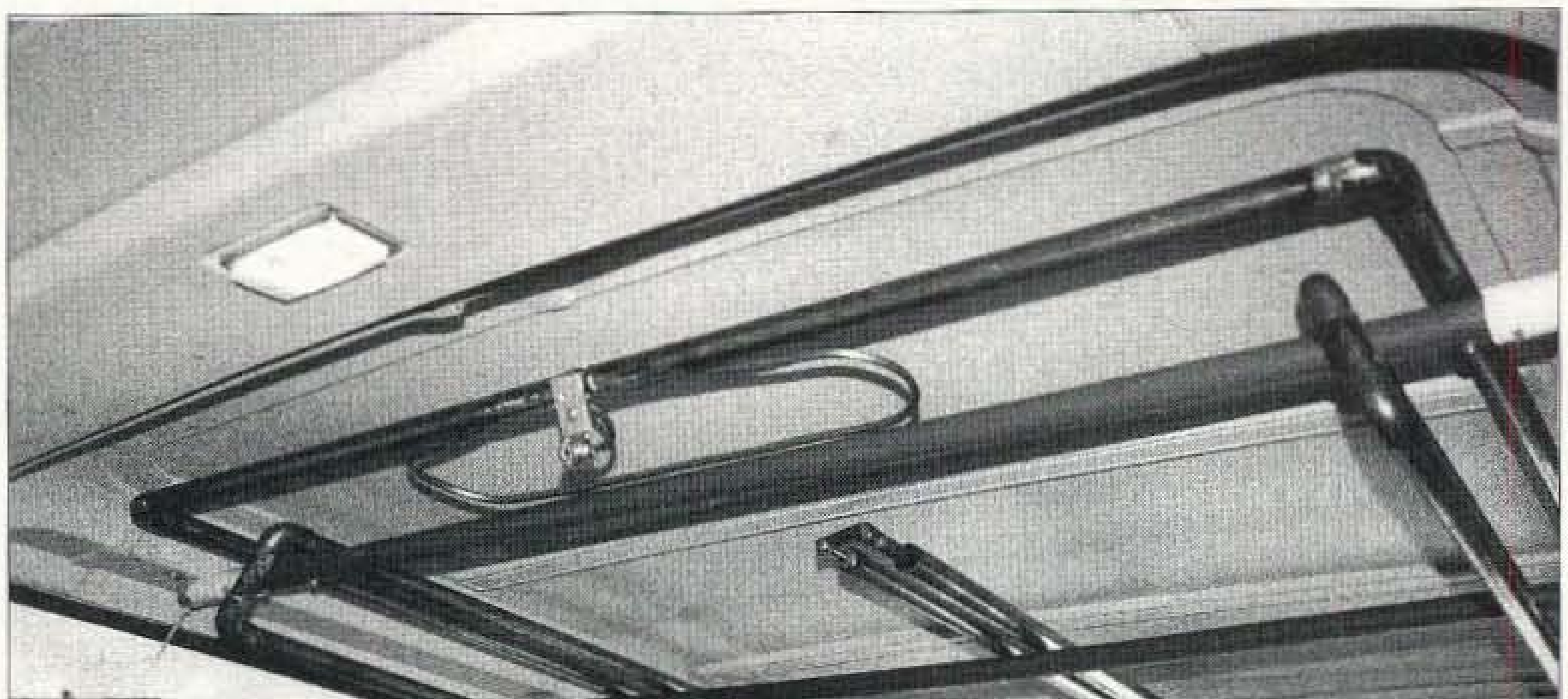

***Photo B.** Interior of truck from the driver's position with loop mounted on underside of Fiberglas shell. Mount loop with connector forward.*

Photo C. Close-up of the tuning assembly of the coaxial capacitor.

mobile environment. Neither is significantly better than the other.

Later in this article, I will share with you my personal comparisons of the two antennas, based on operational experience. Like most antenna articles, the proof of the pudding comes from using the antennas on the air. I will say here, though, that my experience with the loop has been quite good.

Designing the mobile loop

Now that we are armed with all this theory, let's design the loop. The first consideration in the mobile environment always is space. Realizing that big is better, I made the loop as big as I could. It had to fit on the underside of the Fiberglas shell of my truck. It's a rectangular loop 47 by 51 inches, but I made it a little smaller than necessary so that it would fit on a smaller truck (my pickup is a full-sized model).

Loops, incidentally, do not have to be round. Shape isn't important. Only the total area of the loop matters. That's what couples to space, not the shape. For calculating purposes, my 47- by 51-inch rectangular loop is roughly equivalent to the round 4.5-foot loop shown in the figures.

You will notice from **Fig. 1** that the loop is more that just a simple loop. There is a good reason for this, and I will get to that shortly. First, however, we need a little more theory.

The tuning capacitor

A small loop antenna is essentially a parallel tuned circuit, an inductor in parallel with a capacitor. By making the inductor physically large enough to have usable radiation resistance, the circuit will act as an antenna. Making the inductor into a single-turn loop accomplishes this nicely. Then, by adding capacity across the ends of the loop, usually in the form of a tuning capacitor, we bring the circuit to resonance.

The capacitor, however, is the difficult part of this design. Remember, voltage and current in any small antenna are high. My loop has a radiation resistance of roughly 0.02 ohms. A dipole, at 73 ohms, is almost 4000 times higher. The voltage and current multiply by this ratio. In a small loop they can reach tens of thousands of volts, and many dozens of amps. It takes a very substantial tuning capacitor to withstand this.

So I set out to do something about the tuning capacitor. Could I eliminate or minimize it? The answer to both of these is yes. By taking advantage of another characteristic of all antennas, I eliminated the conventional tuning capacitor entirely. In theory, all coils also possess a small amount of capacitance. We call it *distributed capacity*.

If we could make the loop large enough, the distributed capacity would bring the loop to resonance all by itself. Loops are naturally self-resonant, without a capacitor, at a circumference of roughly 1/4-wavelength. On 40 meters, this would be a loop roughly 10 feet in diameter.

A 47- by 51-inch loop is too small to be self-resonant at 7 MHz. I measured mine with an FET dip oscillator. It resonated at 21–22 MHz without a capacitor. If I had wanted to use it on 15 meters, that would have been fine. I mostly work 40 meters mobile, however.

So I added more conductor. To maintain the required 47- by 51-inch size, I folded the extra length back. Notice **Fig. 1**. This is an old trick to increase distributed capacity that I read in a 50-year-old antenna textbook. The self-resonant frequency now dropped to between 13–14 MHz. Again, if I had wanted to work 20 meters, I would have been close.

Then by extending the ends of the loop downward, to form a linear capacitor, as shown in **Fig. 1**, I lowered the resonant frequency a couple more MHz. I was getting close. A small air-variable would have taken me the rest of the way, had I wanted. My objective, however, was to completely get rid of the conventional tuning capacitor.

You'll see my final solution in **Fig. 1**. It's a coaxial capacitor also made of copper pipe. It's inexpensive and you can make it yourself. You won't have to locate a large, expensive tuning variable. This capacitor will handle a 100-watt mobile transceiver. I haven't tested its maximum power handling capacity. If you want to run more power, all you have to do is use larger pipes for the capacitor.

Tuning the loop

As you can also see, I made the center conductor of the coaxial capacitor adjustable like the slide of a trombone. With this arrangement I can tune the loop to any segment of the 40-meter band. Yes, the loop is a fixed-frequency

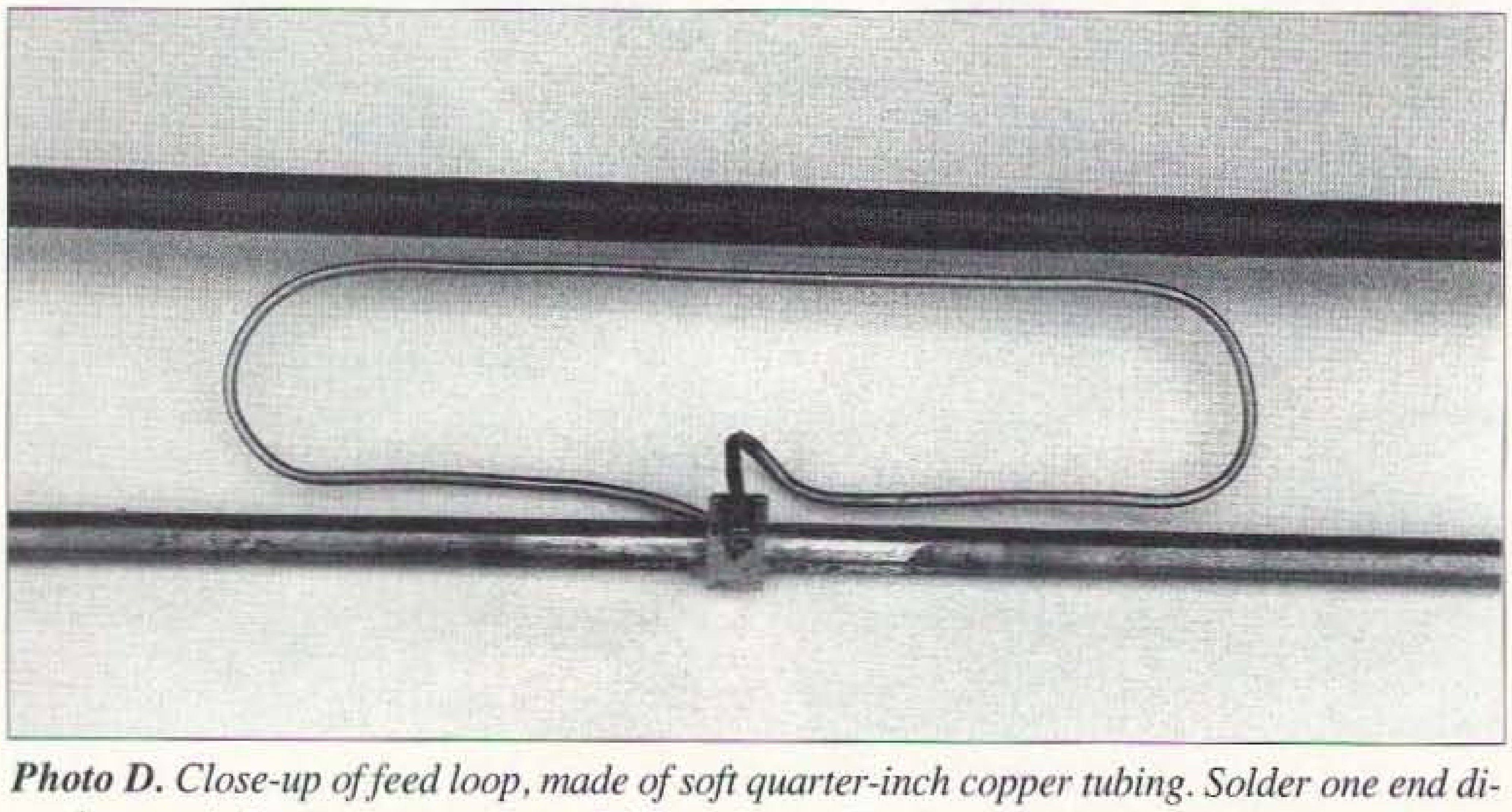

Photo D. Close-up of feed loop, made of soft quarter-inch copper tubing. Solder one end directly to main loop near connector. Solder other end to the center pin of the feed connector.

device, but so is my mobile whip. I have to change the length of the whip for a different band segment. Where's the sin in doing the same for a loop? In my particular vehicle, the tuning adjustment is right behind the driver's seat.

Also, like any small antenna, the loop is extremely sharp in tuning, but so is my whip. Any small antenna that isn't sharp isn't efficient. A small antenna that is broad has high losses. It's a law of physics. Incidentally, from bandwidth alone I know that the two antennas are very similar in total efficiency.

With the loop or the whip, you must operate within roughly a 25 kHz window to stay below 3 to 1 SWR. Otherwise, you will need to move the adjusting assembly. For convenience, you could parallel the coaxial capacitor with a small wide-spaced variable. 20 picofarads would be adequate.

Automatic antenna tuners

While I'm talking about bringing the loop to resonance, let me say something here about automatic antenna tuners. While it is theoretically possible to feed a loop with an automatic antenna tuner, it's not a good idea. You'll have the same problem if you use a tuner with a loaded whip. The tuner is able to provide a matched load for your rig. It won't, however, necessarily maintain the efficiency of the antenna. Worse yet, you may damage your tuner.

For a loop or small loaded whip to work properly, high circulating currents must flow. Remember, it has low radiation resistance. Once we tune out the reactance, high currents will flow in the low radiation resistance. We don't, however, want these high currents in the tuner. If you use a tuner to cancel the reactance as you move frequency, some of the high current will begin to flow in the tuner and in the transmission line. Neither may be able to stand it. It is best to bring a loop or mobile whip to resonance by reactance located in the antenna, not in a tuner. That's why the commercial loops have heavy-duty motor-driven tuning capacitors in them. In my particular case, I tune the loop by distributed capacity and the coaxial tuning capacitor. Both are part of the loop.

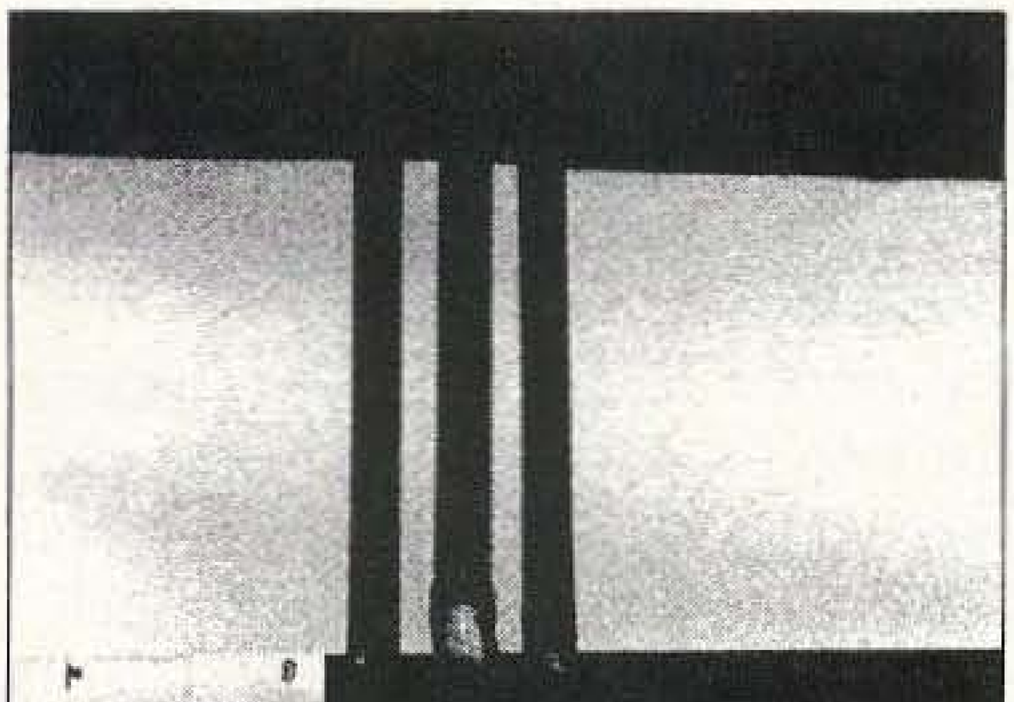

Photo E. Close-up of the end of triple pipe sections at the sides of the loop, showing how to orient pipes and elbows. These sections increase the distributed capacity of the loop and lower its self-resonant frequency.

Feeding the loop

To couple the loop to your transceiver, you will need a feed network. Most conventional feed techniques work well. I tried a gamma match, a shunt match, a capacitive match, and a loop match. All of these worked, once I got them tamed. The easiest method proved to be loop coupling, however. You can see the details in **Fig. 1.**

To my surprise, the shape size, location, and wire size of the coupling loop are not critical. For durability, I made it out of 1/4-inch soft copper tubing. Make it roughly one-quarter of the diameter of the main loop. Mine is a rounded rectangular loop roughly four inches by 18 inches.

The most convenient place to locate it appears to be at the midpoint of the main loop. Here the impedance is very low. Solder the grounded end of the coupling loop directly to the main loop, as shown. Mount the feed connector on a small copper strap also soldered to the main loop.

Key	Qty.	Item
A	2	49-inch lengths, 3/4" copper pipe
B	4	45-inch lengths, 3/4" copper pipe
C	1	35-inch length, 1" copper pipe
D	1	36-inch length, 3/4" copper pipe
E	1	43-inch length, 3/4" copper pipe
F	2	18.5-inch lengths, 3/4" copper pipe
G	3	47-inch lengths (min.), 3/4" schedule 80 PVC pipe
	4	3-inch lengths, 3/4" copper pipe
	1	18-inch length, 1/2" copper pipe
	14	Elbows, 3/4" copper
	1	Reducer, 1" to 3/4" copper
	1	End cap, 3/4" copper
	1	End cap, 1/2" copper
	1	Strap, 1/2" x 2-1/2" x 1/16" flat copper
	1	Screw, 1/4–20 RH brass
	3	Nuts, 1/4–20 brass
	15	Screws, 10–24 x 2-1/2" RH brass
	15	Nuts, 10–24 brass
	5	Feet of tubing, 1/4" copper
	1	SO-239 connector, chassis mounting
Teflon™ for insulators (see text)		

***Table 3.** Parts list for folded loop.*

Constructing the loop

Cut all the copper pipe pieces to size according to the parts list. Make the center conductor of the coaxial tuning capacitor roughly a foot longer than specified. You'll need this for final tune-up. Then assemble the entire loop unsoldered, flat on the floor. Before soldering the pieces together, you will need to get a good picture of how everything fits.

Pay particular attention to the three parallel pieces at the sides of the loop. Note that the middle pipe does not lie in the plane of the loop, like the other two. When viewed from the top, the three side pipes form an equilateral triangle. Make certain to space the two that lie in the plane of the loop by three inches. Connect the elbows at the ends of the side sections with the three-inch pieces of pipe specified in the parts list.

Also, be careful to space the two pipe pieces in the center of the loop half an inch apart. This spacing is important in order to obtain adequate capacitance at the ends of the loop.

Then solder the entire loop together. Clean all connections thoroughly with steel wool and apply a coating of solder flux. This is important. I used liquid rosin flux, but the acid paste type is fine also. Use a propane torch. The biggest soldering iron will not be adequate. Any type of solder is fine. I used electrical-type.

Be careful not to allow too much solder to collect on exterior surfaces. Surface solder will reduce conductivity. Use a file to clean surfaces down to bare copper again. Afterwards, clean off the flux with solvent. It isn't necessary to polish the loop. Moderate surface corrosion will have little effect on performance. I spray-painted the loop to match the interior color of my truck.

Next, install the three pieces of schedule-80 PVC pipe. Their function is to keep the loop rigid. Drill holes through the loop and the PVC pipe for the screws. Do not, however, drill a hole through the coaxial capacitor. I used the PVC pipes to mount the loop in my vehicle. You may make them longer than specified for easier installation.

Now solder together the tuning assembly of the coaxial capacitor. Remember to solder a brass 1/4-20 nut inside the three-quarter-inch end cap that fits on the end of the loop. Use a stainless steel bolt and nut to hold the brass nut in place during soldering.

Then fabricate the insulators that separate the inner and the outer conductors of the coaxial capacitor. If you have access to machining facilities, turn them from Teflon™ or polystyrene.

A word of caution. Not all plastics are suitable. The electric field inside the capacitor is intense. Many plastics, PVC for example, exhibit too much dielectric loss. I constructed my insulators by wrapping heavy half-inch Teflon™ tape around the center conductor and securing the outer end with electrical tape. In any case, make the insulators as small as possible. Most of the capacitor's dielectric should be air.

Initial tune-up

For initial tune-up, a dip oscillator is most convenient. When you built the loop, you left the center of the coaxial tuning capacitor longer than required. With mine this way, the loop resonated at roughly 6.5 MHz. Then, with a tubing cutter, I shortened the center conductor in small increments until I brought it onto the 40-meter band. I performed the initial tune-up by hanging the loop on short ropes from the ceiling of my garage. You may want to leave the center conductor just slightly too long, to allow for final adjustment on the vehicle. The resonant frequency did not change much when I installed it in my truck, however.

Once you get the loop in band, an SWR bridge is sufficient to indicate the resonant frequency of the loop. The SWR bridge is a permanent part of my mobile installation. It dips sharply as I quickly tune across the band while applying very low power.

You will adjust the coupling loop in much the same way. First, tune the main loop to resonance. Then bend the coupling loop until the SWR is best. I was able to obtain an almost perfect match. The procedure is remarkably simple to perform. Once you find the correct shape and position, you will never again have to adjust the coupling loop.

How well does the loop work? Very well, thank you. As I promised earlier, let me give you some comparisons between the loop and my mobile HF whip.

The whip is the popular Hustler™ mobile antenna with the large high-efficiency kilowatt resonator. It's mounted at the top center of the tailgate, on the spare tire rack. This is a good location because of the Fiberglas back on my truck. All of the whip is above the metal body. I installed a shunt-feed network at the base of the whip to be sure that the whip was properly matched to 50 ohms.

At the operating position, I installed a two-way coax antenna switch and two identical feed cables to make the comparison. In all cases I operated both antennas on the same frequency, very near the resonant frequency. Power was the same for all tests, roughly 100 watts RMS.

What did I find? To be honest with you, there isn't very much difference. Most of the difference is caused by the height of the loop compared with the whip. Being lower, the loop puts more of its energy straight up. Therefore, I noticed the biggest difference in ground wave contacts. Here the loop is usually an S-point weaker on both receive and transmit. For short skywave contacts, the loop is at times the same as the whip. On receive, the loop is less sensitive to noise. In terms of making an effective contact, this offsets the slightly weaker signal.

My conclusion is that the loop is a good mobile antenna. A large mobile whip may be a little better. The more compact types that are popular today would be the same. The loop obviously won't work on every vehicle, but for the ham with a Fiberglas truck shell, motor home or boat, the loop is certainly worth considering. It might be your best answer on a vehicle totally without a metal body. I want to try it on a large Fiberglas boat, for example.

I mounted my loop so that I could easily remove it from the truck. On camping trips it is an outstanding performer if I hoist it up into a tree. Give it a try—you won't be disappointed. 73