TX Loop Antennas for the 1W Lowfer Band Part 2

By Bill Ashlock

This second loop article is a no-nonsense step by step approach to assembling an effective 50’ x 50’ loop antenna and efficient 1W final, and should be particularly useful to those having tall trees on their back yard.

The increased success of TX loop antennas in the 160-190kHz Lowfer band since my first article appeared in the March 2002 Lowdown has been exciting to say the least! At least five other known loop users have joined the ‘loop group’ and a number of others are making plans to install loop antennas in time for this winter season. The increased usage, particularly in the US Lowfer band, where the power is limited to 1W, has resulted in a better understanding of the loop variables, including loop propagation, which until now has been pretty much *hit and miss.* In the event of the opening of the new 136-137kHz band in the US this antenna will give those having no open areas, for the traditional vertical, the ability to participate.

First a short review of loop-related findings over 4 years of experimentation:

1) The conductor can be routed over the top of, and resting on, a group of trees with almost no measurable loss (certainly less than 1db), including summer operation when the trees are fully covered with foliage.
2) No ground system is required – a big advantage over vertical antennas that require a large array of wires, either above-ground or buried.
3) The installation time for a loop can be as short as a couple of hours.
4) Field strength measurements and signal reports indicate the overall efficiency of the loop is close to that of a vertical of comparable size located in a treeless environment but it can easily outperform a vertical located in a wooded environment.
5) The driving electronics are very simple and low in cost. Operation at nearly 100% efficiency is easy to achieve.
6) The loop is less sensitive than a vertical to rain, wind, and snow, both from a performance and a rigidity standpoint
7) Lightening protection is much more effective for the loop than for the vertical.
8) The loop is almost invisible a short distance away, making for better neighbor acceptance (even wife acceptance).

Loop Basics

Note: Assume an operating frequency of 185 KHz

Figure 1 represents the three main components of the transmitting system. The transmitter itself is simply a switch that connects the coupling capacitor ‘C’ to either Vcc or ground at a 185 kHz rate. This results in a square wave voltage with a +/- ½ Vcc amplitude. The current waveform at the output is a sine wave that results from the high Q resonant loop load at 185kHz. The step-down transformer matches the 0.3 to 1.5 ohm AC resistance of the loop (Rac) to the transmitter output. This system can deliver just about any level of power from a fixed Vcc input such as 22vdc to the loop load from miliwatts to kilowatts simply by changing the transformer's turns-ratio. The equations in figure 1, however, assume a 1W power level at all points and 100% efficiency at the three components – not a bad assumption at this power level. This figure can be used to trouble shoot any 1W system by calculating the voltages and currents from the equations given.

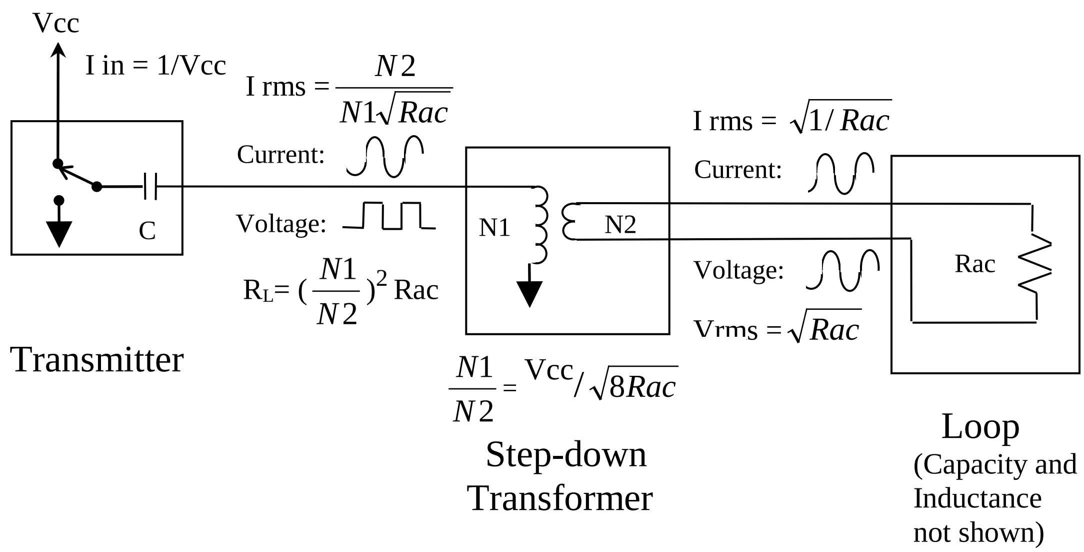

Figure 1: Block diagram of major components including Signal computations for a 1W system

Step 1 Selecting the location

Look over the area over which you plan to install the loop with a vision of the loop wire installed over tops of the trees. You will need at least two trees that are 50ft tall with their trunks separated by at least 20ft. No large metal structures should be within 25 feet of the loop. Guy wires supporting other antennas could be a problem if within 10ft. If you have numerous tall trees, allowing for a choice of direction, the vertical plane of the loop should be in line with your favored coverage area, not only local, but the whole US. This positioning, however, does not need to be exactly on line with the receiving location since only a 3db signal decrease will result from a 45 deg misalignment. The reduction in signal for other angles is given in the following table. The scattering effect in the ionosphere actually reduces further the need to precisely aim the loop for skywave reception.

Angle, deg	Reduction in signal, db
0	0
10	.13
20	.54
30	1.24
40	2.31
50	3.83
60	6.02
70	9.32
80	15.2

Table 1: Signal reduction resulting from loop misalignment

Step 2 Selecting a loop conductor

A wide rage of conductor types can be used from a #12 copper wire, which was discussed in my first Lowdown article, to copper pipe - and all can be installed without the aid of another person. The choice is based on the cost and effort to build and install versus the performance. The performance for each conductor configuration can be compared by inspection of column 5 in Table 2. These values are listed in terms of the performance compared to the #12 loop. In a constant 1W power comparison the antenna current is dependent on Rac which depends to a large degree on the *skin depth* at the frequency of use. To better understand the concept of skin depth, think the loop conductor as having the same outside diameter as a thin-walled cylinder . Within the wall of this cylinder is where 100% of the current in the wire flows. The equation for this wall thickness, or ‘skin depth’, d, is defined in equation 10, Appendix A, for any frequency. At 185k the skin depth is only .007 inches and a #2 AWG conductor, for example, utilizes only 10% of its copper to conduct current when connected to a 185kHz energy source. Another representative example from Table 2 is that a ½” copper pipe weighs only a little more than #2 wire of the same length but it’s Rac is less than half.

The Rac for any circular conductor at any frequency can be calculated from Equation 11 Of appendix A. Appling this equation to 185kHz, and with a 200ft perimeter loop, the value of Rac is .093/d where d = the conductor diameter in inches. The Rac values for single conductors in Table 2 are based on this equation.

<u>House Wire</u>

The term ‘House Wire’ will be used to define any wire intended for home electrical utility wiring. I recommend the stranded type because of its ability to hold up under more severe bending conditions that occur during a wind storm. The lowest cost versions of this wire are found at discount home building supply stores, but don’t rule out surplus sources. Shorter lengths can be spliced and soldered together in order to save on cost.

The simplest initial approach to loop building is to use #12 as was covered in Loop Article #1. After numerous hours of experimentation with 10 other conductor types I still believe that this is the best ‘starter’ conductor. It is certainly the fastest to install - often in just a few hours. The current in the loop with 1w of transmitter power will be approximately .83A and this will be sufficient to be copied at 150 miles over a surface wave path and at over a thousand miles when skywave conditions are favorable. At a later date the wire can be used as a leader to pull a larger conductor in place. The #12 loop can also be used in the upcoming 136k band since it can handle the voltages and currents resulting from the 100W power level.

Larger diameter copper conductors can be used but the reduction in Rac with size is rather dismal as can be seen from a comparison of #12 through #2 in Table 1. In order to reduce the total Rac (including soil loss) to ½ of the value for #12 you will have to drop all the way to #4, which is over 6 times heavier and much more expensive. This is due, again, to skin effect which limits the improvement in Rac according to the diameter of the wire, not the area of the wire, as it is for the DC resistance.

Multiple house wire conductors

A number of conductors may be run in parallel to reduce the Rac value. By comparing the Rac versus weight of multiple conductors in Table 1 it can be seen that this is a more effective use of copper compared to a larger solid conductor of the same weight. The reason is that the area in which the current flows, by virtue of the skin depth, is the product of the current for one conductor times the number of conductors. Thus by using four #12 wires the Rac would be ¼ of the value for one. This improvement, however, can be realized only if the conductors are widely spaced because of another factor relating to RF currents flowing close to each other – proximity effect. If two current-carrying conductors are closely spaced the magnetic field in one will tend to force the electrons in the other to the opposite side thus reducing the effective current-carrying size of the conductor. Spacers can be fabricated from slotted ½” PVC pipe sections forming a ladder-like conductor. A single cable tie can be inserted on the inside of each pipe to keep the wires from coming out. 1” PVC pipe sections with grooves around the periphery can form a circular cable spacer when the wires are taped to these grooves. Unfortunately, I have not found a spacer design that is simple to construct and will allow sliding of the complete cable over the tops of trees. I, therefore, recommend the ‘spacer approach’ only for loop antennas supported by ropes and not directly by the trees.

Litz wire

This type of conductor takes into account the skin depth problem for solid or stranded conductors by using a large number of insulated conductors each having a radius smaller than the skin depth. Additionally, the wires are grouped and twisted in a way that reduces the proximity effect as identified above under multiple paralleled conductors. My experimental results have shown that Litz wire having #38 or smaller individual wires will halve the Rac of the same sized non-Litz wire. In other words a #12 Litz wire would have the same Rac as a #6 standard copper wire. The cost of Litz wire is a major barrier for use in loop antennas. I was lucky to be able to obtain enough #12 Litz at low cost to allow building of a 4-wire cable. Some spacing of these conductors was required to reduce the proximity effect, even though it is much less than for non-Litz wire. My prototype cable had a total installed Rac of only 0.38 ohms including ground loss, but after a few months of service this began to rise. It turned out that a large number of kinks formed in the wire during the assembly of the cable, and in spite of the rubber hose protecting the cable from contact with the trees, the pull on the cable caused a significant percentage of the individual Litz wires to break. My next experimental Litz cable will allow the 4 main wires to slide freely within the rubber hose, thus eliminating the axial stress on the wires.

<u>RG-8 Cable</u>
When it was first suggested over the internet that large diameter coax cable might make a good loop conductor I didn't believe it. I figured the braided copper shield would have a much higher Rac than a solid copper pipe, of the same OD. I was wrong about this. My measurements indicate the Rac is only 16% less than a solid cylindrical conductor with the same OD. Since RG-8 and RG-11 are widely available in the surplus market, sometimes as low as $50 for 200ft, this cable is high on my list of good conductors.

<u>Copper water pipe</u>
Thin wall hard-temper copper pipe (also known as type M) is an excellent loop conductor since the wall thickness is not much greater than the skin effect thickness where most of the current in the conductor flows. Another feature is that when formed into a curved shape the stiffness tends to add three-dimensional stability which transfers a potion of the upper load into the vertical sides. My main concern with using pipe was the difficulty of installation but I was pleasantly surprised with the *ease* of installation. A #8 wire can be used to pull up a 200ft long conductor, comprised of 20-10ft sections laying on the ground, over the tops of the trees. It turns out that because of its large diameter and smoothness, the pipe slides over the tree limbs with minimal friction.

One problem I have experienced with this loop is that the lead-free solder joints come apart for apparently no reason after about a year after installation. After some investigation I discovered that the acid in the rain caused the solder to weaken. An attempt to silver-braise the joints met with failure because the red-hot braising temperatures caused the temper in the pipe to be lost over about 2" from the joints. Consequently most of the pipe flexing took place near these joints causing early failures. My next attempt will be to use 60/40 tin/lead solder rather than lead-free and painting the joints with a sealer to keep out the acid rain. I will also reduce the flexing at the joints by inserting 9" long wooden dowels before soldering.

<u>Copper tubing</u>
Soft-temper copper tubing can be used in place of copper pipe but the cost will be much higher. Also because there is no 'stiffness effect', described above, there could be a large amount of sagging of the tubing between tree limbs.

Ground Losses

Think of the loop as large single-turn a low loss inductor surrounded by a huge doughnut-shaped field. Unless the loop can be elevated to an exceptional height a good portion of this field must pass though the ground. It is desirable to elevate the loop as high as possible because field intensity falls off rapidly as the distance from the wire increases. The loop area will be compromised, however, if the maximum height becomes less than 50ft. A practical minimum spacing between the ground and the lower run is 6ft. This distance also provides some safety for animals (typically deer) and unsuspecting people walking under the loop.

The ground loss value is approximately the same value for all loop conductor types and appears in series with the conductor Rac and adds to the total Rac. By subtracting the conductor Rac and the total Rac from Table 1 it can be shown that the value varies from .22 to .33 ohms with a lower horizontal run spaced of 6 foot above ground. The quantity of moisture in the ground has the largest effect on the actual value. Fully saturated ground represents .33 ohms and fully dry ground represents .22 ohms. The sandier the soil the quicker will be the return to ‘dry’ Rac values (which can take days).

Table 2 Conductor Characteristics

Conductor Type	**Rac ohms** (note 1)	**Tot Rac ohms** (note 2)	**Antenna Current** (note 3)	**Perform ance** (note 4)	**Xfmr Turn ratio**	**Wt LB**	**Cost dollars** (note 5)	**Notes**
#12 awg	1.15	1.37/1.48	0.83/.80	0 db	7	4	12	Smallest practical wire siz
#10 awg	0.92	1.14/1.25	0.91/.87	+0.8 db	7	6.3	17	
#8 awg	0.72	.92/1.03	1.02/.96	+1.8 db	8	10	22	
#6 awg	0.57	.79/.90	1.09/1.03	+2.4 db	9	16	40	
#4 awg	0.45	.68/.79	1.18/1.10	+3.1 db	10	25	60	
#2 awg	0.36	.57/.68	1.29/1.18	+3.8 db	11	32	92	Max size for tree support
#12 x 2	0.65	.87/.98	1.05/.98	+2.0 db	9	8	24	One inch spacing
#12 x 3	0.43	.63/.74	1.23/1.13	+3.4 db	10	12	36	“
#12 x 4	0.32	.55/.66	1.31/1.20	+4.0 db	11	16	49	“
#12 Litz	0.57	.79/.90	1.10/1.03	+2.4 db	9	4	See text	
#12 Litz x 2	0.30	.59/.70	1.27/1.16	+3.7 db	11	8	“	1/4” average spacing
#12 Litz x 3	0.24	.46/.57	1.44/1.29	+4.8 db	12	12	“	“
#12 Litz x 4	0.16	.38/.49	1.58/1.39	+5.6 db	13	16	“	“
RG-8/11	0.38	.60/.71	1.26/1.16	+3.6 db	11	18	180	Inter cond tied to shld
½” Cu pipe	0.15	.37/.48	1.60/1.41	5.7 db	13	40	73	OD = .630”

Notes:

1) AC resistance of conductor alone, without soil loss, for a 200ft perimeter loop
2) Total Rac including soil loss. Smaller value for dry or frozen soil; larger value for moisture saturated soil.
3) Table values are for .95w into a loop operating over dry soil where antenna current = $\sqrt{P / Rac}$
4) Performance is based on a loop using single #12 conductor.
5) Cost for AWG wire and copper pipe is based on discount store pricing on 10/20/02

Step 3: Installing the loop

The recommended installation method is still the bow and arrow. See my first loop article for the procedure and various suggestions for installation. I have since determined if you have no clear location off to the side of the trees in which to make a shot over the top you can shoot an arrow from within an area of dense trees with little difficulty if there is a small opening in the canopy. In this case the bow must have a 45-55lb pull-back to allow the weighted arrow to be delivered at a steep angle and reach at least 100ft in elevation. The arrow must have approximately 2 oz of weight added to the tip so that it will fall at a high rate of speed and not be snagged by leaves and branches on the way down. Caution: No less than 20lb monofilament line should be used or the line could break if there is even a small snag in the delivery reel. Attempt this steep-angle delivery only if the wind is essentially calm and you can make it impossible for anyone to be hit by the arrow.

An addition discovery since the first article is that tall pine trees can be used as the upper support for the loop by shooting a leader line through the tree near the top. In spite of the lack of upward pointing branches, and a much narrower top compared deciduous trees, the final installed conductor will likely be captured by the many thick branches and will not slip out.

Step 4: Building the final

Part 15 FCC requirements dictate the final stage of the transmitter be located as close as possible to the loop terminals. This constraint posses no major difficulty since the stage can be constructed on a small circuit board and mounted within the same weather-proof enclosure as the matching transformer and resonating capacitor bank. This also isolates the more expensive exciter components from the possibility of damage from a nearby lightening hit. The power can be supplied with low-cost small gauge wire since the current is under 50ma. Additionally, the power can be supplied via the coax signal line by inserting isolation transformers at both ends.

The circuit below, I'll call the 'Ashlock final', is a modified version of the original "Simple Lowfer Transmitter" by Lyle Koehler. The additional diodes connected from the two bases to their collectors, as well as the individual series base resistors, form a voltage divider that limits the degree of collector saturation to reduce the turn-on time. When adjusted properly this circuit will operate close to 100% efficiency and will remain there under the full range of environmental temperatures as the result of the compensating effect of the diodes. The balance pot allows compensation for differences in turn-on characteristics between the transistors. The recommended transistors for this circuit are the readily available plastic TO-92 MPS6602/MPS6652 devices by ON Semiconductor. They were selected because they have the highest available current gain at 200ma for any transistor I could find in the 'small signal' category. A wide range of transistors having an Ft >40 MHz can be used with slightly lower collector efficiency including the popular 2N4400/2N4402 as well as the 2N2222/2N2907 but it will be found the balance adjustment will be well to the 2N2907 side due to the higher saturation current required for this device.

A PCB blank of this circuit will be made available in the near future as well as a kit of the parts including the ferrite core, mica capacitors, and trimmer capacitor.

The loop is driven in the series tuned mode partly to simplify the output transformer design. The normal turns count on the primary ranges from 7 to 13 with only a single turn used on the secondary. If the parallel mode is used the turns count on the primary would have to be at least 6 with a secondary of 48 to 78 turns. Another factor favoring the series mode is the reduction of the harmonic radiation and will be covered in the following section.

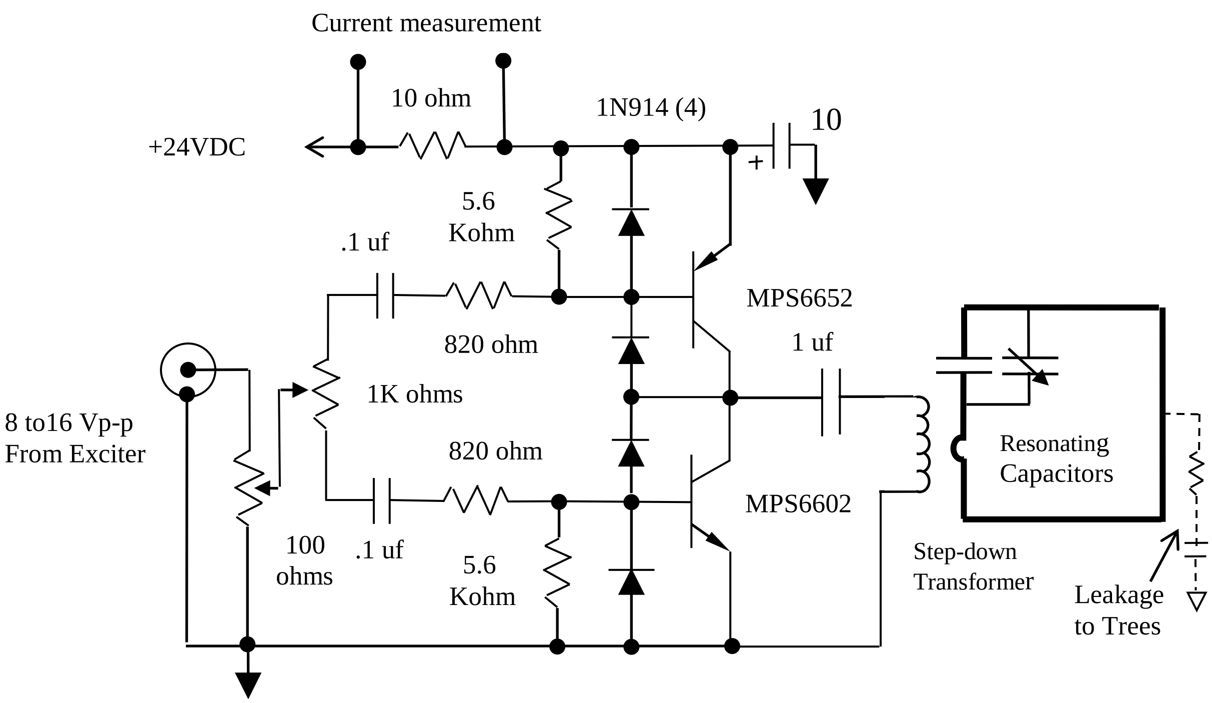

Fig 1 **The Ashlock Final**
(Located at base of loop)

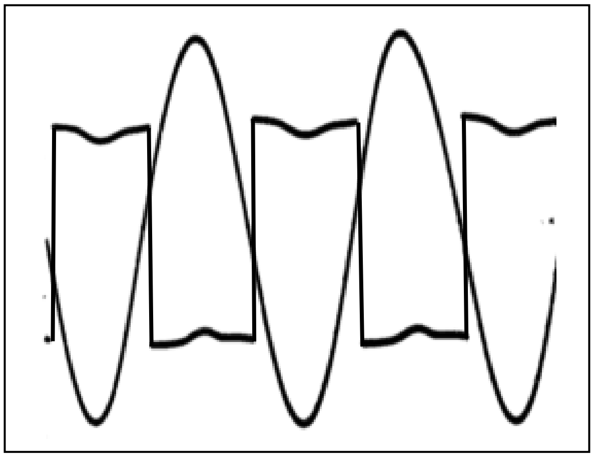

Figure 2 Scope waveforms for base drive balance adjustment.
(The square wave is the waveform at the transistor collector junction and the sine wave is the current in the loop)

The output filter controversy

It should be mentioned that the Ashlock final requires no output filter to meet the FCC requirement for 20db out of band radiation in spite of the square wave, non-filtered output. The Q of the loop, ranging from 100 to over 200, along with a step-down ratio ranging from of 7 to 13 results in greater than 66db reduction in radiation at the third harmonic. The loop antenna, however, becomes a more efficient radiator as the frequency increases. At 5MHz the 50'x50' loop is one wave length in size and has a gain of approximately 2db. Fortunately the 27^{th} harmonic of a 185k square wave (5 MHz) is down by 85db. With the theoretical 200 ohm loop impedance at 5MHz there is less than 1uw of power radiated.

In order to insure the above calculations were correct I hit the road with a wideband E-field antenna connected to my Icom R75 receiver. At a distance of 200ft from the loop I tuned to each of the odd harmonics of 185k and recorded the S-meter reading. The maximum signal did in fact occur at 5 MHz. I then drove through the neighborhood in close to a circular pattern around the antenna and determined the distance from the loop to the location where the signal was totally lost in the atmospheric noise (This was a low-noise, storm-free night). In the direction of maximum signal I could not detect anything beyond ½ mile and feel this represents no interference to other usage unless my next door neighbors happened to want to receive WWV at 5 MHz and were annoyed by a faint 3.2KHz beat note.

To satisfy the purest I spent numerous hours experimenting with various harmonic filters between the output of the final and the step-down transformer both on the bench and with P-spice simulations. It turned out that none of these filters worked well in this application. As the result of the high Q loop load on the filter occurring only at 185k the filter sees no load at other frequencies and this typically introduces massive ringing that consumes power. Additionally, I found that if the filter was not tuned precisely to the transmitted frequency a moderate loss in efficiency occurred. This tuning is particularly an annoyance during the initial loop tune-up and if any change in frequency is desired at a later date. Even a simple series LC filter performed poorly. I therefore strongly recommend that no filter be used for 1W Lowfer loop applications – at least until a performance baseline is established.

Step-down transformer considerations:

As stated previously the general formula for the step down ratio at 1W is: $\frac{N1}{N2}$ = $Vcc/\sqrt{8Rac}$. A requirement for efficient transformer performance is that the primary inductive reactance is at least 4 times the load resistance reflected from the loop. Two popular ferrite cores, #43 and #77, in sizes from .75" OD and higher will perform with good efficiency in this circuit. The preferred core material is type 77 but type 43 is a close second. Type 43, however, will have about 5 times less primary inductance for the same number of turns as type 77 and this sometimes can be a problem in meeting the above inductive reactance criteria. The turns ratio is given in table 1 for each conductor type and assumes the Vcc is 22vdc. This allows for two 10 ohm current measuring resistors and 20 ohms in the lines running to the final. If type 43 ferrite is used it may be necessary to double the primary winding and use two turns in the secondary. As an example a #12 loop with an Rac of 1.38 : N1/N2 = 22/$\sqrt{(8)1.38}$ = 6.62 which would indicate either 13 turns to 2 or 7 turns to 1 depending on the core type.

A number of #43 cores sold by DigiKey will work in this circuit. The DigiKey P/Ns are 11381-ND thru 11386-ND. The larger cores have slightly lower loss than the smaller ones. There is common #43 bead that is used for the numerous EMI applications that works well in this circuit that you may already have. This bead has an OD of 0.75" and a length of 1.13" and are found on numerous monitor cords and video connections.

Step 5: Selecting the correct resonant capacitors

The loop inductance will range from 90uh for the lower Rac conductors to 112uh for #12 wire. The capacitance needed for resonance will be 6000pf to 8000pf at 185kHz This capacity should be built up from 500v dipped mica capacitors - typically three paralleled 2000pf caps, a compression mica trimmer, and a smaller value mica capacitors. Do not attempt to cut corners by using smaller, lower voltage, capacitors because it will be difficult to separate capacitor failures from a number of other transmitter/loop related problems.

At the time of writing the 2000 pf mica caps are available from All Electronics Corp for only 35 cents each and a 2000pf compression mica trimmer is available from Dan's Small Electronic Parts for $2.50.

Step 6: Debugging and tune-up

Required test equipment:

1. DVM
2. Scope
3. Current probe for DVM or scope
4. Loop simulation coil (see text)
5. LCR Meter

It is important to be able to measure the voltages at all locations of the loop driving circuitry to be able to determine if everything is working properly. Therefore an oscilloscope is a necessity although the speed does not have to be faster than 10MHz. Older scopes are often available for the asking. The all-important loop current can be measured with a current probe attachment to the scope constructed simply from a 100 turn winding on a #43 toroid loaded with a 100 ohm resistor. The current/voltage conversion for this combination will be 1A/volt and insertion loss resistance will be only 0.01 ohms.

As a way to reduce the difficulty in the ‘de-bug’ portion of this project it is highly advisable to connect all components together on the bench before installing outside. A test loop having approximately the same inductance as the loop inductance (90uh for the Low Rac loops to 115uh for the #12 loop), and approximately the same Rac, should be constructed according to the following table:

Rac	PVC Pipe outside diam	Wire gauge	Wire diam incl insul	No of Turns	Inductance uh
1.25	2.35”	26	50 mil	50	112
1.0	2.35”	24	54 mil	50	105
.75	2.35”	22	50 mil	50	100
.60	4.0	18	70 mil	29	95
.50	TBD	14	TBD	TBD	

Table 3: Test coil parameters

I have found that monitoring of the input current to the final an excellent way to keep track of loop performance and readings are very close to being proportional to the actual loop current. This measurement can be accomplished by monitoring the voltage drop across a 10 ohm resistor back in the shack. Another 10 ohm resistor should be installed in series with the Vcc line at the final in order allow monitoring of this current as the resonant capacitor is tuned. I have installed a pair of pin jacks on the final’s enclosure for this purpose.

Warning: The final power stage described in this article delivers power according to the applied load resistance and if the turns ratio is incorrect can deliver up to 5W to the loop. To meet the 1W maximum per FCC Part 15 requirements the load must be adjusted via the stepdown transformer to the correct value. It is the responsibility of the operator to understand how to calculate the load required to draw 1W from the transmitter and adjust the turns ratio of the transformer accordingly.

Debugging procedure

1. Finding the resonant capacitance: The resonant capacitor will be a bank of 500v dipped mica capacitors plus a trimmer having a total capacity of approximately 7000pf. (See step 5). Set up the loop as a receiving loop using the same or a similar step-down transformer as is used in the transmitter. This includes using the same step-down ratio indicated in Table 2. Connect a receiver having coverage in the same area of the Lowfer band where it is desired to transmit to the primary of the transformer via a coax cable (the side with 7 to 13 turns). Connect the resonant capacitor bank in series with the loop and the transformer secondary as in figure 1. Locate the resonant frequency of the loop by tuning the receiver across the band and note the frequency where the background noise reaches a sharp peak. Add or remove capacity from the capacitor bank to reach the desired transmitting frequency.

2. Initial transmitter adjustment: Disconnect the transformer from the final and connect the drive signal to the input. (Insure the signal level is within 8 to 16vp-p with a scope) Set the input pot to the full CW position and the balance pot to the middle position. Connect the power supply and turn on the power. Connect a scope to the output of the final and insure a perfect square wave is present having the same P-P amplitude as the Vcc value. Reduce the setting of the input pot and find the point where the output drops off sharply and then set the level to a point well into the turn-on point. Determine the Vcc current by measuring the voltage drop across the 10 ohm resistor. The current in milliamps is the voltage drop times100. For example a .01v drop is 1ma. Insure this value is less than 2ma.

   Turn off the power and reconnect the transformer to the output but with no connection to the secondary. Turn on the power and insure the input current is less than 4ma. If greater than 4ma the transformer core is not suitable for this application and/or the primary inductance is insufficient.

3. Final transmitter adjustment with test coil: If the circuit passes above tests connect the loop test coil and capacitor bank to the secondary of the transformer and tune the trimmer to reach a peak maximum in the Vcc current. Note: This resonant point should be extremely sharp since the Q is greater than 100. Determine the input current to the final and multiply this value by the value of the supply voltage at the transmitter side of the 10 ohm resistor to find the input power. Depending on whether the input power is greater or less than 1 watt either add or subtract turns from the primary of the transformer. It will be found that only one turn, plus or minus, has a large effect. Be sure to re-adjust the resonant capacity after each change is made to the transformer. This is a good time to check the loop current if a current meter is available. Compare the

measured current with the value in Table 2 corresponding to the loop conductor used.

Connect a scope to the output of the final and slowly back off the input pot setting until dips appear on the top or bottom of the square wave (Fig 2). Adjust the balance pot and the level pot to equalize the dips on the top and bottom. Finally, set the input pot to a point that insures no dip is seen in the waveform. Check the input current to insure the input power is 1W.

4. <u>Final check with loop antenna:</u> Connect the transmitter final to the loop and re-adjust the trimmer to reach the maximum Vcc current. Measure the input power as above and change the number of turns on the stepdown transformer primary to make this under 1W. Note: Be sure to measure the actual Vcc value because there will be some drop due to the resistance of the power cable.

Appendix A

Some useful relationships:

Equation 1: Conversion between sine wave RMS voltage and peak to peak voltage

$$\text{Vrms} = \frac{Vp-p}{2\sqrt{2}}$$

Equation 2: Conversion between sine wave RMS current and peak to peak current

$$\text{Irms} = \frac{Ip-p}{2\sqrt{2}}$$

Equation 3a: Power out in terms of RMS voltage and Rac $\text{Pout} = \text{Vrms}^2 / Rac$

Equation 3b: Power out in terms of peak to peak voltage and Rac $\text{Pout} = \text{Vp-p}^2 / 8Rac$

Equation 3c: Power out in terms of RMS current and Rac $\text{Pout} = \text{Irms}^2\ \text{Rac}$

Equation 4: Input Power to final $\text{Pin} = (\text{Vcc})(\text{Iin})$

Equation 5: Resonant frequency of the loop $\text{fo} = \dfrac{1}{2\pi\sqrt{LC}}$

Equation 6: Loop Q in terms of loop inductive reactance and Rac $Q = X_L / Rac$

Equation 7: Inductive reactance of the loop $X_L = 2\pi f L$

Equation 8: $L = N^2 La$ where La is the inductance of a single turn

Equation 9a: The stepdown transformer voltage and current ratios $\frac{N1}{N2} = \frac{Vin}{Vout} = \frac{Iout}{Iin}$

Equation 9b: The stepdown transformer resistance ratio $(\frac{N1}{N2})^2 = \frac{R1}{R2}$

Equation 10: Skin depth = $2.63 / \sqrt{f}$ inches

Equation 11: Rac $\cong 1.02 \times 10^{-6} \sqrt{f}$ L/d ohms where: L = length of conductor in feet
d = conductor diam in inches

References:

1. The ARRL Antenna Book 19th edition page 5-4. Map of soil conductivities in the US.

2. The ARRL Antenna Book 19th edition page 5-10 Table 1: Inductive Equations for Loop Antennas.

3. The ARRL Antenna Book 19th edition page 5-10 Table 3: Transmitting loop Equations

4. Lyle Koehler's Low Frequency Web Site: http://www.cpinternet.com/~lyle