A Small Transmitting Loop Antenna for 14MHz and 21MHz
(This is an antenna you might consider if you have limited space)
by Lloyd Butler VK5BR

Introduction

By definition, the small transmitting loop is one which has a circumference less than one quarter of a wavelength. Because of its small size, it is possibly an attractive proposition for someone with inadequate space to erect a larger aerial. For example, an efficient loop can be constructed for the 14MHz band about one metre square. The small loop might also be attractive for operation in the field.

The small transmitting loop has been around for a long time but it appears to have been improved for amateur radio by Ted Hart W5QJR who developed a set of equations to calculate the various loop constants and set down parameters for a new design (refer QST, June 1986). The 15th edition of the ARRL Antenna Handbook also has some excellent material on both transmitting and receiving loop aerials. A section on small transmitting loops, written by Ted Hart, includes his design formulae (see appendix) plus a complete set of worked-out data for practical loops.

To gain some experience with the small transmitting loop, I constructed a loop which is less than 1 meter square and gives high efficiency on 14 and 21 MHz.

Because of its narrow bandwidth, the transmitting loop tuning has to be tracked as frequency is shifted across the band. Ted Hart suggests remote motor controlled tuning. The construction of the loop is described and another method is introduced which I used to track the tuning across the band without the use of the motor controlled tuning.

The Difference Between Transmitting & Receiving Loops

One might well ask why our typical receiving loops are unsuitable for transmitting. Most other aerial systems are reciprocal in operation, so why not these? To answer this, we must point out that in our typical receiving loop we are interested only in signal voltage. The loop is parallel tuned and coupled to the high impedance input of an amplifier enabling the Q factor of the tuned loop to multiply the signal voltage. In our receiving loop, we are not really interested in power efficiency. If we were, we would find that most of the signal power is consumed in the loss resistance of the loop. However, to transmit a signal, RF power must be transferred into the loop and developed across the radiation resistance of the loop.

The radiation resistance of a small loop is typically only a fraction af an ohm. To achieve any reasonable figure of efficiency, the loop loss resistance must also be a very low value otherwise most of the power is dissipated in the loss resistance. Wire loops as used in receiving have a loss resistance in the order of ohms, and to achieve the low loss resistance needed, transmitting loops are made with large diameter copper tube. Special attention must also be given to minimising resistance in the loop tuning and matching components, particularly the loop tuning capacitor.

Of course loops specially designed for transmitting with high power efficiency can also be used in reciprocal for receiving. But they are physically much larger than can be achieved using Q multiplication of signal voltage interfaced by the high impedance input of a follower stage. Very small receiving loops are practical for good reception on the LF and VLF bands but physical size inhibits the use of high power efficiency transmitting loops (as decribed in this article) for LF and VLF.

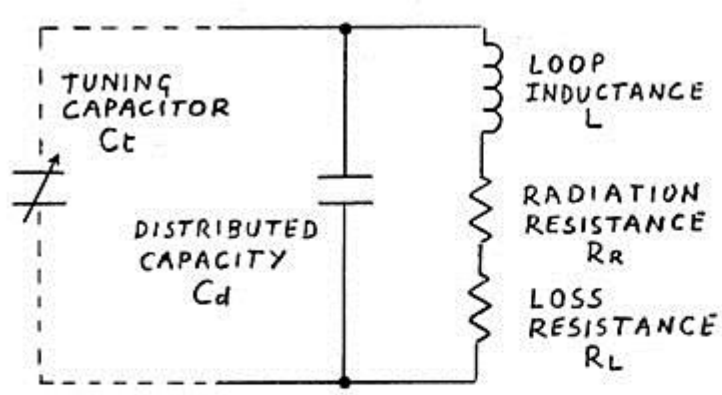

Figure 1 Equivalent Circuit of Loop antenna

The equivalent circuit of the loop aerial is shown in figure 1. The predominant component is the loop inductive reactance, which is large compared with the sum of the radiation resistance Rr and the loss resistance RL. Because of the high ratio between reactance and resistance, Q factors are extremely high, in the order of many hundreds, and often greater than 1000. The loop is set to resonance at the operating frequency by parallel capacitance Ct connected across the loop. Maximum operating frequency is limited to a frequency set by the resonance of the loop inductance L with the loop stray capacitance Cd. Because of the high Q, bandwidth of the loop is very small and it is necessary to alter the tuning capacitance when changing frequency more than a few kHz. The Ted Hart design calls for remote control of the tuning network which adds some complication to the construction of the loop aerial system.

Tuning Capacitors

Selecting the tuning capacitor requires special attention. In the QST article, Hart used the two halves of a split stator capacitor in series so there were no wiper contacts (normally in contact with the rotor) to add series resistance. He also recommended the capacitor plates be welded together to reduce resistance rather than be separated by spacers.

Because of the high Q factor, the voltage developed across the capacitor is quite high. Even using only 100 watts of power, the voltage can be as high as 10 to 15 kilovolts. Not only must the capacitor be selected for low resistance, but also its plates must be wide spaced to withstand the voltage. As a guide to the spacing required, breakdown voltage in air is around 30 peak kilovolts per centimetre. The split stator capacitor used for 14MHz and 21MHz in the loop described had plate spacing of 1.5mm. As the loop voltage is applied to two sets of plates in series , this equates to a peak breakdown voltage of 9Kv.

The Loop

Ted Hart has pointed out that, for a given length of conductor, a circular loop (or something approaching a circle such as a hexagon) gives more loop area than any other shape and hence it is the best choice of shape. However I made my loop square because I thought it was easier to assemble with heavy copper pipe and pipe elbows used for household water distribution..

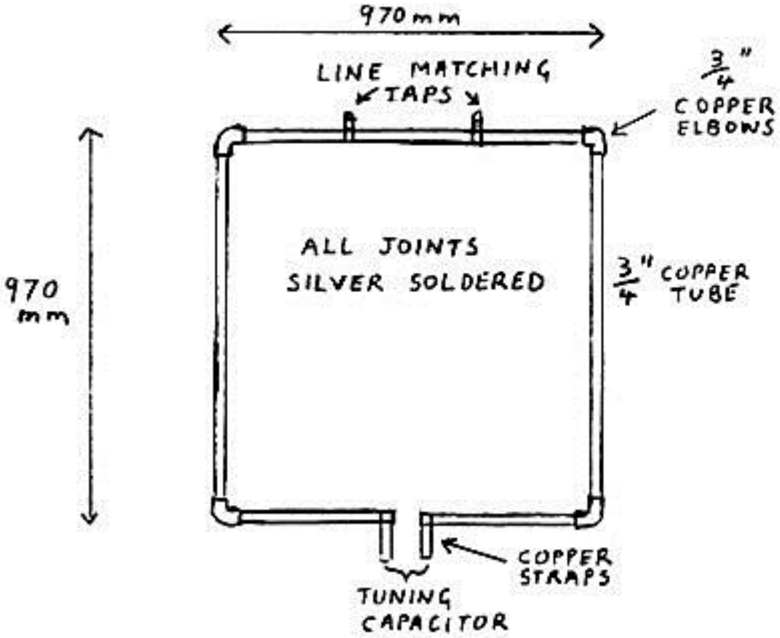

Figure 2 Loop Assembly

The loop was made up 0.97 metre square with 3/4 inch copper tube obtained from the local plumber. The tube was cut and assembled to the form shown in figure 2 using copper elbows for the right-angle joints which were silver soldered. Details of the loop and calculated constants for 14.2MHz are as follows: (Imperial measurements are used because the published formulae was given in these units):

Tube Diameter d 0.75 inch
Circumference S 12.7 feet
Area A = 10 square feet
Frequency f = 14.2MHz
Power P 100 watts
Radiation Resistance Rr = 0.137 ohm
Loss Resistance RL = 0.064 ohm
Efficiency n = 68%
Inductance L = 3.27 micro-henry
Q factor = 723
Inductive reactance XL = 291 ohms
Bandwidth B = 19.6kHz
Distributed capacity Cd = 10.4pF
Capacitor potential Vc = 4587V
Tuning capacitor Ct = 28pF

To tune 14MHz and 21MHz, a split stator capacitor is used with 80pf maximum capacity in each section. To tune 14MHz, the capacitor plates are well into mesh. To tune 21MHz, the plates are well out of mesh. Because of the high Q, tuning is very sharp and the capacitor adjustment is coupled via a reduction drive.

Split Stator Tuning Capacitor and Vernier Drive

Whilst the loop design data is specific for the14MHz band, the loop can be tuned to other bands, and calculated constants for some of these are as follows:

Frequency	Rr	RL	Efficiency	Tuning C
7MHz	0.008	0.045	15%	148pF
10MHz	0.034	0.053	39%	67pf
21MHz	0.66	0.077	89%	8pf

(Rr and RL are in ohms)

It can be seen that operation at as low a frequency as 7MHz is possible, but with low efficiency. The efficiency is improved as the frequency is increased, and at 21MHz efficiency is very high. Operation at 28MHz is not possible because self resonance occurs at a frequency just below 28MHz. The calculations do not take into account losses in the tuning capacitor which could further decrease the efficiency. Operation on bands lower in frequency than 14MHz requires the use of a tuning capacitor larger than the double 80pf one used for 14MHz and 21MHz.

Tuning the Band Without the Drive Motor

I found a way to remotely tune over the band without the drive motor. The gamma match is replaced by a delta match which is fed with 300 ohm balanced TV open wire line. This type of line has extremely low loss at HF even if used in a tuned mode. The loop tuning capacitor is set for resonance in the centre of the band (say 14.2MHz) and at this frequency the delta taps are adjusted for a 300 ohm match. The open wire line is fed from the transmitter via some form of balanced tuning system (refer figure 3). The Z match tuner does the job very nicely.

Delta Match

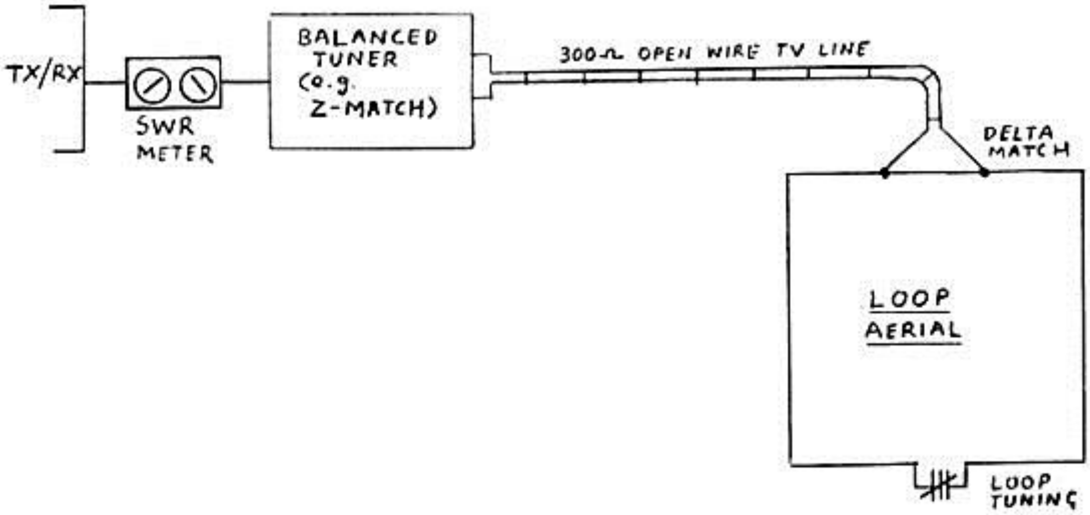

Figure 3 Matching System using Open Wire TV Line
The Loop is resonated with the line matched at centre frequency. To tune the loop across the band, reactance is reflected down the line using the tuner.

To set up the system, the tuner is first loaded into a 300 ohm resistor and adjusted for matching at the centre frequency. This can be done by connecting a noise bridge at the transceiver output and operating in the receive mode. The open wire line is then connected in place of the resistor and the loop tuning is adjusted for best balance of the noise bridge. Some adjustment of the delta match taps might also be required, but the tuner adjustment must not be altered from the setting determined using the 300 ohm resistor. Remove the noise bridge and verify that there is low SWR on transmit. If necessary, the loop tuning can be trimmed for best SWR. This whole operation is a little tricky because the loop tuning must be carried out within listening distance of the transceiver for noise dip or within sight of the SWR meter. I found it necessary to tune the loop with it first located close to the transceiver and connected via a short length of the open wire line. If matched properly, the loop tuning can be assumed to be correct for whatever length of line is ultimately used.

Another problem is that the loop is very susceptible to detuning if in close proximity to any conductors, including the human body. This makes setting the tuning capacitor by hand a little tricky.

Now, having set the loop tuning and matching, this is how the system works. If we shift very far from the centre frequency, the high Q loop goes out of tune. The procedure is then to readjust the tuner for low SWR, in effect reflecting down the open wire line into the loop a reactance sufficient to correct for the detuning. Off the centre frequency, the open wire line works partly in a tuned mode. The nature of the impedance change placed across the line by the tuner is obviously a function of line length, but for the various random lengths of line I have used, a Z match tuner handles the correction nicely.

For the loop described, I found a good match to the 300 ohm line is achieved, at 14MHz and 21MHz, when the delta match taps are set to 17.5cm from the centre. At lower frequencies, wider spacing of the taps worked better.

As constructed, the delta match is at the top of the loop and tuning across the open ends is at the bottom. A reason for this is that with the heavy variable capacitor at the bottom, the centre of gravity is lower and it hangs better on my rope support. A second reason is that tests were carried with the loop just above body level, and by running the feeders to the top of the loop, they were kept clear above head height.

Unfortunately the 300 ohm open wire TV line is difficult to obtain these days unless a disposal source can be found. Over past years it was in common use to feed TV antennas in fringe TV areas. If this type of line is unavailable, open wire line can be made up using parallel wires kept apart by pieces of perspex, polystyrene or similar insulating material. Although more lossy for the tuned feeder mode of operation, 300 ohm TV ribbon could also be used.

Operational Performance

Operational tests have been carried out with the loop suspended under a tree at about 1 metre from the ground. Signal reports on transmission from the loop at 14MHz were equal to those from a half wave horizontal wire dipole. Tests on a field day were carried out at 21MHz to compare the loop with a trapped verticle antenna. Reports on signals from the loop were several S points higher than the vertical.

Summary

An introduction has been given to the small transmitting loop aerial. Considering its small size, its performance is quite surprising. If one has space for a full sized aerial then there is not much point in building this type of loop. However, if you have limited space, or you need a compact aerial system to operate in the field, then the small transmitting loop might be a proposition. Its biggest, problem is its narrow bandwidth and the need to carefully peak up its tuning whenever shifting frequency across the band. This can be done using a remote controlled motor with reduction gearing system driving the tuning capacitor. However I have suggested another method using a partly tuned open wire TV transmission line and a coupled Z Match tuner.

The loop described is just under 1 meter square. It has a calculated efficiency of 68% at 14MHz and 89% at 21MHz. At 7MHz and 10MHz it can be used but efficiency is much lower.

Basic Equations for a Small Loop

Radiation resistance, ohms	$R_R = 3.38 \times 10^{-8} (f^2A)^2$
Loss resistance, ohms	$R_L = 9.96 \times 10^{-4} \sqrt{f} \frac{S}{d}$
Efficiency	$\eta = \frac{R_R}{R_R + R_L}$
Inductance, henrys	$L = 1.9 \times 10^{-8} S\left(7.353 \log_{10} \frac{96\,S}{\pi\,d} - 6.386\right)$
Inductive reactance, ohms	$X_L = 2\,\pi\,fL \times 10^6$
Tuning capacitor, farads	$C_T = \frac{1}{2\,\pi\,f\,X_L \times 10^6}$
Quality factor	$Q = \frac{f \times 10^6}{\Delta f} = \frac{X_L}{2(R_R + R_L)}$
Bandwidth, hertz	$\Delta f = \frac{f \times 10^6}{Q} = (f_1 - f_2) \times 10^6$
Distributed capacity, pF	$C_D = 0.82S$
Capacitor potential, volts	$V_C = \sqrt{PX_LQ}$

where

f = operating frequency, MHz
A = area of loop, square feet
S = conductor length, feet
d = conductor diameter, inches
η = decimal value; dB = $10 \log_{10} \eta$
P = transmitter power, watts