The Reference Loop

Martti Nissinen OH4NV from Finland, decided that he and his friends needed a comparison antenna for use in their experiments. So, the Reference Loop for DX was created!

Some years ago when a VK friend and I were experimenting intensively with small antennas, it became clear to us, that for more accurate comparisons, we need a fixed reference antenna. The horizontal length of such reference antenna should be somewhere between full size (λ/2) and really short (λ/20). Study of the antenna books showed that a loop having horizontal side length of around λ/8 could be an optimum compromise between radiation resistance (R_r) and size.

After many prototypes, the non resonant loop described here was 'born'. This loop has been a very good reference antenna for a number of experimental small antennas we've built. Also, I have enjoyed its exceptional performance as a DX antenna. So, should you not have room for full size dipoles, beams or big antennas, or if you just enjoy building wire systems, then try this non-resonant loop.

Many of the properties of this simple loop will surprise you and the design should cost almost nothing to build. To make adjustments, you need nothing more than your rig and a little r.f. output power from it.

Loop Dimensions

The illustration shown in **Fig. 1**, shows the dimensions of the loop for the 14MHz (20m) band. The horizontal sides are 2.66m long and the vertical sides 6.5m. Total circumference is 18.32m, which is less than one wavelength (21.3m) at the design frequency (14MHz) so the loop is non-resonant.

Dimensions for the loop are not critical so, you could easily make the sides somewhat shorter, or longer, but for now try to keep to the dimensions shown. The upper horizontal part of the antenna is made from three wires in parallel. These three wires minimise the ohmic resistance at the centre of the upper horizontal element of the loop (the current maximum) so, reducing losses at this point.

The upper horizontal element and the top four metres down each of the vertical sides, form a full half-wave long dipole. This layout has the advantage that the high impedance (or high voltage) points are well separated from the supporting parts of the loop. This separation of support and high voltage point, minimises both losses and any detuning effect that there may be on rainy days.

The lower part of the loop (2.66m + 2×2.5m) remains shorter than λ/2, making the feed terminals impedance (Z_a) reactive - it's actually capacitive reactance. Also, the resistive component of this impedance is comparatively high, which means that the lower element carries less current than the upper element. The voltage levels present on the lower section are rather higher to compensate though.

The direction of the r.f. currents (flowing in the lower limb), although smaller than the upper limb currents, flow in the same direction as those in the upper part. As it's the r.f. current flowing that generates the outgoing radiation, the lower horizontal element has lesser role in the radiation from the loop. Because of this reduced effect, we may leave the lower element at a low level without a great detrimental effect to the loop's overall radiation pattern.

It's interesting to see that the upper four metre sections of the vertical sides act as 180° out of phase λ/8 spaced radiators. In practice, this property makes this kind of loop a very interesting DX antenna. The radiation pattern of this loop has both horizontally and vertically polarised radiation lobes. This combination of polarisation could be useful under some DX propagation conditions.

Quick Summary

To quickly summarise the form design of this loop, you will see that it consists of one short horizontal element and two phased short vertical elements in series. The main radiating part of the loop is like an inverted U. The lower part of the loop acts as a wide spaced feeder. Yes, I know, the lower part isn't just a feeder - in that it also radiates. But as can be shown, it's radiation capability is well below the upper part's capability.

Now we've completed the form analysis of the Reference Loop! At this point, you may have started to consider building your own. I'm sure that you'll appreciate its simple non resonant design, physically small horizontal size and easy erection possibilities. I can also assure you that it'll work, I know this since I've found that most loops work well. But the design here promises a little more than most loops!

The loop may be suitably constructed from any wire having diameter of about 1.5 to 2.5mm in cross section. The wire I used in the test model is pvc insulated multi-strand wire, with a diameter of 1.55mm. Triple the upper horizontal wire to minimise its ohmic resistance. Only the bottom horizontal element needs support. A glass fibre reinforced (g.r.p.) or water-proofed wooden rod is an ideal support. That's all! Then cut the wire and measure the corner points.

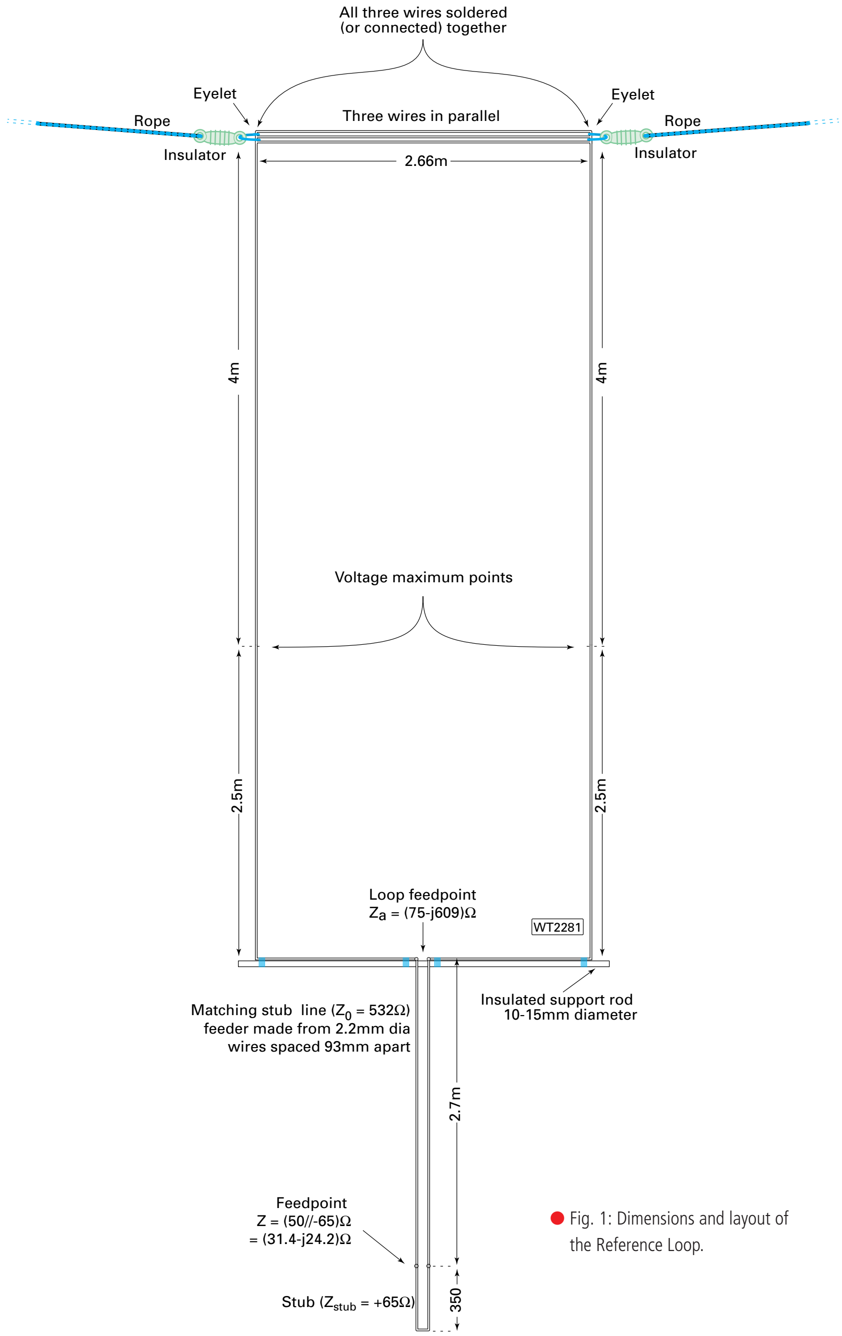

Fig. 1: Dimensions and layout of the Reference Loop.

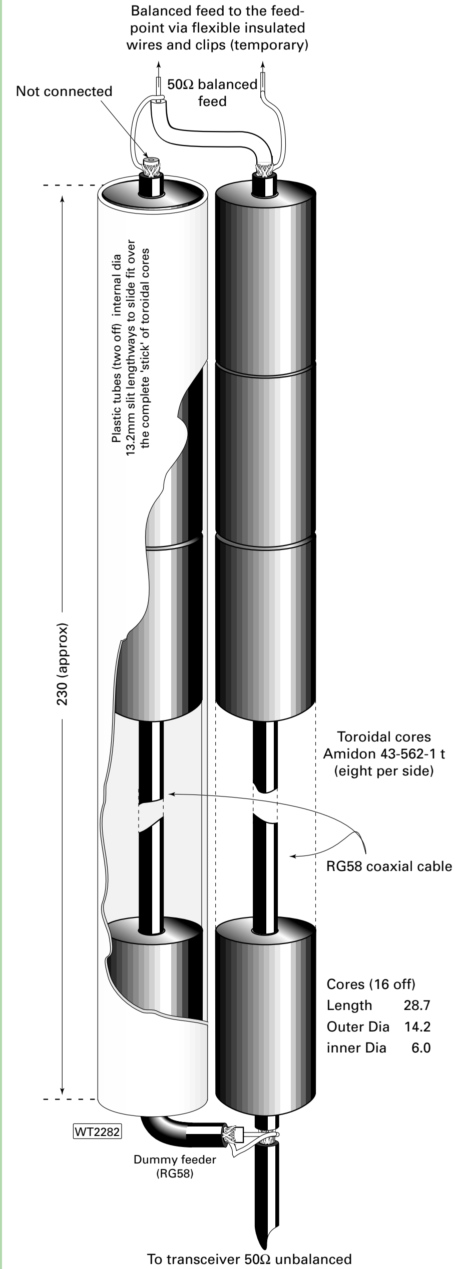

Fig. 2: The feeder balun is made from two parallel runs of RG-58 coaxial cable shrouded with ferrite toroids.

Next form a small eyelet to both upper corners for nylon type ropes. (An open knotted rope ring works well). Using a proper insulator at each upper corner improves the construction and working. Fasten the open-wire line to the support rod and solder the loop wires to the open-wire feedline's ends.

Tape, or tie the loop's bottom horizontal run to the rod with the self-amalgamating, or other waterproof tape. Secure the corner fastening points with a piece of tying wire. Now, your new small loop is ready. As simple as that! But now you'll have to arrange to feed it properly!

The loop's terminal impedance R-jX must be matched to the coaxial cable's characteristic impedance Z_0 (which should be taken as 50±j0Ω). The open wire line works as a matching line. If you follow the suggested dimensions of my version, you'll need to build up a 532Ω line.

Impedance Chosen

The open wire line's impedance Z_0 = 532Ω, was chosen, although other impedance values (around 500-5kΩ) would work as well. However, the designed dimensions shown here have been calculated using a line with the Z_0 of 532Ω. Construction of this open wire line is, perhaps, the hardest job with this loop. But you will like this low-loss matching element in your loop.

Take the two 3.3m long and 2.2mm diameter multi-strand base antenna wires, or equal diameter solid copper wires and space them 93mm. This dimension produces a Z_0 of 532Ω. For the spacers, I use 16.3mm wireman's PE-tube and saw the sides open. Each piece of the tube gives four spacers of the total number needed for the complete run.

Don't try your nice loop without an effective balun! For enjoyable and trouble-free operation the loop must be well balanced against ground. A good wideband sleeve-balun is shown in Fig. 2. I used the Amidon ferrites, type 43-562-1. The inner hole diameter of the ferrites is just about right for RG-58. The length of these ferrites is 28.8mm and the outer diameter is 14.2mm. Use eight ferrites per branch, total 16 pieces.

The construction of the Sleeve Balun is shown in **Fig. 2**, which shows the idea in skeletal form. Amidon ferrites, type 43-562-1 or equal other ferrites are inserted into the two plastic tubes. The tubes I used have an inner diameter around one millimetre smaller than the outer diameter of the ferrites. However, I put a sawcut slit along the length of each of the tubes, which allows the ferrite sleeves to be inserted. The resulting mechanical tension keeps the ferrites firmly in place.

Mounting Plate

Place both the plastic tubes with the ferrites on the insulated material mounting plate (34×260mm and not shown in the diagram) and tape them together (lightly). Couple the feeder and the dummy feeder as shown in Fig. 2. Don't overheat the bottom soldering point. Solder the clips to the ends of the pvc insulated flexible wires at the balanced end of the balun.

The clips are needed during the tuning. After the correct match is obtained and after many 'rainy days' testing, the clips have to be replaced by the screw joints. Do the same with the shorting link clips on the stub. After soldering all the joints, place a piece of good r.f. insulating material (as a cover) over the upper coaxial cable joints.

Finally, tape the finished balun with self-amalgamating insulating tape. Start the wrapping at the bottom end (coaxial feeder end) and finish with about 10mm beyond the output (balanced) wires. Thus, the whole balun becomes waterproofed. Then check to ensure that you have a good seal all around.

During the setting-up phase crocodile clips are used to make the connections.

The weight of the made-up balun is about 450-500g and obviously the loop cannot carry that without a vertical support rope. But because of the low elevations (the upper element at 12m or lower), a supporting pole under the feed-point would be a good solution for the balun's weight problem.

The supporting pole should be mounted below the loop, to support the balun and allow the balanced output leads to be connected and changed along the matching line. The idea of this ferrite covered 'two branch' balun is to prevent r.f. currents flowing on the outer surface of the feeder's braid and to balance the feed-point physically.

During my tests, I found that the dummy 'feeder' is necessary for complete balance. The inner of the dummy feeder coaxial cable can either be left unconnected, or it may be soldered together with its braid at the balanced end too. In some tests this latter method improved the balance still further.

At the bottom end the dummy coaxial lead both conductors are soldered to the braid of the feeder. This two branch ferrite balun is a low loss wideband balun. It keeps both feeding terminals well isolated from the ground over the frequency band 0.1 - 145MHz. Response is flat (at least over this band). I have carried out tests using a sensitive bridge instrument to verify the response.

Tuning Matching

Now, the initial set-up for matching is ready. But before the final tuning, match your rig to 50Ω dummy load using the c.w. mode. Use the minimum r.f. power, just enough to give good s.w.r. meter operation. Normally a few watts is enough. Next, you can erect the ready loop to the height of 10m for example. Not too high, as you've got to have easy access to the feed point clips and the shorting bar clips.

To begin the impedance transforming check, start with a length of the open wire feedline a little longer than you will need (I found that a length of about 3.2m is ideal). Connect the coaxial feed line, RG58 for example, and the balancing 1:1 balun with clips, to the points 2.7m from the loop's terminals Z_a. The connect a shorting bar, again using clips, a further 350mm down from the balanced feed-point (a distance of of 3.05m from the loop's terminals Z_a).

Now transfer the rig's output from the dummy load to the loop's RG58 coaxial line feeder (**remembering not to transmit while doing it**) and apply a low power into the feeder. The s.w.r. meter will probably indicate a reading above 1:1 at this this point, whatever the figure is, write the reading down. Now go out and move the stub feed-point clips about 10mm up or down.

If after moving the feed-point connections, the s.w.r. reading decreases, the direction of the change was correct. Again write this new reading down, and continue the procedure by moving the feed-point clips a similar amount again in the same direction.

If you arrive at a position where the movement of the feed-point clips has no affect on the s.w.r. reading (but it's still above 1:1), then try changing the position of the end shorting clips too. By sequential change of the either, or both clip pairs, you should be able to achieve a complete match with an s.w.r. reading of 1:1. This point is the correct match situation.

Somewhat Exhausting

The task of tuning the antenna can be somewhat exhausting if the coaxial cable run is quite long and you're on your own. It's easier with two people, one operating the rig, the other making changes. **However, r.f. energy can cause nasty flesh burns - even at comparatively low power.** Effective communications must be used to minimise the chances of this happening!

If you're working alone, I've found that tuning can become very easy if you make some arrangements for extending the key line and the s.w.r. meter lines. With these extensions you can obtain the wanted tuning situation easily, without running out and back in continuously. If you can't manage to extend the lines, look on the bright side - the physical exercise is very good for the experimenter too!

The horizontal main radiator of this loop has the length of 2.66m. This element (even though there are three wires side-by-side) looks very small when comparing it to a beam and many dipoles in the backyard. Even with the vertical sides at 6.5m in length, the whole loop still looks small when comparing it to the other h.f. antennas. The Reference Loop is a small antenna. We all like small and effective combinations with antennas ... but is this loop effective?

To find out if the loop's effective, we can first do a 'noise test'. DX hunters know that when the band is open for long exotic distances, the basic band noise has a little different tone. If an antenna system is working correctly, then surely you can distinguish that. The stronger the 'DX noise' is the more capable of receiving distant stations the antenna will be.

Compare the noise by setting your receiver's a.g.c. to fast and then switching between dummy load - your best beam - loop - dipole, etc. At this location, the Reference Loop (top run at around 11m high) sounds very much the same as my 3-element beam at the height of 26m, though not the same all the time. Sometimes the beam out performs the loop in this special test.

Note: If the balance of your loop is poor, because you may not be using the balun, you may not be able to distinguish that special component of the noise. Under these conditions, anything special usually sinks into the surrounding rough man-made noise.

Our 'real QSO' results with the Reference Loop have been very good, sometimes surprising. I tested the loop mainly with W and VK stations (from here in Finland). The loop works well in the pile up situations too. My best report to date, was from a W station giving is RST599. Confirmation results came from a VK station, when I received an RST579 report. Both of these contacts were with a power output of 100W.

I have liked and enjoyed working with the Reference Loop. Sometimes I feel it's operating like my beam. But generally, with DX operation, the 3-element beam (at 26m) is 6-10dB (1-2 S-points) better than the loop. Though sometimes there's no difference, which can be explained by the wave angle under certain conditions.

You may consider this non resonant loop as being a quite normal loop having the circumference close to 18m. But more detailed study shows that it differs completely from the ordinary design. To help, I'll list some points where the Reference Loop has advantages (even superiority) over ordinary loops.

- Due to its non-resonant design, the upper half of the Reference Loop radiates the majority of the outgoing power. It fulfils every antenna designer's goal. With ordinary loops both the loop halves radiate equally, forcing higher mount points. The price paid with the non-resonant design is a little more complicated matching.
- The radiation pattern of the Loop has both horizontally and vertically polarised lobes. So, the loop is almost omnidirectional.
- The bonus bandwidth of the Reference Loop for an s.w.r. 2:1 ratio is 350kHz (using Bird 43 power measurements and the HP803A impedance measurements). The half power bandwidth s.w.r. at 5.82:1 is much wider. So, tune it on one middle frequency and then all of the band is yours!

A Little Theory

For those with an interest, here's a little theory of the matching method. After the correct match is obtained, we know that the parallel impedance at the feeder's connecting point (on the 532Ω line) Z_s has value of R_p in parallel with X_p ($R_p//X_pF$). When, the shorted parallel stub Xp= +j65Ω.

The Smith chart shows that the equivalent series impedance at the same point is Z_s = (31.4 - j24.2)Ω. The distance between the feed-point connection and the loop's terminal point (Z_a) is 0.129λ. By Smith's Calculator we can now solve Z_a = (75 - j609)Ω.

So, let's go through all this once again starting from the loop's terminals. The loop's terminal impedance is Z_a = (75-j609)Ω. The open wire line (0.129λ section) transforms it to (31.4 - j24.2)Ω. The equivalent parallel impedance of the latter is (50//-j65)Ω. We cancel the parallel -j65Ω by the parallel short circuited stub of +j65Ω. Now the correct match to the pure 50Ω coaxial cable is obtained.

It's interesting to see that in practice this procedure progressed in opposite order, firstly we solved, by s.w.r. meter, the parallel impedance $R_p//X_{p\text{-stub}}$ = (50//+j65)Ω.

We understand that the line's parallel impedance at the feed point is (50//-j65)Ω. The equivalence calculation and the Smith's Chart show that the series impedance at the same point is (31.4-j24.2)Ω. Then, going backward to Z_a point on Smith's Chart we can read Z_a=(75-j609)Ω.

(‡ the '//' characters are used to show that the values are considered to be in parallel)

Technical Merit

I feel that this study has only some technical merit. For the correct match we need only the s.w.r. measurement, as I said at the beginning of this article, but let's consider the meaning of the matching line losses. The s.w.r. on the open wire feedline section averages out at 16.4:1. The length of the line is 3.05m (the stub included).

A typical loss figure for matched open wire (at 14MHz) is around 0.07dB per 30m run. So, for the length of 3.05m the matching line loss is 0.007dB. Now knowing this loss and the s.w.r. at the input end of the of the matching stub line, we can calculate the total loss, which works out as 0.06dB.

Such a small loss figure puts only a small need for loss-correction of the impedance values obtained by the Smith Chart for example. So, for all practical purpose, the loss of the relative short open wire line may be completely ignored. Another thought to keep in mind is the quality of the open wire line matching actually outperforming a matching system using coaxial line.

Now, after we know the antenna feed point impedance Z_a = (75-j609)Ω - we can also ask is the matching line's impedance Z_0 (at 532Ω) the optimum relative to Z_a? The optimum should be Z_0 of 613Ω, since this would give a minimum s.w.r. on the matching line. In our case however, the optimum s.w.r. is only marginally smaller with a 613Ω line so, our line is still very close to the optimum.

Radiation Resistance

The question of the loop's radiation resistance R_r is interesting, but a difficult question at the same time. When referring to formulas for the calculation of R_r in textbooks, we can infer the loop's R_r value. By extrapolation, we get the radiation resistance of the Reference Loop as around 18Ω.

Where can we find this radiation resistance value? The only current maximum exists at the centre of the upper horizontal element, so the R_r should in essence be there. On the other hand, when we cancel the input reactance of Z_a, the centre point resistance of the bottom element is 75Ω.

Since the power fed into the loop must be the same independent of the feed point, only the impedance values change. The centre of the upper element carries twice the current than the centre of the bottom element. Hence, the directive power radiated along the middle line normal to the horizontal elements is about four times higher at the upper element.

Up the ladder - Martti makes some adjustments. And with trees that tall, any antenna would have to be effective.

The result was a design goal, so that the bottom element's elevation isn't a significant factor. **Note:** this kind of simplified calculation may easily generate pros and cons. Thinking of the normal dipole fed with a constant power at different points along its axis will clarify the idea.

It's possible to reduce the bottom element's directive radiation still more by reducing the circumference of the loop. Taking off lets say, half a metre per side, increases both resistive and reactive values of Z_a. This, in turn will decrease the loop's R_r and the bottom element's current. It also increases the s.w.r. on the matching open line and brings the side high voltage points closer to the supporting rod, etc. The non-resonant loop is a continuous challenge to a designer.

I've taken the description of this loop antenna a little further than was really needed, but I think that sometimes a little theory is a good thing! However, the loop still works well without all that. Enjoy your own building and testing! *PW*