VLF-LF and the Loop Aerial

by Lloyd Butler VK5BR

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Introduction

The article discusses the theory of loop aerials for receiving and how they reduce the level of local noise. A Loop Aerial is described suitable for use on the LF and VLF bands together with a circuit of an interface loop tuner and preamplifier. The discussion extends to the problems of amplifier noise and the advantages of tuning the loop.

Loop Aerial Theory

A major problem in receiving VLF and LF signals is the high level of local noise generated from noisy power lines and consumer electrical equipment. In the presence of this type of noise, the received signal-to-noise ratio can be improved with the use of a loop aerial.

To explain this, it is necessary to briefly discuss the fields around a radiating element. At distances up to around half a wavelength, the induction or near field is prominent but it falls away at a greater rate with distance than the radiation field. At distances greater than one half wavelength, the radiation field is prominent. The relationship between field strength and distance is as follows:

1. The electric component of the induction field decreases with the cube of the distance and dB = 601og (d2/d1) where d2 and d1 are the relative distances.

2. The magnetic component of the induction field decreases with the square of the distance and dB = 40log (d2/d1)

3. Both the electric and magnetic components of the radiation field decrease directly with distance and dB = 20log (d2/d1)

The effect of all this is that, in the near field, the electric component is much stronger than the magnetic component. This is illustrated graphically in Figure 1.

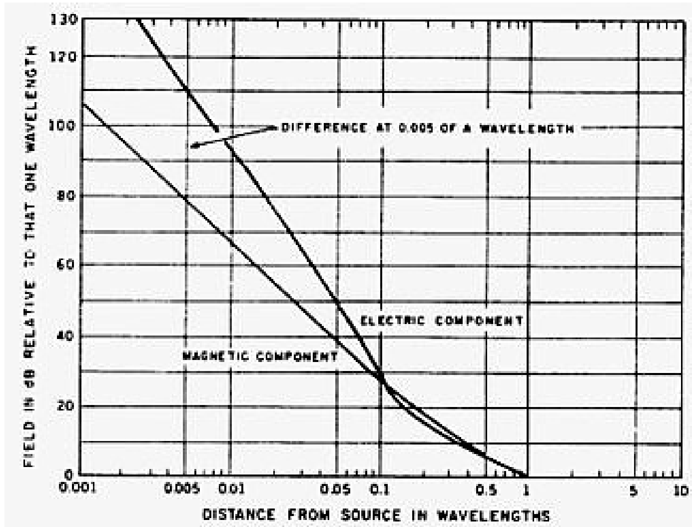


Figure 1 - Comparison of Electric and Magnetic components of received field up to distances of one wavelength from the source.

At VLF and LF (10 to 300 kHz) we are concerned with half wavelengths between 500 and 15,000 meters, and reception of localised noise is clearly in the induction or near field region. The loop aerial is essentially sensitive only to the magnetic component, and because this is lower in level than the electric component in the near field, the level of noise interference is reduced. Furthermore, if the source of interference is from a different direction than that of the signal to be received, the noise is further reduced by the directional properties of the loop. The loop has a very sharp null at right angles to the plane of the loop and can be rotated to position the noise source at the null.

The equivalent circuit of the loop aerial coupled to a load resistance (RL) is shown in Figure 2. Es is the voltage induced into the loop, RT is the resistance of the circuit (the sum of radiation resistance and loss resistance), L is the inductance of the loop, C is the shunt capacitance of the loop with its cable coupled to the load and Eo is the output voltage across the load.

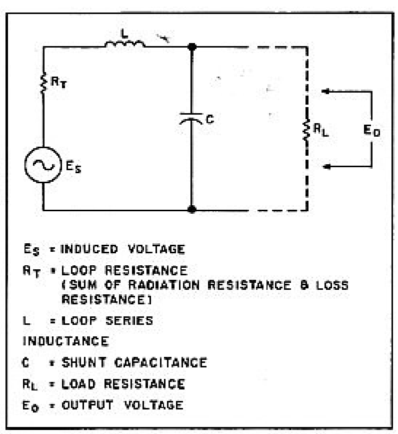


Figure 2 - Equivalent Circuit of the Loop Aerial.

When the loop plane is in line with the direction of the signal for maximum signal level, induced voltage Es is given by the following formula (valid providing the loop dimensions are small compared to a wavelength):

$$Es = \frac{(2\pi eNA)}{\lambda} \quad (1)$$

where Es is expressed in μV
e = field strength in μV/meter
N = number of turns
A = area of loop in square meters
λ = wavelength of the signal in meters

You can also express the formula in terms of frequency (f) as follows:

$$Es = (2\pi eNAf)/V \quad (2)$$

where V = wave velocity (3×10^8 meters/second)

From the formula, it is clear that the induced voltage is directly proportional to both the loop area and the number of turns. The larger you make either of these, the higher the induced voltage. However, increasing these also increases the series inductance and shunt capacitance and, depending on frequency, their reactances have a profound effect on the actual voltage Eo delivered to the load. Resistance RT is also in series with the load, but its value is normally low enough to make little difference to the voltage delivered to the load.

Resonance

The loop aerial has a natural resonant frequency at which the reactance of L equals the reactance of C and at which the response peaks such that the output voltage, Eo, equals the induced voltage, Es, multiplied by the Q factor of the circuit. Clearly, there is much to gain by operating the loop in a parallel-tuned mode. This can be achieved at any frequency lower than the natural resonant frequency by simply adding shunt capacitance across C. At frequencies above the natural resonant frequency, resonance is not possible. Good performance is then better achieved the by decreasing the number of turns on the loop to make natural resonance equal to or above that of the frequency used.

To obtain good performance in a resonance mode at a wide range of frequencies, a number of loop aerials with different numbers of turns, or one with a selected number of turns, is needed. At low frequencies, a large number of turns is desirable to achieve good signal sensitivity. At higher frequencies a lesser number of turns might have to be used to raise the natural resonant frequency. Referring back to Formula 2, you will see that induced voltage Es is proportional to both the frequency and number of turns, so while you lose signal level with less turns, this tends to be compensated for by the increase in frequency.

As output voltage,Eo is proportional to the Q factor at resonance, it is important to make load resistance RL a high value to prevent the lowering of Q. This calls for coupling directly into an amplifier with a high impedance input.

Shielded loop

Whilst the loop aerial essentially operates on the magnetic component, there can be a residual pick up of electric component. For Direction Finding use, it is important to electrically shield the loop to minimise the electric field induction. In practical use for just receiving at LF-VLF, there seems to be little to gain by the small reduction in electric pick-up. In fact shielding increases the residual capacitance of the loop and reduces the maximum tuning frequency for a given number of turns.

Loop Interface

The dynamic impedance of the tuned loop can be very high, hence the circuit must be interfaced with the high impedance input of an operational amplifier or a FET stage. Figure 3 is the circuit of an amplifier that has been used by the writer. The amplifier is set for a maximum gain of 10 to increase further the signal level from the loop which, even with tuning, produces a much lower signal than that received from a random wire of reasonable length. The amplifier is provided with a switch to reduce its gain to unity in the event of very high signal levels causing cross modulation.

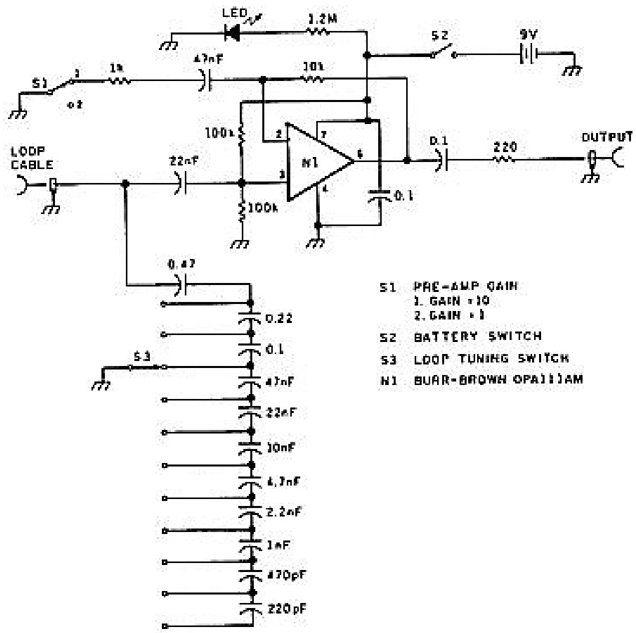


Figure 3 - Loop Aerial Tuning and Pre-Amp Circuit.

Sometimes there is an advantage in balancing out any residual vertical pick-up using a balanced amplifier input. For another circuit using a balanced input, **CLICK HERE.** This is desrcibed in another article on 1.8 MHz receiving Loops.

Amplifier noise

When operating VLF-LF using a wire aerial, the atmospheric noise level received is normally well above the noise floor of the first amplifier, and amplifier noise is insignificant. With the loop aerial, the signal pickup is much lower, and when the atmospheric noise level is low, the minimum discernible signal level can be set by the amplifier noise floor rather than the atmospheric noise level. It is therefore important to select a preamplifier with a low inherent noise, much as one would do for a VHF or UHF front end.

For the amplifier used in the circuit of Figure 3, a Burr-Brown low-noise FET operational amplifier type OPA111AM was selected. This is specified as having the low voltage noise figure of 6 nV per root hertz of band width, with the negligible current noise characteristic of the FET input circuit. It has a gain-band width product of 2 MHz and hence it can maintain the gain of 10 up to a frequency of 200 kHz with a falling response at higher frequencies down to a gain of 4 at 500 kHz.

Another choice for a low-noise amplifier could have been the bipolar input Precision Monolithics type OP27 amplifier. This has a voltage noise of only 3 nV per root hertz of band width but, having a bipolar input, there is a current noise component which would add noise when connected across the high impedance tuned loop circuit (ref 2). The amplifier has a gainband width product of 8 MHz and hence could maintain the gain of 10 well up to 800 kHz. A further approach might have been to use one of the low-noise MOSFET VHF transistors such as the BF981.

Of course, good signal-to-noise ratio also gets back to the design of the loop for highest possible signal voltage. Recapitulating previous parts of this discussion, signal voltage is increased with more turns or larger area (consistent with natural resonance being not less than the operating frequency), or by designing the form of the loop for the highest possible Q factor.

Loop aerial circuits are frequently published with an amplified signal fed back to the loop to form what is called a Q multiplier. This, of course, is a different name for what has been known as regeneration or reaction. Feedback in phase with the input signal raises the effective Q of the circuit to increase its gain and reduce its band width.

There is also a disadvantage with using regeneration in that the noise generated by the amplifier is also fed back to be re-amplified. While the regeneration narrows the loop band width and reduces the band width of the incoming noise, it actually increases the level of the amplifier noise within the band. However the writer has found that regeneration is quite useful at LF frequencies to restrict the front end bandwidth and increase sensitivity. (Refer to Active Loop article).

A Typical Loop Aerial

The natural resonant frequency of the loop and hence its upper frequency limit for a given number of turns, can be increased by spacing the wires and spacing the shield from the wires so that residual capacitance is reduced. With this arrangement, the residual capacitance can be reduced to provide a considerable increase in the upper frequency of the loop.

Good results have been achieved by a loop assembled by the writer (refer figure 4). This consisted of 20 turns of 1 square mm hook-up wire spaced laterally 10mm apart on a wood frame 0.8meter square. To achieve the spacing, the wire was wound around four pieces of doweling fitted through two wood cross pieces. This aerial measured an inductance of about 500 uH and had a natural resonant frequency close to 500kHz. This sets the highest tuneable frequency which allows tuning of Aeronautical Non Direction Beacons which are on frequencies of 200kHz upwards.

Figure 4 - Loop Aerial

Amateur bands have been allocated in some countries (such as New Zealand) in the region of 160 to 190 kHz. If operation is confined to no greater than these frequencies, a lower natural resonant frequency can be tolerated and the loop dimensions increased. A suggested loop of similar construction is 28 spaced turns on a 1 metre square frame. Maximum tuneable frequency for this one is around 200 kHz.

The higher one can make the loop Q, the greater its signal sensitivity and its ability to present a signal level which can override the interface amplifier noise. Q can be improved by using as heavy a gauge wire as can be obtained. Signal level is also increased by increasing the number of turns or the area of the loop but increasing either is limited to the point where natural resonance is just above the operating frequency.

Concerning the choice of increasing turns or increasing area, an article from Break-In, July 1997 (ref 4). discussed this issue relative to the loop noise generated by its own loss resistance. The writers point out that the ratio of signal level to noise generated by the loop is improved by increasing area but increasing turns makes no difference to this ratio. Concerning the New Zealand LF band, the writers also say that to ensure that the noise floor is set by atmospheric level and not the loop itself, the diameter of a circular loop should not be less than 1 meter.

Measurement of loop constants

At this point, it might be useful to explain how the loop constants were measured. Having constructed a loop aerial, you need to know its natural resonant frequency and its self inductance so the maximum tuneable frequency can be determined and the capacitance values worked out for the tuning range required. These factors can be measured using a signal generator fed via a fairly high resistance (say 10 k) to the loop as shown in Figure 5. More than one signal generator might be needed to tune from VLF to ME The voltage across the loop is monitored on a CRO (or perhaps a VTVM) via a high impedance probe. The signal generator frequency is adjusted for a peak in voltage at which the natural frequency is indicated. You now add a large capacitance (at least 20 nF) sufficient to make the loop capacitance insignificant by comparison, and retune for a peak at the new lower frequency. Inductance is then calculated from the normal resonance formula (or a resonance chart), using the parallel capacitance as the value of C and ignoring the self-capacitance of the loop as this makes little difference to the accuracy of calculation.

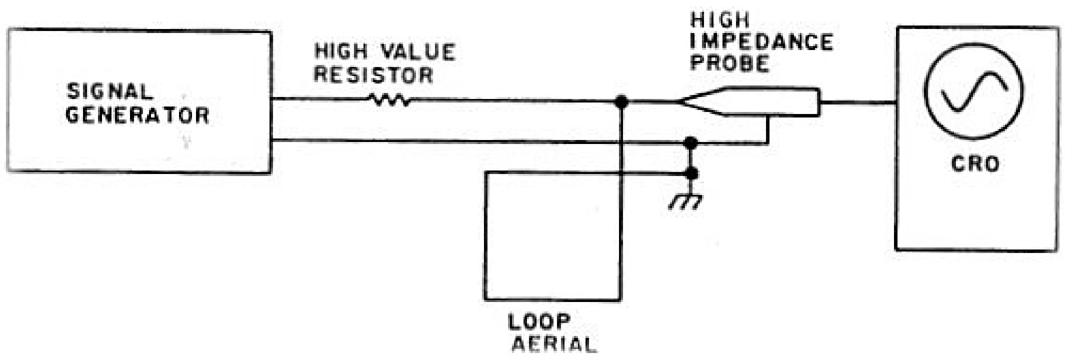


Figure 5- Measurement of Loop Aerial constants.

Having measured the self-resonant frequency and calculated the inductance, the loop self-capacitance can also then be derived from the resonance formula.

As a further operation, Q factor can be measured using the same equipment, except that the resistance in series with the signal generator must be increased to around 500 kohm to prevent the Q being lowered by the signal source. With extra signal loss across the resistor, a high signal level and a sensitive CRO are needed. The procedure is simply to measure the frequencies either side of resonance which give 0.707 of the voltage at resonance. The Q factor is equal to the resonant frequency, divided by the difference between the two frequencies recorded. The Q factor at a range of frequencies can be carried out by varying the value of the shunt capacitor to obtain resonance at each of the frequencies.

To go one step further, you can now calculate the AC resistance of the loop (Rt) at any frequency for which you have derived Q. The inductive reactance at that frequency is calculated from 2PifL and the reactance is then divided by Q to obtain Rt. You now know all the constants Rt, L, and C, as shown in Figure 2.

Performance

Whilst the level of its signal pickup is low compared to the long wire aerial, the loop aerial can separate out signals in the presence of localised noise which overrides the signal on the long wire. As with any directional aerial, it also improves the signal-to-noise ratio for atmospheric noise by restricting noise received -in particular from a direction at right angles to its plane.

With a suitably designed loop aerial and highly selective front-end tuning system, good signals at VLF and LF can be received even indoors-right down to 10 kHz. This is gratifying if one does not have room for an outdoor aerial. Of course, there are the odd traps. It is very easy to miss a signal if it happens to arrive from a direction close to the null of the loop. It is also very easy to home in on some inside-based signal source such as a frequency counter.

Untuned loop

Discussion has been centred around loop aerials tuned to resonance and giving output voltage as in Formula 1 or 2 multiplied by Q. However, loop aerials can also be operated in a broadband mode and a design procedure for doing this over a range of frequencies is described in the April 1989 issue of Lowdown (ref 3). The procedure is to load the loop aerial into a fairly low resistance at the preamplifier input, equal in value to the loop inductive reactance at the lowest frequency of the frequency band required. Parallel resonance is set to a frequency calculated from the geometric mean of the lowest and highest frequency required. According to the article, the design produces a loop response which is flat with frequency.

Whilst the broadband loop eliminates the complication of loop tuning when changing frequency, the loss of Q multiplication can drop atmospheric noise below the noise floor of the amplifier, thus limiting the sensitivity to weak signals. As an example, if we apply Formula 2 to the 12-turn 0.8meter square loop described, and use a typical atmospheric noise for 100 kHz, which can be around 0.2 uV per meter per root hertz, we get a loop output voltage of 3.2 nV per root hertz. This output level is barely comparable with equivalent input noise voltages at low impedance of the best of amplifiers.

Conclusions

A properly designed loop aerial system, with a low-noise preamplifier, is a useful part of the VLF-LF receiving equipment and can enable signals to be picked out from noise which otherwise overrides the signal from the wire aerial. It also provides a means to obtain good signal reception at VLF-LF without the use of a large aerial installation usually considered necessary for low frequency reception.

The signal level received from the loop aerial is low compared to the wire aerial and the signal-to-noise ratio can be limited by the noise generated in the first amplifier. To minimize this problem, a low-noise preamplifier is used, and the loop circuit is tuned so that the signal level into the amplifier is multiplied by the Q factor of the loop circuit.

Some experimental loop aerials and a loop tuning and interface circuit have been described.

Following articles (Just Click)

Active Loop Converter for LF

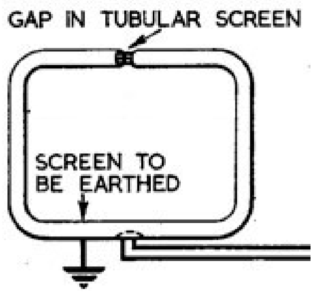
Additions to Active Loop Converter for VLF

Noise Cancelling at LF

RECEIVING LOOP AERIALS FOR 1.8 MHz

by Lloyd Butler VK5BR

Originally Published in Amateur Radio September 1990)



Localised noise in the receiver can be reduced by using a small loop aerial. Shielded coax loops, unshielded loops and ferrite rod loops for 1.8 Mhz have been compared here. Best peformance has been achieved with with 6 & 1/2 turns unshielded on a 0.8 metre frame and connected via a balanced interface amplifier.

Basic Shielded Loop

Introduction

The theory of how a small loop aerial can reduce locally generated noise is described in a previous article.

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In the March 1982 issue of 'Amateur Radio', Clarrie Castle VK5KL described a receiving loop aerial for 1.8 MHz. The octagonal shaped loop, some three metres in length and breadth, was formed by a single turn of coaxial cable, the outer braid of which provided the electrostatic shield. From all accounts, the aerial was very successful in improving the received signal-tonoise ratio in the presence of localised noise interference.

It seemed to me that perhaps the same performance could be achieved with a loop of smaller dimensions but with more than one coaxial turn. This would allow operation in a more confined space and even inside the radio shack. With this in mind, the performance at 1.8 MHz of an 0.8m square multi-turn coax loop aerial has been investigated. Also examined is an unshielded version of the same sized loop aerial and a ferrite core loop aerial made for the 1.8MHz band. The performance of each is individually discussed and then compared.

Loop Sensitivity

For a tuned loop oriented to give maximum signal (that is, its plane in line with direction of signal source) the loop sensitivity (Es/e) can be defined as follows:

Es/e = (2nNAQ)/lambda

where Es = Output Voltage from loop
e = Field strength in Volts per metre
N = Number of loop turns
A = Loop area in square metres
Q = Loop Q factor
lambda = Wavelength in metres

Three-Turn Loop

Comparing the 0.8m square loop to the larger VK5KI, loop, the area is only 0.64 square metre compared to 6.2 square metres for the latter.This reduction factor of around 1:10 means a loop sensitivity loss of around 1:10, but this can be partly compensated by increasing the number of turns. However, increasing the number of turns also increases the inductance of the loop and its inherent shunt capacitance thus reducing the loop natural resonant frequency. This frequency must be higher than the operating frequency (1.8 MHz) otherwise it cannot be tuned to the operating frequency.

Three coax turns of 0.8 metre square appeared to approach this limit, and an experimental 0.8m square loop was assembled with three turns of 75 0hm TV coax. There was no particular reason for selecting this type of coax except that I happened to have a piece just the right length! The construction of this aerial is illustrated in figures 1 and 2. Observe that the outer braids of each of the coax turns are broken at the apex of the loop, and all braids are joined at the base of the loop. The square loop is oriented with its diagonals vertical and horizontal. The reason for this is that it is convenient to mount the loop interface box, with its connection to the loop, on one of the crossed pieces of wood which support the loop. It also makes it convenient to hang the loop from a hook in the wood at the apex.

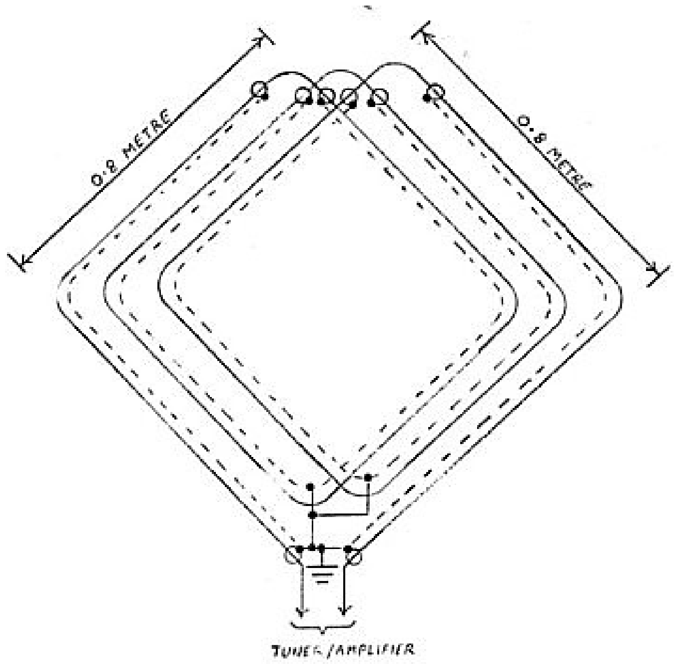

Figure 1 - 3 Turn Coax Loop Aerial Circuit Diagram

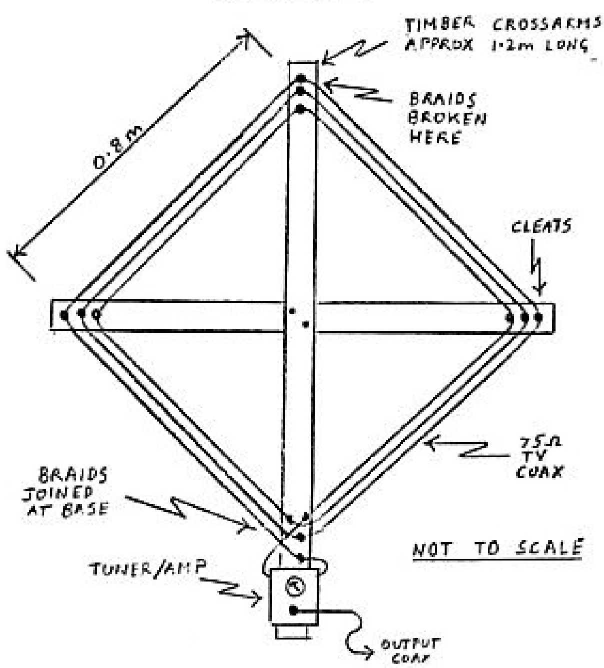

Figure 2 - 3 Turn Coax Loop Aerial Assembly

The increase in the number of turns of three to one does not fully compensate for the loss of 1:10 in area. However, the smaller three-turn loop measured a Q factor of 54 compared with 16 for the larger one-turn loop. The net result of all this was that loop sensitivity (Es/e) calculated as 3.9 for the smaller loop compared with 3.7 for the larger loop. Hence their performances could he expected to be much the same.

The natural resonant frequency of the three turn.loop was found to be around 3.5 MHz and well above the 1.8MHz operating frequency. It is possible that four turns could also have provided a natural resonance above 1.8 MHz, with a possible further improvement in sensitivity. However, this was not checked out.

Unshielded Loop Aerial

Theory on how a shielded loop aerial reduces localised noise interference was given in my earlier article on loop aerials for VLF-LF (Reference 1). If localised noise is not a problem, loop sensitivity can be improved by not shielding the loop.This reduces the loop self capacitance and hence the number of turns for a given upper frequency limit can be increased. I found that seven turns of lightgauge hook-up wire, spaced 5mm apart on the 0.8m square frame, produced a natural resonance of 2 MHz, just conveniently above the 1.8 MHz required. The Q factor at 1.8 MHz measured 39 and loop sensitivity calculated to a value of 6.5, which is very close to a value calculated for a 10m high vertical aerial.

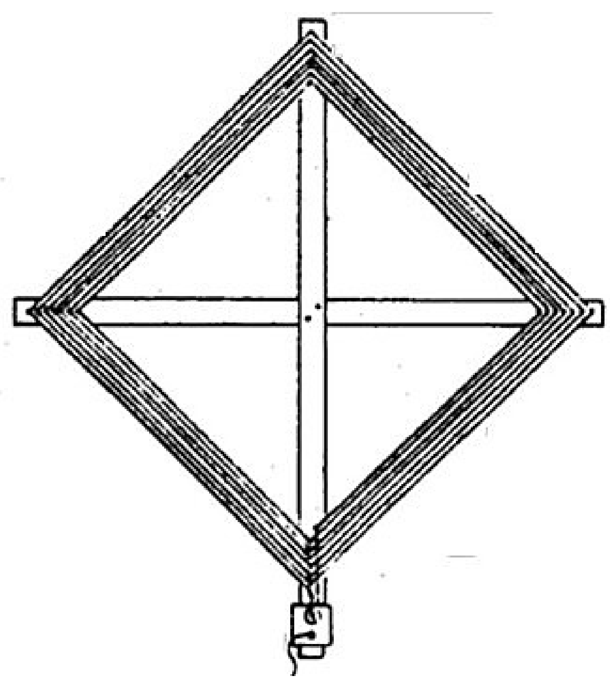

Figure 3 Unshielded Loop Aerial

Conductor Size

As we have discussed earlier, the loop sensitivity at resonance is directly proportional to its Q factor which, in turn, is the ratio of its inductance to series resistance. The resistance is the sum of radiation resistance and the AC loss resistance in the loop, the latter being the prominent factor as the value of radiation resistance is very small. The AC loss resistance can be reduced by increasing the surface area of the loop conductor.

The original seven-turn unshielded loop was wound with 0.4mm diameter wire and produced a Q factor at 1.8 MHz of 39. The wire was ultimately replaced with a 1.7mm stranded conductor to improve the Q. A side effect in doing this was an increase in the selfcapacitance of the loop, making it barely possible to peak the loop tuning at 1.8 MHz. To correct for this, the inductance was reduced by reducing the number of turns to 6.5 or, more correctly, one of the seven turns was returned from halfway around the loop across one of the crossarms so that the one turn had half the area of the others. The larger diameter conductor increased the Q factor to around 100. It would have been higher had it not been limited by the 200 kOhm input resistance of the interface amplifier. Correcting for the reduced area of one turn and the increase in Q, the loop sensitivity (Es/e) was derived as a value of 15.6, considerably higher than the 6.5 derived for the 0.4mm conductor.

In all fairness to the original VK5KL large single-turn loop, I must point out that this was made with RG8 coax, which has an inner conductor diameter around 2.2min compared with the smaller diameter 0.8mm conductor in the coax used for my tests. The Q factor of the VK5KL loop might well have been much higher than I have quoted and hence its sensitivity greater. It also follows that I could have achieved higher sensitivity in my three turn coax loop had RG8 been used. However, it is assumed that relativity between the signal sensitivities of the two shielded loop forms tested would have been much the same had the larger cable been used in each..

Loop interface

To obtain the best advantage of the high Q factor of the loop (and hence its highest sensitivity) the loop is tuned to resonance at the operating frequency and connected via a high impedance input interface circuit. For the experiments described, this was achieved with the circuit shown in figure 4.

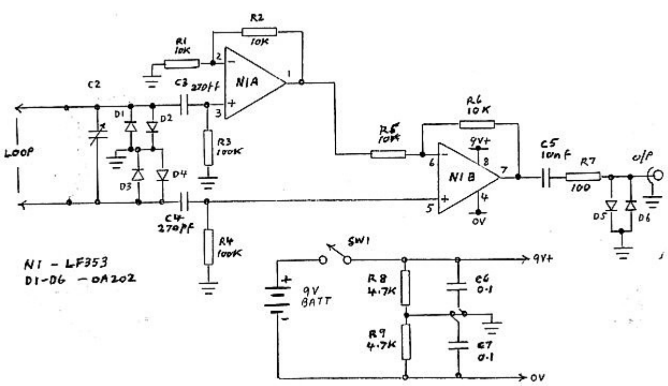

Figure 4 Loop Tuner and Interface Amplifier
For 6 & 1/2 Turn Loop, C2 is 3-56 pf miniature variable Capacitor

The circuit makes use of twin JFET amplifier package type LF353 connected for balanced input. For the benefit of those who might not be quite familiar with operational amplifier theory, we will examine the stage gains. In the amplifier circuit around N1B, the gain via the inverting input is defined by the ratio R6/ R5 and since R5 and R6 are equal, the inverting gain is equal to -1. However, the gain via the non-inverting input is defined by the ratio R6/(R5+R6) and hence the non-inverting gain from the lower loop connection in the diagram is equal to 2.

The other loop connection is fed via the non-inverting input of N1A. As the circuit around N1A is identical to that around N1B, it also has a gain from the non-inverting input of 2. Since this connection of the loop is in anti-phase to the other connection, its signal via N1A must be inverted in mixing with the other signal in NlB. This is done via the inverting input of N1B without change of amplitude.

The loop aerial output is equally shared between the two amplifier inputs and hence the overall gain, balanced to unbalanced, is 2 or 6dB. This is about the limit one can get from the LF353 package at 1.8 MHz as its gain-bandwidth product is 4 MHz.

Tuning of the loop is set by variable capacitor C2 and, where necessary, parallel fixed capacitor Cl. The input circuit resistance is 200 kOhms, set by R3 and R4 in series. This is sufficiently high to prevent the loop Q from being lowered excessively.

The output resistance is largely set by R7, included for stability. Operational amplifiers can be very temperamental if operated directly into a capacitive load (such as a coaxial cable) without some series resistance.

The multitude of diodes at input and output are protection against excessive RF signal which might happen to be fed in. At the home installation, the loop aerial amplifier was connected via a switch into the receive side of the transceiver transmit/receive relay. This provided an interlock to prevent feeding the transmitter directly into the loop circuits. However, there was still a concern about RF induced from the transmitting aerial back into the loop and hence the diodes were included.

The amplifier circuit provides a very high impedance to low impedance conversion without loss of signal voltage developed by the loop Q.

Ferrite Core Loop Aerials

A further exercise was carried out to compare the performance of the loop aerial wound on a ferrite rod with that of the larger air-wound loops. Whilst this type of loop aerial has a very small loop area, the loss in area is compensated by the large number of turns which can be used and a high multiplying factor determined by the ferrite material permeability. For the aerial oriented to give maximum signal, the loop sensitivity formula is expanded to the following:

Es/e = (2nNAQu')/lambda

Where u'= The corrected permeability

Permeability requires some explanation. Permeability (u) of the material is the multiplying factor which applies to the inductance of the winding compared to when it is air wound, assuming all lines of magnetic flux pass through the winding. In the ferrite rod, not all lines of flux pass through the winding, so there is leakage flux. The inductance is therefore less, and a multiplying factor called rod permeability (ud) applies. Curves relating rod permeability to material permeability, for different rod length to diameter ratios, are published in the ARRL Antenna Handbook (reference 2) and in Amidon Associates brochures.

The corrected permeability (u') is the multiplying factor applied to the loop formula. If the coil winding is the full length of the ferrite rod, then corrected permeability is equal to rod permeability. If the rod is longer than the winding, the corrected permeability is increased as follows:

u' = urod x cube root(a/b)

where a = Length of the rod
b = Length of the winding

To carry out my tests, 1 purchased a ferrite rod (Cat L1401) from Dick Smith Electronics. The rod dimensions are 20cm. long by 9.5mm diameter. No information seemed to be available on permeability, hence the rod permeability was derived by calculating the ratio of inductance, measured for a given number of turns on the rod, to that for the same sized winding in air. The inductance in air was determined by two different methods which gave much the same answer. The first method was to apply the well-known Wheeler's formula for air-wound coils which can be found in many handbooks. The second method was to wind the same number of turns on a length of bamboo which happened to have the same diameter as the rod, and the inductance of this coil was then measured. The value of rod permeability was determined as 74, and from the curves previously mentioned, material permeability appeared to be around 120.

To operate at 1.8 MHz, 64 turns of 0.44mm single-core PVC-covered wire were wound around the ferrite rod. For this number of turns, the maximum which could be achieved, self-resonance was just above the 1.8MHz band at 2 MHz. The 64 turns occupied 7cm of the length of the rod and, from this measurement, a corrected permeability of 81 was derived.

The Q factor of the loop at 1.8 MHz was measured as 57, and loop sensitivity was calculated as 0.86, considerably less than all the air-wound loops discussed.

Comparison of Loop Sensitivities

Table 1

Comparison of Loop Aerial Characteristics

Aerial

A 2.8m cross-section single-turn RG58 coax loop — inner conductor diam = 0.8mm
B 0.8m square three-turn TV cable coax loop — inner conductor diam = 0.8mm
C 0.8m square seven-turn unshielded loop — conductor diam = 0.4mm
D 0.8m square 6-1/2-turn unshielded loop — inner conductor diam = 1.7mm
E Ferrite rod 20cm x 0.95mm diam overwound with 64 turns 0.4mm diam wire
F 10m high vertical aerial

Aerial	Es/e	L	Q	Max F	Tuning C(1.8MHz)	Self C
A	3.73	12μH	16	2.5MHz	500pF	150pF
B	3.9	26μH	54	3.5MHz	220pF	80pF
C	6.5	130μH	39	1.98MHz	10pF	50pF
D	15.6	110μH	100	2.05MHz	10pF	60pF
E	0.86	223μH	57	2MHz	5pF	35pF
F	6.36					

Legend

Es/e	= Aerial sensitivity — ratio of output Volts to Volts/metre in space
L	= Loop inductance
Q	= Loop Q factor
Max f	= Resonant frequency with no capacitance added
Tuning C	= Capacitance added to resonate at 1.8 MHz
Self C	= Derived self-capacitance

The characteristics of the various loop aerials discussed are compared in Table 1. Despite its smaller area, the 0.8m square coax loop (B), with more turns and higher Q, has a signal sensitivity as good as the larger single-turn coax loop (A). With a self-resonance at 3.5 MHz, well above the required frequency of 1.8 MHz, it is probable that the sensitivity of (B) could have been improved further by adding another turn, still being tunable to 1.8 MHz.

The additional turns made possible by not shielding the seven-turn loop (C), enabled a higher signal sensitivity to be achieved comparable with that of a 10m vertical aerial (F). The importance of using a large sized conductor to reduce AC resistance is shown by comparing aerial (C) with aerial (D), which is similar to (C), but which has a large diameter conductor. The sensitivity of (D) is considerably higher than that of (C).

The ferrite rod loop aerial (E) works quite well because of the high permeability of its core, but it is no match in terms of signal sensitivity when compared with the larger air core loops.

Operational Performance

With the various loop aerials connected in turn to a receiver, the relative signal levels received followed much the same pattern as loop sensitivity shown in Table 1. Signal levels received on the three turn coax loop were comparable with those received on a sloping wire Marconi aerial loaded for 1.8 MHz and normally used as the transmitting aerial. The unshielded loops, with more turns, delivered considerably higher signal levels than the sloping wire. Some of the extra level is due to the 6dB gain in the interface amplifier but, even taking this into account, there was still quite a level difference.

Quite apart from the ability of the loop aerial to reduce interference from a localised noise source, its directional properties can be used to improve the signal-to-noise ratio in the presence of atmospheric noise. This particularly applies if the noise has a directional property and the loop is oriented so that its null position faces the direction of maximum noise. Of course, the same technique can be applied to a source of QRM. For these applications, the unshielded loops, with their higher signal sensitivities, seemed to work best and they clearly improved the readability of signals otherwise difficult to copy on the sloping wire.

One would expect that the coax loop aerial would be more suitable than the unshielded loop in an environment of high local noise. Notwithstanding this, the seven-turn unshielded loop did not appear to be any more sensitive to localised noise which was introduced in the radio shack.

In actual fact, the unshielded loops could be expected to have quite reasonable rejection of the electric field component when operated into the type of interface amplifier circuit used. The electric field component of localised noise is the one which is the highest level and this is induced into the loop in a common mode with equal voltage at the loop output terminals referred to ground. The amplifier has a differential input circuit and hence the electric field component is essentially balanced out (see footnote). If the balance is good, there would appear to be a lesser need for electrostatic shielding to reduce localised noise.The additional shield might be needed more in using the loop for accurate direction finding (DF) work where a small amount of pick-up as a vertical aerial (called vertical or antenna effect) could make an error in the position of the signal null.

The ferrite rod loop aerial has an advantage in its small size and suitability for portable applications. However, its performance when connected to a receiver did not match that of the 0.8m square loops.

Conclusions

The performance of 0.8m square loop aerials for 1.8 MHz has been discussed. It is concluded that a three or four-turn coax loop aerial of this size would work as well as the larger single-turn coax loop aerial. The discussion has also extended to experiments with the ferrite rod loop aerials. As stated earlier, the aerial has its limitations.

By using a loop of unshielded turns to reduce the capacitance, the number of turns and hence the loop sensitivity, can be increased. Provided that the unshielded loop aerial is operated in a balanced mode, rejection of localised noise is still quite good. Loop sensitivity is dependent on its Q factor, and to achieve a high Q, the conductor size, or at least its surface area, should be as large as practicable.

Provided that the loop circuit is well balanced, I see little point in shielding the loop unless accurate DF work is envisaged. Some texts describe a step down coupling transformer to interface the loop to the receiver input. As a preference, I favour the use of the high impedance amplifier for the following reasons: Firstly, the transformer reflects a load from the receiver input and this must lower the loop Q. Secondly, the transformer provides a high-to-low-impedance transfer with step down of voltage. The amplifier does this as a voltage follower, or even with voltage gain. The only precaution is that the amplifier must be selected for a noise level below that received expected from the loop. The higher the loop sensitivity, the less is the chance of this being a problem.

My recommendation for a good performance 1.8MHz loop aerial, small enough to operate both inside the radio shack or outside, is six or seven turns of a heavy gauge copper wire spaced 5mm to 10mm on a 0.8m square frame (See Figure 3). As an alternative to ordinary wire, one might consider connecting up the outer braid of the old style heavy shielded wire or some discarded coax cable. Connect via the interface amplifier of figure 4. Use an input tuning capacitor 3-56pf (miniature variable). The amplifier is mounted at the base of the frame to keep short connecting leads to the loop.

1. Lloyd Butler VK5BR - VLF-LF and the Loop Aerial. - Amateur Radio, August 1990.

2. C H Castle VK5KL - A l0 ft Diameter Receiving Loop Aerial on 1.8 MHz - Amateur Radio, March 1982.

3. The ARRL Antenna Handbook 15th Edition 1988 - Chapter 5, Loop Antennas, and Chapter 14, Direction Finding Antennas.

Footnote

I have pointed out in the text that when the loop is connected via the differential input circuit the electric field component is induced in a common mode against earth and is essentially balanced out by the circuit. This should be qualified as being conditional on the loop dimensions being small compared with a wavelength. If the plane of the loop is in line with the direction of signal, a phase difference must exist between the voltages induced into each side of the loop. This will develop a differential voltage between opposite sidewires of the loop. In the loop aerials discussed, the distance between the sides of the loop is 0.8m, small compared with a wavelength of 160m. Hence, the phase difference is small and the voltage generated is also assumed to be small.