A9-4-1

THE SHIELDED FERRITE LOOP: PRINCIPLES AND PRACTICE.

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GENERAL CONSIDERATIONS.

The use of a loop on the standard broadcast band is what you might call "playing it smart". This band is characterized as noise limited. In other words, with a standard inverted L antenna, the external noise pick-up is much too great to permit the full utilization of the sensitivity capabilities of the receiver.

The extent to which the external noise exceeds the locally generated noise of the receiver is surprising. The usual inverted L antenna can easily have an effective height of several meters, yet a full size transistor portable has an effective height of only ½ centimeter and a 2 foot flat loop about 2 centimeters. The loss of signal pick-up, then, when using a loop is of the order of 100 times, yet the effective station-getting ability is actually better with the loop, indicating that the external noise pick-up is many hundred times greater than the receiver noise.

Theoretically a loop responds only to the magnetic field while locally generated external noise is concentrated in the electric field to which the long wire antenna responds. In practice, however, an air loop still has considerable capacitance to space (electric field pick-up) which attracts considerable local noise and militates against a perfect null for local station rejection. If a 2 foot loop is bad in this respect, a 4 foot loop is worse and seems to be heading back in the direction of the long wire which is the wrong way to go.

Now if we reduce in size the 2 foot loop to a ferrite rod say 12" long and 1" in diameter, we have achieved a tremendous reduction in capacitance to space, since this is proportional to the size, and reduced further the noise pick-up and nulling imperfections. However, in a noisy location, if a faraday shield is placed over the ferrite loop, the resulting noise reduction can only be described as startling. If an unshielded ferrite loop is that imperfect, consider the plight of the 2 foot and larger air loops. With a shielded ferrite loop of the type to be described, there is no response to the electric field, the full signal-to-noise capabilities of the receiver can be utilized and perfect nulling is achieved. Perhaps now is the time to consider the modus operandi of the ferrite loop.

FERRITE LOOP THEORY.

Literature on ferrite loop operation is scanty and hard to comprehend because the formulas contain some variables that are not independent. In this treatment, we will avoid the formulas, except to point out that the voltage generated across the loop terminals is proportional to three factors - (1) the flux ϕ, (2) the number of turns, N, and (3) the quality factor, Q.

The only major difference between the air loop and the ferrite loop is in the treatment of the first factor, the flux, ϕ. In the case of the air loop, it is simply the flux flowing through the cross-section of the loop and accordingly ϕ is proportional to the cross sectional area in the case of the box loop and the average cross sectional area in the case of a flat loop.

Now let us consider the ferrite loop. First we will assume a rod having infinite permeability (no reluctance to the flow of flux) and, further, in order to avoid being buried in geometry, take a somewhat naive approach which, however, faithfully describes the basic situation.

Take a look at Figure 1. What we are trying to do is determine the maximum flux field that is available to the ferrite rod. A flux line has two choices: it can continue as a straight line as it did before the ferrite rod appeared or it can deviate into the ferrite rod, pass through it and then re-establish its original trajectory. Obviously, it will select the path of least flux resistance. For a line close to the rod, it would prefer to take the short air path to the rod, travel through the rod of assumed perfect flux conductivity and return, rather than to maintain its normal flow which would require a much longer air travel equal to the length of the rod.

However, a line further away such as the one we have dimensioned has a more difficult choice since the lengths of the two paths both equal L (the rod length). This then determines the outer boundary of the available flux field. Flux lines farther away will prefer to continue their undeviated path. If the rod were longer, the critical L/2 path would be longer and it would attract more flux; if shorter, less. We can see now that while the flux picked up by an air loop is determined by its cross-sectional area, the flux picked up by a ferrite rod is proportional to its length. If this is not clear, please re-read as it is an important point to grasp.

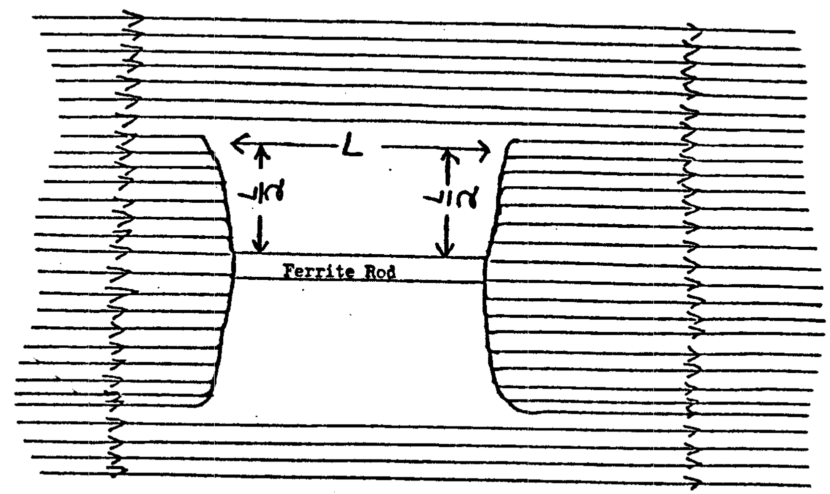

Fig. 1

To continue with our theory but to become a bit more practical, we will throw out our rod of assumed infinite permeability and substitute one that the facts of life dictate. The only way this will change the picture, just described, is this: instead of our rod collecting all of the available flux field (AFF) it will collect only a part of it. What we now want to do is to determine the rod diameter that will provide a "match" to the environment and absorb one-half the AFF.

Figure 1 showed a side view of the situation. Figure 2 indicates the picture if we look at the end of the rod. The inner circle shows the ferrite rod with diameter, D. The outer circle represents the outer boundary of the AFF and this has a diameter equal to the length of the rod. This should be clear from the discussion of Figure 1. If it is not clear, we have lost you; please re-read.

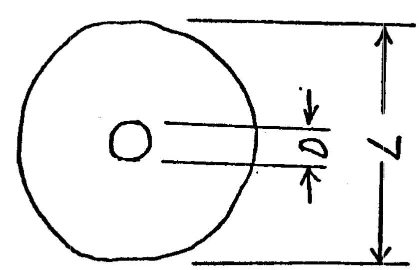

Fig. 2

FERRITE LOOP THEORY. (continued)

Now we said previously we wanted to match the ferrite rod to the flux field so that half of the AFF will flow in the rod and half continue undisturbed. This means that the reluctance of the ferrite rod and the reluctance of the ferrite rod and the reluctance of the air sheath represented by the AFF should be the same. In this way, equal flux division will be obtained in the manner of two parallel connected equal resistors. Of course, we would like to capture more than half the AFF if possible, but to do this would require a still larger diameter and the cost would increase alarmingly.

The toroidal permeability of the rod is a measure of how freely the flux will flow through the rod as compared to its flow through the air when the rod is removed. To state it somewhat differently, if the permeability is 100, the same flux will flow in the rod as in an air sheath 100 times the cross-sectional area of the rod. Obviously, then, to obtain a matched condition, the cross-sectional area of air sheath divided by the cross-sectional area of the rod should be μ_o, the toroidal permeability of the material. To convert to diameters, the diameter of the air sheath is L (the rod length) as we showed previously so now, $L/D = \sqrt{\mu_o}$ for the matched condition.

PRACTICAL ANTENNA FERRITES.

We are now in a position to consider practical ferrite materials available for antenna rod use. Since the early 1950's, one material has dominated the antenna field since it had the highest $\mu_o Q$ product. Since these two factors, along with the number of turns, determine the developed voltage, the importance of as high a $\mu_o Q$ product as possible is obvious. This material was originally called Q-body and can generally be identified by the presence of two, closely spaced, indented lines running the length of the core. I believe it is now called Ferramic Q1 and has a μ_o of about 125. The L/D ratio for a matched condition is then the square root of 125 which equals 11.2.

FERRITES vs AIR LOOP.

We can approximate the above relation with a 12" rod, 1" in diameter. However, how will this compare with, say, a 2 foot flat loop as far as signal pickup is concerned... To begin with, we can say it will be down in flux pickup to half that of a one foot box air loop since the air loop utilizes all the flux entering its cross-section and the ferrite loop captures only half. Since a two foot flat loop has an average length of about 17.5 inches, on an area basis the ferrite loop is down by an additional factor of .48. This means that the ferrite loop has only .24 the pick-up of the flat loop, right? - Wrong! It is wrong because only the flux factor has been considered.

NUMBER OF TURNS COMPARISON.

The ferrite loop will have approximately 1.4 times the number of turns of the 2 foot air loop just because of the different winding configuration. In addition, there will be a further increase in turns due to the much lower distributed capacitance. The C_D of the ferrite loop will be less than 5 mmf, while that of the air loop will be about 30 mmf. To convert this to turns, we need to determine the total minimum capacitance in each case. For the ferrite loop, we have 5 mmf in the coil, plus 10 in the tuning capacitor, 4 in the trimmer, and since we can mount a small plastic Japanese gang right on the faraday loop shield, the wiring will only be 1 mmf. This makes a total of 20 mmf and will require a variable of 9 times that or 180 mmf to tune the band. In the case of the air loop, the winding contributes 30, the gang 10, the trimmer 4 and the wiring at least 5 since it is necessary to physically remove the gang from the vicinity of the loop to avoid detuning effects. This totals 49 mmf for the air loop and the required variable to tune the band will be 441 mmf.

The ratio of 49 mmf for the air gang to 20 for the ferrite is 2.45. The turns increase will then be the square root of 2.45 which equals 1.56. The total turns increase for the ferrite loop will then be a factor of 1.56 x 1.4 = 2.2. To bring the overall comparison up-to-date, we find the ferrite loop now .24 x 2.2 or .53 that of the air loop and we still have Q to consider.

Q COMPARISON.

The Q of an air loop in free space is one thing, the Q of the same loop in its natural surroundings can be quite another. The basic Q is reduced by objects in the flux field and the denser the field in which the objects lie, the greater is the Q reduction that results. The flux, of course, concentrates in passing through the loop and in the return path through the immense air sheath, the flux lines are rather sparce. Unfortunately for the air loop, the entire cross-sectional area contains the concentrated flux and this is free to contact all sorts of energy absorbing objects such as venetian blinds, hot water radiators, telephones, house wiring, lamps, people, etc. On the other hand, the concentrated field of the ferrite loop extends only out the ends through its cross-sectional area. The only nearby object is the faraday shield and by locating this in the weak return field and parallel to it so that a minimum of flux lines are intercepted, along with the use of aluminum, the Q reduction can be held to a minimum.

If a calibrated frequency source is available, it is possible to check the Q of an air loop in its operating position. Disconnect the pick-up leads from the receiver and attach them to an RF millivoltmeter. Radiate into the loop by a single turn connected to the frequency source and located a few feet away. Tune in the radiated signal and then measure the bandwidth corresponding to a 3 db drop in output. The Q is then f/BW. In other words, if your radiated signal is 1000 kc/s and the measured 3 db bandwidth is 10 kc/s, the Q is 1000/10 = 100. If the 3db bandwidth measures 5 kc/s, the Q equals 200, etc. The chances are that your air loop will measure somewhere between the two values.

So much for the effects of objects in the flux field. An even greater problem in large air loops can result from loading by the receiver. Unfortunately, it is necessary to use an integer number of turns for the pick-up winding. In other words, less than one turn is impossible. If the total loop turns is 8, the turns ratio is 8 and the impedance ratio 8 squared or 64. If the tuned circuit impedance (QX) is 200,000 ohms, the impedance of the pickup winding is over 3000 ohms. If the receiver is designed to work with an inverted L antenna, the primary of the antenna coil in the receiver may be matched to an impedance representing approximately a 250 mmf capacitor in series with a 200 ohm resistor. This will, of course, severely load the loop and the Q will drop much farther. The above assumes that the loop is a perfect transformer and, of course, it is anything but, so the loading effect is relieved considerably. However, an imperfect transformer means leakage reactance is present and this causes a further problem which will be described later.

But I digress; the 2 foot loop is the object of our comparison and this may have 20 turns with a tuned circuit impedance of 300,000 ohms so one turn will present an impedance of 300,000/400 = 750 ohms which is not too bad.

The free air Q of the ferrite loop should be at least 400. The effect of the aluminum faraday shield, rotating assembly and receiver cabinet should reduce the Q to not less than 300. I think we are reasonable in pegging the Q of the 2 foot air loop at 125. This means the ferrite loop will have 2.4 times the voltage across its tuned circuit but due to the necessity of matching to a fixed impedance, part of this will be lost in the increased turns ratio required so the net improvement in favor of the ferrite loop is the square root of 2.4 which equals 1.55. So now let's take another look at our comparison scoreboard. It is now .24 x 2.2 x 1.55 = .82 or about 2 db below the 2 foot air loop. Of course, the alternative of adding an inch or two to the length of the rod to achieve parity is always available.

Summarizing to this point, we can say that the 12" x 1" ferrite loop will be down about 2 db in raw sensitivity but will respond entirely to the magnetic field and not at all to the electric field thus permitting noise-free reception with the white noise of the receiver the basic limitation on sensitivity. In addition, it will permit the complete rejection of unwanted locals by nulling.

An additional obvious benefit is having the whole ball-of-wax wrapped up in a compact package mounted on top of the receiver instead of a more or less unmanageable, unsightly mess.

Q COMPARISON. (continued)

As also noted above, the low distributed capacitance of the ferrite winding will permit the use of a small, compact tuning capacitor and do away with the haywire and inconvenience of switching in additional capacitance to reach the low frequency end of the tuning range. The low variable capacitance required by a ferrite loop will be further appreciated when varactors are readily available, suitable for tuning the entire band with a voltage variation of only 1-9 volts. Going into the varactor matter further is outside the scope of this report but I would like to cover it at a later time, if a reader interest develops.

It was also mentioned above that a high coefficient of coupling is not possible with an air loop but with the high permeability of the core material, the ferrite version can have a coupling coefficient very close to unity. To provide this, the coupling turns should be wound over the main winding and spaced to occupy the grounded half of the main winding as shown in figure 3.

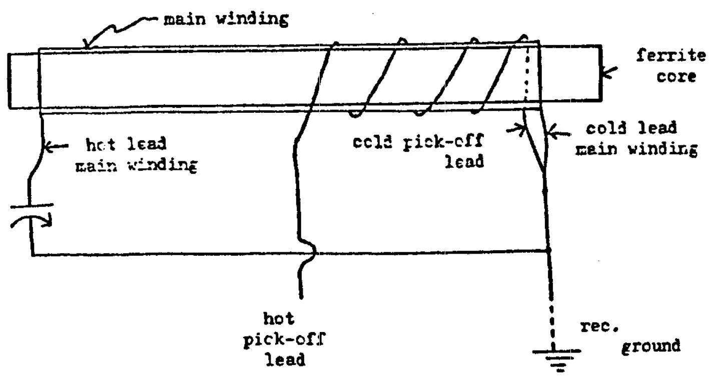

Figure 3

If the coupling is not tight, the arrangement does not act as a perfect transformer and leakage reactance results. This reactance can resonate in the shortwave band and can cause serious shortwave interference if the preselection in the receiver is not sufficiently high.

FERRITE COSTS AND AVAILABILITY.

A 12" x 1" rod of ferrite is a sizeable chunk as ferrite rods go and cannot be fabricated by the usual extrusion process. It is necessary to manufacture the rod by the isostatic method which is considerably more expensive. Since there is no demand for such a large rod in the entertainment industry, quantity becomes a further factor affecting the cost adversely. It appears that in quantities of 100, these rods would cost about $20 each from Indiana General.

Several Japanese companies have been licensed to make this material and preliminary information at hand suggests that the pupils may now excel the teacher as they are making high Q materials with permeabilities as high as 400. This would provide a major breakthrough in cost since our L/D ratio can now change to the square root of 400 which equals 20. Hence, for a 12" rod, the diameter would be only 0.6". This would reduce the ferrite volume to almost 1/3 of the 1" diameter core and would be less expensive to fabricate as well. If a suitable Japanese source develops, it is therefore reasonable to expect a rod cost of $5 or less.

I must apologize for not being able to furnish specific constructional details as I do not have, as yet, a suitable rod to work with. Two samples are on order from Indiana General but in the usual manner of a corporate giant, a delivery time of 10 to 12 weeks must be endured. Letters have been written to five Japanese companies, three of which have New York offices, to determine further the suitability of their materiel and the cost of 100 pieces providing they will accept such a small order. The Japanese situation should be clarified by the time the sample pieces arrive. Incidentally, the IRCA might be interested in hearing from members who would be interested in obtaining a ferrite rod and what cost they would tolerate. A more definite idea of the total quantity might be a substantial help in lowering the piece price. In the meantime, for the benefit of members who might be interested in experimenting with available smaller rods, the following constructional information is included.

CONSTRUCTIONAL DETAILS.

When using small rods, it is entirely possible to bundle them up to obtain a larger diameter but attempts at increasing the length by combining rods will not be fruitful as the unavoidable air gap that results will reduce the permeability to a low value.

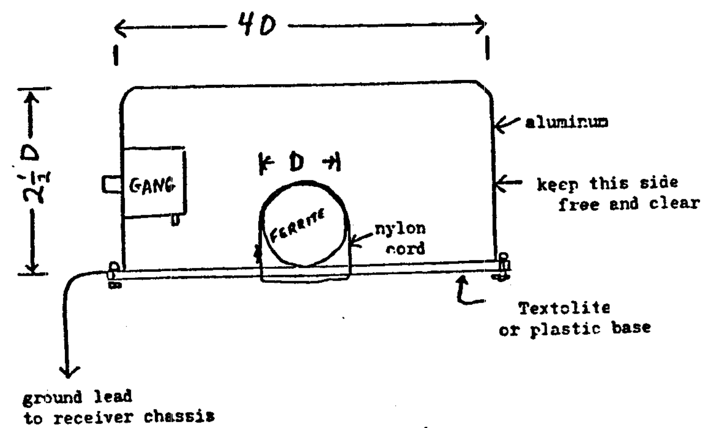

Figure 4

The faraday shield should be made of aluminum and need not be thicker than that necessary to support a small tuning capacitor. Figure 4 shows the general arrangement. It will be noted that the aluminum piece is basically an inverted U which is mounted to a base of insulating material. In order to preserve the original Q, it is desirable that the sides be not less than 2½ times the rod diameter in height; while the width of the top should be a minimum of 4 times the rod diameter. The length of the shield should be sufficient to over-extend the rod about an inch on the "hot" end. The shield is grounded to the receiver chassis by a lug on one mounting screw. Do not use more than one grounding lead for the shield.

It must be emphasized strongly that the shield should not in any manner become a complete turn around the loop. If it does, the pickup and Q are completely ruined. It is a good plan, then, to leave one side completely alone and mount the grounding lead and tuning capacitor on the other. If a pre-amp is to be used, also mount the on-off switch and the battery (clamp it outside the shield) on this same side, leaving the other side completely isolated. The pre-amp can be mounted to the baseboard between the loop and the side of the shield to which the components are mounted.

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Mount the tuning capacitor near the hot lead of the main winding and connect this lead to the stator of the capacitor. The rotor of the capacitor, the cold lead of the main winding (the one nearest the take-off winding as shown in figure 3) and the cold end of the take-off winding are connected together. This take-off terminal is connected to the ground of the receiver; while the hot terminal goes to the antenna terminal. This lead should be shielded to avoid noise pick-up and nulling problems. You might want to consider using a heavy duty plug and jack assembly to perform this electrical connection and at the same time solve the mechanical problem of providing the necessary rotating facility. The jack would mount on the cabinet top while the plug would mount on an outboard bracket connected to the loop base. Make sure, however, that the bracket does not contact the shield. Also, do not attempt to combine the shield ground with the loop ground as electric field pickup by the shield would be induced by common coupling into the loop circuit.

It is suggested that the loop be mounted to the board by nylon cord loops as indicated. This will help to preserve the Q. If a pre-amp is used, make sure none of the parts are in the concentrated field of the loop. Figure 5 shows the right way and the wrong way.

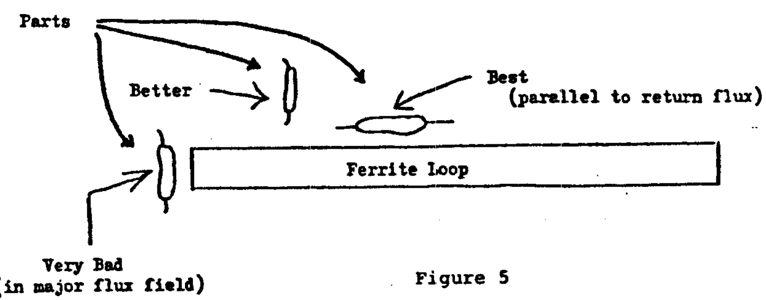

Figure 5

In connection with the winding of the loop, the main winding should be spaced to occupy nearly the whole length of the rod, rather than concentrating the winding at or near the center. Just leave ½ inch or so at each end to tape down the leads using high grade electrical tape. The flux will be higher for the concentrated winding but the number of turns is greater for the distributed winding and due to the different manner in which the self-induced and received flux patterns distribute, the net pick-up is about 40% greater for the distributed winding.

When using ordinary broadcast radio cores, it will be found that the Q maximizes when using about #28 wire. For smaller sizes, the ohmic losses degrade the Q and for larger sizes, eddy current losses in the copper predominate. Glyptal may be used sparingly to prevent the winding from moving.

The number of turns required on the main winding will, of course, depend on the core geometry and will have to be determined from trial and error. The turns should resonate the loop to, say, 1620 kc/s with the gang all-out. If it is found that your first effort tunes to 1800 kc/s, then increase the turns to N x 1800/1620 (1.1 N) and you should have it about right.

Once the correct number of turns for the main winding has been determined, it is necessary to determine the proper turns for the pick-up winding. If a transistor pre-amp is used, this is relatively easy. The tuned impedance is close enough to 300,000 ohms and the input impedance of the transistor, 1000 ohms. The impedance ratio is 300 to 1 and the required turns ratio is the square root of 300 which equals 17 or 17 to 1. As stated, this winding should be spaced over the grounded half of the main winding.

If a pre-amp is not used and the pick-up winding is connected to the antenna and ground terminals of the receiver, something should be known about the design of the antenna coil as far as its primary impedance is concerned. If you do not know this, you should obtain it from the manufacturer. If the designer used a standard I.E.E.E. broadcast band dummy as he should, this can be approximated by a 250 mmf capacitor in series with a 200 ohm resistor, even though the actual dummy is a complicated network of R, L and C. In this case, it is probably best to match a 200 ohm impedance and include the 250 mmf in series with the "hot" take-off lead. The classic antenna coil design employs a high impedance primary which is a coil having an inductance slightly in excess of one millihenry so that it resonates at about 350 kc/s with the 250 mmf antenna capacity. This frequency is picked so that it is close enough to the low frequency end of the band to boost the low end gain but not so close as to upset the tracking. If this capacitor (normally supplied by the antenna) is missing, the primary will resonate in the band and completely upset the tracking and general performance of the receiver.

In my opinion, the direct connection of the loop to the receiver, via the pickup coil, is undesirable. The best you can expect is a 6 db insertion loss and if you match lower than this, the insertion loss will increase and if higher, the loop Q will be affected adversely. The use of a pre-amp is much to be desired and this could be either transistor or FET. There are all sorts of FET's, however, and some can get you into real trouble, so this story is too long to include here but can be covered later if an interest develops. As a matter of fact, a transistor amplifier is not too easy to beat, anyway. A collector load resistor of 220 ohms will provide a gain of about 8 times with a current drain of 1 milliampere. Of course, a h.f. transistor should be used such as the inexpensive, plastic planar silicon types designed for RF use. To be on the safe side, include the 250 mmf capacitor in the coupling circuit.

Again, I hope to be able to provide more specific constructional information when suitable cores become available. If additional information is required, write J. (Joe) A. Worcester, R. D. 1, Frankfort, New York 13340. If a personal reply is necessary, please include SASE.

J. A. Worcester

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