An Overview of the Underestimated Magnetic Loop HF Antenna

It seems one of the best kept secrets in the amateur radio community is how well a small diminutive magnetic loop antenna can really perform in practice compared with large traditional HF antennas. The objective of this article is to disseminate some practical information about successful homebrew loop construction and to enumerate the loop's key distinguishing characteristics and unique features. A magnetic loop antenna can very conveniently be accommodated on a table top, hidden in an attic / roof loft, an outdoor porch, patio balcony of a high-rise apartment, rooftop, or any other space constrained site.

A small but efficacious HF antenna for restricted space sites is the highly sort after Holy Grail of many an amateur radio enthusiast. This quest and interest is particularly strong from amateurs having to face the prospect of giving up their much loved hobby as they move from suburban residential lots into smaller restricted space retirement villages and other communities that have strict rules against erecting elevated antenna structures. In spite of these imposed restrictions amateurs do have a practical and viable alternative means to actively continue the hobby using a covert in-door or portable outdoor and sympathetically placed small magnetic loop. This paper discusses how such diminutive antennas can provide an entirely workable compromise that enable keen amateurs to keep operating their HF station without any need for their previous tall towers and favourite beam antennas or unwieldy G5RV or long wire. The practical difference in station signal strength at worst will be only an S-point or two.

Anyone making a cursory investigation into the subject of magnetic loop antennas using the Google internet search engine will readily find an overwhelming and perplexing abundance of material. This article will assist readers in making sense of the wide diversity of often times conflicting information with a view to facilitate the assimilation of the important essence of practical knowledge required to make an electrically-small loop work to its full potential and yield very good on-air performance.

A few facts:

A properly designed and constructed small loop of nominal 1m diameter will outperform any antenna type except a tri-band beam on the 10m/15m/20m bands, and will be within an S-point (6dB) or so of an optimised mono-band 3-element beam that's mounted at an appropriate height above ground.

Magnetic loops really come into their own on the higher HF bands from say 40m through to 10m; oftentimes with absolutely stunning performance rivalling the best conventional antennas. Easily field deployable and fixed site tuned loops have been the routine antenna of choice for many years in professional defence, military, diplomatic, and shipboard HF communication links where robust and reliable general coverage radio communication is deemed mandatory. On 80m and 160m top-band the performance of a small loop antenna generally exceeds that achievable from a horizontal dipole, particularly one deployed at sub-optimal height above ground. This is a common site limitation for any HF antenna.

So where's the catch; if the small loop is such a good antenna why doesn't everyone have one and dispense with their tall towers? The laws of nature and electromagnetics cannot be violated and the only unavoidable price one pays for operating with an electrically-small antenna is narrow bandwidth. Narrow instantaneous bandwidth rather than poor efficiency is the fundamental limiting factor trade-off with small loops.

Any small antenna will be narrow band and require tuning to the chosen operating frequency within a given band. Users of magnetic loops must be content with bandwidths of say 10 or 20 kHz at 7 MHz or a little more than 0.2%. They are content as long as the antenna can be easily tuned to cover the frequencies that they wish to use. For a remotely sited or rooftop mounted antenna implementing this tuning requires just a modicum of that ingenuity and improvisation radio hams are renowned for.

A small transmitting loop (STL) antenna is defined as having a circumference of more than one-eighth wavelength but somewhat less than one-third wavelength which results in an approximately uniform current distribution throughout the loop and the structure behaves as a lumped inductance. The figure-8 doughnut shaped radiation pattern is in the plane of the loop with nulls at right angles to the plane of the loop. The loop self-inductance can be resonated with a capacitance to form a high-Q parallel tuned circuit. The attainment of a high-Q tells us that the loop antenna is not lossy and inefficient. When power is applied to the loop at its resonant frequency *all* of that power will be radiated except that portion absorbed in the lumped I^2R conductor and capacitor losses manifesting as wasteful heat. With proper design these series equivalent circuit losses can be made negligible or at least sufficiently small compared to the loop's radiation resistance that resultantly high *intrinsic* radiation efficiency and good antenna performance can be achieved.

Current through the loop's radiation resistance results in RF power being converted to electromagnetic radiation. However, since the small loop's radiation resistance is very small compared to that of a full sized resonant ½ λ dipole, getting this favourable ratio of loss to radiation resistance is the only "tricky" and challenging part of practical loop design and homebrew construction. Through utilizing a split-stator or a butterfly style air variable capacitor construction or preferably a vacuum variable capacitor, low loss can be achieved in the tuning capacitor. Conductor loss can then be controlled by optimal choice of the diameter of copper tubing used to form the loop element and paying very careful attention to low ohmic interconnections to the capacitor such as welded or silver soldered joints, etc. With 100 Watts of Tx drive power there are many tens of Amperes of RF circulating current and Volt-Amps-Reactive (VAR) energy flowing in the loop conductor and tuning capacitor.

In the case of an air variable, capacitor losses are further minimised by welding the rotor and stator plates to the stacked spacers to eliminate any residual cumulative contact resistance. When connected across the loop terminals the butterfly construction technique inherently eliminates any lossy rotating contacts in the RF current path. The configuration permits one to use the rotor to perform the variable coupling between the two split stator sections and thus circumvent the need for any lossy wiper contacts to carry the substantial RF current. Since the fixed stator plate sections are effectively in series, one also doubles the RF breakdown voltage rating of the composite capacitor. In view of the fact the loop antenna is a high-Q resonant circuit, many kilovolts of RF voltage can be present across the tuning capacitor and appropriate safety precautions must be taken. Small transmitting loop antennas capable of handling a full 400 Watts PEP or greater are readily achievable when appropriate construction and tuning components are selected.

Feeding and matching:

Although loop antennas have deceptively simple appearance, they are complex structures with radiation patterns and polarisation characteristics dependent on whether they're fed in a balanced or unbalanced fashion. The method of feeding and matching the loop resonator, ground plane configuration, as well as the geometric form factor and physical proportions of the loop element itself are all fertile ground for experimentation. Various matching methods include series capacitor, transformer coupled subsidiary shielded-Faraday loop, and gamma-match, etc; each with their respective merits.

The choice really boils down to personal preference as both the gamma and Faraday feed techniques work well. However, the Faraday shielded auxiliary loop located at the bottom central symmetry plane yields better loop electrical symmetry and balance that can in turn provide sometimes beneficial deeper front-to-side ratio and pattern nulls. In addition to imparting slight pattern asymmetry the Gamma match method can also result in some deleterious common-mode current flow on the outer braid of the feed coax that might need choking-off and isolating with ferrite decoupling balun to prevent spurious feeder radiation and extraneous noise pick-up on Rx. Much also depends on the site installation set up in respect of conductive objects in the loop's near field that can disturb symmetry.

With the elegantly simple transformer-coupled Faraday loop feed method the 50Ω signal source merely feeds the auxiliary loop; there's no other coupling / matching components required as there are no reflected reactive components to deal with (the main loop appears purely resistive at resonance with just the core R_{rad} and R_{loss} components in series).

The impedance seen looking into the auxiliary feed loop is determined solely by its diameter with respect to the primary tuned resonator loop. A loop diameter ratio of 5:1 typically yields a perfect match over a 10:1 or greater frequency range of main loop tuning. Simple transformer action occurs between the primary loop and the feed loop coupled circuit due to the highly reactive field near the resonant primary loop which serves to greatly concentrate magnetic flux lines which cut the small untuned feed loop. The degree of magnetic flux concentration is a function of the Q of the tuned primary which varies with frequency, i.e. the highest Q occurring at the lowest frequency of operation and the lowest Q exhibited at the highest frequency. This variation in Q results from the variation in the sum of the loss resistance and the complex mode radiation resistances of the primary radiator loop as a function of frequency. The effective feed impedance of the secondary loop is controlled by its diameter / ratio of area and by the number of flux lines cutting it; thus the impedance seen looking into the secondary loop will be essentially independent of frequency. One can intuitively see this because when the feed loop is extremely small in relation to a wavelength at the lowest frequency of operation, the number of magnetic flux lines cutting it is large because of the very high Q, whereas when the feed loop becomes a larger fraction of a wavelength as the frequency of resonance is increased, the concentration of flux lines is reduced due to the lower Q.

If one seeks mode purity and figure-8 pattern symmetry with deep side nulls, the fully balanced Faraday transformer coupled subsidiary broadband impedance matching loop with its 5:1 diameter ratio would be the preferred choice of feed structure.

Loop balance is also important for rejecting local electric E-field conveyed noise; whereas the small loop is predominantly H-field responsive, any electrical imbalance results in common-mode currents on the feeder that will impart deleterious E-field sensitivity which may contribute to additional local noise pickup. That inherent loop imbalance and asymmetry is one of the slight trade-offs associated with a Gamma feed compared to an auxiliary Faraday loop transformer feed. This aberration is not an issue with Tx mode of course.

Loop radiation characteristics:

Small loop antennas have at least two simultaneously excited radiation modes; a magnetic and an electric folded dipole mode. When the ratio proportions of loop mode and dipole mode radiation are juggled to achieve equal strengths some radiation pattern asymmetry results and a useful degree of uni-directionality can be achieved with a typical front to back ratio of about 6dB or so.

The small loop with its doughnut shaped pattern exhibits a typical gain of 1.5 dBi over average ground and a gain of 5 dBi when deployed with either short radials (the length of each radial need only be twice the loop diameter) or mounted over a conductive ground plane surface. By comparison a large ½ λ horizontal dipole mounted ¼ λ above average ground has a gain of 5.12 dBi and a ¼ λ Vertical with 120 radials each ¼ λ long has a gain of 2 dBi over average ground. The front to side ratio of a well balanced loop is typically 20 to 25 dB when care is taken to suppress spurious feeder radiation due to common-mode currents flowing on the coax braid.

However the small loop has one very significant advantage over any other antenna due to its unique radiation pattern. If the vertically oriented loop's figure-8 doughnut pattern radiation lobe is visualised standing on the ground the maximum gain occurs at *both* low and high angles, radiating equally well at all elevation angles in the plane of the loop, i.e. radiation occurs at all vertical angles from the horizon to the zenith. Because the loop radiates at both low and high angles, a single loop can replace both a horizontal dipole and a Vertical. This is particularly beneficial on 160, 80 and 40m where the loop will provide outstanding local / regional coverage and easily match and often outperform a tall ¼ λ Vertical for long haul DX contacts, i.e. an exceptionally good general purpose antenna.

Energy radiated by the small loop is vertically polarised on the horizon and horizontally polarised overhead at the zenith. It will be quickly realised that a loop has the distinctive property of providing radiation for transmission and response for reception over both long distances and over short to medium distances. This is achieved by virtue of low angle vertically polarised propagation in the former case and by means of horizontally polarised oblique incidence propagation in the latter case. In contrast, a Vertical monopole is useful only for low angle vertically polarised propagation since it exhibits a null overhead and poor response and radiation at angles in excess of about 45 degrees. Such antennas are of course very useful for long distance communication by means of low angle sky wave skip propagation, or for short range communication via the ground wave propagation mode.

In further contrast, a horizontal ½ λ dipole (or beam arrays comprising dipole elements) at a height above ground of a just a fraction of a wavelength (as opposed to idealised free space or mounted very high) exhibits maximum polar response directly overhead (good for NVIS) with almost zero radiation down near the horizon. Such popular "cloud warmer" antennas in residential situations as the surreptitiously hung ubiquitous G5RV, End-feds, dipoles, inverted-V, etc. are thus most useful for short to medium range communication in that portion of the HF radio spectrum where oblique incidence propagation is possible.

Importantly it should be noted when comparing small loops with conventional antennas that a 20m Yagi beam for example must ideally be deployed at a height above ground of at least one wavelength (20m) in order to work well and achieve a low take-off angle tending towards the horizon for realising optimal no compromise long-haul DX operation.

Unfortunately such a tower height is impractical in most residential zoning rule situations imposed by municipal councils and town planners. If the Yagi beam is deployed at a lower 10m height then a diminutive loop will nearly always outperform the beam antenna. This writer never fails to be amused by folks who acquire a potentially high performance Yagi HF beam and sacrilegiously deploy it in suboptimal installations in respect of height above ground or proximity to a metal roof. The problem worsens on the lower bands below 20m where the resultant high angle lobe pattern direction is not at all very conducive to facilitating good DX communication.

In comparison to a vertically mounted / oriented loop, the bottom of the loop does not need to more than a loop diameter above ground making it very easy to site in a restricted space location. There is no significant improvement in performance when a small loop is raised to great heights; all that matters is the loop is substantially clear of objects in the immediate surrounds and the desired direction of radiation! Mounting the loop on a short mast above an elevated roof ground-plane yields excellent results.

A good HF antenna for long haul DX requires launching the majority of the Tx power at a low angle of radiation; things a good, efficient and properly installed vertical, a properly sited small magnetic loop, and a big multi-element beam atop a very tall tower do very well.

Receiving properties:

In a typical high noise urban environment a loop will nearly always hear more than a big beam on the HF bands. The small magnetic loop antenna (a balanced one) responds predominately to the magnetic component of the incident EM wave, while being nearly insensitive to the electric field component; which is the basic reason why loops are so impressively quiet on receive; often times dramatically so. They will pull in the weak signals out of the ambient noise and you will very likely receive stations that you'd never hear when switching across to a vertical, dipole or beam antenna.

In a propagating radio wave the magnitude of the electric vector is 120π or 26 dB greater than the magnitude of the magnetic vector, the difference being due to the intrinsic impedance of free space (377 Ohms). On the other hand the induction fields associated with man-made noise have electric E-field components many times greater than a normal radiation field (radio wave). While a dipole or vertical antenna is sensitive to both the electric and magnetic components of a wave, the small loop is responsive only to the magnetic H-field component and it will be substantially "blind" and offer a high degree of rejection to pickup of undesired man made noise and atmospheric disturbances.

Hence the widely used term "magnetic loop" antenna to signify this field discrimination to the components of the incoming incident EM wave. Antenna theory treats the loop as the electrical conjugate of the dipole, i.e. the loop is a "magnetic dipole" while an ordinary dipole is an "electric dipole".

Significantly, a small loop antenna will typically produce a signal-to-noise ratio / SNR that is some 10 to 20 dB greater than a horizontal dipole in a noisy urban environment and an even greater improvement in SNR when compared to a vertical antenna as a result of the man-made noise comprising a strong electric field component and being largely vertically polarised.

The most important criterion for reception is the signal to noise ratio and *not* antenna gain or efficiency. In the HF band, particularly at the low-mid frequency portion, external man-made and galactic / atmospheric noise is dominant.

The magnetic loop antenna has one other important practical advantage in receive mode. The aforementioned high-Q resonator imparts a very narrow band frequency selective bandpass filter ahead of the Rx front-end stages. Such an incidental preselector comprising the antenna itself imparts greatly improved receiver performance on the congested lower HF bands with high power broadcast stations and particularly when lightning strikes and atmospheric electrical discharges are present in the regional area. Unwanted overload causing and adjacent-channel QRM interference signals are rejected or heavily attenuated.

As well as eliminating strong-signal overload and intermodulation effects, the filtering dramatically reduces the amount of lightning induced broadband impulse energy fed to the Rx front-end and weak signals can still be heard when reception under such adverse conditions was previously impossible.

It is these collective characteristics of small loop antennas that enable them to often very significantly outperform their large dipole, Yagi or Quad beam counterparts during direct A/B comparative testing. Conversely in Tx mode the antenna’s inherent filter action selectivity causes any transmitter harmonics to be greatly attenuated and not radiated. This can help with eliminating some forms of TVI.

Effects of ground on loop antenna performance:

When a dipole antenna is placed horizontally above ground, its electrical “image” in the ground is of the opposite phase. As a consequence, if the height above ground of a horizontal dipole is reduced to less than ¼ wavelength, fairly high system losses develop due to a rapid decrease in radiation resistance concurrent with a rapid rise in loss resistance resulting from dissipation of power within a less than perfect ground. This represents a classic double-whammy scenario and deleterious performance for dipoles deployed at insufficient height above ground.

By way of contrast, the oscillatory RF currents associated with the image of a small vertical oriented loop antenna above ground are “in-phase” with those of the loop. Therefore the effect of ground on the performance of a vertically oriented loop is relatively small. In fact, because the magnetic component of an electromagnetic wave is maximum at the boundary between the ground and the space above, loop performance is usually best when the loop is located near the ground at a distance outside of the loop’s close-in induction field (just a loop diameter or two). However, if nearby conductive objects such as power lines or buildings exist in the direction of transmission / reception; it is normally preferable to choose a height above ground which will provide the loop with a clear and unobstructed view of the intended signal path.

In comparing the performance of a vertical whip and a small vertical loop located atop of a building, it may be said that the loop will generally be the clear winner with respect to vertical and horizontal radiation patterns. This is because the pattern of a whip antenna driven against the top of a building is usually not predictable with any accuracy at all because vertical currents will flow all the way up and down the several conductive paths between the antenna and the earth; each path contributing to the total radiation pattern in the form of multiple lobes and nulls.

A balanced loop antenna, however, is inherently immune to such problems because the ground below the antennas does not form the missing half of the antenna circuit in respect of supporting ground-return currents as it does with a vertical whip / monopole antenna. Therefore the multiple current paths to ground (earth) are eliminated with the loop. Of course both the loop and the whip are subject to the well-known wave interference effects in elevation due to height above the ground (or water).

Reflective metal objects having a size greater than about 1/3 of a wavelength and at a distance of less than about 2 wavelengths from the loop antenna can produce standing wave “nulls” in a given direction at various frequencies. If the antenna is to be mounted atop a metal roof, diffraction interference from the edge of the building roof should be considered if undesirable nulls in certain directions at some frequencies are to be avoided. Usually the best location is near the edge of such a conductive roof, in the direction of the desired signal or signals.

Loop Directivity:

It is commonly believed that a vertically oriented loop antenna exhibits a bi-directional pattern with maximum reception occurring in the plane of the loop. Although this is true for vertically polarised sky-wave signals arriving at very low elevation angles (less than about 10 degrees) and for ground-wave signals, it is certainly not true for reception of high angle sky-waves (greater than about 30 degrees) whose polarisation usually rotates from vertical to horizontal at a fairly random rate due to “Faraday Rotation” of free-electrons within the ionosphere. At angles exceeding 45 degrees, the loop response shifts to a preference for horizontal polarisation arriving at an azimuth angle of 90 degrees with respect to the plane of the loop. Thus, for short-range communication links, i.e. less than about 500 km, best reception will usually occur with the loop rotated 90 degrees, that is, the plane of the loop perpendicular to the azimuthal arrival angle.

It is not easy to predict which azimuthal bearing will provide the best night-time reception with a loop over paths of less than about 500 km at frequencies of less than about 7 MHz. This is due to the prevalence of both sky-wave and ground-wave signals which randomly combine to produce rather serious fading. Usually, trial and error is the best solution for determining which antenna orientation will produce the most favourable compromise between the highest average signal-strength and the least troublesome fading. Generally for distances exceeding 500 to 1000 km, the best orientation is with the plane of the loop in the direction of the arriving signal. Further, the side nulls exhibited by the loop at low elevation angles may be used to “null-out” the ground-wave signal to reduce fading when sky-wave propagation exists simultaneously. In comparison a vertical whip has a null overhead and thus is ineffective for short and medium distances. A vertical loop antenna located less than about 0.15 λ above ground exhibits excellent coverage from the zenith down to almost zero degrees in the elevation plane making the loop useful over almost any distance range. At elevation angles higher than about 20 degrees, a loop is almost omnidirectional in azimuth when receiving sky-wave signals.

For a loop above average ground, as opposed to ground having perfect conductivity, the response at very low vertical angles e.g. less than about 5 degrees, is typically 10 dB or more below the achievable response above perfect ground. It is perhaps worthy to note that the ground immediately below the loop principally affects the response at high vertical angles while the properties of the ground at a large radius distance from the antenna tends to characterise the performance of the loop at low vertical angles in the plane of the loop.

Construction and siting issues:

Without a good quality low-loss split stator or butterfly or vacuum variable capacitor of adequate RF voltage and current rating, it is quite futile building a magnetic loop antenna and expecting it to yield the impressive results it's potentially capable of. The minimisation of all sources of loss is particularly important in Tx mode. By virtue of the shorter rotor, the butterfly style capacitor has slightly lower rotor loss than the split-stator construction style. The tuning capacitor is undoubtedly the single most critical component in a successful homebrew loop project. Although more expensive and harder to find, vacuum variable capacitors have a large capacitance range in respect of their min/max ratio and allow a loop to be tuned over a considerably wider frequency range than that achievable with an air variable capacitor. Vacuum capacitors also have lower intrinsic losses than most air variables. Good quality Jennings vacuum variable capacitors and a multitude of Russian made equivalents can be readily found on the surplus radio parts markets and eBay, as can their associated silver-plated mounting and clamp hardware to ensure a low contact resistance connection to the loop antenna conductor. A very low contact resistance interface is essential between the capacitor terminals and the copper loop conductor.

Other creative means can also be used to fashion a high VAR rated low-loss capacitor such as trombone, piston, or interdigitated meshing plate configurations. Air is always the preferred dielectric as most other materials have high loss tangents and dissipation factors. Whether a vacuum or air variable or homebrew capacitor is chosen, their mechanical shafts can be readily interfaced to a reduction gearbox and motor drive to facilitate easy remote tuning of a roof top or covert loft mounted loop. The antenna tuning can be manual or automatic based on VSWR sensing and a self-tuning servo system to control the drive motor. Peaking the loop tuning capacitor for strongest band noise on Rx will get the loop antenna tuning in the right ballpark for Tx with a low VSWR.

Failure to pay very careful strict attention to construction details in relation to eliminating all sources of stray losses and making bad siting choices such as close proximity to ferrous materials are the two main reasons why small magnetic loop antennas sometimes fail to live up to their performance potential; instead behaving as a proverbial "wet noodle" with associated poor signal reports. Conversely a well built / sited loop is an absolute delight.

Transmitting loop antennas intended for optimal coverage of the most popular portion of the HF spectrum from 3.5 MHz to 30 MHz are best segregated into at least 2 distinct loop sizes. A nominal 0.9m diameter loop for covering all the upper HF bands from 20m through to 10m (and perhaps also tunable down to 30m depending on capacitor min/max ratio), and a 2m diameter loop for covering the lower bands 80m through to 30m. For best operation down at 160m and improved 80m performance increased loop diameters of 3.4m to 4m should be considered.

An important thing to note about vacuum capacitors is they don't have a uniform RF amperage current rating over their entire capacitance range, but it is less at small plate mesh / low capacitance end. So one needs to factor this characteristic into design calculations and make sure you operate the capacitor within its ratings over the desired loop tuning range. Manufacturers like ITT Jennings provide Nomographs of this. This is another good reason for restricting the loop tuning / operating range over a nominal 2 to 3:1 range so the Vac cap always works in its optimal VAR / current "sweet-spot" region. The saving grace with the current ratings of vacuum capacitors is they are continuous RMS Amps, i.e. key-down CW operation; and can be considerably safely exceeded when running relatively low duty cycle SSB voice modes / PEP transmissions. All is OK with vacuum capacitors as long as the rated glass/ metal seal temperature is not exceeded. This is unlikely to occur in practice as the silver plated copper mounting clamps efficiently heatsink and remove any heat into the copper loop conductor.

Mono-band loop operation yields the best result as the optimum loop inductance to capacitance ratio can be chosen and the majority of the tuning capacitance can be provided with a fixed vacuum capacitor. A much smaller vacuum variable capacitor can then be deployed in parallel to achieve fine vernier “bandspread” tuning across the whole band of interest, e.g. 40m or 80m, etc.

Top-band operation at 1.8 MHz is always the hardest challenge for any antenna type, small loops (typical dimensions of 0.02λ) included; but their on-air performance can nevertheless be authoritative with a commanding signal presence. There are no "free lunches" (and few cheap ones) when shrinking the size of antennas as the free space wavelength has not yet been miniaturized by nature redefining the laws of physics! Consequently antennas of such diminutive size must always be placed into proper perspective when compared with the performance attainable from a full-sized λ/2 horizontal dipole for 160m. However, most amateurs haven’t got sufficient residential block size and/or mast height in a fraction of wavelength to accommodate a 160m dipole that works properly with a decent radiation efficiency and ability to put its radiated power in a useful direction. Similarly, reasonably efficient and efficacious Verticals for 160m operation unfortunately exceed the allowed height by a great margin that’s permitted by local council and residential building code regulations. Then a huge amount of real estate is required to accommodate the extensive radial system.

The practical on-air performance of a loop on the 160/80m bands will be highly dependent on what antenna you use as a reference comparison, e.g. a centre-loaded mobile whip or full size resonant dipole/monopole, etc. and what path is used, NVIS, ground wave, sky wave, etc. The loop conductor diameter is determined by the desired loss resistance due to skin-effect, and choices can range from modest 6mm copper tubing to large bore 100mm copper or aluminium tube. Commonly used conductor diameters used to construct a magnetic loop are 20mm and 32mm soft copper tube. Heavy wall thickness tubing is not required as the RF current flow is confined to the conductor surface due to the skin-effect.

Note that the radiation efficiency is *not* related to the loop size. Loop antenna efficiency is determined by the conductor tube diameter and its conductivity. This conceptual notion is counterintuitive for many folks. A small loop will also be efficient and radiate power very effectively on 80m and 160m but the resultant L–C ratio and stored energy will often be such that the loop’s Q factor will be so high as to yield an impractically small instantaneous bandwidth that’s not useful for SSB communication purposes. Achievable bandwidth is roughly proportional to loop size / diameter and Q is inversely proportional to the loop diameter. Depending on its construction a small loop of nominal 1m diameter can exhibit an *intrinsic* radiation efficiency of 90% over the 1.8 to 30 MHz frequency range.

Copper tubing is the preferred material to fabricate the loop as it has a higher conductivity than aluminium.

Larger size semi-rigid Heliax coax such as LDF550 / LDF650 / LDF750 will conveniently make excellent loop construction material for the smaller diameter 20m to 10m HF band loops when run at the 100 to 400 Watt power level.

The larger bore 2-inch LDF750 can be used on the lower bands to beyond 1 kW. In relation to resistance and conductivity, small loop antennas inherently exhibit very low radiation resistances, which compete with the ohmic resistances of the loop conductor and the resistances from connections and welds, including the tuning capacitor connection. Magnetic loop antennas will typically have a radiation resistance in the order of 100 to 200 milliohms. This means that every additional milliohm caused by a poor contact will cost you one percent efficiency. That is why professional magnetic loop antennas for transmitting purposes will never have mechanical contacts and *everything* including the capacitor plates should be welded or silver soldered. It is not uncommon to experience 60 Amperes or more of RF circulating current in the loop and capacitor when fed with several hundred Watts of power.

In the practical deployment and siting of a loop antenna there are extrinsic factors of both a beneficial and deleterious kind affecting the radiation and loss resistances when the loop is not strictly deployed in a free space scenario. When the loop is mounted over a perfectly conducting ground plane reflector or copper radial wire mat an electrical image is created that increases the effective loop area. This increase in turn beneficially increases the loop’s radiation resistance by a substantial factor. Such a favourable situation is easy to facilitate.

Conversely if the loop is placed over average ground (a reasonable reflector) the radiation resistance increases but a reflected loss resistance is also introduced due to transformer effect coupling near-field energy into the lossy ground. Similarly when ferrous / iron material is too close, the magnetic near-field of the loop will induce by transformer action a voltage across the RF resistance of the material causing a current flow and associated I^2R power loss. This situation might for example arise when the loop is mounted on an apartment balcony with nearby iron railing or concrete rebar etc; the deleterious influence can be minimised by simply orienting the loop to sit at right angles to the offending iron or steel material. Another loss contributing component is due to current flowing in the soil via capacitance between the loop and the soil surface. This capacitive coupling effect is again minimised by keeping the loop at least half a loop diameter or more above the ground.

The transformer analogy for the loop antenna is a good one. The HF communication link may be visualised as a reciprocal “space transformer” with the loop acting as a secondary “winding” loosely coupled to the distant transmitting antenna. The magnetic field component of the incident electromagnetic wave induces a small RF current to flow in the loop conductor by means of induction that in turn gets magnified by the loop resonator’s high Q that’s appropriately impedance matched to the coax transmission line.

A freestanding transmitting loop is best supported a metre or two in height on a short non-metallic mast section of 100mm diameter PVC drainpipe and pedestal foot fashioned from plastic plumbing fittings. The loop can also be placed on a rotator drive plate and turned for best signal strength or it can be oriented in angle to null-out particularly bad QRM.

Care must be taken not to touch the loop when transmitting and to keep a safe distance away from the loop’s magnetic near-field to ensure conservative compliance with electromagnetic radiation / EMR standards for human exposure to EM fields. A distance equal to or greater than one or two loop diameters away is generally a safe field strength region. RF burns to the skin from touching the loop while transmitting are very unpleasant and take a long time to heal.

Concluding remarks:

The proof of the pudding is always in the eating so experimentally inclined amateurs are encouraged to gain some first hand experience by getting into the shack workshop and constructing some homebrew loops. Such empirical validation of efficacy is always very gratifying, particularly when a VK station can have a solid 5 and 9+ QSO on 20m with a USA or Canadian station from an elegant looking Lilliputian indoor loop sitting on a table fed with a modest 50 Watts! What we ultimately seek from any antenna is reliable HF communication at all times when a band is open for DX and, simply put, that means radiating most of the RF that's applied to the antenna in a useable direction and take-off angle. The underestimated magnetic loop antenna satisfies that basic criteria very well.

A well designed and constructed small magnetic loop antenna is perhaps one of the rare few instances were a proverbial gallon of performance can be extracted from a pint bottle!

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