Interchange of Discussions on Transmitting Loop Antennas

A record of discussions between Lloyd Butler VK5BR and Leigh Turner VK5KLT via Email concerning the operation of the Transmitting Loop Antenna and reference to the recent talk at AHARS Adelaide by Mike Underhill.

INTRODUCTION

The discussions here were initially started because of a talk given to AHARS members by Mike Underhill on small antennas and which included claims of 70% efficiency at 1.8 MHz for a 1 metre diameter transmitting loop antenna.(Refer; ***All sorts of small antennas better by heuristics.pdf***).

This 70% efficiency of a 1 metre loop at 1.8 MHz was questioned by Lloyd Butler VK5BR in a paper - ***Notes on Small Antenna.pdf.*** Lloyd suggested that the power assumed to be radiated in Mike's experiments might in fact be power lost due to induction into nearby objects and/or earth. In further comments (listed in an email following), Lloyd also questioned the degree of balance achieved in the loop by using the Gamma match and whether this might generate a common mode current component down the transmission line causing radiation from the line thus contributing to the total power radiated.

All this initiated discussions on the subject between Leigh Turner VK5KLT and Lloyd and these discussions were carried out via email as recorded in the following text.

The email messages initially start between John Elliote VK5EMI and Lloyd and ultimately move on to dialogue between Lloyd and Leigh.

---

1 From: Lloyd Butler
Sent: Thursday, 8 May 2008 11:46 PM
To: dellio2
Subject: Re: Comments on Mike Underhill Talk

John VK5EMI

I agree that a properly constructed low resistance copper tube loop can be very efficient - A 1 metre square or 1 metre diameter loop can produce very high efficiency around 14-21 MHz. My own on air tests with such a loop around these frequencies gave results comparable with a half wave dipole and considerably better than a trapped vertical. However, the loop dimensions have to be sized up relative to the wavelengths in use. Referring to QST June 1986, Ted Hart did some substantial research on these loops - To get 50% efficiency at 160 metres, his information indicates a 3/4 inch diam copper loop of around 8 metres in diameter.- A little bit cumbersome for the typical backyard. Hi!!

If we could get 74% efficiency on 160 metres with just 1 metre diameter, we would all have been using them years ago.

So there we go!!

Lloyd VK5BR

2

From: Lloyd Butler
Sent: Friday, 16 May 2008 10:29 PM
To: dellio2

Subject: Re: Comments on Mike Underhill Talk

John

Reference comparison of performance with such as your G5RV:

The loop is good for the 10 and 20 metre bands where one doesn't have the available space to put up a full sized antenna such as a half wave dipole. It has extremely high Q and hence very narrow bandwidth. So you have to progressively retune it to bring it to resonance if you want to traverse across the band. The classical method of doing this is to couple the tuning capacitor to an electric motor which can be controlled from within the shack.

However in the loop I made, I delta fed it via open wire line pair and used a Z Match Tuner to reflect reactance up the line and control tuning of the loop without need of the tuning motor.

My loop was around 1 metre square - its maximum efficiency was on the 21 MHz band but still quite good at 14 MHz - It could not tune 28 MHz because it was slightly too big (too much inductance to bring it to resonance). See http://users.tpg.com.au/ldbutler/HFTXLoop.htm

Lloyd

3
From: Lloyd Butler
Sent: Thursday, 22 May 2008 11:13 PM
To: dellio2
Subject: Re: Comments on Mike Underhill Talk

John

It didn't enter my mind when I wrote the report on the Mike Underhill talk but there is something else which might make the small tuned loop appear to radiate as a loop on 1.8MHz.

The Underhill loops are Gamma fed, an unbalanced type of coupling system.

If you read my article: http://users.tpg.com.au/ldbutler/ReverseFeedTopLoading.htm , you see that I found out that if you feed a small resonant antenna unbalanced, the degree of unbalance of current reflected down the legs of the transmission line (the coax feeder) is multiplied by the Q of the terminal antenna. In fact in the EH antenna, the current in the inner conductor was measured as about twice that in the outer conductor. (Most of the radiation is from the the common mode or the longitudinal current component in the feeder and not from the crossed fields as the inventor still would have us believe).

It seems to me that gamma feeding the small tuned loop with a length of coax and the loop Q being extremely high, the same phenomena would also occur to unbalance the feeder current and radiate at 1.8MHz very nicely from the feedline - One could easily be misled into believing that a good performance was due to radiation from the loop.

Of course I no longer have the loop (I donated it to Rob) and I am not now well set up myself in the Village to verify all this. But a simple test of an RF ammeter in each leg of the coax feeding into the loop is all that would be needed.

Lloyd

4

----- Original Message -----
From: Leigh Turner
To: ' dellio2'
Cc: ' Lloyd Butler'
Sent: Monday, June 02, 2008 1:19 PM
Subject: RE: Comments on Mike Underhill Talk

Hi John / Lloyd,

Lloyd has made some valid observations below that might potentially apply; however, I'm sure Mike has the wherewithal and experimental experience to factor such obvious precautions into his testing and loop evaluation regime that one might attribute spurious / incidental radiation to.

I'm still awaiting Mike's comments to Lloyd's last communication, but like me, he's also been busy of late.

Yes, an RF ammeter in the feeder would quickly lay the issue of common mode currents and associated radiation to rest.

Yes a dinky 1m diam loop suitable for upper HF band should be appropriately up-scaled for use down at 160m or 80m, otherwise the instantaneous bandwidth will be too narrow for practical use. It's not an efficiency issue though, but rather a BW issue.

Yes, you had previously forwarded me that referred to e-mail; thanks for that.

73

Leigh

VK5KLT

5

From: Lloyd Butler [mailto:ldbutler@tpg.com.au]
Sent: Tuesday, 3 June 2008 10:10 PM
To: Leigh Turner
Cc: John Elliote
Subject: Re: Comments on Mike Underhill Talk

Hi John/Leigh

Reference:

"Yes a dinky 1m diam loop suitable for upper HF band should be appropriately up-scaled for use down at 160m or 80m, otherwise the instantaneous bandwidth will be too narrow for practical use. It's not an efficiency issue though, but rather a BW issue."

Well to transmit a single sideband speech signal with minimal distortion, I would suggest a bandwidth of little less than 3 kHz. This implies a loop Q of not greater than 600 at 1.8 MHz and not greater than 1200 at 3.6 MHz. In practice, I doubt if Qs higher than these figures would be likely using a 1 m loop tuned with a large capacitor to these frequencies. (The Q would be set by the ratio of inductive reactance of the loop to its loss resistance. - Radiation resistance would be too small to be a factor in the calculation).

Anyway the bandwidth would also be more than adequate for practical use in narrow band modes such as CW.

The bandwidth limitation is really only an obstacle in maintaining resonance whilst tracking across a band. Of course this obstacle is still there for say the 20 metre band.

So I would have to disagree that the problem is a bandwidth issue rather than an efficiency issue. The latter (radiation inefficiency) is the difficulty if the loop is too small relative to the operating wavelength..

regards

Lloyd VK5BR

6

From: Leigh Turner
To: ' Lloyd Butler'
Cc: ' John Elliote'
Sent: Tuesday, June 03, 2008 11:57 PM
Subject: Loop efficiency and bandwidth

Hello Lloyd,

Nice to hear from you with some comments; it's always great to enter into a technical dialogue with keenly interested folks and such a prolific empirically based experimenter as your good yourself.

I don't think there's any real disagreement here; I would not advocate the use of a small 1m diam loop for 80m or 160m; but rather an up-scaled one of proportions around 3.5m diameter.

There are commercial product designs for such sized loops that offer -4 dBd gain @ 1.8 Hz w.r.t. a 1/2 dipole and - 0.3 dBd gain @ 7.0 MHz with a 6 dB front to back ratio and 25 dB front to side ratio. Not bad performance when an S point = 6 dB and compared to the alternative of a massively tall Vertical and huge radial system for 160m or a horizontal 1/2 dipole suspended at great height between two tall towers.

I've just finished writing a short paper on the subject of practical issues pertaining to grossly underrated HF magnetic loop antennas for radio amateurs; here's an extract below:

" Transmitting loop antennas intended for optimal coverage of the HF spectrum from 3.5 MHz to 30 MHz are best segregated into 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 80m an additional loop diameter of 3.4m should be considered. The performance on the low bands will be highly dependent on what antenna you use as a reference comparison, e.g. a centre-loaded mobile whip or full size dipole/monopole, etc. and what path is used, NVIS, ground wave, sky wave, etc. The conductor diameter is determined by the desired loss resistance due to skin-effect and choices can range from 6mm copper tubing to large bore 100mm copper or aluminium tube. Commonly used conductor diameters are 20mm and 32mm copper tube.

Note that the radiation efficiency is not related to the loop size. Loop 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 so useful for SSB communication purposes. Achievable bandwidth is roughly proportional to loop size and Q is inversely proportional to the loop diameter. Depending on construction a small loop of nominal 1m diameter can exhibit an intrinsic radiation efficiency of 90% over the whole 1.8 to 30 MHz frequency range."

You may enjoy reading the whole paper in due course. A version of it will be posted on our AHARS website and upcoming newsletter.

Since renewing my callsign about 18 months ago I've developed a renewed interest in magnetic loops after a 20 year hiatus; in the 1980s as a young postgraduate I once had the pleasure of having worked with the late and great John H. Dunlavy as his Technical Director / Chief Engineer. John was the original inventor of the original "Mini-Loop" transmitting loop antenna and numerous other innovative antennas for the US military / US Navy, defence and intelligence signals reconnaissance community and was the founder of Antenna Research Associates (ARA) in Beltsville Maryland who still to this day make many of the world's defense and military communications antennas. John and I used to design and make Tx and Rx loops and esoteric communications systems of all kinds for these specialist customers as well as for diplomatic communications, foreign missions, embassies, etc. I therefore gained extensive experience and insight into magnetic loops, their unique capabilities and limitations. The field of antennas and electromagnetics is where I've dwelled my entire professional career to this day.

73

Leigh

7

Hello Leigh

Thanks for your letter relevant to my comments on the small transmitting loop and detail of your background experience concerning the design and manufacture of these in your professional capacity. With that early experience you would have gained a lot of knowledge about how they can be designed to work efficiently and of course it explains your revived interest in magnetic loops and such material as has been presented by Mike Underhill.

I must apologise for taking so long to reply to your email but we have had a visitor from Sydney staying with us coincident with one son also over on a short visit from Melbourne - All this has put a damper on getting to the computer and attending to the incoming email file.

I worked a major part of my work life on developmental projects but apart from several short encounters with receiving type loops in the workplace, most of my experimentation with loops has occurred in my own backyard since retirement. As far as transmitting loops are concerning, I was initially guided by design material which Ted Hart originally published in QST and which was later repeated in a section of the ARRL Antenna Handbook. Performance tests on my own built loops seemed to confirm his design criteria and I have always thought since that his articles on the transmitting loop were right on target.

I have always praised Ted' s work on the transmitting magnetic loop but unfortunately I have to say that I now question some of his theories concerning his EH antenna.

To just deviate a bit off the magnetic loop and talk about the EH antenna. - I spent a couple of years having a say on the EH Forum which Ted had set up, initially accepting that here was a great new principle but ultimately realising that there were fundamental flaws in theories which he offered (and on which he had based his patent submission).

For example: The whole basis of his EH antenna evolved around the idea that by putting a phase shift network in series with the feed to the antenna, it can alter the phase relationship between the voltage across that connection and the current running into it. (Of course this was done to get the E and H fields in phase to satisfy the Maurice Hately Crossed Field Theory). Several of us on the forum pointed out that considering the antenna input as a lumped impedance, you could only alter the relationship between the phase of the voltage across that impedance and the current running into it by altering R and/or X constants within the impedance itself. (A phase shift network in series with but external to that impedance would simply shift the phase of voltage and current by the same amount). Simple AC circuit fundamentals, but Ted would never accept that he might have got it wrong,

Getting back to the magnetic loops, I read the extract from your short paper with interest. Concerning the sentence "Depending on construction a small loop of nominal 1m diameter can exhibit an intrinsic radiation efficiency of 90% over the whole 1.8 to 30 MHz frequency range", the Depending on construction would seem to be the vital phrase. Clearly the loss resistance would have to no greater than 10% of the value of calculated radiation resistance at 1.8 MHz.to get 90% efficiency. What diameter of copper tube would be needed to achieve this value of surface resistance around the circumference of the 1m diam loop? (Whatever the calculated copper size, I assume it would be considerably larger than that used in the Mike Underhill experiments). The loss resistance of the capacitor necessary to resonate the loop at 1.8 MHz would also have be included as part of the maximum loss resistance.- I wonder what practical value of capacitor loss resistance might be achievable.

Thanks again for your email - I will give some more thought later to the above.

regards

Lloyd VK5BR

8

Leigh's comments (in blue) to Lloyd's previous email
(Lloyd in black)

I was initially guided by design material which Ted Hart originally published in QST and which was later repeated in a section of the ARRL Antenna Handbook. Performance tests on my own built loops seemed to confirm his design criteria and I have always thought since that his articles on the transmitting loop were right on target.

Yes Ted W5QJR was the first to popularize the transmitting loop in amateur radio circles based on the earlier work and patents of John Dunlavy and his ARA commercial developments under contract for the US Army. Ted by the way had spent a stint working at the then WRE (now DSTO) here in Adelaide many years ago.

Now what used to puzzle everybody back then was how well diminutive magnetic loops worked in practice despite their apparent / alleged lousy radiation resistance, and how properly built ones always ran as cool as a cucumber without getting hot and self-destructing when seriously high RF power was applied to them. Mike Underhill’s subsequent insightful studies based on practical measurements and theoretical analysis work many years later has elegantly put that once partly understood issue squarely to rest. The only logical and inescapable conclusion is low and behold all/most of the power dutifully departs from the conductor structure as EM radiation. Impossible; what tommyrot and heresy according to some head-in-the-sand antenna experts and guardians of old and now supplanted EM theories! As it turns out these folks are applying time honoured design formulae that do not tell the whole story in respect of calculating the small loop’s true radiation resistance. This elusive parameter and consequent radiation efficiency is of course accurately deduced indirectly, even for an in situ loop, from a Q measurement undertaken with a VNA using a simple method described by Mike.

I have always praised Ted' s work on the transmitting magnetic loop but unfortunately I have to say that I now question some of his theories concerning his EH antenna.

Agreed to some extent

Nevertheless Ted’s avant-garde / quirky ideas have been commercialized by an Italian company and these compact EH antenna products have quite a devotee following in space constrained Europe and the UK. This ostensible contradiction of popularity and wide end-user acceptance often occurs because the HF radio link tends to be rather forgiving of inefficient antennas; especially when propagation conditions are favorable and where negative dBi gain antennas still produce good / acceptable results at the distant Rx site. The production of antenna radiation in a useful direction and angle is really what counts most, and is arguably a better metric to compare antennas over any given path. A few dBs of extra forward gain merely adds a bit more headroom for accommodating normal path variations.

To just deviate a bit off the magnetic loop and talk about the EH antenna. - I spent a couple of years having a say on the EH Forum which Ted had set up, initially accepting that here was a great new principle but ultimately realising that there were fundamental flaws in theories which he offered (and on which he had based his patent submission).

For example: The whole basis of his EH antenna evolved around the idea that by putting a phase shift network in series with the feed to the antenna, it can alter the phase relationship between the voltage across that connection and the current running into it. (Of course this was done to get the E and H fields in phase to satisfy the Maurice Hately Crossed Field Theory). Several of us on the forum pointed out that considering the antenna input as a lumped impedance, you could only alter the relationship between the phase of the voltage across that impedance and the current running into it by altering R and/or X constants within the impedance itself. (A phase shift network in series with but external to that impedance would simply shift the phase of voltage and current by the same amount). Simple AC circuit fundamentals, but Ted would never accept that he might have got it wrong,

Yes indeed. I have some of Ted's most interesting papers where he convincingly discusses how small loops can (apparently) be drastically improved in both efficiency and bandwidth terms by driving them with a 90 degree phase shift network and allegedly converting them into slick EH radiators! If I recall correctly, Ted was advocating that after the normal loop antenna is tuned to a nominal operating frequency and matched to 50 ohms, one then builds an external L+T lumped network placed at the coax feed that gives 45 + 45 degrees for a total of 90 degrees at the chosen frequency. Then magically the loop efficiency and BW is supposed to be boosted by a significant factor of 4.7 times and the loop voltage and current also reduces because of a claimed increase in radiation resistance!

Now much of this controversial EH stuff defies what I had once learned in EE graduate school and subsequent years of professional practice in electromagnetics and antennas. Nevertheless Mike Underhill has also done a lot of insightful investigative work in Poynting Vector Synthesis and the CFA and EH dipole field that throws valuable light on the often controversial subject and proffers a lot of plausible explanation for keenly interested folks to ponder upon, some of which is succinctly presented in his AHARS Feb 2008 lecture slides. Those voluminous slides posted on our AHARS website contain a rich wealth of empirical data. Real world data that I trust and quite a gold mine of information for keen antenna experimenters.

Getting back to the magnetic loops, I read the extract from your short paper with interest. Concerning the sentence "Depending on construction a small loop of nominal 1m diameter can exhibit an intrinsic radiation efficiency of 90% over the whole 1.8 to 30 MHz frequency range", the Depending on construction would seem to be the vital phrase. Clearly the loss resistance would have to no greater than 10% of the value of calculated radiation resistance at 1.8 MHz to get 90% efficiency.

Correct.

Lloyd, I understand your irrefutable argument here.

An appropriate construction technique and form factor to minimize loop conductor skin effect loss is only part of the story. Here's the rest of it:

The (sometimes huge) discrepancies come about when attempting to calculate the small loop's actual radiation resistance. There are additional dominant radiation modes not accounted for in the classical / traditional Kraus or text book formula that greatly increase the loop's effective radiation resistance, and also practical Qs and efficiencies are found that contradict those predicted by the classical Chu-Wheeler criteria. These text book formula and relationships (and corresponding NEC simulation results) do not hold for the case of small tuned loops of typical ?/160 dimensions. However they do predict Rr quite well in the loop's mid to upper HF frequency range where the loop circumference begins to approach self-resonant lengths and where an additional folded dipole mode also begins to kick-in. Moreover the dominant loop modes that come into play to augment Rr at the lower frequencies do not scale with frequency. Each discrete mode has its associated radiation resistance appearing at the antenna terminals.

The radiation efficiency based on the classical Kraus prediction of Rr is some 30 to 40 dB in error at 160m (compared with above mentioned Q method to implicitly deduce Rr) and the formula becomes quite irrelevant to the loop antenna's efficiency calculation. This incongruence between traditional loop antenna theory and measurement is where the controversy and debate arises.

The intrinsic efficiency that Mike speaks of is the proportion of radiated RF energy that is not dissipated as heat from the operative surfaces of the antenna conductor. It's defined as one minus the ratio of the antenna conductor loss resistance to the combined resistances of this and all the effective radiation modes. It does not include any losses in the near-field environment or any ground losses underneath the antenna, i.e. a free space situation. These environmental factors impact all antennas. However, the extrinsic factors must be considered separately and not wrongly attributed to losses of the antenna itself.

What diameter of copper tube would be needed to achieve this value of surface resistance around the circumference of the 1m diam loop? (Whatever the calculated copper size, I assume it would be considerably larger than that used in the Mike Underhill experiments). The loss resistance of the capacitor necessary to resonate the loop at 1.8 MHz would also have be included as part of the maximum loss resistance.- I wonder what practical value of capacitor loss resistance might be achievable.

Note that nobody, including Mike, would seriously propose a 1m diameter loop for optimal Tx antenna operation at 160m, but rather a larger 2m to 4m one that will compete very favourably with any large traditional antenna for that band. Nevertheless, such a small loop of 22 mm copper conductor diameter can be 90% efficient even at 160m, but might have the BW constraints that I mentioned in my e-mail below.

The loss resistance contribution of a good quality Jennings vacuum tuning capacitor is very small tending towards negligible. They have large surface area heavily silver plated mounting clamps that achieve exceptionally low contact / interface resistance to the loop conductor. The high KVAR rated vacuum caps on the aforementioned ARA Mini-Loop transmitting loops for US Army were massive several Kg devices that allowed the loop to handle 1 kW of Tx input power and 70 Amperes of RF circulating current in the loop structure! Some larger Tx loops spec'd down to 2 MHz were made from 140 mm diameter high-purity copper tube silver plated and painted. But such wonderful structures were/are used in military army and naval comms applications where cost is not a factor.

Thanks again for your email - I will give some more thought later to the above.

OK Lloyd, hope my further comments have provided additional food for more thought on this fascinating subject. Ubiquitous knowledge and understanding is not yet complete within the broader community.

9

Hi Leigh

I will put aside your latest comments for the moment and this will give me some time to properly digest it all first.

However in the interim I have again attached the short note "The Xfield Question" which I posted on the EH forum a couple of years ago and which I also sent on to John Elliott earlier in the year for possible discussion relevant to the Mike Underhill presentation. One would have thought that someone on the EH forum would have said "look you haven' t got it quite right here"- but no! - deadly silence!! To take a spell in the meantime, someone here might like to chew it over.

Best Regards

Lloyd

ATTACHMENT TO PREVIOUS EMAIL re:Validity of Crossed Field Theory

10

Some Thoughts on the validity of the Crossed Field Theory

(Lloyd Butler VK5BR)

Foreword

Controversy has reigned on the validity of the Crossed Field Antenna (CFA) theory for a number of years. Opinions, both supporting the theory or declaring it invalid, have been expressed by many eminent writers, better qualified to express an opinion on the basic physics than myself. In experimenting with derivatives of the CFA theory, I have accepted its validity. But as time has progressed and test results have unfolded, I find I have developed some doubts about this. The following summarises some of my present thoughts.

The Electromagnetic Wave

We know that if an alternating current is passed through a conductor at a given frequency, an electromagnetic wave at that frequency can be generated.
The accepted theory is that an electromagnetic (EM) wave can be resolved into two fields at right angles to each other, one Magnetic and the other Electric. Both fields are considered as being acting at right angles to the direction of transmission and both fields are in time phase with each other. The relationship between the strength of the E field in volts/metre and the strength of the H field in amp-turns/metre is equal to 377 ohms, the impedance of space.

The Induction Fields

If an alternating current is passed through a conductor two induction fields are generated around the conductor, one Magnetic and one Electric. Generally speaking the Magnetic field is 90 degrees time phase shifted to the Electric field. The magnetic field strength falls away relative to the distance from the conductor following an inverse square law. The electric field strength falls away relative to the distance from the conductor following an inverse cube law.
By comparison, the strength of an EM wave (and its field strength vectors) falls away with distance following a direct inverse law.

The Cross Field Theory

In the 1980's, Scottish Professor Maurice Hately (GM3HAT) concluded that by arranging the induction fields such that they were in the same format as that of an EM wave, EM radiation from the conductor could be enhanced to the degree that a small length conductor or antenna section (relative to a wavelength) could be made to radiate as well as a full size resonant antenna. To do this, the two induction fields would be in time phase, act at right angles to each other and hopefully have the field strength ratio between them close to that found in an EM wave (usually defined as 377 ohms).

As a result of this, Professor Hately, together with several associates, introduced (and in fact patented) various forms of the Crossed Field Antenna which were designed to generate the E and H fields in this format in a comparatively small space. Hence the name Crossed Field Antenna (CFA).

All this assumed that the EM wave is generated by the combining of the two induction fields. (It has been said that in a normal full size resonant antenna this combining takes place at some distance from the antenna where the induction fields find an in-phase state). There seems to be something wrong with this combining explanation when one considers that a carefully designed magnetic loop can be made to radiate efficiently with just a magnetic induction field and the electric induction field virtually non existent.

Further Down the Track

The single dipole EH antennas introduced (and patented) by Ted Hart have been based on the principles (as introduced by Prof. Hately) to align and phase the induction fields as defined for an EM wave. Further experiments with my own balanced X2/X3 antennas were aimed at more easily proving this theory valid by taking a slightly different tack using separate coils around the dipole to generate the H field. I initially thought I had this proof when I measured very high resistance in antenna samples and which I thought was radiation resistance resulting from the combining induction fields. However I eventually discovered other explanations for that high resistance as my later articles on these antennas have described. Furthermore, it became obvious that all these assumed crossed field mode antennas only performed really well when currents flowing in the feedline legs were unbalanced. At this point I started to have some doubts about the validity of the theory.

The fact is that having experimented with these antennas for a couple of years, I really have no results which I can say positively demonstrates or proves that the EM wave is generated from the induction fields by combining the two induction fields, or that the strength of the radiated wave is influenced by the relative orientation, phasing and strength of the two induction fields.

I now rather suspect that the Hately theory is wrong and instead that the EM wave is generated directly from current in the radiating conductor, being directly dependent on such factors as the strength of that current, the conductor length relative to a wavelength, how the current is distributed along that length and the electric potential difference developed over that length. I suspect that the orientation, phase and relative order of magnitude of the E and H induction fields, which are also developed, might have limited effect (or even no effect) on the strength of the radiated EM wave.

Unfortunately it is impossible to monitor what happens to the E and H fields of the radiated wave, in their own right, close to the antenna as they are swamped by the strong E and H induction fields. (As stated earlier, these follow an inverse cube law and inverse square law respectively, compared to the inverse direct law of the EM wave). If only one could separate measurement of the fields in the EM wave from those from direct induction as seen close to the radiator, we might be able to learn more. I am not aware of any form of detector or measuring instrument, which can separate the fields defined as induction fields from those which are formed by the EM wave.

As I stated earlier: It has been said that, in a normal full size resonant antenna, the combining of the induction fields, to form the EM wave, takes place at some distance from the antenna where the induction fields find an in-phase state. However if the fields of the EM wave could be separately measured in the presence of the strong induction fields, we might find that the EM wave follows the direct inverse law as a function of distance right back to the radiating antenna element.

Reciprocity

Generally speaking, we usually accept that if an antenna has certain characteristics in the way it transmits the EM radiation (such as directivity and polarisation), in reverse, it has the same characteristic form on how it receives EM signals and converts the energy back to an electrical conduction current in the antenna.

In sending a current through the antenna radiating element, we convert electrical energy into an outgoing EM wave, inherent with its electric field and its magnetic field. In reverse, the fields of an incoming EM wave, induce energy in the form of an electrical current back into the antenna element. So we can say that there is also reciprocity of operation in the antenna between the send condition and the receive condition.

But let’s assume that it is the induction fields which combine to generate the EM wave when we transmit (as per the Hately theory). Doesn’t this imply that here is a two step operation? - first the energy is transferred from the electrical conduction current of the induction fields and then from the induction fields to the EM wave. However, on receiving a signal, there does not appear to be a two step operation as the EM wave fields directly induce current into the antenna element. Induction fields do not appear to come into the equation for receiving the signal.

So if it is the induction fields which combine to form the EM wave, there is hardly a reciprocity of operation between receive and send. Just this fact adds a bit more suspicion to the theory that the EM wave is formed from the induction fields.

The Big Question

For various practical reasons, I ceased my experimentation some time ago. However I still receive the EH forum emails and still read a bit about what transpires. As things have evolved following more recent experiments on EH antennas with no feedlines, now seemed a good time to go back and ask a few basic questions on how electromagnetic radiation occurs and in particular with reference to the crossed field theory.

So here is the the big question: Is the EM wave really generated from the induction fields or it it generated directly from current flowing and voltage developed from that current in the conducting radiating element?

END of THE BIG QUESTION

END of ATTACHMENT - THE BIG QUESTION

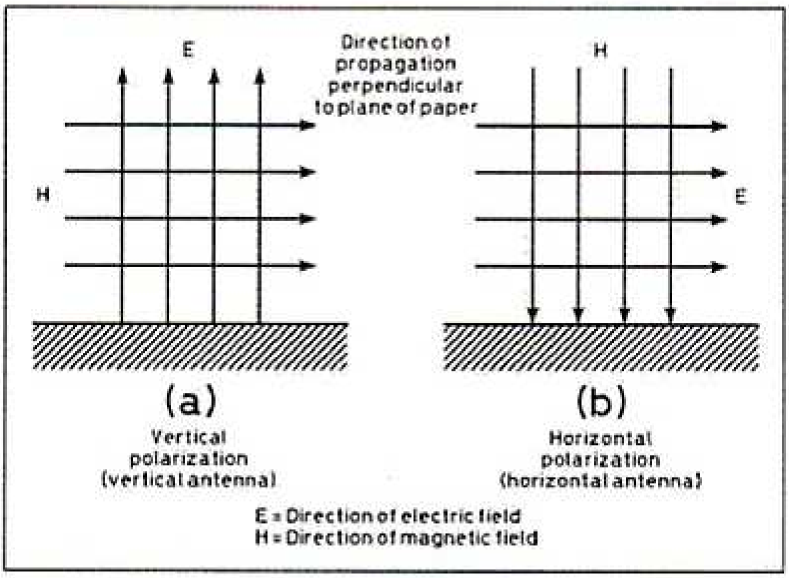
11

From: Leigh Turner
To: ' Lloyd Butler'
Cc: ' John Elliote' ; ' Rob & Carlein Gurr'
Sent: Thursday, June 12, 2008 9:42 PM
Subject: RE: CFA / EH / small loop antennas, radiation mechanisms, etc

OK Lloyd,

I’ve been far too busy these past years to follow any of the EH forums etc, but tonight here’s my quick and simple qualitative answer-in-a-nutshell to your “Big Question” as well as providing a succinct response covering some of the issues you raise in your short note titled “Some Thoughts on the validity of the Crossed Field Theory” / the Xfield Question:

A radiated electromagnetic (EM) wave energy field contains both electric and magnetic fields at right angles / mutually orthogonal to each other as shown below.



E and H Polarization

The radiation production means for a magnetic loop antenna occurs in a very similar way as an electric dipole antenna. The primary field is generated as a magnetic field as a result of RF current flow through the wire conductor (loop). The field which began as a magnetic field is then continuously transformed into an electromagnetic field by induction. Reactive energy is stored at an instant of time in the electric E field and then ½ an RF period later the oscillatory energy is stored in the magnetic H field so as to continuously sustain a lossless energy exchange mechanism. It should be noted at this point that a small loop antenna has an analogous radiation characteristic to that of a small dipole antenna. At a distance of about l/2p the electromagnetic field with its associated power transferring Poynting vector breaks free and separates from the antenna region and starts propagating into space in the form of an electromagnetic (EM) wave. The 3-dimensional volume of space from the antenna surface to the point where the complex EM field forms is called the antenna's near field. The magnetic field strength rapidly dissipates at a rate of about 1/r3 where r is the distance in metres. The area after the point at which the radiated EM wave has fully formed (ratio of E/H = 120p or 377 Ohms) and separated from the antenna is called the propagating far field.

Radiation stems from the localized energy storage in the reactive near-field contained in the 3 dimensional volume of space immediately surrounding the antenna structure. This is where the below aforementioned additional modes that are coupled to the antenna surfaces fit in and each such field type dependent mode has its associated radiation resistance and Q factor appearing at the antenna terminals. The transmitted or received power fills these modes with stored energy. These antenna impedance modes exist spatially distributed in the near-field space for the local ratio of displacement current and potential. These magnetic and electric displacement currents are responsible for radiating, receiving and storing the antenna energy. At any point in the near-field the real part of this complex impedance represents the power flow transfer impedance and the imaginary part represents the stored energy capacity. Energy is also stored in the conductor (inductor) and the tuning components (capacitor) and can raise the overall structural Q factor. Power flow attributed to radiation lowers the actual Q and is why practical magnetic loops do not behave as the classical Chu-Wheeler criteria for radiation Q would predict (see earlier comments below). The antenna Q is simply the ratio of total stored energy to the transmitted or received energy per RF cycle.

The small loop or CFA can be conceptually and conveniently viewed as an effective reciprocal electrical transducer between free space and the antenna terminals and vice versa. The local impedance distribution in the 3-D near-field analogously behaves as a spatially refractive index variable / wave velocity gradient lens to focus and couple incoming EM radiation and power flows onto the antenna surfaces, the "lens" comprising the local impedance distribution and stored energy in the near-field space surrounding the antenna creates the antenna's effective capture area. Conversely, for reciprocal transmission the "lens" creates an extended "image" of the antenna as seen at a distant point. The field/energy distribution surrounding the antenna redirects the transmitted power, by the generation of large displacement currents, to form the antenna pattern.

I think attempts by various folks to mess around with Mother Nature in respect of reconfiguring the antenna near-fields, boundary conditions, and spatial region where attempts at combining the induction fields takes place are probably futile; also reciprocity between Tx and Rx operation must always prevail and be satisfied in any alternative new theory to explain antennas that shouldn't work in accordance to existing antenna theory. J

It's arguable whether or not Hateley's crossed field loop works by PVS as he postulates in his patent. However, what I think is happening here is the local energy storage fields associated with high Q partially cancels to give a reduction in the antenna reactance relative to the radiation resistance and hence a significant reduction in Q and the increased bandwidth for which the CFL comprising its pair of tightly couple loops and quadrature phasing is noted for. This part of the CFL demonstrably works as GM3HAT claims, but perhaps for different reasons to what GM3HAT believes. Maybe that's what Ted was attempting to emulate with his external lumped element phase shift network on the feed of a single loop that I mentioned below. CFA and EH antennas are also often remarkably low Q structures. Since many EH constructions don't go up in smoke or get excessively hot when driven with high RF power, low efficiency and high intrinsic losses cannot always be characteristic traits. Power flow into radiation is of course the only explanation in such cases.

When all is said and done one can usually judge the worth of any alternative / avant-garde antenna design by whether it appears in a reputable / professional antenna manufacturer's commercial product Catalog. If it doesn't then there's a pretty good underlying reason for it being conspicuous by its absence. J

73

Leigh

VK5KLT

12

Hi Leigh

Thanks for answer relative to the "Big Question". You have said quite a bit in a relatively short bit of documentation. I am not sure that I am able to absorb all the progression of the explanation. In a previous email you ended it with: "Ubiquitous knowledge and understanding is not yet complete within the broader community." I think I have to include myself in that broader community. (Hi!!}

So I will have to ask a few questions.

Re: The field which began as a magnetic field is then continuously transformed into an electromagnetic field by induction.

I have previously assumed that the near field (or what I have generally referred to as the induction field) around a magnetic loop is essentially magnetic (or H field). What you are telling us is that by some process called induction, this is transformed into an E field component as well as the H field component. Being the inquisitive ignoramus that I am, I have to ask "induction into what?" - "Space"?- I guess. - This perhaps gets us into the mystical subject of a field developed from "displacement current" induced into space. [Of course the difficulty with accepting this concept is that space has no atomic particles (as we know it) to displace].

Re: It should be noted at this point that a small loop antenna has an analogous radiation characteristic to that of a small dipole antenna and: The magnetic field strength rapidly dissipates at a rate of about 1/r3 where r is the distance in metres.

I had always understood, for a dipole antenna in the near field, that whilst the electric field strength follows an inverse cube law with distance, the magnetic field follows an inverse square law.

Re: At a distance of about l/2p the electromagnetic field with its associated power transferring Poynting vector breaks free and separates from the antenna region and starts propagating into space in the form of an electromagnetic (EM) wave.

I am sure you are defining a well accepted theory. But how can we be certain that the EM wave isn' t being formed right close into the antenna? Because the EM wave follows a direct inverse law with distance and it were present, it would be a low signal level close to the antenna compared to the induction fields and be impossible to detect by measurement, its E and H components in separation from those of the induction fields.

I think that will do for the moment

regards

Lloyd

13

From: Lloyd Butler [mailto:ldbutler@tpg.com.au]
Sent: Friday, 13 June 2008 11:45 PM
To: Leigh Turner
Cc: John Elliote; Rob Gurr
Subject: Re: CFA / EH / small loop antennas, radiation mechanisms, etc

MORE QUESTIONS & ANSWERS

(Leigh' s following comments in blue)

Hi Leigh

Thanks for answer relative to the "Big Question". You have said quite a bit in a relatively short bit of documentation. I am not sure that I am able to absorb all the progression of the explanation. In a previous email you ended it with: "Ubiquitous knowledge and understanding is not yet complete within the broader community." I think I have to include myself in that broader community. (Hi!!}

(Leigh: The pursuit of enlightenment is a noble and intellectually rewarding one. Antennas are a fascinating subject and fertile ground for a lifetime's research and experimentation.)

So I will have to ask a few questions.

From previous Leigh message Re: The field which began as a magnetic field is then continuously transformed into an electromagnetic field by induction.

I have previously assumed that the near field (or what I have generally referred to as the induction field) around a magnetic loop is essentially magnetic (or H field). What you are telling us is that by some process called induction, this is transformed into an E field component as well as the H field component. Being the inquisitive ignoramus that I am, I have to ask "induction into what?" - "Space"?- I guess. -

Leigh:
Yes; correct. The near-field can also be thought of as the volumetric transitional region close to the antenna (the boundary extent of which is loosely defined by l/2p) where the ratio of E/H is not yet 120p or 377O and where the radiative far-field is still developing / evolving into a propagating plane wave front. The classic electromagnetics texts of Schelkenoff and Kraus had vivid illustrations and lucid descriptions of this.

This perhaps gets us into the mystical subject of a field developed from "displacement current" induced into space. [Of course the difficulty with accepting this concept is that space has no atomic particles (as we know it) to displace].

This gets very complex and difficult to describe qualitatively. The E and H field equations are not independent and cannot be decoupled and have a local value at each point in space surrounding the antenna. Maxwell's equations and the Lorenz condition don't hold up in the complex near-field as they conflict with the boundary conditions at the antenna surfaces and the B and H fields have differing spatial distributions.

Re: It should be noted at this point that a small loop antenna has an analogous radiation characteristic to that of a small dipole antenna

Now radiation is all about RF current flow in an elemental conductor wire and retarded potentials; it's inconsequential whether it's a traditional wire electric dipole or its electrical conjugate / analogue the "magnetic dipole" / small magnetic loop. Current flow in the conductor is inevitably boosted by either a natural systemic resonance in the case of a ?/2 dipole, or by an artificially created resonance in the case of a capacitively tuned small magnetic loop. As mentioned, the primary field is generated as a magnetic field as a result of RF current flow through the wire conductor (loop). The two fields are inextricably linked; generate one and you create the other, e.g. create some E-field and H is generated from the resultant displacement currents; the field which began as a magnetic field is then continuously transformed into an electromagnetic field by induction / Faraday's / Gauss / Biot-Savart laws. Electric dipoles receive signals by means of the E-field component of the incident EM wave inducing a current to flow and a resultant voltage to appear across the dipole terminals, i.e. an electric voltage source. The loop receives signals by means of the H-field component of the EM wave inducing a current flow through the loop conductor by means of induction, i.e. a magnetic current source where the loop can be thought of as a "space transformer"; as a "secondary winding" loosely coupled to the distant transmitting antenna. Although a Tx magnetic loop is small in terms of a wavelength, it radiates / receives very well due to the compensatory high Q times boost in the current and Mother Nature's conservation of energy in the form of EM radiation.

and
From previous Leigh message Re: : The magnetic field strength rapidly dissipates at a rate of about 1/r3 where r is the distance in metres.

and Lloyd previous reply:
I had always understood, for a dipole antenna in the near field, that whilst the electric field strength follows an inverse cube law with distance, the magnetic field follows an inverse square law.

No, the magnetic field of a small loop definitely follows in inverse cube law and this can be readily verified using a small magnetic field probe or "sniffer" to map out the spatial extent of the B and H fields. The magnetic flux B is sensed with a tiny sniffer balanced loop the magnitude of which is proportional to the sensor loop's open-circuit induced voltage as it couples to the localised flux lines. An LED with a high value series resistor connected across a small loop makes a convenient floating sensor to visually map the flux field. The magnetic field will be found to decay / asymptote to a very small value beyond one or two diameters distance away from the main Tx loop. Conversely, the open-circuit voltage developed at the terminals of a tiny field-sensor dipole or monopole is a measure of the electric E field. The inductively coupled HF and UHF energy exchange near-fields and far-fields are things that I routinely work with and exploit in my RFID technology development and commercialisation work of the past 20 years to power and communicate with passive transponder identification tags and labels; an area where I have about 16 or so global patents granted in this now rapidly evolving discipline.

Re: At a distance of about l/2p the electromagnetic field with its associated power transferring Poynting vector breaks free and separates from the antenna region and starts propagating into space in the form of an electromagnetic (EM) wave.

I am sure you are defining a well accepted theory. But how can we be certain that the EM wave isn' t being formed right close into the antenna? Because the EM wave follows a direct inverse law with distance and if it were present, it would be a low signal level close to the antenna compared to the induction fields and be impossible to detect by measurement, its E and H components in separation from those of the induction fields.

Leigh: Yes, this hypothesis poses a measurement dilemma. I don't see it making much practical difference in many applications whether or not the EM wave is formed at the antenna or l/2p away; surely it's a moot point?

I think that will do for the moment

regards

Lloyd

14

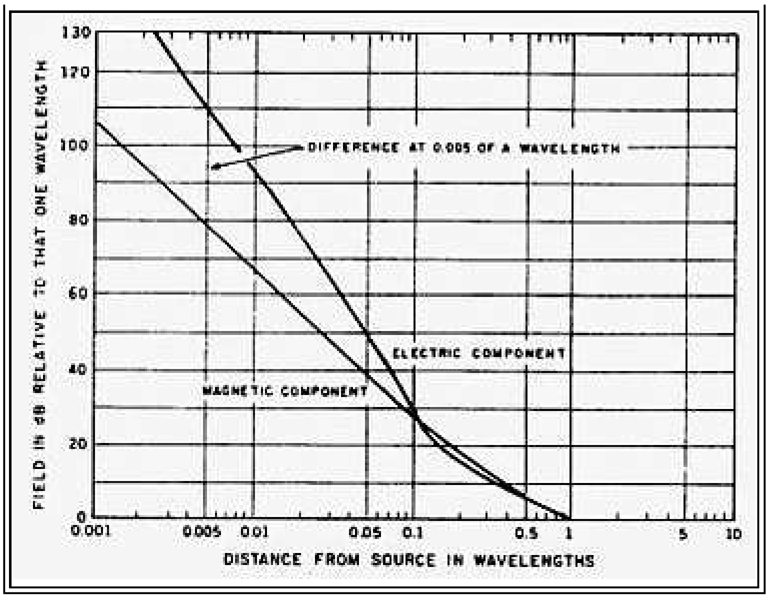
Leigh Hello again

Reference: QUOTE " The magnetic field strength rapidly dissipates at a rate of about 1/r3 where r is the distance in metres.

I had always understood, for a dipole antenna in the near field, that whilst the electric field strength follows an inverse cube law with distance, the magnetic field follows an inverse square law.

No, the magnetic field of a small loop definitely follows in inverse cube law " UNQUOTE

Well I am confused here - are you specifically referring to a small loop and not antennas in general?



I copied many years ago the attached curves from a book "VLF Radio Engineering" by A.D.Watt. These show for the near fields, the field strength of the electric field decreasing in a law 60dB (d2/d1) and for the magnetic field 40dB(d2/d1) where d2 and d1 are the relative distances from the antenna. Expressed in decibel form this is in line with what I said before "I had always understood, for a dipole antenna in the near field, that whilst the electric field strength follows an inverse cube law with distance, the magnetic field follows an inverse square law."

Of course the writer was specifically writing about low frequency antennas (normally inductance loaded radiators short compared to a wavelength) but I interpreted it as to apply to antennas in general.

Over to you

Lloyd

14A

From: Leigh Turner
To: ' Lloyd Butler'
Sent: Sunday, June 15, 2008 9:11 AM
Subject: RE: near field clarification Hello Lloyd,

Correct; I was referring to the case of small loop (magnetic dipole) antennas; not antennas in general.
Watt's curves are indeed correct and applicable for any electric dipole radiator in the near field.
Leigh

15

Hi Leigh

It was nice to meet up with you at the recent AHARS meeting. I seldom get to a meeting these days - I don' t drive the car very far now and not at night. However a friend gave me a lift and hence I was able to enjoy the excellent talk on how they are able to monitor the performance of the heart. Fortunately I am able to say that whilst at my age I have developed a few troubles, my heart still happens to be in excellent shape. Hi!

For Leigh' s article, referred following, on the AHARS web site:
http://www.qsl.net/vk5bar/AHARS-Resources/Small-Loop_Antennas/VK5KLT-papers/small__loop__antennas-VK5KLT.htm

I read over your article "SMALL LOOP ANTENNAS - An Overview of the Underestimated Magnetic Loop HF Antenna" and I think you were looking for some feedback.

An excellent review of the loop antenna. A good job Leigh.

Perhaps I can write a short summary:

The "Overview" has emphasised that the small loop antenna can be made to radiate efficiently over the span of HF amateur bands (and 1.8 MHz)giving comparable performance to well accepted typical large antennas and be fitted in locations which space would prohibit the erection of larger antennas. This is on provision that the loop (or loops) are designed and constructed within the guidelines given in the "Overview" concerning loop dimension, the diameter of copper tube used, low resistance joints and the use of a suitable low loss tuning capacitor. Also emphasised is the main limitation of restricted bandwidth due to the high values of Q created and hence the need for some means to track tuning over a range of frequencies and perhaps a restriction in accommodating wide band transmission modes at the lower frequencies for loops which are made too small in size.

Considering that our discussion interchange commenced because I questioned the Mike Underhill 70% efficiency at 1.8MHz using 10mm copper tube and a diameter of 1 metre, I note that your recommendation is for a 3.4 metre diameter loop at 1.8 MHz. However from our previous discussions, your reasons for the large loop diameter are more to do with Q and bandwidth wide enough for a SSB signal rather than the problem of efficiency in the 1 metre loop. However from a purely efficiency criteria, I think you have implied that 70% efficiency at 1.8 MHz is quite attainable assuming an adequate diameter of copper tube is used. But I think the adequate tube diameter is much more than the 10mm tube used by Mike.

Of course (as described in my initial report) I still think that much of the 70% power leaving Mike' s loop (and apparent rise in Rr) could be induced power into ground or surrounding objects. (Much as I experienced in my experiments with 2% wavelength short dipoles).

Also as discussed later (but not in the report), I wondered how well the gamma match worked as a balun and whether there was any unbalance of current in the legs of the transmission line to cause radiation from the line. My experience with the EH antennas showed that you could adjust the antenna with an SWR metre right at the antenna for 1:1 SWR ratio indicated (a perfect match) and still measure a 2:1 ratio of current between the inner coax conductor and its outer conductor.

Just to expand a little on that discussion, the 2:1 ratio between the inner and outer legs of the coax also existed right at the transmitter end. By isolating the transmitter mains connection with a LP filter, I was able to measure RF current returning to the transmitter via its connection direct to earth and establish that the earth current measured was equal to the difference in current flowing in the two legs of the coax. So Kirchoff' s Law was established. (Precisely the same thing happened when I connected up my X3/X2 antennas using open wire lines connected to the antenna in an unbalanced form). Based on much of these tests, I was able to come up with the theory of why the degree of current unbalance was so large.(see attachment) .

Of course all of Ted Hart' s EH amateur band antennas are connected unbalanced and exhibit this feedline unbalance of current. . He did come up with a balanced version of his Star antenna but it was disbanded because it didn' t radiate very well. Ted' s explanation - the E and H fields mysteriously didn' t line up in phase when the antenna was driven in the balanced form. The obvious explanation - in the unbalanced case, most of the radiation could be attributed to the longitudinal current component in the feedline.

Back to loop antennas - I really made use of the loops when I became a bit interested for a while in listening on the VLF and LF bands. - Of course the particular aim in design of the receive loop is to maximise signal level relative to noise level referred to the receiver input.

I have to say that particularly at VLF, I found it impossible to resolve signals in the presence of the horrendous noise down there without the loop. (An open wire antenna just delivered too much noise). In fact I normally just hung up the loop inside my garage. The fact that the garage walls and roof were made of steel didn' t seem to deter the reception of signals, many of which originated from outside of Australia. I could always hear the Omega tones within the 10 to 20 kHz region and which were still operating at that time from Victoria. The North West Cape station always came in at a very strong level.

Apart from the loops characteristics in being insensitive to electric field noise and its directional properties, the narrow bandwidth created by its Q was invaluable in restricting the noiseband. If the Q on VLF was a bit too high, I switched in resistance to control the bandwidth to suit the type of signal. At LF frequencies, there was an advantage sometimes in being able to raise the Q higher than the natural Q of the loop and further down the track, I made up a loop interface with regeneration (or positive feedback) to raise the effective Q of the loop. The loop I mainly used is shown in the second attachment. Its natural resonance was a bit below 500 kHz which of course set its lowest tunable frequency. I no longer have the loop - Due to lack of available space, I gave it away with a lot of other things when I moved into the village here.

I also used a small receive loop on 1.8 MHz - I used to talk to a group on Sunday mornings including VK5MF at Victor Harbor. I often had trouble with receiving his signal on the transmitting antenna. So I used to just hang the loop under my carport and this normally raised his signal well above the noise level. The loop was about 0.8 metre square with 6.5 turns. (7 turns put self resonance just higher in frequency than 1.8 MHz). It was interfaced right on the loop with a battery operated balanced FET input stage with low impedance output to drive a 50 ohm coax line.
I assume that the signal in the morning from VK5MF was essentially ground wave - it certainly improved the s/n ratio. I didn' t think it gave any advantage on night signals which clearly arrived via the sky path.

But I am sold on the fact that for receiving signals at lower frequencies, the loop aerial, properly designed, reigns supreme.

Anyway that' s enough for this session.

regards
Lloyd VK5BR

16

Hello Leigh

Reference the paragraph in my previous email:

"Considering that our discussion interchange commenced because I questioned the Mike Underhill 70% efficiency at 1.8MHz using 10mm copper tube and a diameter of 1 metre, I note that your recommendation is for a 3.4 metre diameter loop at 1.8 MHz. However from our previous discussions, your reasons for the large loop diameter are more to do with Q and bandwidth wide enough for a SSB signal rather than the problem of efficiency in the 1 metre loop. However from a purely efficiency criteria, I think you have implied that 70% efficiency at 1.8 MHz is quite attainable assuming an adequate diameter of copper tube is used. But I think the adequate tube diameter is much more than the 10mm tube used by Mike."

I thought I would insert the dimensions of Mike' s 1 metre square, 10mm copper tube loop into the equations (first attachment) from the ARRL Antenna handbook and calculate efficiency and Q for 1.8 MHz. I think we can assume that they are supposed to be correct at least for the antenna mounted in space and outside of the near field (away from any the influence of ground or nearby object). The equations are given in imperial form so I had to convert dimensions to that form.

Assuming I haven' t made any arithmetic error (a likely possibility), I get a radiation efficiency of 0.07% using 10mm (0.39 inch) tube. Considering the implication that high efficiency is attainable using a larger size tube, I re-calculated for a massive increase to 10 inch diameter tube. The surface resistance of the tube is still much higher than the calculated radiation resistance so that radiation efficiency appears around 1.8%. (See second attachment).

I went on to look at the calculated value of Q and bandwidth (see third attachment). The value of Q came out to 464 giving a bandwidth of 3879 Hz - OK for SSB. Note that in the formula, XL/R is divided by 2 - no doubt assuming that the source resistance is equal to the antenna load resistance. (I added a little note in my bit of paper. If the transmission line is short and the output amplifier is a transistor or tetrode/pentode valve stage with no feedback, the source resistance could be much higher than the load resistance and the resultant Q might be near double and in this case too high for SSB. I wrote a whole article about this source resistance once:).

Of course increasing the tube diameter to 10 inches, came up with a Q of 11884 and bandwidth of 151 Hz.

I think that in Mikes' s article, he implied that his tests showed that the formulae were wrong. I rather think that they are incomplete in that they do not include an additional resistance component in series with Rr and RL which represents the induced energy into objects within the near field (or induction field) space where that applies. Whilst the resistance component resulting from energy leaving the loop might be higher than calculated from the formulae, Rr as calculated might still represent the energy component of direct EM radiation from the loop.

Best Regards

Lloyd

Table 4

Basic Equations for a Small Loop

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

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

Basic Loop Equations from ARRL Antenna Handbook

$$R_R = 3.38 \times 10^{-8} (f^2 A)^2$$

$$R_L = 9.96 \times 10^{-4} (\sqrt{f}) \frac{S}{d}$$

S = conductor length in ft

A = loop area in square ft

d = conductor diam in inches

Given 1 metre diam loop, - conductor diam 10 mm

$$S = \pi D = \frac{39.37}{12} \times \pi = 10.3 \text{ ft}$$

$$A = \pi R^2 = \pi \left(\frac{39.37}{12 \times 2}\right)^2 = 8.45 \text{ sq ft}$$

$$d = \frac{10}{25.4} = 0.39 \text{ inch.}$$

$$R_R = 3.38 \times 10^{-8} (1.8^2 \times 8.45)^2$$

$$= 2.53 \times 10^{-5} \ \Omega$$

$$R_L = 9.96 \times 10^{-4} \sqrt{1.8} \cdot \frac{10.3}{0.39}$$

$$= 3.53 \times 10^{-2} \ \Omega$$

$$\text{Efficiency} = \frac{R_R}{R_R + R_L} \simeq \frac{R_R}{R_L} \quad (\text{as } R_L >> R_R)$$

$$= \frac{2.53 \times 10^{-5}}{3.53 \times 10^{-2}} \times 100 \ \%$$

$$= 0.07 \ \% \qquad (1)$$

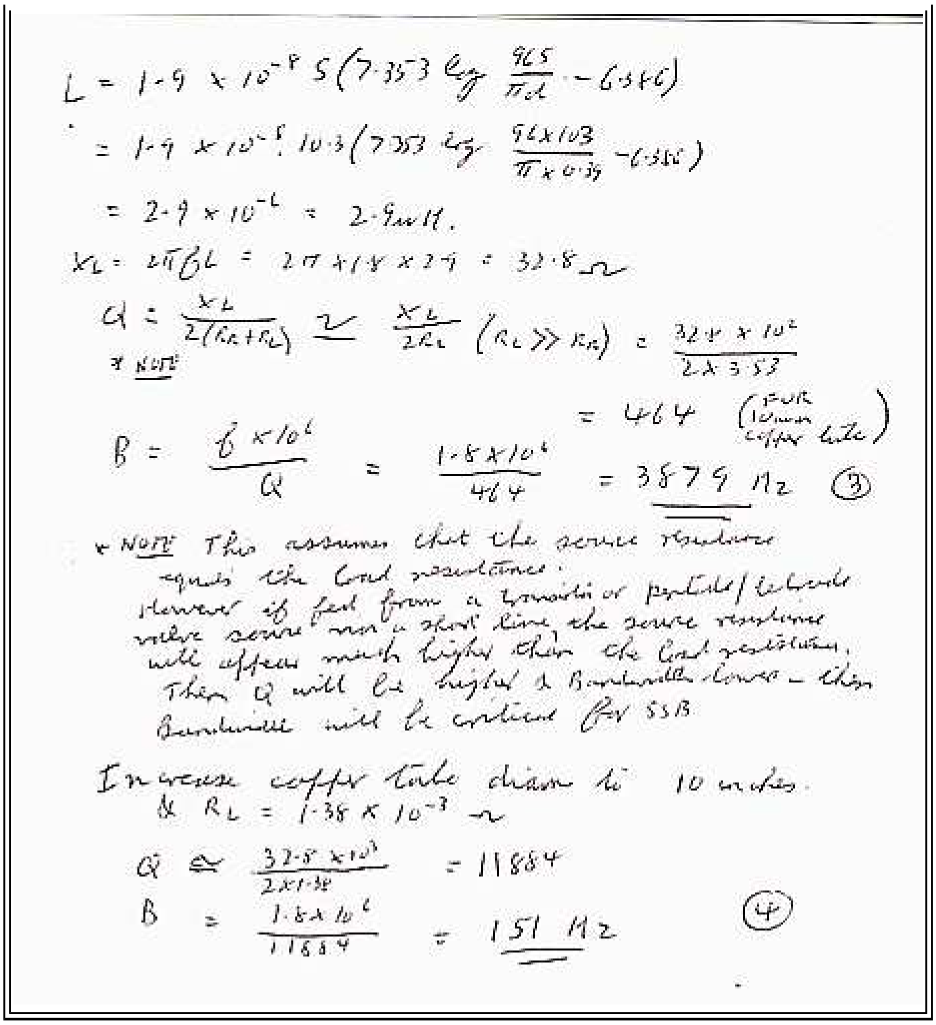
Increase copper diameter to 10 inches

$$R_L = 9.96 \times 10^{-4} \sqrt{1.8} \times \frac{10.3}{10}$$

$$= 1.38 \times 10^{-3} \ \Omega$$

$$\text{Efficiency} \simeq \frac{2.53 \times 10^{-5}}{1.38 \times 10^{-3}} \times 100$$

$$= 1.8 \ \% \qquad (2)$$



$$L = 1{\cdot}9 \times 10^{-8}\, S\left(7{\cdot}353 \log \frac{965}{\pi d} - 6{\cdot}386\right)$$

$$= 1{\cdot}9 \times 10^{-8} \cdot 10{\cdot}3\left(7{\cdot}353 \log \frac{96 \times 103}{\pi \times 0{\cdot}39} - 6{\cdot}386\right)$$

$$= 2{\cdot}9 \times 10^{-6} = 2{\cdot}9\,\mu H.$$

$$X_L = 2\pi f L = 2\pi \times 1{\cdot}8 \times 2{\cdot}9 = 32{\cdot}8\,\Omega$$

$$Q = \frac{X_L}{2(R_R + R_L)} \simeq \frac{X_L}{2R_L} \; (R_L \gg R_R) = \frac{32{\cdot}8 \times 10^2}{2 \times 3{\cdot}53}$$

* NOTE

$= 464$ (FOR 10mm copper tube)

$$B = \frac{f \times 10^6}{Q} = \frac{1{\cdot}8 \times 10^6}{464} = 3879\ Hz \quad (3)$$

* NOTE This assumes that the source resistance equals the load resistance. However if fed from a transistor or pentode/tetrode valve source on a short line the source resistance will appear much higher than the load resistance. Then Q will be higher & Bandwidth lower – then Bandwidth will be critical for SSB.

Increase copper tube diam to 10 inches.
& $R_L = 1{\cdot}38 \times 10^{-3}\,\Omega$

$$Q \simeq \frac{32{\cdot}8 \times 10^3}{2 \times 1{\cdot}38} = 11884$$

$$B = \frac{1{\cdot}8 \times 10^6}{11884} = 151\ Hz \quad (4)$$

17

Hello Lloyd,

The problem with those old ARRL published formulae sourced from Ted is they're incomplete and do not take into account all the factors attributing to the small loop's actual radiation resistance (as we've discussed in our correspondence previously, notably the 10th and 12th June). If you use the formulae, then you'll remain puzzled and unable to reconcile theory with practice and have sleepless nights

Likewise the Q values from such formula and popular loop calculator programs so derived from them give an overestimate of the practical working Q; mainly because more radiation is occurring than is predicted.

I agree with your belief / assertion the old formulas are incomplete descriptors of what's really happening. They certainly need additional terms factored-in in order to be more correct indicators; however these terms are not necessarily those associated with or ascribed to energy dissipating near-field ground loss (this can be minimized by proper antenna deployment in terms of mast / pole height in loop diameters above the ground or lossy surface or eddy current inducing ferromagnetic objects). See attached photos jpg 2 and jpg 35 of loop installation of both fixed and mobile sites.

For some insight into what's routinely achieved in practice, I've attached the rather impressive Specifications for Ciro Mazzoni's professional magnetic loop antennas from Verona Italy (see jpg 16, jpg 15, and jpg 38). These are not unlike those products of older US company Antenna Research Associates who have even higher power rated HF field deployable transmitting loops specifically tailored for the military, and the highly commendable performance of these structures is consistent with my own experiences of 20 years ago when working with magnetic Tx loops with the late John H. Dunlavy Jnr. (founder of ARA).

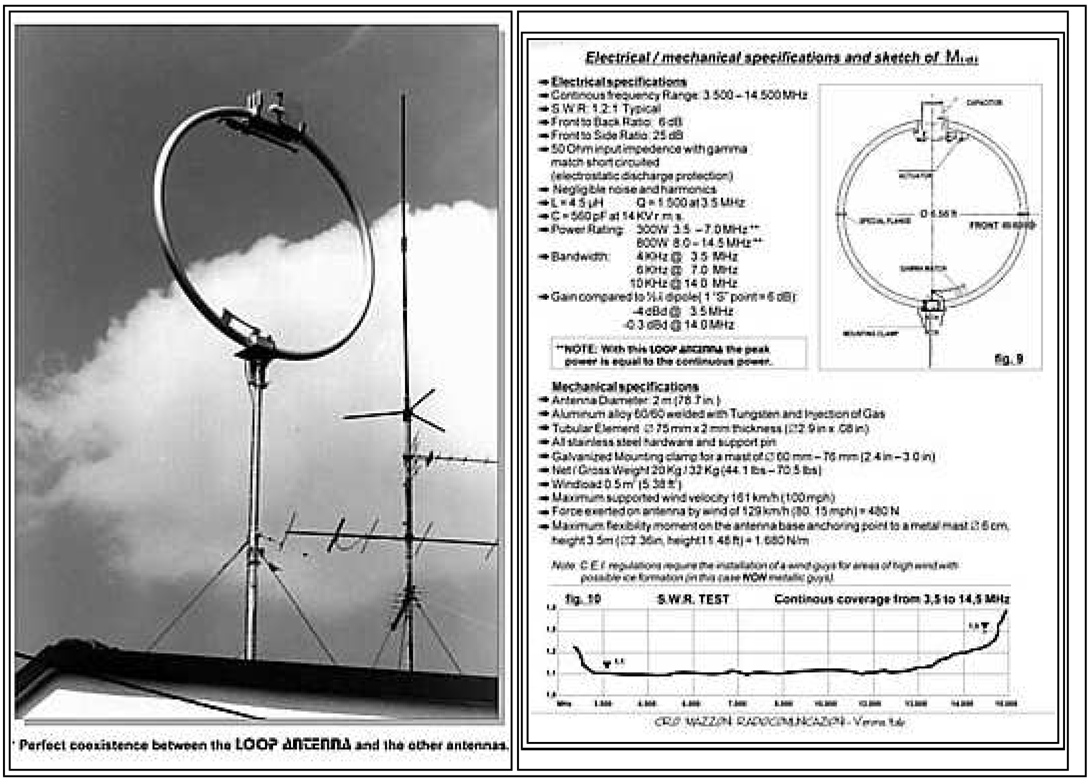
If you plug Mazzoni's loop parameters into the traditional formula you'll get nothing like what's predicted for the efficiency, bandwidth, and dBd gain that's achievable down @ 1.8 MHz. The formulae also do not predict the achievable received field strength in the distant far-field from the transmitter. If you were to believe the formula then you'd expect the small loop antenna would behave like a piece of wet string; i.e. absolutely useless and operation at such long wavelengths would be quickly dismissed. To the contrary, even a small 1m loop operated down at 1.8 MHz will produce a prodigious Rx field strength at a distant receiving site with a Tx and field creation performance that belies its diminutive stature compared to a huge full-sized ?/2 dipole antenna for 1.8 MHz. Nevertheless, bigger is better; and a 3 to 4 m diameter loop will not disappoint those folks who like to communicate in the 1.8 MHz band. This larger size is because of the relative dominance of the 4th power dependency term of Rr with frequency; quite inescapable and humbling!

Lloyd, the fundamental question here in this dichotomy really is: where is the lost RF power going?

If you hang Mike's dinky 1m loop tuned to 1.8 MHz on a sky hook or elevate it in quasi free space on top a tall crane or mast, then the deleterious extrinsic / power absorbing ground influences vanish. Since the loop still doesn't get hot and self destruct, then the only logical conclusion is the RF energy MUST be going into the radiation field, i.e. the Chu-Wheeler theory / criterion and the NEC simulator in the case of small loop antennas are not compatible with the First Law of thermodynamics and the energy conservation law. This is the underlying essence of all of Mike's carefully conducted measurements and teachings.

73

Leigh



* Perfect coexistence between the LOOP ANTENNA and the other antennas.

Electrical / mechanical specifications and sketch of M[illegible]

- Electrical specifications
- Continous frequency Range: 3.500 – 14.500 MHz
- S.W.R. 1.2:1 Typical
- Front to Back Ratio: 6 dB
- Front to Side Ratio: 25 dB
- 50 Ohm input impedence with gamma match short circuited (electrostatic discharge protection)
- Negligible noise and harmonics
- L = 4.5 μH Q = 1.500 at 3.5 MHz
- C = 560 pF at 14 KV r.m.s.
- Power Rating: 300W 3.5 – 7.0 MHz ** / 800W 8.0 – 14.5 MHz **
- Bandwidth: 4 KHz @ 3.5 MHz / 6 KHz @ 7.0 MHz / 10 KHz @ 14.0 MHz
- Gain compared to ½ λ dipole(1 "S" point = 6 dB): -4 dBd @ 3.5 MHz / -0.3 dBd @ 14.0 MHz

**NOTE: With this LOOP ANTENNA the peak power is equal to the continuous power.

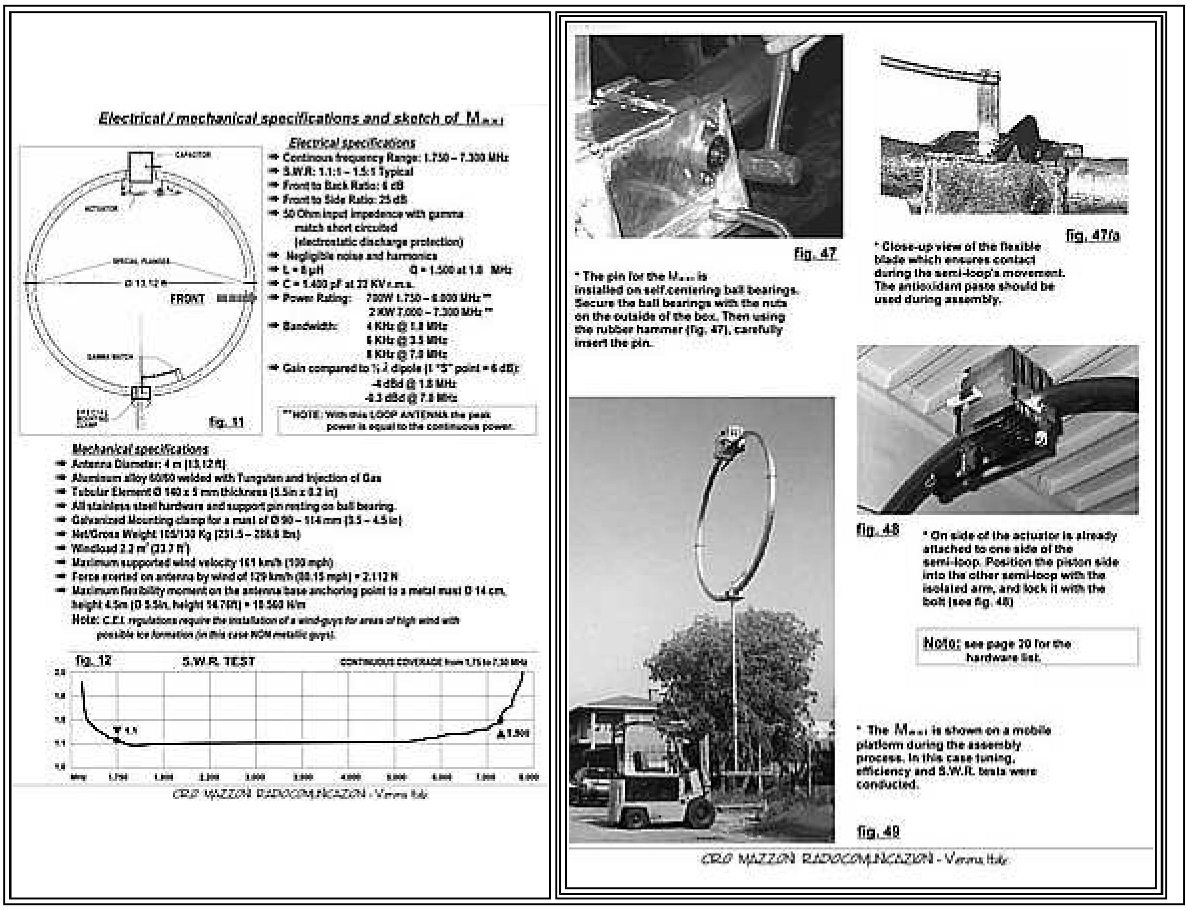
fig. 9

Mechanical specifications
- Antenna Diameter: 2 m (78.7 in.)
- Aluminum alloy 60/60 welded with Tungsten and Injection of Gas
- Tubular Element: Ø 75 mm x 2 mm thickness (Ø 2.9 in x .08 in)
- All stainless steel hardware and support pin
- Galvanized Mounting clamp for a mast of Ø 60 mm – 76 mm (2.4 in – 3.0 in)
- Net / Gross Weight 20 Kg / 32 Kg (44.1 lbs – 70.5 lbs)
- Windload 0.5 m² (5.38 ft²)
- Maximum supported wind velocity 161 km/h (100 mph)
- Force exerted on antenna by wind of 129 km/h (80. 15 mph) = 480 N
- Maximum flexibility moment on the antenna base anchoring point to a metal mast Ø 6 cm, height 3.5 m (Ø 2.36 in, height 11.48 ft) = 1.680 N/m

Note: C.E.I. regulations require the installation of a wind-guys for areas of high wind with possible ice formation (in this case NON metallic guys).

fig. 10 S.W.R. TEST Continous coverage from 3,5 to 14,5 MHz

CIRO MAZZONI RADIOCOMUNICAZIONI - Verona Italy



Electrical / mechanical specifications and sketch of M[illegible]

fig. 11

Electrical specifications
- Continous frequency Range: 1.750 – 7.300 MHz
- S.W.R: 1.1:1 – 1.5:1 Typical
- Front to Back Ratio: 6 dB
- Front to Side Ratio: 25 dB
- 50 Ohm input impedence with gamma match short circuited (electrostatic discharge protection)
- Negligible noise and harmonics
- L = 8 μH Q = 1.500 at 1.8 MHz
- C = 1.400 pF at 22 KV r.m.s.
- Power Rating: 700W 1.750 – 6.000 MHz ** / 2 KW 7.000 – 7.300 MHz **
- Bandwidth: 4 KHz @ 1.8 MHz / 6 KHz @ 3.5 MHz / 8 KHz @ 7.0 MHz
- Gain compared to ½ λ dipole (1 "S" point = 6 dB): -4 dBd @ 1.8 MHz / -0.3 dBd @ 7.0 MHz

**NOTE: With this LOOP ANTENNA the peak power is equal to the continuous power.

Mechanical specifications
- Antenna Diameter: 4 m (13,12 ft)
- Aluminum alloy 60/60 welded with Tungsten and Injection of Gas
- Tubular Element Ø 140 x 5 mm thickness (5.5 in x 0.2 in)
- All stainless steel hardware and support pin resting on ball bearing.
- Galvanized Mounting clamp for a mast of Ø 90 – 114 mm (3.5 – 4.5 in)
- Net/Gross Weight 105/130 Kg (231.5 – 286.6 lbs)
- Windload 2.2 m² (23.7 ft²)
- Maximum supported wind velocity 161 km/h (100 mph)
- Force exerted on antenna by wind of 129 km/h (80.15 mph) = 2.112 N
- Maximum flexibility moment on the antenna base anchoring point to a metal mast Ø 14 cm, height 4.5m (Ø 5.5in, height 14.76ft) = 10.560 N/m

Note: *C.E.I. regulations require the installation of a wind-guys for areas of high wind with possible ice formation (in this case NON metallic guys).*

fig. 12 S.W.R. TEST CONTINUOUS COVERAGE from 1,75 to 7,30 MHz

CIRO MAZZONI RADIOCOMUNICAZIONI - Verona Italy

fig. 47

* The pin for the M[illegible] is installed on self.centering ball bearings. Secure the ball bearings with the nuts on the outside of the box. Then using the rubber hammer (fig. 47), carefully insert the pin.

fig. 47/a

* Close-up view of the flexible blade which ensures contact during the semi-loop's movement. The antioxidant paste should be used during assembly.

fig. 48

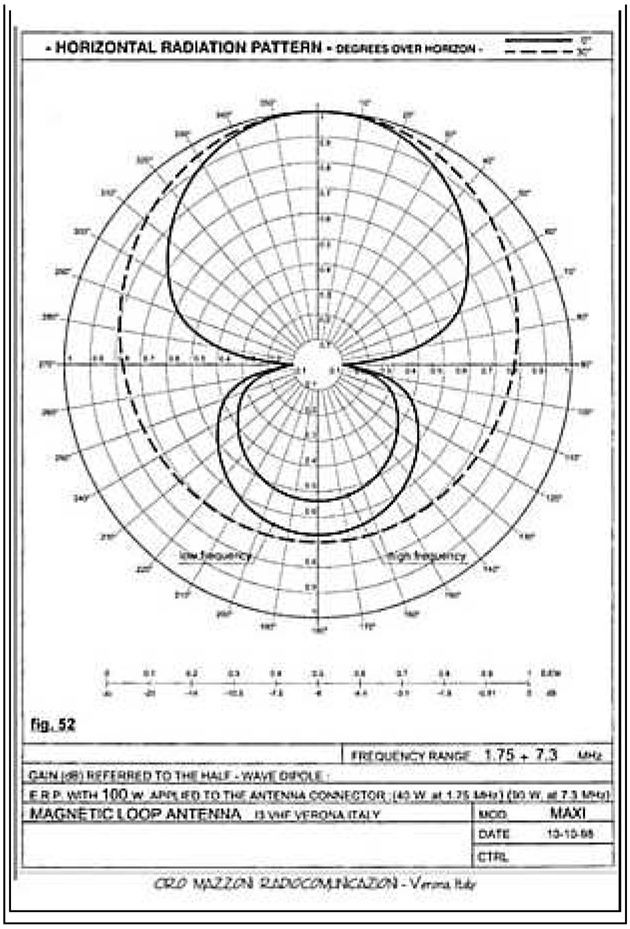
* On side of the actuator is already attached to one side of the semi-loop. Position the piston side into the other semi-loop with the isolated arm, and lock it with the bolt (see fig. 48)

Note: see page 20 for the hardware list.

* The M[illegible] is shown on a mobile platform during the assembly process. In this case tuning, efficiency and S.W.R. tests were conducted.

fig. 49

CIRO MAZZONI RADIOCOMUNICAZIONI - Verona Italy



18

Thanks for the reply and the info on the professional loops from Italy. From the specifications, they look pretty impressive. Since I am now in a Retirement Village with limited back yard space, I probably need one - assuming I could persuade the Village authorities (and my wife) that a 4 metre heavy tube was a thing of beauty in the back yard. (Hi).

Of course the MAXi with a loop diameter of 4 metres and tube diameter of 140mm to get down to 1.8 MHz is quite a far cry than trying to do the same with Mike' s 1 metre loop diameter and tube thickness of 10mm which was what I questioned in the first place.

But back to the MAXi and MIDi antennas. - I assume they have a large enough tuning capacitor to tune to resonance over the specified frequency range and this must be driven by a remote controlled motor. - I couldn' t quite pick this up from the attached info. I wondered how the SWR of 1:1 (as recorded) could be maintained over the whole range of 1.75 to 6 MHz with precisely the same setting of the Gamma Match tap. I am inclined to feel that it might be difficult to achieve without some adjustment over the wide tuning range..

One other thing puzzled me: In the horizontal bi-directional radiation pattern, why are the two lobes unequal?

Reference your sentences:

"If you hang Mike's dinky 1m loop tuned to 1.8 MHz on a sky hook or elevate it in quasi free space on top a tall crane or mast, then the deleterious extrinsic / power absorbing ground influences vanish. Since the loop still doesn't get hot and self destruct, then the only logical conclusion is the RF energy MUST be going into the radiation field, etc"

Yes I agree. But since we are talking about a wavelength of 160 metres, was he really physically able to do his temperature rise measurement with accuracy outside of the influence of the surrounding objects within the near field region for this wavelength?

Also on a point I raised before - when he did the tests, did he measure what longitudinal current component was running in the feedline and whether radiation from this might have accounted for some of the energy not dissipated in heating the loop? Of course if this were happening it would also show up in the radiation pattern as less pronounced nulls at right angles to the plane of the loop.

Anyway all this is partly academic as I think we are satisfied that if we want to operate a loop on 1.8 MHz, then a loop diameter of 3 or 4 metres is recommended to be certain that good results can be achieved.

73

Lloyd

19

From: Leigh Turner
To: ' Lloyd Butler'
Cc: ' John Elliote' ; Rob Gurr
Sent: Monday, July 14, 2008 9:49 PM

Subject: Unidirectional loop patterns

One other thing puzzled me: In the horizontal bi-directional radiation pattern, why are the two lobes unequal?

Lloyd, you may recall that I had fleetingly touched on the reason for this beneficial pattern directionality in a short paragraph contained in my AHARS paper;

I quote: "Small loop antennas have at least two simultaneously excited radiation modes; magnetic and electric folded dipole modes. 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."

In addition to the classical loop mode as defined by the traditional formulae, there are other antenna radiation modes in existence each with their own radiation resistances that varies as different powers of frequency, that contribute to a sometimes substantial boost to Rr. One of these additional modes is the "folded dipole mode". At certain frequencies and conditions, the tuned loop has been found to be unidirectional and capable of giving a desirably useful amount of directionality. This can only happen when the loop and dipole modes, or other contributing modes, are approximately the same strength. This practical behavior of course supports the hypothesis that the traditional loop formulae are indeed incomplete descriptors of what' s happening.

73

Leigh

20

Hi Leigh

Well that' s pretty technical stuff Leigh which I am sure you would have well researched**But I did think of a simpler explanation which could cause the effect.**

Lets go back to the simple Direction Finding loop which provides the two nulls to find direction. Since there are two of them 180 degrees apart, the wanted one must be identified. This is done by coupling in a bit of signal from a vertical antenna or from the loop and its feed system operating like one. The combination of the two pick up fields is to produce a uni-directional effect which allows the operator to identify or "Sense" which is the right null.

All I am saying is that a little bit of unbalance in that gamma match could allow some pick-up (or radiation for transmit) in the vertical antenna mode and produce the precise effect of the "sense" antenna and unbalanced lobes.

As I have indicated before, I am suspicious that the gamma match might be somewhat less than perfect in eliminating a longitudinal current component. This suspicion has been increased by my discovery that a high Q radiating tuned radiating element at the end of the transmission line multiplies the effect of any unbalance.

But to change the subject - I have been playing around with formula substitution in the Maxi 4 metre antenna to see what answers (right or wrong) this might produce - but this something for another day.

73

Lloyd VK5BR

21

From Leigh:

Lloyd, you're absolutely correct with that simpler explanation in respect of the unidirectional pattern of the large Mazzoni loop design. In his lower frequency range Maxi loop the inherent imbalance that a gamma match feed gives is indeed the mechanism that provides the vertical monopole mode component producing the asymmetric unidirectional pattern.

The folded dipole mode I mention below doesn't kick-in and become predominant in a balanced loop until around 8 MHz or so, and somewhat lower for an unbalanced loop feed. In frequency ranges where that mode is strong one can have the unidirectional pattern asymmetry without resorting to inducing unbalanced feeds with monopole radiation.

You may recall my brief AHARS paper also made fleeting mention of feed complexities and subtleties; "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." If one seeks mode purity and pattern symmetry, 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. Whether one wants to deliberately induce feeder imbalance currents and judicious feeder radiation is a "horse for courses" design decision. There's an interesting variety and rich diversity of design options with magnetic loop antennas and their feed methods.

73

Leigh

22

From: Lloyd Butler
Sent: Thursday, 10 July 2008 11:43 PM
To: Leigh Turner
Cc: John Elliote; Rob Gurr
Subject: Calculations on 1 Sq Metre loop at 18MHz

Hello Leigh

Reference the paragraph in my previous email:

"Considering that our discussion interchange commenced because I questioned the Mike Underhill 70% efficiency at 1.8MHz using 10mm copper tube and a diameter of 1 metre, I note that your recommendation is for a 3.4 metre diameter loop at 1.8 MHz. However from our previous discussions, your reasons for the large loop diameter are more to do with Q and bandwidth wide enough for a SSB signal rather than the problem of efficiency in the 1 metre loop. **However from a purely efficiency criteria, I think you have implied that 70% efficiency at 1.8 MHz is quite attainable assuming an adequate diameter of copper tube is used. But I think the adequate tube diameter is much more than the 10mm tube used by Mike.**"

I thought I would insert the dimensions of Mike' s 1 metre square, 10mm copper tube loop into the equations (first attachment) from the ARRL Antenna handbook and calculate efficiency and Q for 1.8 MHz. I think we can assume that they are supposed to be correct at least for the antenna mounted in space and outside of the near field (away from any the influence of ground or nearby object). The equations are given in imperial form so I had to convert dimensions to that form.

Assuming I haven' t made any arithmetic error (a likely possibility), I get a radiation efficiency of 0.07% using 10mm (0.39 inch) tube. Considering the implication that high efficiency is attainable using a larger size tube, I re-calculated for a massive increase to 10 inch diameter tube. The surface resistance of the tube is still much higher than the calculated radiation resistance so that radiation efficiency appears around 1.8%. (See second attachment). I went on to look at the calculated value of Q and bandwidth (see third attachment). The value of Q came out to 464 giving a bandwidth of 3879 Hz - OK for SSB. Note that in the formula, XL/R is divided by 2 - no doubt assuming that the source resistance is equal to the antenna load resistance. (I added a little note in my bit of paper. If the transmission line is short and the output amplifier is a transistor or tetrode/pentode valve stage with no feedback, the source resistance could be much higher than the load resistance and the resultant Q might be near double and in this case too high for SSB. I wrote a whole article about this source resistance once: http://users.tpg.com.au/ldbutler/OutputLoadZ.htm).

Of course increasing the tube diameter to 10 inches, came up with a Q of 11884 and bandwidth of 151 Hz.

I think that in Mikes' s article, he implied that his tests showed that the formulae were wrong. I rather think that they are incomplete in that they do not include an additional resistance component in series with Rr and RL which represents the induced energy into objects within the near field (or induction field) space where that applies. Whilst the resistance component resulting from energy leaving the loop might be higher than calculated from the formulae, Rr as calculated might still represent the energy component of direct EM radiation from the loop.

Best Regards
Lloyd

23

From: Lloyd Butler
Sent: Tuesday, 15 July 2008 11:30 PM
To: Leigh Turner
Cc: ' John Elliote' ; ' Rob & Carlein Gurr'
Subject: Re: Calculations on 4 Metre diam loop at 1.8MHz

Hi Leigh

In my previous email I said I was fiddling around a bit with substituting dimensions of the Maxi loop into the loop formulae (as I used before in the 1 metre loop) to see what answers that gave.
You might like to have a look at the results.

Calculations of 4 metre (3.12 ft) diam loop of 140mm (5.5 inch) copper tube at 1.8 MHz using ARRL equations.

Radiation Resistance Rr = 6.5/1000 ohms

Loss Resistance RL = 0.01 ohm

Efficiency = 39% (Comment: I would be pretty happy with this as a wire strung up in the typical back yard might not fare any better considering that it might be less than a 1/4 wave long & hence low Rr, added loss resistance in the loading inductor and probable considerable loss resistance in the earth system or counterpoise).
Inductance L = 8.58 uH

XL = 97 ohms

Bandwidth B = 613 Hz.

Now the Italian Maxi loop of these dimensions has an aluminum loop. From charts in the Radiotron Designers Handbook, aluminum has a specific resistance 1.64 times that of copper. So I figured that I should multiply RL by 1.64 and again look at the results:

Calculations of 4 metre diam loop of 140 mm aluminum tube at 1.8 MHz using ARRL equations
RL = 0.0164 ohms

Efficiency = 28%

Q = 2117

B = 850

(On these figures, the bandwidth is to small for our SSB.)

But as we think the calculation of Rr in the formula might be inadequate, lets work backwards and start with a bandwidth of 3 kHz to satisfy the SSB requirement and see what value of Rr we need for this bandwidth.

To do this we need an Rr of 3.5 times that from the previous calculation or 0.0228 ohm to achieve a Q = 600.

The change also gives a calculated increase of efficiency to 58%.

Tuning Capacitor
On these figures, I wondered what sort of tuning capacitor might be needed to get down to 1.8 MHz.
Based on my calculation of a loop inductance of 8.58 uH, we would need a 912 pf capacitor.
(I note that the Maxi spec. says 8 uH and a 1500 pf capacitor with a low frequency limit of 1.75 MHz - so this calculation is close to the mark).

What about maximum voltage across the capacitor. Assume we have a Q of 600 (as suggested above) and we feed 100 watts down to the 50 ohm termination of the antenna, the voltage at the termination would be 70.7 VRMS.
Multiplied by 1.414Q to get the peak voltage developed across the capacitor, we get a value close to 60,000 volts.
Where does one get a 900+ pf variable capacitor which could withstand 60,000 volts?

My ITT Handbook suggests a breakdown gradient for air is about 30 peak kilovolts per cm. (It suggests certain gasses to have improved dielectric strength up to 2.5 times air - it doesn' t discuss a vacuum but implies that the figure decreases with a drop in air pressure).

Query of Q
In both the Italian loops, the specifications include a value of Q equal to 1.500. In the Maxi loop it is given as this value for 1.8 MHz. Is this a misprint of a dot shown instead of a comma and should read 1,500? If the Q is just 1.5 then the resistive component (Rr+RL) would have to be about 67 ohms. Also the bandwidth would be 1.2 MHz - this can' t be right.
But if the Q is actually equal to 1500 then the bandwidth is 1200 Hz and too narrow for SSB. - a bit of a question here also.

Without drawing any conclusions of my own, I leave it all for comment.

73
Lloyd

24

From: Leigh Turner

To: ' Lloyd Butler'

Cc: ' John Elliote ' Rob & Carlein Gurr'

Sent: Wednesday, July 16, 2008 9:28 PM

Subject: RE: Calculations on 4 Metre diam loop at 1.8MHz

Hi Lloyd,

An interesting exercise, but as I said you won't get much satisfying correlation with those old formulae.
Mazzoni's Q of 1500 in the spec is quoted for the inductor, not the composite antenna. The practical antenna Q is much lower due to radiation that sets an asymptotic upper limit to both the Q and the capacitor voltage. The BW really opens up and broadens as the "folded dipole" mode kicks in above 8 MHz or so and the radiation resistance rapidly rises. His 1m diameter loop has a BW of 20 kHz at 28 MHz.

From the Maxi loop product's spec we note the BW @ 1.8 MHz is 4 kHz and @ 7 MHz it is 8 kHz, and a 22 kV RMS rating for the tuning capacitor (an interdigitated vane style whose plate mesh is controlled by a linear actuator that pushes the blades of the cap open and shut). We also note a frequency dependent power rating varying between 700 W and 2 kW CW. See attached photo for details of the vane capacitor and motorised actuator.
73

Leigh

25

Hi Leigh

You are several emails ahead of me now but I will just reply to this one first .

I enjoyed the AHARS members equipment and ideas display on Thursday night. They have been doing one night each year for a lot of years now but the last one had a wide variety of different things on show and probably rates as one of the best nights of this type the Club members have come up with. There are many aspects of the hobby of amateur radio and this sort of display demonstrates that there is still plenty of individual interest in experimenting with different ideas and getting enjoyment in personally constructing and making work various items of operational equipment.

I was interested in your own submission of the dummy load and the series connecting load resistors in a form that presented the load as a lossy transmission line of the appropriate characteristic impedance.

But back to replying to the email:
I did speak with you about the following at the meeting but I think the conversation got side stepped

Reference "Mazzoni's Q of 1500 in the spec is quoted for the inductor, not the composite antenna."
Well I don' t know. I think you mean XL/RL (and ignoring Rr} I worked out XL = 97 ohms and RL = 00164. That gives a XL/RL = 5900.

Reference: "From the Maxi loop product's spec we note the BW @ 1.8 MHz is 4 kHz"
and "and a 22 kV RMS rating for the tuning capacitor"
That assumes a Q of 450.

For 100 watts of power we get 70.7V RMS into the 50 ohm termination hopefully presented by the loop input.
Multiply that by 1.414Q we get close to 45000 volt peak value. - a bit high for the 22 kV rating.
73 for now
Lloyd

26

Correction
I realised I had made a mistake on calculating voltage developed acros the capacitor. The calculation asumed that voltage on the line was inserted in series with the loop. But it isn' t and is fed in shunt with part of the tuned circuit. So I calculated a different way:

Q = 450, XL = 97 ohms.

Total R = XL/Q = 97/450 = 0.22 ohm

For 100 watts of power (P), current (I) though R = root(P/R) =root(100/0.22) = 21.3 amps (which circulates through R & L in series)

Voltage developed across XL (and Xc) = IR = 21.3 x 98 = 2087 volts RMS (or 2951 Peak V)

That' s looks better!!

Lloyd

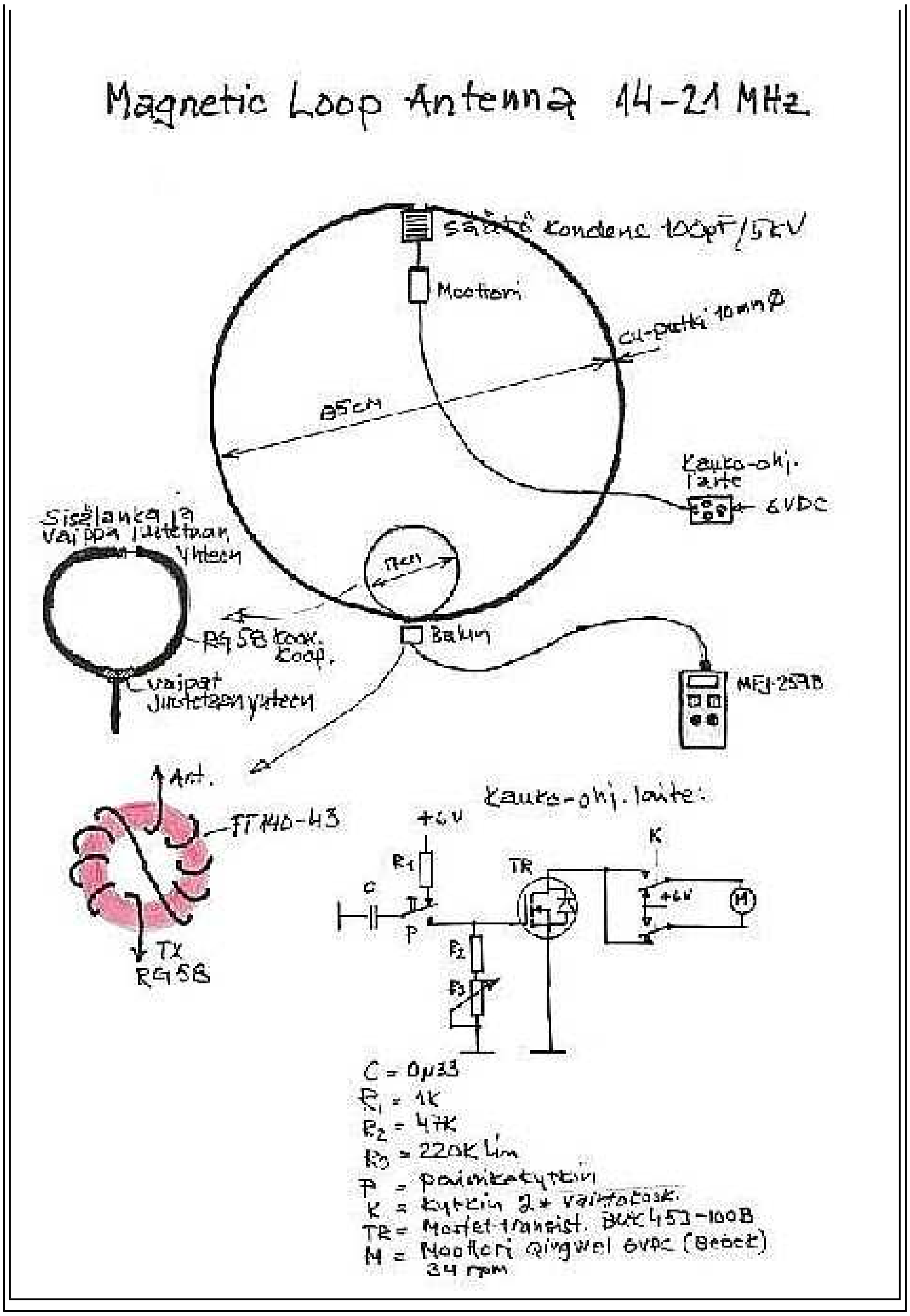
27

To: ' Lloyd Butler'
Cc: Rob Gurr John Elliott ;
Sent: Friday, July 18, 2008 8:48 PM
Subject: Magnetic loop with remote control

Hi Lloyd,
Following up on some of your earlier concerns, here is an e-mail I received today that shows what many homebrewer folks do to prevent the potential issue you often speak of about circumventing feeder radiation attributing to unbalanced longitudinal feeder currents, and thus maintain purity of the main loop pattern, i.e. the auxiliary 5:1 diameter feeder loop placed at the symmetry plane of the main loop and fed with an efficacious choke balun.

If you want to be doubly sure, you can also augment this with a ferrite cored feedline common-mode choke locate further down the coax line; something I routinely do with most of my antennas of any kind.

Pekka is president of the Tampere Amateur Radio Society in Finland when I spend a lot of my time on professional business. The design below was recently constructed by a club member OH3FER and described on the club website. The 20m and up loops have been shown time and time again to outperform their dipole equivalents in a range of application environments and scenarios on popular European paths.



73

Leigh

28

Hi Leigh

Thanks for the information on the OH3NE antenna arrangement with auxiliary coupled loop.
Is the signal source (from the coax line) connected in series with the primary auxiliary loop or is there some form of shunt coupling into the primary loop similar to the gamma match? Considering the two loops as a coupled circuit with a coupling factor less than one, I guess a reactive component is reflected in series with the resistive component.

The reactive component could be corrected using a series phasing reactance but I wondered whether tuning the main loop a fraction off resonance might correct that.

But there would certainly seem to be a need for some way to adjust the reflected resistive component to 50 ohms across the coax line.

(Maybe the written comments on the diagram explain this if I was able read them).

Reference the choke balun, - Its effectiveness to block longitudinal current component on the coax line became a big subject on the EH Forum. The longitudinal impedance at the choke insertion point in the longitudinal path could be quite high. For the choke to work, its reactance had to be much higher than that impedance. A number of EH Antenna users tried inserting these chokes using a winding of the coax line on a ferrite core - doubt was raised whether there was sufficient reactance in just the choke. Some users also experienced considerable heat dissipation in the core.

I came up with the idea of tuning the choke so that it became a trap (I called it a trap as it functioned the same as the trap in such as a trapped multi-band antenna). This gave a rejection impedance Q times the choke reactance. I extracted a section concerning these traps from one of the articles I wrote when I was playing around with the EH antennas - I thought you might be interested (Refer to the attachment).

In making the traps, I discarded the use of ferrite core and stuck to air core wound on a section of PVC tube. One reason for doing this was the possible detuning of the tuned inductance due to permeability change in the ferrite as flux was increased.

A lesson I learned many years ago in my workplace - I had a requirement to feed a 100 watts at frequencies of several Kilo-Hertz into an underwater acoustic transducer via a filter I had designed . I had made up the inductors using large ferrite toroidal cores which, from the design data, were more than adequate to take the flux induced in the cores. The filter plots using the spectrum analyser were fine, exactly as predicted in the design but when the gear was excited with the 100 watts, the whole experiment went haywire. I found that the inductors were shifting quite largely in value as the power was increased.

Apparently the ferrite permeability changes with the flux density - Although permeability of iron dust is typically lower in value than ferrite its value is much more stable for iron dust. I re-ordered suitable iron dust toroidal cores for the experiment which of course fixed the problem.

The ferrite core is fine for transformers where a bit of change in inductance is of little consequence. But from that day on, I have never used ferrite in inductors where high power is involved and stability in the value of inductance (such as in tuned circuits) is required.

Anyway I thought you might be interested in the traps I made up. The small diameter RG174 coax used is not readily available in the local electronic shops but Ted Hart had some which he kindly sent over from the States. I have used the larger diameter coax, which is normally available, but the assembly gets a bit bulky, particularly at the lower HF frequencies.

The traps are certainly more effective than the bare choke. Of course they are restricted to one amateur band but maybe more than one (one each for each band) could be connected up in series if multi-band were required.

Best Regards

Lloyd VK5BR

ATTACHMENT TO PREVIOUS EMAIL Re: BALUN CHOKES $ TRAPS

20 metre trap with ferrite core

To enable tests on the 20 metre L+L with the coax shield current removed, I made up the coax line choke shown in figure 1. The balun is 10 turns of RG58 wound on a 1.25 inch diameter former with a 8 inch x 1/2 inch diameter ferrite rod down the centre. The inductance measured from one end of the outer sheath to the other is 11.5 uH. (This provides a rejection impedance at 14 MHz of over 1000 ohms.) The ferrite rod was held in place with by masking tape as a temporary means..

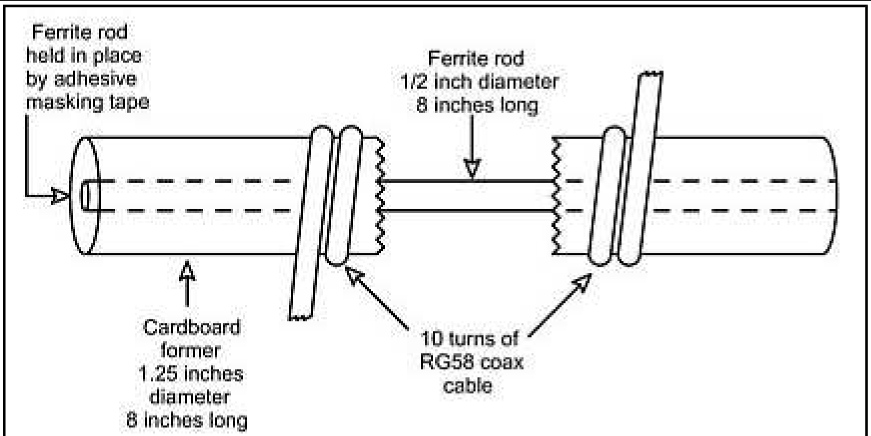


Figure 1 - Coax Cable Line Choke

Whilst the choke reduces the unwanted current to a considerable extent, it is far more effective to tune the choke with a parallel capacitor so that it forms a trap. The capacitor is connected to the coax braid between input and output of the choke. The choke described is tuned with about 10 pf of capacitance (including distributed capacity). The resonance at 14 MHz can be easily checked by inserting the coil of a dip meter into the tubular former. With a Q of around 100, the trap increases the rejection impedance to around 100,000 ohms.

One consideration using the trap, is IR loss due to circulating current within the tuned circuit. Circulating current loss is minimised by keeping the L/C ratio as large as possible. Of course the limit is when L is too large to tune in the presence of the coil distributed capacity. In the trap described, circulating current loss was derived as about 4% of the power fed differentially through the trap.

Air wound 20 metre trap

Obtaining a large ferrite rod might be difficult and expensive and a second air wound trap has been tested as shown in Figure 2. The inductor for this trap is wound on 55 mm PVC tube and requires no ferrite core. What is really required for winding the inductor is a small diameter coax and a suitable type is RG174.

The winding is arranged with sufficient turns to resonate at 14 Mhz with a 10 pf capacitor. Details of the trap formed are as follows:

Former - 55 mm PVC Tube
Cable - RG174
Winding - 13 turns
Length of coil - 36mm
Inductance - near 11 uH
Q - near 50
Measured differential through loss at 14 MHz - 0.2 dB

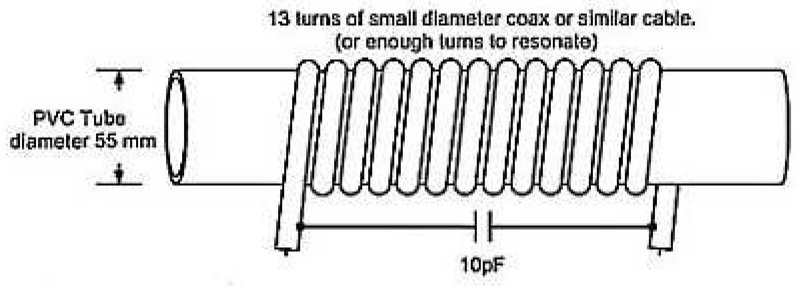


Figure 2 - 20 MetreTrap, Air Core

The tuned choke as a trap directly substituted for the original ferrite cored tuned choke. As with the ferrite core choke, interaction between the antenna tuning and the coax cable was inhibited and no coax shield current could be detected.

Circulating current through the tuning capacitor was measured as 0.28 amp for 50 watts of power transmitted. Based on the 20 ohms of loss resistance in the choke, this represents 3% of the power lost due to the circulating current.

With continuous power of 50 watts fed to the antenna, a slight warming of the choke was evident.

The air wound choke is quite good enough for the job and does away with the expense of the ferrite rod and problems sometimes experienced with flux saturation in the ferrite material.

40 Metre Air Cored Trap

A trap has also been made for 40 metres with similar construction to that described above for 40 metres.

Former - 55 mm PVC Tube
Cable - RG174
Winding - 26 turns
Length of coil - 77mm
Inductance - near 27 uH
Tuning Capacitor - 19 pf
Measured differential through loss at 14 MHz - 0.5 dB

All in all, the air cored traps are quite sucessful. There is a small through loss due to the traps. The 20 metre trap has a loss of 0.2 dB and the 40 metre trap has a loss of 0.5 dB. Connected through into a precision 50 ohm load both traps show an SWR reading of 1:1.

Figure 3 - 20 MetreTrap, Air Core

With continuous power of 50 watts fed to the antenna, a slight warming of the choke was evident.

The air wound choke is quite good enough for the job and does away with the expense of the ferrite rod and problems sometimes experienced with flux saturation in the ferrite material.

END of ATTACHMENT

29

From: Leigh Turner
To: ' Lloyd Butler' <mailto:ldbutler@tpg.com.au>
Cc: John Elliott; Rob Gurr
Sent: Sunday, July 27, 2008 5:16 PM
Subject: RE: Magnetic loop OH3NE

Hi Lloyd,

A few succinct musings about small loop antennas and balun chokes on a cold and miserable Sunday afternoon to address your latest comments:

Yes, the 50 ohmslash; signal source merely drives 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 resistive at resonance with just the Rr and Rloss components).

The impedance seen looking into the feed loop is determined by its diameter with respect to the primary tuned resonator loop. A 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, as we' ve discussed, 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 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.

Another qualitative explanation for the constant feed impedance behaviour of the small secondary loop may be found in examining the relationship between the loss resistance and the radiation resistance of the primary loop which is of course reflected into the secondary feed loop by transformer action. In a practical wide-band design, the loss resistance at the lowest frequency of operation will generally be greater than the radiation resistance by some considerable factor; however, the radiation resistance of the primary loop increases rapidly with frequency and soon overtakes the loss resistance. If the design is such that the maximum radiation resistance, which occurs at the highest frequency of operation, is made no more than about three times the value of the loss resistance, then a maximum impedance mismatch of only 2:1 will be exhibited when looking into the feed loop terminals since the maximum possible impedance excursion is within a 4:1 ratio.

Lloyd, I like your excellent idea of parallel resonating the air-core choke balun to form efficacious high impedance traps to significantly boost the feedline decoupling impedance to many 10' s of Kohms. That would fully eradicate the potential longitudinal current problem and additional radiation from that often undesirable spurious cause. It' s otherwise a challenge getting enough low-loss reactance from the choke in a broadband application scenario. The resultant narrow band operation is quite OK in many applications and you can as you say series up the traps for operation on multiple amateur bands.

Yes, I keep small quantities (rather expensive) of the ¨ù inch RG-142 and the smaller bore ¨û inch RG-188 / RG-316 Teflon coax at hand in my lab just for winding QRO baluns and transformer, both ferrite / iron powder toroids and the air-cored kind. When you put a too tight a bending radius on winding ordinary polyethylene coax you can risk cold flow deformation and potential short circuits / catastrophic arc-over breakdown. Teflon coax with its silvered braid and high temp capability solders well too. I' d used some RG-142 in that QRO dummy load I brought along to the Show & Tell.

Thanks for sharing those choke balun / trap designs and that experience about the often unpredictable behaviour of nonlinear ferrite cores; fully agree with your sentiments there, and one has to be wary. The small signal characteristics of LC networks as seen on a spectrum analyzer or network analyzer often bear little resemblance to the corresponding high power RF behaviour! I often mentor young engineers in the R&D department of some big companies in both Finland and the USA, and getting that message across has been a perennial issue over the years, but is a lesson seldom in need of repeating!

For broadband work I' m also a fan of toroidal baluns. The losses in an air core balun are mainly I2R and copper loss; remembering that skin effect comes into play and raises its ugly head substantially reducing an otherwise good RF current carrying ability for a given gauge wire. Also, the thing about ferrite toroid cores is their closed magnetic flux path and high permeability ¥ì, allowing far fewer turns (wire length) and hence deleterious skin effect losses in the wire. An RF transformer wound in transmission line form has very tight coefficient of coupling between windings; its insertion loss is virtually immeasurable.
To get enough choke winding reactance with a ¥ì = 1 air core you unfortunately need too many turns L

Saturation is never an issue because there is virtually no flux in the core of a properly constructed transmission line transformer (that is the elegant beauty about them compared to ordinary transformers). In the HF frequency range of interest where true transmission line behaviour is experienced the symmetrically disposed transmission line currents should cancel resulting in no net core flux. There are commercial toroidal baluns such as these from companies like Array Solutions in the USA with multi-kW power handling capability.

In a QRO application short winding lengths are always best from a copper loss point of view, and use of a ferrite core of say ¥ì = 125 (for 61 grade) would allow you to reduce the length of winding wire by at least a factor of 3 or more. The reactance of the winding (hence higher impedance chocking action) increases with core permeability.
When a balun of any kind is getting too hot, it might also suggest the reactance of the coiled windings at the operating frequency is insufficient to prevent conventional transformer currents (noting that RF energy is ideally transferred by a transmission line mode; not by magnetic flux linkages). Another important requirement of baluns is that the magnitude of the winding reactance be much greater than the 50 Ohm antenna load impedance. A reasonable criterion for the balun' s winding impedance for attaining negligible common mode current in the feeder coax braid shield is that it be at least 10 to 20 times this, or greater than 500 to 1K ohms or so.

I think folks sometimes get into trouble with air core choke baluns for multi-band operation because the coil' s inherent inter-winding self-capacitance parallel resonates with the coil inductance and can raise the impedance. That' s fine and beneficial up to some frequency. Above this parallel resonant frequency the winding reactance is undesirably rapidly reduced by this stray capacitance and things fall apart with decoupling performance degrading rapidly. So one needs to make sure the real part of the parallel equivalent shunt impedance of the device windings are sufficiently high, otherwise the power dissipation from this cause could dominate and far exceed the aforementioned copper losses. The real part of this parallel equivalent impedance represents dissipation and power loss, so you don' t want this to be more than a few percent.

In an optimally designed air core balun, you don' t want the winding' s self-resonant frequency to be at a point in relation to a multi-band antenna' s operating frequency where it' s working against you in so far as its impact on the effective shunt impedance that' s sucking u real power. Having a high winding inductance (high impedance) with fewer turns (less I2R copper loss and less stray inter-winding capacitance) greatly helps in solving all the issues.

While efficacious over certain frequency ranges, perhaps air core baluns of the popular trifilar style are probably a hangover legacy of a now bygone era in radio when high-¥ì ferrite and iron powder cores and toroids were unavailable or too expensive. Such a toroid core based balun choke design with proper choice or core material and winding construction will perform well over a wideband and run as cool as a cucumber with constant QRO power levels.

Another QRO construction method I like when a simple no impedance transformation 1:1 broadband choking balun is required, rather than using a pair of large toroid cores one can consider merely deploying a short length of small diameter RG-141 / RG-142 teflon coax onto which is threaded say 30 or so Amidon FB-73-2401 ferrite beads and the whole thing meandered up into a small potted / encapsulated plastic enclosure box with an SO-239. That would be a cheaper option than say buying a pair of big FT-240-61 toroid cores. The impedance of the outer braid conductor surface increases in proportion to the number of beads, and chokes-off the common-mode currents and thereby isolates the balanced output terminals that feed the antenna. Series impedances in the outer coax surface above 1000 to 1500 Ohm are readily achievable over most of the HF band with very differential mode low insertion loss in the feeder.

The subject of choke baluns is indeed a very interesting one; another area in which you have great experience Lloyd.

73

Leigh

30

Hi Leigh

Thanks for your extensive information concerning choke baluns. The principles you have outlined concerning their design are certainly in phase with my line of thinking on the subject.

Reference: Another important requirement of baluns is that the magnitude of the winding reactance be much greater than the 50 Ohm antenna load impedance. A reasonable criterion for the balun' s winding impedance for attaining negligible common mode current in the feeder coax braid shield is that it be at least 10 to 20 times this, or greater than 500 to 1K ohms or so.

I think I might have rather said that the winding reactance be much greater than the longitudinal (or common mode) impedance seen at the point of insertion of the balun. The transmission line with a longitudinal current component developed could represent quite a long length of radiating element. It could have a standing wave characteristic along its length with nodes and anti-nodes representing a range of low to high impedance points. If you happened to insert the choke balun at a high impedance point, it might be very difficult to create enough series reactance in the choke to inhibit the common mode current component. On the other hand if you carefully measured the length down the cable to find the quarter wave point or perhaps looked for a point of low electric field with a detector, then put the choke there, you might more easily deter the common mode component.

This was the sort of thing I ran into in experimenting with the EH antenna and why I went to parallel resonance of the choke. As I found out by measurement, the current running in the centre conductor of the EH antennas was around twice that running in the outer shield. (My experiments showed that it radiated well like that, but balance up the currents in the transmission line legs with the effective trap inserted and it worked much like any other short fat dipole).

Choke baluns (or chokes created by ferrite rings) on signal or mains lines are used a lot to stop noise getting into gear from an external source (or in reverse, perhaps stopping noise generated by the gear from getting out). But it always seemed to me to be a hit or miss business - it might work or it might not work, much dependent on whether the series reactance was large enough to be effective .

Of course the noise current one might try to stop often results from different points in a circuit being referenced to a different earth or common bus location and a noise voltage difference across those locations generates the noise current loop. Returning all the reference points to the one location or in the case of lines or cables, joining the line centre tap or cable shield to earth only at one end to break the loop, may eliminate the need for such as the choke. I learnt very early in my youth never to earth the shield of a microphone shielded cable at both ends. (But getting rid of noise interference or perhaps preventing it in the first place is another lengthy subject).

Reference: When a balun of any kind is getting too hot, it might also suggest the reactance of the coiled windings at the operating frequency is insufficient to prevent conventional transformer currents

Absolutely - I am sure that is why some of the chaps experienced the ferrite core getting hot in their choke baluns.

73

Lloyd VK5BR
