All sorts of small antennas – they are better than you think – heuristics shows why!

By Professor Mike Underhill - G3LHZ

Heuristics – what is it? – 1

- Heuristics can be defined most simply as ‘learning from experience’. It is the process of ‘trial and error’ or ‘guess and confirm’.
- It leads to the process of ‘discovery’, and stimulates and educates ‘intuition’. It is the way to ‘do research’ in any field.
- The word ‘Heuristics’ has the same root as the old Greek word ‘eureka’ – “I have found it”.
- Wikipedia says that the root for both is ‘heurisko’ (εὑρίσκω), which means “I find”.
- Archimedes was using ‘heuristics’ when he realised he had a theory to explain the ‘observation’ that he was floating in his bath. For him the *theory* came from *observation*, <u>not</u> vice versa.
- So ‘heuristics’ here means ‘deriving the theory from measurements and observations’. It is the *scientific process*!

Heuristics – what is it? – 2

- 'Practical, real, not computer simulated, EXPERIMENTS are the first and only priority for heuristics – all else is subservient to this. The process is:-
- EXPERIMENTS = observations, measurements, calibrations – leading to:
  – Discovery and initial understanding from *observation*
  – Extraction of all the 'information' in a set of *measurements*
  – Deduction of consequences, leading to
- HYPOTHESIS (unproven or uncalibrated theory)
  – Initial Prediction of Performance Simulation. (For antennas: efficiency; input impedance; bandwidth; radiation modes; and mode patterns.)
- VALIDATION and CALIBRATION Experiments to check the simulations and assumptions behind the theory to convert hypothesis to
- HEURISTIC THEORY (Practically proven calibrated theory. Not 'trust-me' theory.)
  – Deeper Understanding
  – Models, Formulas, 'Rules of Thumb', Optimisation Strategies, and Design Rules
- RESEARCH (look again):- new ideas, new designs, new aims and objectives
  – And then back to EXPERIMENTS
- **Relying on theory, whether old or new, without <u>experimental confirmation</u>, is the road to self-delusion - *Caveat emptor – buyer beware!***

Heuristics – what is it? – 3

- In summary, 'Heuristics is **The Paradigm of Experimental Science**'
  - It is theory and understanding from experiment and observations.
  - It is the way to do research and to achieve understanding
- For antennas and propagation:
  - It is the way to explore propagation modes, old and new
  - It is the way to invent new antennas
- ***It is what radio amateurs do!*** –
  - When a signal report is given or received
  - When signal reports are compared in a regular net
  - When a comparison A/B antenna test is made
  - As an intrinsic part of any contest
  - When antenna impedance Q or bandwidth is measured
  - When antenna efficiency is measured
  - When an antenna pattern, or front-to-back ratio, is measured

Contents of This Talk

1. **What is *Heuristics*?** – already done
2. **Practical Demonstration of 'Mag-Loops'** – to make *heuristic* 'observations'
3. **'The Schopenhauer Effect'** - in any new Science? A reaction to new antennas?
4. **The Loop Controversy** – *heuristics* resolves it once and for all time! (No, it is not losses in the tuning capacitor – it does not get hot!)
5. **Small Antennas <u>are</u> Efficient**. *Heuristics* demonstrates and proves this using the **'First Law of Thermodynamics'** = conservation of energy and power.
6. **Heuristic Antenna Impedance Measurements** – extracting maximum information for design improvement – multiple antenna modes are measured
7. **Heuristic Antenna Pattern measurement –** extracting maximum information for design improvement – separating mode patterns?
8. **Heuristic (ground wave) propagation measurements** – reveals the main misunderstanding that has fuelled the 'loop controversy' – an olive branch?
9. **The CFA and EH antennas** – first hand practical experiences
10. **Simple Heuristic EM theory of radiation and reception** proposed
11. Discovering, Inventing and Demonstrating **'Impossible' Antennas – that are supposed not to work!**
12. **Local Ground Sensing by Loops**
13. **The Future?** – what does it hold? – does heuristics help?

3 HF Transmitting loops in an attic ~λ/25 to λ/6 (in 2004)

A 'small antenna' is contained inside a sphere of radius $\lambda/2\pi$

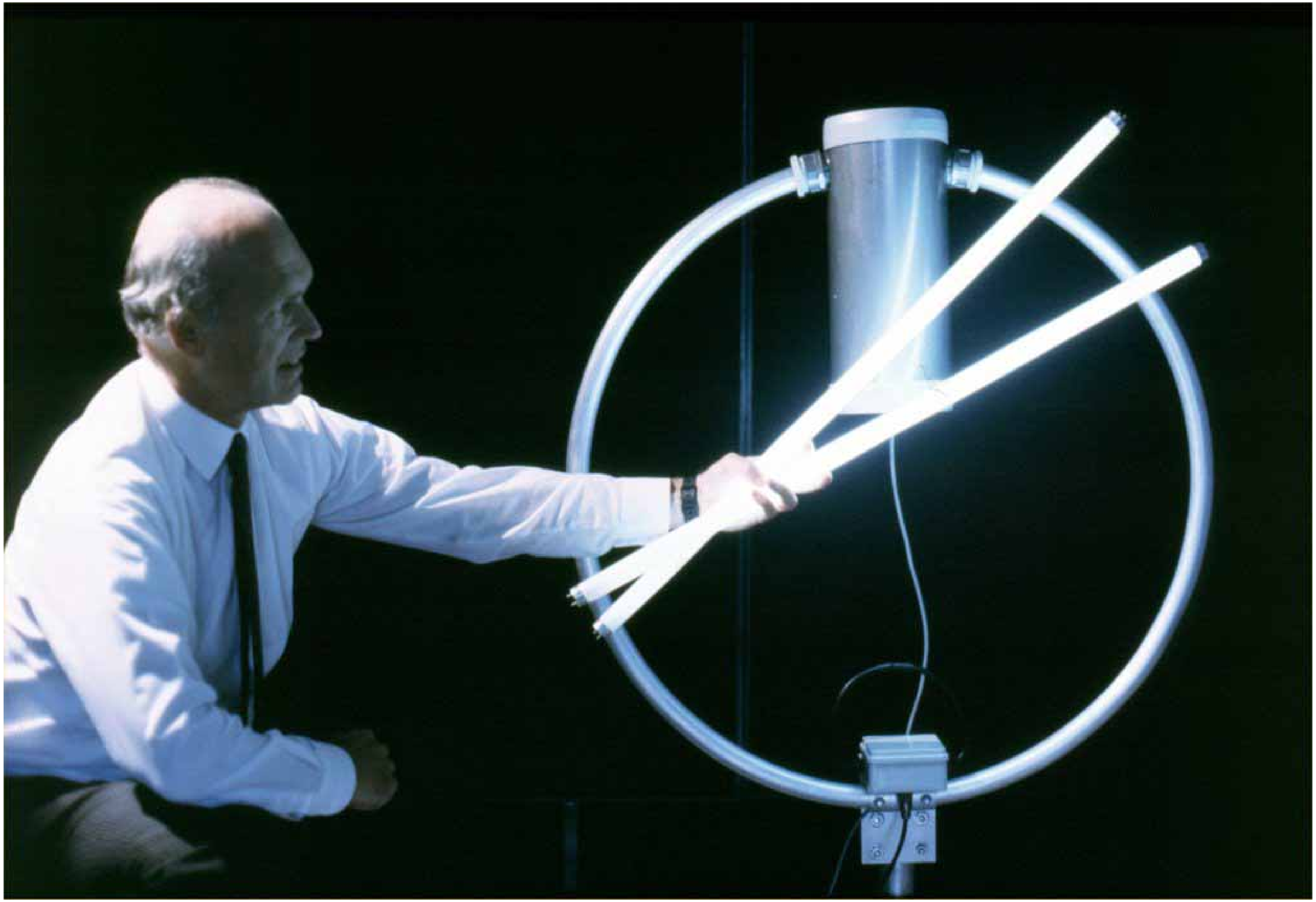
In picture from furthest to nearest:

(a) AMA3 – 13 to 30MHz, diameter = 83cm

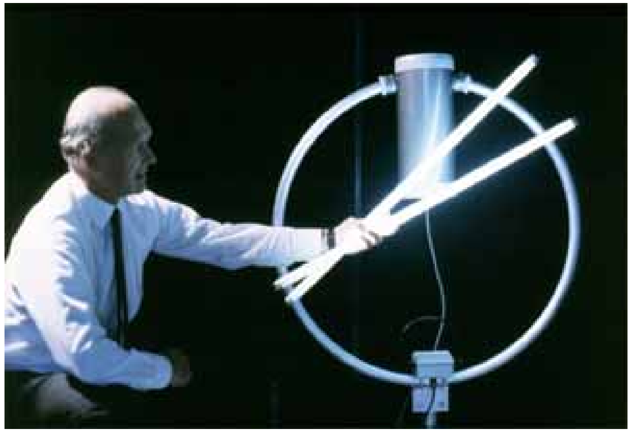
(b) Experimental double tuned 3.5 to 30MHz loop on rotator – diameter = ~1.25m

(c) AMA5 – 3.4 to 11MHz, diameter = 1.7m

Where it started in 1994 – Public Demonstration at IEE and University of Surrey Inaugural Lecture



HFC2000 Demonstration of:
(a) Fields around a Loop
(b) 'Cordless Welding'



Demonstration of AMA3 (from AA&A)

Notes on Loop:

1. 83cm diameter loop of 3.2cm diameter aluminium tube,
2. Original 15cm loop feed not used. 'Twisted Gamma' feed used instead. More convenient and can 'fine tune' the matching
3. Motor tuned capacitor at top – about 250pF?
4. Tunes 13 to 30 MHz with SWR < 1.5:1 over the band – depending on loop environment
5. Rated at 150 watts – will handle about three or four times this after flashing off high points on vanes (or any insects)!
6. New Theory says Q < 250 = 56kHz bandwidth on 14MHz. Actual Q = ~172 and 72kHz bandwidth

Observations for 100 watts input are:

1. Loop not warm to touch. Neither does the capacitor get hot. Compared with 100w bulb in a slightly larger tin, where the surface reaches 90 to 100°C
2. Vertical fluorescent tube shows nulls along loop axis as for magnetic mode.
3. Horizontal fluorescent tube shows nulls along the loop plane, as for a horizontal (folded) dipole.
4. 2 turn iron wire pick-up loop couples magnetically to give a 'cordless welder'

The Schopenhauer Effect

- Joining the march of progress in science (in any field) has its dangers. New ‘truths’ and ‘paradigms’, such as ‘heuristics’, are rarely, if ever, immediately accepted.

- As the German philosopher Schopenhauer (1788–1860) put it:
- “All truth passes through three stages:
  - First it is ridiculed,
  - Second it is violently opposed,
  - Third it is accepted as being self-evident”.
- Taken from “The Universe – a biography” by John Gribbin.

- **Is there something familiar here? – Perhaps the loop controversy?**

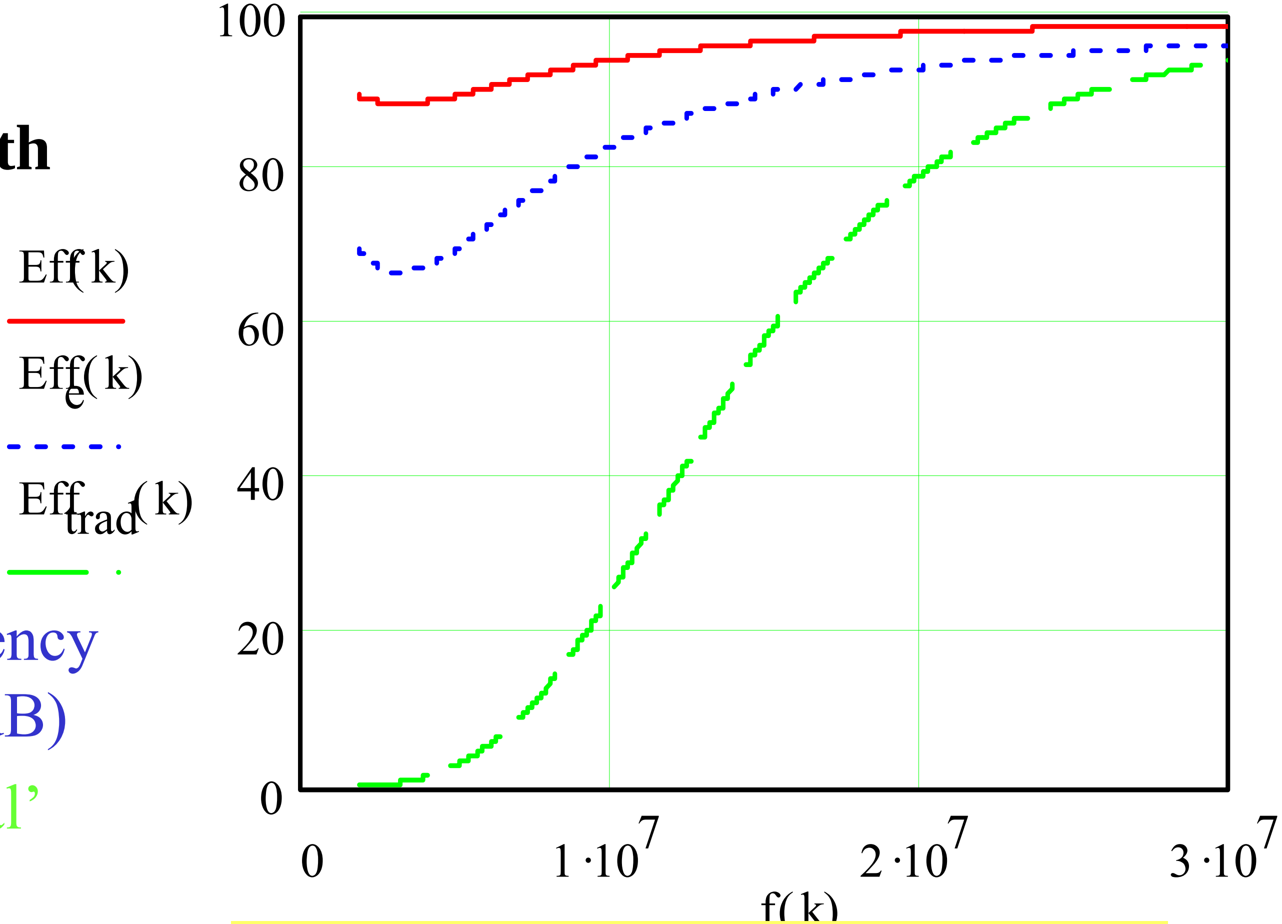
Summary of Antenna Efficiency – Using the First Law of Thermodynamics (conservation of energy law)

- **Antenna efficiency is**

  = (Power out)/(Power in) = 1 - (Heat in antenna)/(Power in)
- This is the only true measure of antenna efficiency.
- Most other methods, including the IEEE method, designate *ground losses* as antenna losses. Errors are then typically 5 to 15dB under the antenna and *also* under the field strength meter.
- *Inefficient small antennas can self-destruct with high power.*
- *High power tuned loops do not self-destruct. They are efficient!*
- *'Heuristics' proves (loop) efficiency* <u>*experimentally*</u> *in five+ ways:*
  - *(a) the 'heat balance' method,*
  - *(b) the 'wide band Q' method,*
  - *(c) the simpler 'rho-Q' (loop) method*
  - *(d) the 'identical antenna pair' propagation/coupling method*
  - *(e) the 'A/B antenna comparison' method*

Tuned Loop Efficiency – The Controversy is 'Classical Theory versus Practical Measurements' ('Wideband Q' measurements)

- **Two turn 1m loop with 10mm copper tube:**
  1. Measured Intrinsic Efficiency = Eff(k) >88% (-0.6dB)
  2. Measured Environmental Efficiency = $Eff_e(k)$ >66% (-1.8dB)
  3. Traditional 'classical' prediction of Loop Efficiency = $Eff_{trad}(k)$. At 1.8MHz = 0.08% or -31dB !!!!



Classical	1.8MHz = -31dB
Theory:-	3.6MHz = -19dB
14MHz = -3dB	5MHz = -13dB
28MHz = -<1dB	7MHz = -6dB

A case to be treated by Heuristics?:- "October 2007 Technical Topics – 'Variable Dielectric Capacitors' – for VFOs and Loops" 1

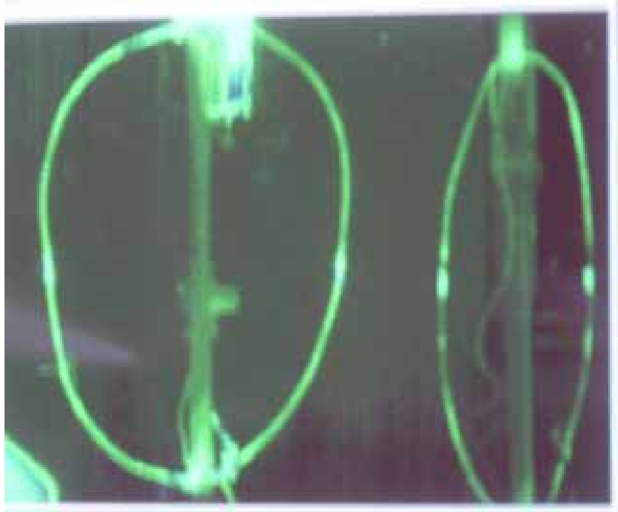
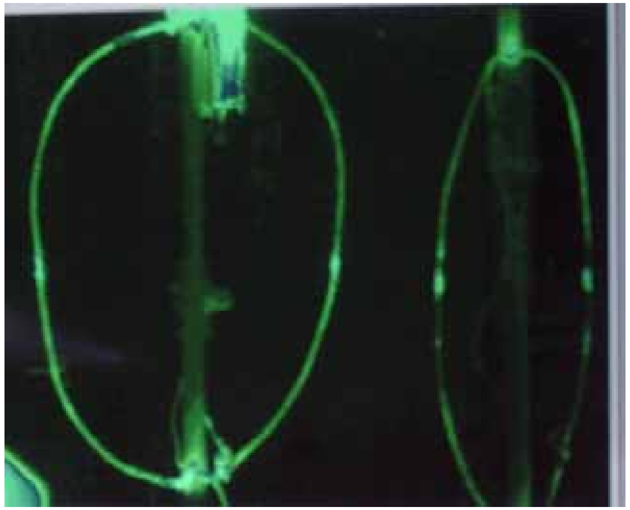
- Brian Austin G0SGF draws attention to an article "Variable Dielectric Capacitors" by Harry Brash GM3RVL (*Sprat*, Issue Nr 131, Summer, 2007, pp10 to 12).
- G0SGF comments: "I can see an immediate application for the technique as the tuning capacitor in an electrically small loop antenna – the so-called 'magloop'.
- " As you may remember, in 'TT' (February, 2006, p73) Jack Belrose,VE2CV put his finger on the contact resistance of the rotor coupling mechanism as the reason why no one has ever managed to achieve, in practice, anything like the theoretical Q with these antennas, *despite the claims in some quarters.*"
- Now as the 'rather unscientific and scornful' statement in italics addressed at (a) 'the capacitor rotor coupling mechanism' or (b) the *undisputed* fact that no one has ever managed to achieve, in practice, anywhere like the (classical) theoretical Q.
- If it is not loss in the capacitor or in the antenna conductor material, then **the *inescapable* conclusion is that the input power is nearly all being radiated.**
- This inevitable consequence and conclusion comes from the application of 'Heuristics' to the problem. (Heuristics is applied 'common sense' really!)

Oct 2007 TT – continued
“The Death of the Chu-Wheeler Small Antenna Criterion”

- **Can the scientific method of ‘heuristics’ prove whether capacitor loss is a true assertion or just ‘ignorant non-sense’?**
  - Heuristics uses basic Physics – in this case ‘The First Law of Thermodynamics’
  - It says: “RF power out is RF power in minus heat generated in the antenna”
  - If capacitor rotor losses are the reason why the ‘classical’ theoretical loop Q is not achieved, then the capacitor will dissipate practically all the input power. **It will get hot!**
- **Heat and power balance method to discover the ‘truth’**
  - (i) Measure with about 100 watts input to small (loop) antenna on 80m or 160m.
  - We find typically there is well less than 10°C temperature rise, at any point.
  - A 100 watt bulb in a 1.3 litre tin typically gives 80 to 90°C temperature rise
  - (ii) Repeat with 400 watts. About four times the temperature rise will occur.
  - Check whether the loop self-destructs!
- **Conclusion**: efficiency is 80 to 90% or more
  - Thus the classical (Chu-Wheeler) theoretical Q formula is pure ‘non-sense’. It 'ignores’ the much larger radiation resistance easily found by the application of ‘Heuristics’
  - How can we repair the damage the damage that has been done in the past by this 60 year-old classical ‘dogma’? Difficult!
  - Perhaps do the measurements and shout about them? But remember for some “the earth is flat, and that’s the final word – that’s that then”, as they say! Schopenhauer stage 2?

‘Heat Balance’ Measurement of Antenna Efficiency (as in Nov 2004 Radcom article on Loops)

- The RF power lost as ‘heat’ is the same as the DC power the loop required to raise the same or an exactly similar loop to the same temperature.
- The DC power heats a resistance wire inside the loop
- Non-contact temperature measurement by Thermal Camera (below) or CHY 110 non-contact thermometer (bottom right).
- Thermal picture is of Marc Harper.
- Thermal emissivities of two loops are made equal by black paint patches at measuring points on the loops.

Thermal Camera Heat Balance Efficiency Results for 1m diameter Loop of 10mm Plumbing Copper Tube

Frequency in MHz	1.98	3.7	7.03	10.12
Efficiency in %	74	86	88	90

Some New Heat Measurements

- The First Law of Thermodynamics says that the power lost in an inefficient antenna will be dissipated as heat. The antenna itself will get hot.
- With high power to an inefficient loop "tuning for maximum smoke" can be too true!
- If loop efficiencies really were the 0.1 to 10% that the critics claim, practically all the RF input power would be dissipated in the loop (or loop capacitor) as heat.
- 150watts DC (14.0 V and 10.7A) into resistance wire in a 1m diameter loop of 10mm tube (in October 2004 RadCom) gave a temperature rise to 100°C. Ambient temperature was 14.0°C
- The temperature rise was 86°C (±1°C). The temperature rise is proportional to heat power lost for both radiation and convection.
- Therefore for 400 RF watts supplied and 396 watts dissipated in a 1% efficient loop, the loop temperature would be rise to 241°C and more for any joints and connecting wires.

Some New Heat Measurements (continued)

- Tin-lead solder melts at about 180°C. PVC melts at 180°C. Nylon washers melts at 220°C. PTFE melts at 327°C. Combustion of paper starts at "Fahrenheit 451"or 233°C. Copper melts at 1085°C.
- **Thus a 1% efficient 1m loop would self-destruct from self-heating with 400 watts input!**
- An 'HF' (10 to 30MHz) loop has typically has the same surface area of copper as above.
- A minimum practical MF loop(1.8 to 10MHz) has about 2.5 times this copper surface area, so about a kilowatt dissipated would be needed to achieve these temperatures.
- 150 watts input dissipated in my 'twisted gamma' wire its temperature would rise to 1095°C. The PVC insulation would melt and catch fire and then the copper wire would melt.
- I think the importance of loop efficiency for high power operation should now be obvious!

Simple Rho-Q Method for Antenna Efficiency -1

- **It is a simplified form of the heuristic Wideband-Q method (shown later)**
- **Given the measured *Q* of a loop, its efficiency is easily found from *its dimensions* and the *loop conductor resistivity ρ (rho)*.**
- **The efficiency is**

$$\eta = Rrad/Rtot = 1 - Rloss/Rtot = (1 - Q\ Rloss/Xl) \qquad (1)$$

- In the above we have used reactance Xl = 2πfL and $Rtot=Xl/Q=2\pi fL/Q$
- The conductor loss *Rloss* is the "skin effect" loss of the loop conductor.
- This can be found from the DC resistivity *ρ* of the loop conductor material, the conductor length, the loop circumference *Cir*, and the conductor tube or wire effective diameter *d*.
- The skin effect loss resistance *Rloss* is proportional to the square root of the frequency and the square root of the DC resistivity *ρ* of the loop conductor
- The skin effect loss resistance for the loop is found to be

$$Rloss = \sqrt{(0.4 \times fMHz \times \rho)} \times Cir/d \qquad (2)$$

How to measure Antenna Q

1. At the frequency of interest f_0 match the antenna to 50 ohms to give 1:1 SWR (on Antenna Analyser)
2. Detune (the analyser) to lower frequency f_1 where the SWR is 2.62.
3. Detune to higher frequency f_2 where the SWR is 2.62.
4. The antenna Q is then: $Q = f_0/(f_2 - f_1)$

Why SWR= 2.62?

•Half-power or -3dB points occur when the reactance of tuned circuit becomes equal to $\pm$ j50 ohms, where $j = \sqrt{(-1)}$.

•Reflection coefficient $\rho = \{1-(1 \pm j)\}/\{(1+(1 \pm j)\}$.

•Modulus of the reflection coefficient = $|\rho| = 1/\sqrt{(2^2 + 1)} = 1/\sqrt{5}$

•SWR = $(1+|\rho|) / (1+|\rho|) = (1 + 1/\sqrt{5})/(1 - 1/\sqrt{5}) = 2.6180$

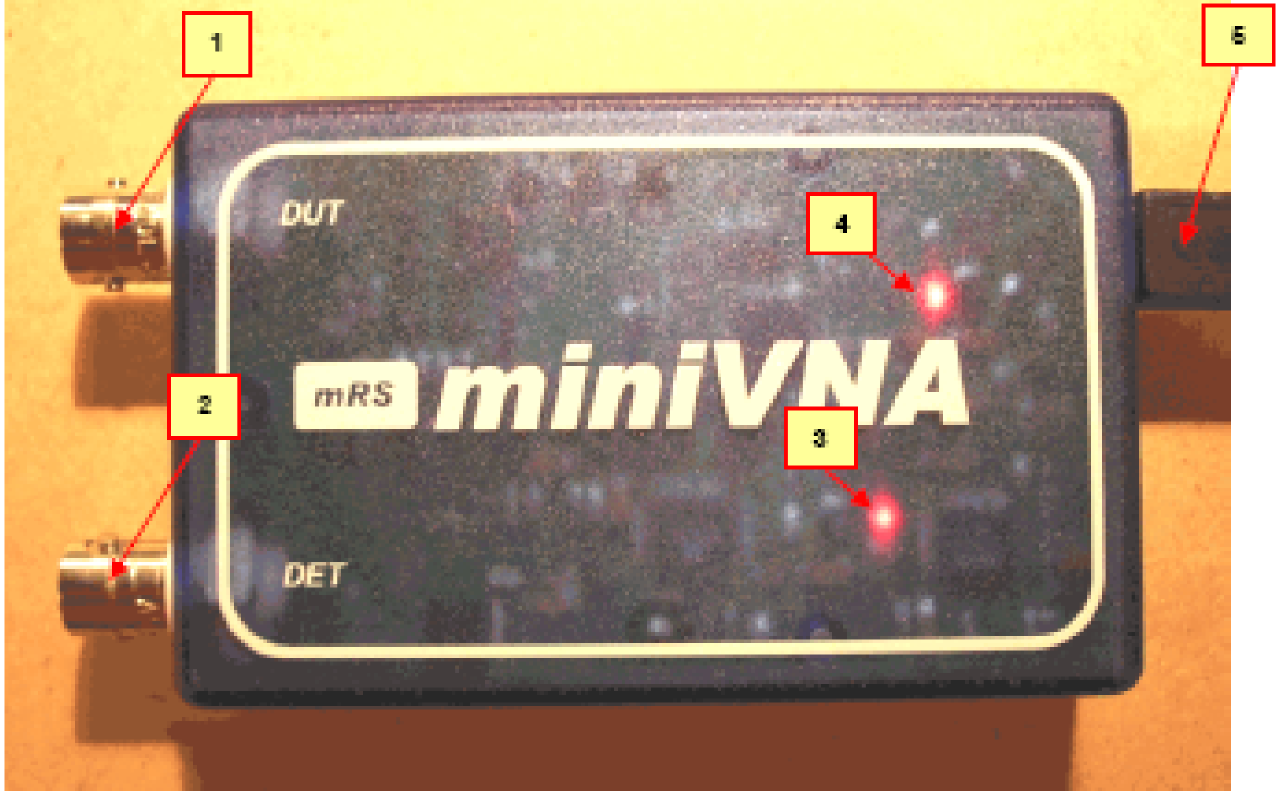
miniVNA Vector Network Analyser

Reference manual for mRS antenna analyser type miniVNA 0.1-180 MHz

The device is designed to measure antenna impedance and filters over the HF and VHF frequency range. The small hardware (9x5.5x3cm) uses an USB connection to a PC where the antenna parameters can be displayed, one full scan takes about 0.5 sec per 500 samples, the instrument will give a big help to tune and design antennas especially for radio amateurs.
The original software runs under Windows PC, by the way many hams worked on different version such as DOS, LINUX and PDA with Windows CE (Windows Mobile 2002-2003).

miniVNA – 'DET' connection makes it a VNA – for 'transmission' measurements

www.miniRadioSolutions.com
miniVNA antenna analyzer V224

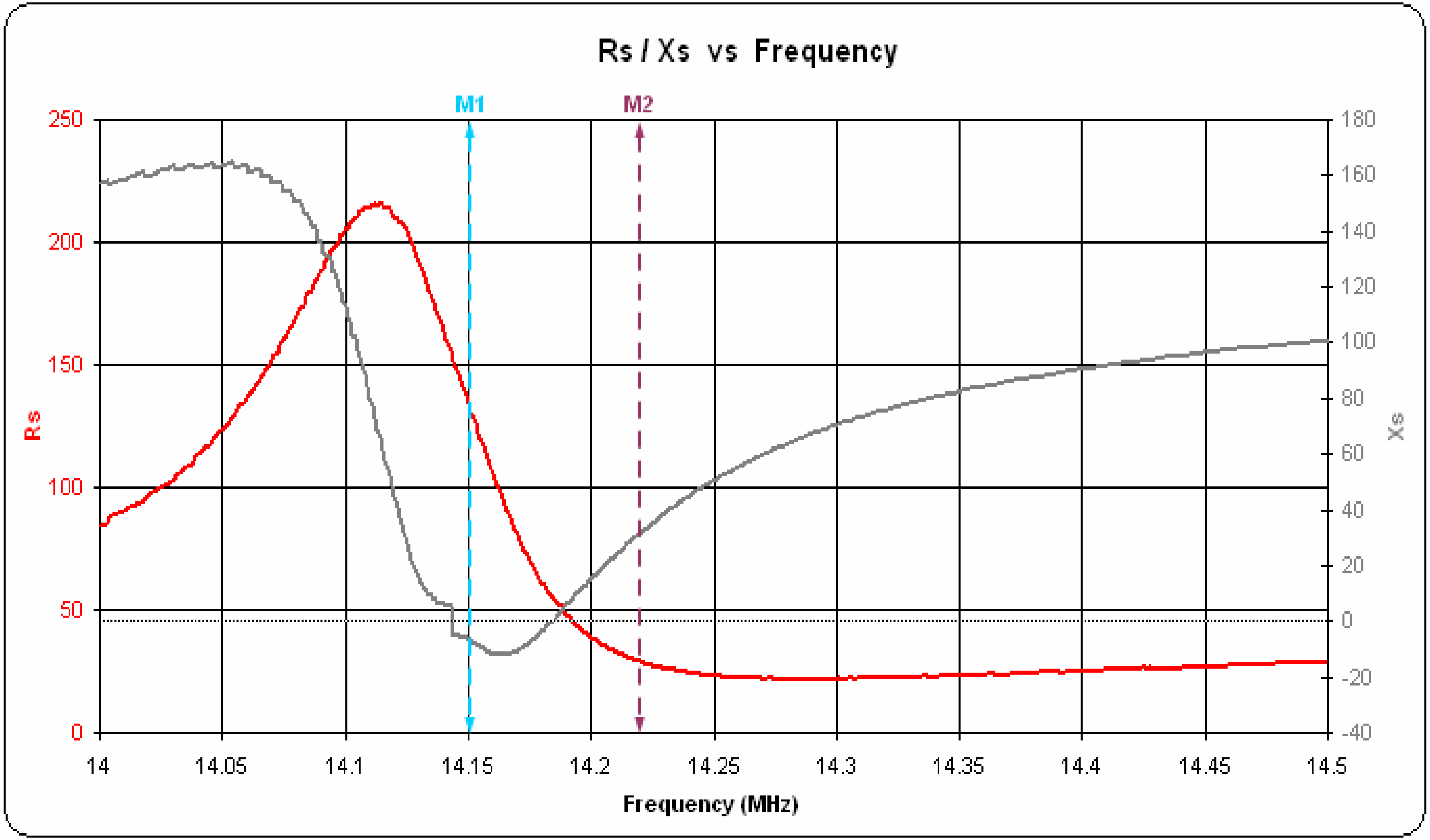


1. BNC DUT: rf out / antenna. WARNING! Do not connect to RF transmitter
2. BNC DET: detector (transmission mode only). WARNING! Do not connect to RF transmitter
3. LED TX, RX: USB communication running (run mode).
4. LED POWER: *miniVNA* power on.
5. USB: USB connection (B type).

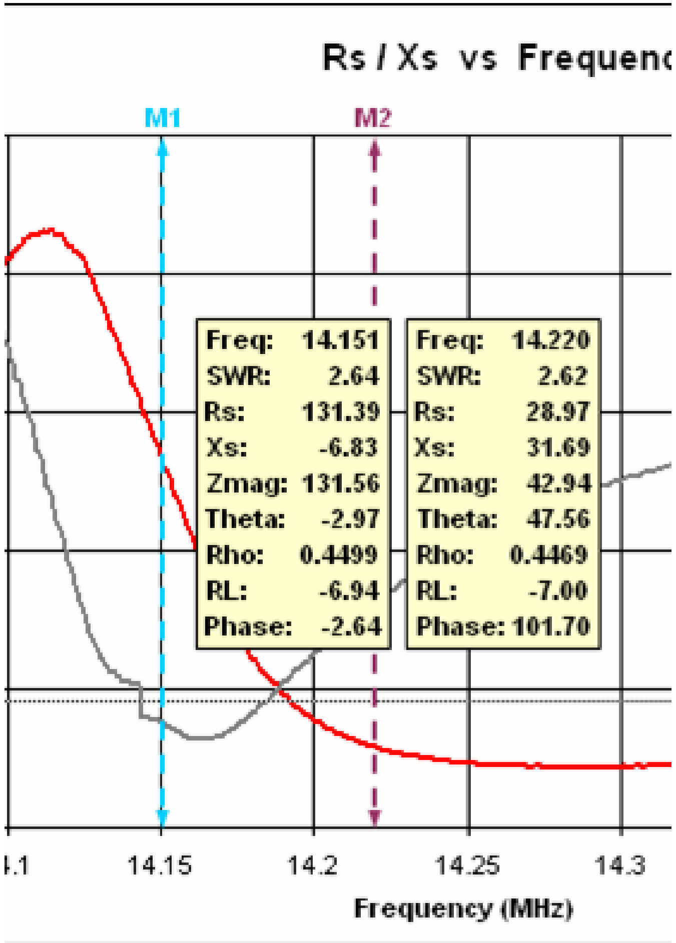
LPA-1C Ramsey Linear Power Amplifier Kit: * Frequency: 100kHz - 1GHz , * Output: 1W, * Supply: 12 - 15V DC @ 250mA

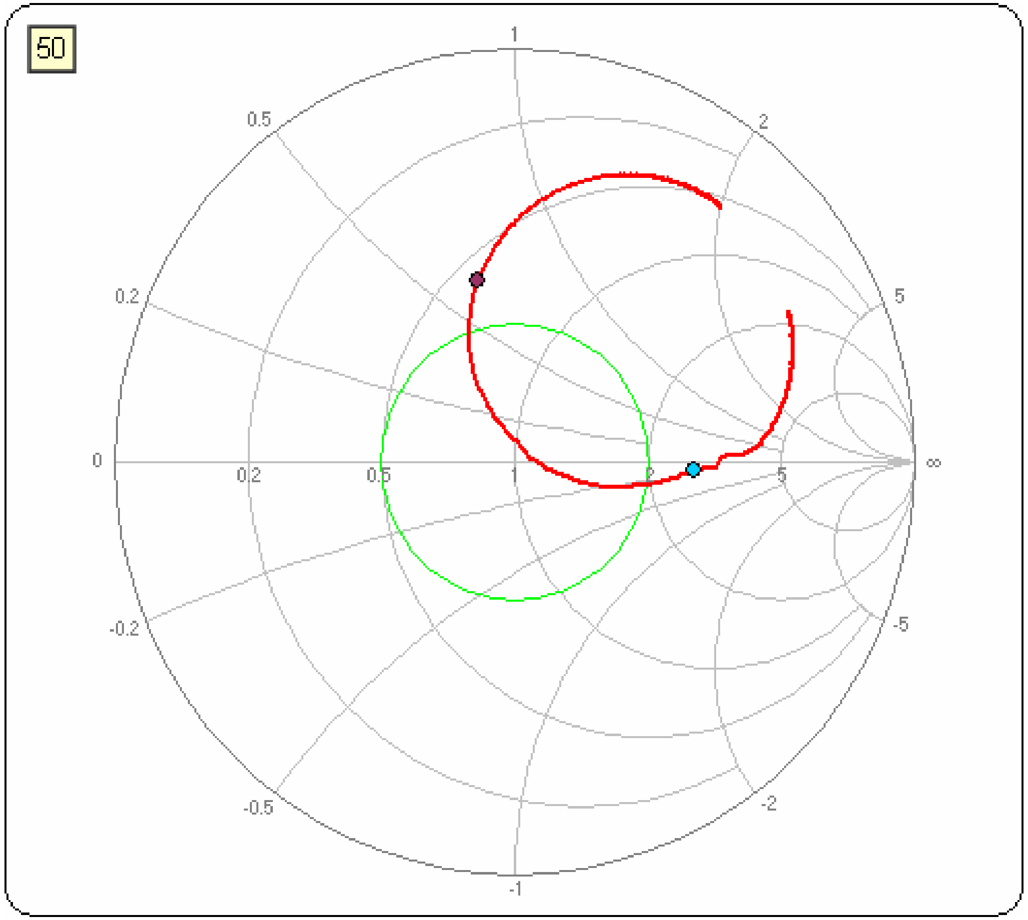
Gain of 25 – 30dB extends transmission range by > 10 times

MiniVNA Plot of AMA3 – as used for the 'fluorescent' tube demo

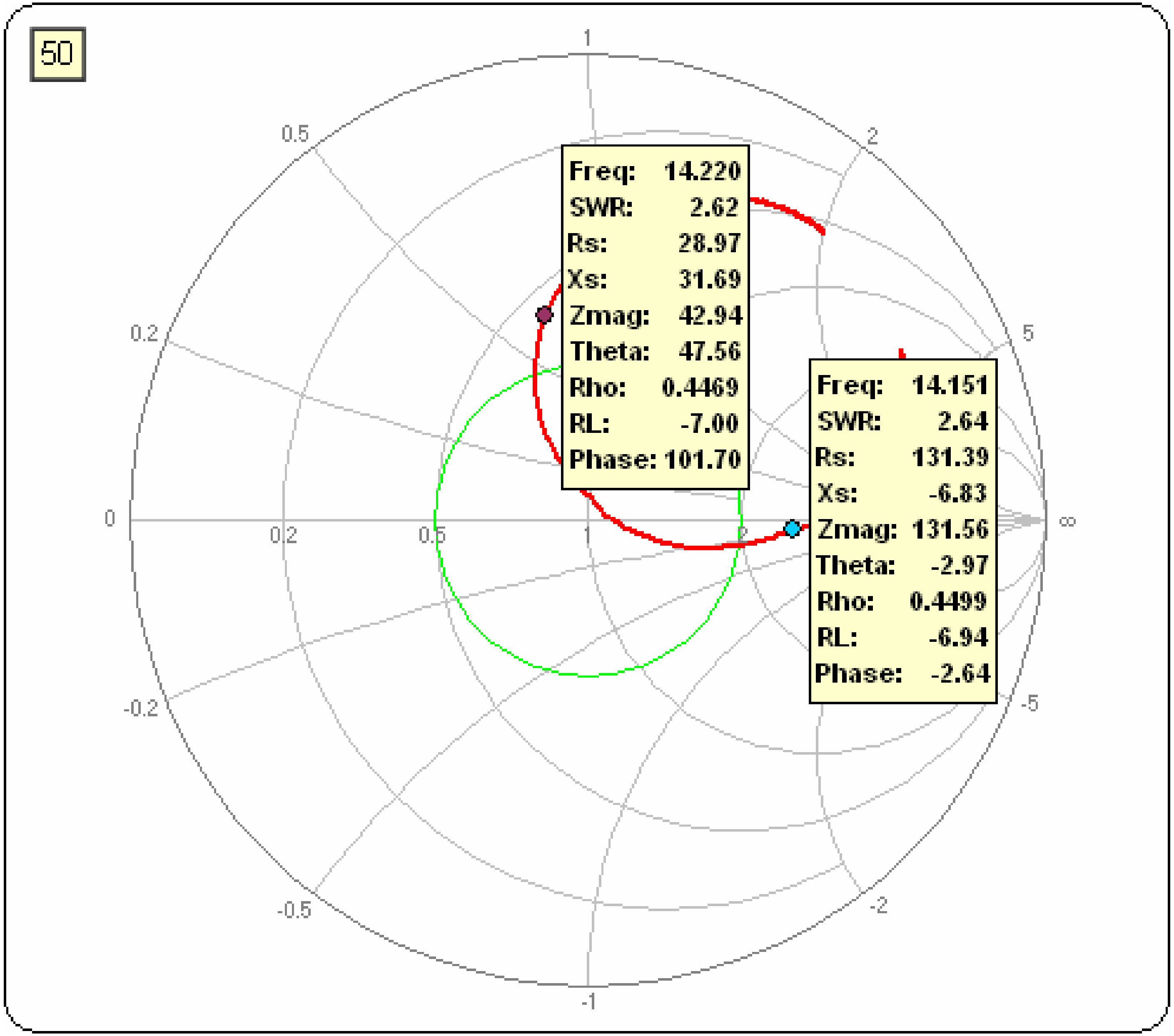


MiniVNA Plot of AMA3

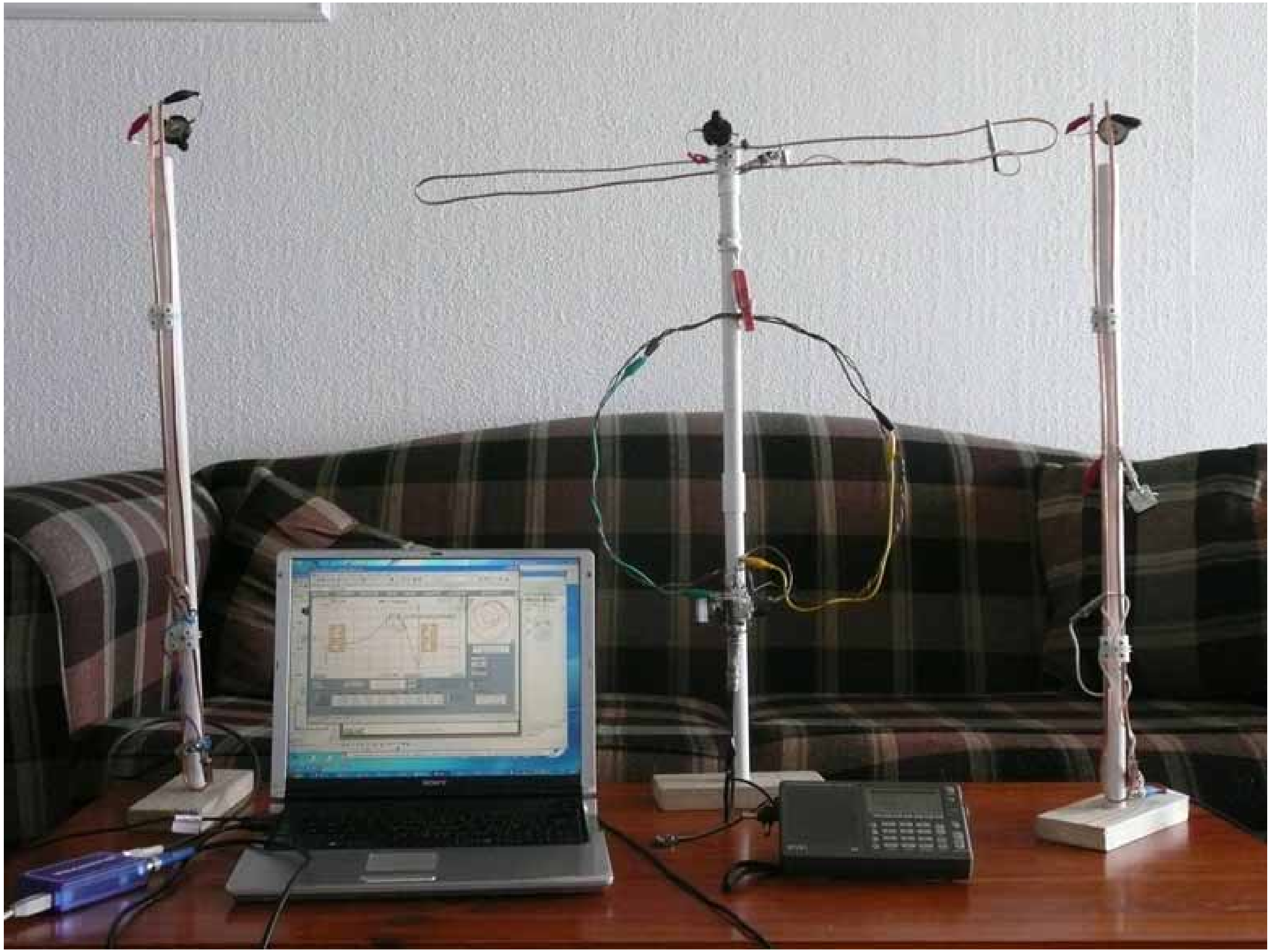




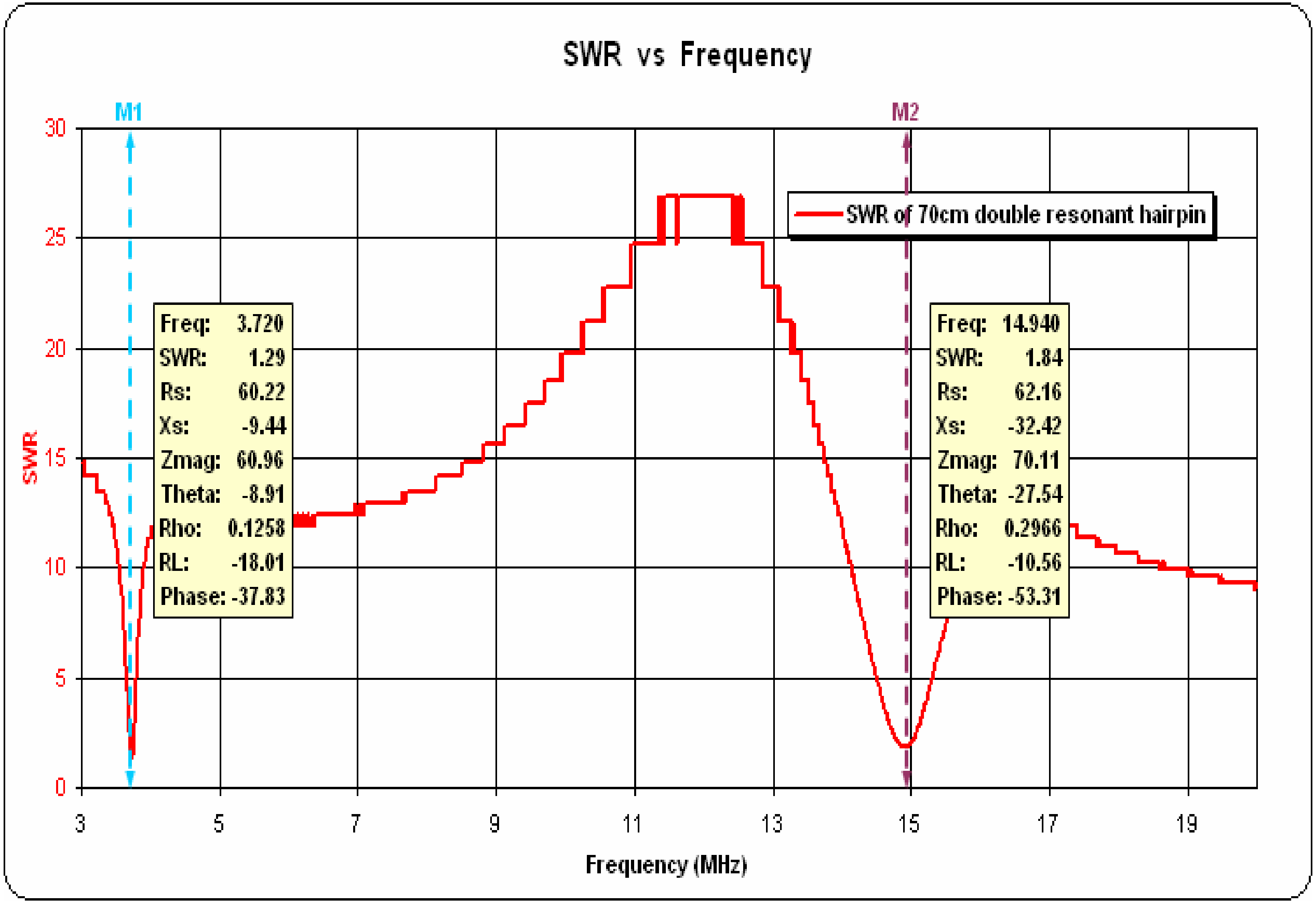
MiniVNA Plot of AMA3



miniVNA demo, 2×70cm hairpins (one double tuned on right), 70cm tuned folded dipole, and 35cm 1-150MHz double tuned loop



Double Tuned 70cm Hairpin SWR Plot



Simple Rho-Q Method for Antenna Efficiency-2

- For (phosphorous de-oxygenated) plumbing copper the DC conductivity is on average 85% that of pure copper. Its DC resistivity is therefore

$$\rho = 1.72\times10^{-8}/(0.85) = 2.0\times10^{-8} \text{ ohm metres.} \qquad (3)$$

- The Rloss for plumbing copper in ohms for frequency in MHz is then

$$Rloss(Cu) = 8.94\times10^{-5}\sqrt{(fMHz)}\times Cir/d \qquad (4)$$

- For typical aluminium the DC loss resistivity is 2.5 times higher than plumbing copper and its skin effect resistance is $\sqrt{2.5}$ = 1.58 times higher. For Q = 300 the loss for aluminium tube can be given as

$$Rloss(Al) = 1.41\times10^{-4}\sqrt{(fMHz)}\times Cir/d \qquad (5)$$

- These values are then use in the above efficiency formula. The following spreadsheet has been created to facilitate this:

Rho-Q Loop Efficiency Spreadsheet

Efficiency of Tuned Loop Antennas by Q Measurement for: Single turn 1m diam,10mm plumbing copper tube,.balanced bottom feed, capacitor at top.

Q = f0/(f2-f1). (NB put title and values in the blue shaded boxes)

f1 = lower 3dB freq, f2 = upper 3dB freq, in MHz, both with SWR = 2.62:1 f0 = (f1+ f2)/2 = centre freq, MHz with SWR = 1:1.

One loop circumference in metres, Cir =	3.14	Conductor diameter, metres, d = 0.01
Measured inductance value in uH, Lm =		Calculated Inductance, Le in uH =m×0.52 Cir/(d)^0.13 = 2.97
Chosen inductance value in uH, L =	2.97	Loop reactance Xl = 2π f0 L Rtot = Xl/Q
Conductor resistivity at DC, ρ =	2.00E-08	Skin-effect Rloss = 2m×√(0.1×f0×ρ)×Cir/d Rrad = Rtot-Rloss
Chu radius in metres, a =	0.5	Loop Eff % = 100%×(Rrad/Rtot) C = Capacitor Value = 1E6/(2πf0Xl)
Half dipole mode length in metres z =	0.5	Cap volts = √(WQXl) Loop current = √(WQ/Xl)
Kraus loop radius in metres r =	0.5	Dipole Efficiency = 100%/(1+Rtot/Rdip) where Rdip =m^2× 4×800(z f0/300)^2
W =Power Input in watts =	400	Kraus Efficiency = 100%/(1+Rtot/Rkraus) where Rkraus = m^2×20×π^2×8(π r f0/150)^4
n loops: m=n if series, m=1/n if parallel, m:	1	Chu Efficiency = 100%/(1+RtotQchu/Xl) where Qchu = 1/(ka)^3 = (150/πf0a)^3

f1 (3dB), in MHz	f2(3dB), in MHz	f0 in MHz	Measured Q	Loop Reactance Xl	Measured Rtot	Skin-effect loss = Rloss	Rrad=Total Radiation Resistance	Measured Efficiency = Eff %	Capacitor Voltage	Loop Current (amps)	Cap Value in pF	Dipole mode Resist.	Efficiency of Dipole mode %	Kraus Loop Resist.	Kraus Loop Eff %	Chu Resist.	Chu Efficiency %
Short twisted gamma match:-																	
1.9804	1.9916	1.986	177.3	37.1	0.209	0.0396	0.170	81.07	1621.6	43.7	2161.5	0.009	4.023	0.00004	0.018	0.0003	0.159
2.4876	2.5006	2.494	191.9	46.6	0.243	0.0444	0.198	81.72	1890.3	40.6	1370.5	0.014	5.389	0.00009	0.038	0.0008	0.341
2.9988	3.0139	3.006	199.1	56.1	0.282	0.0487	0.233	82.73	2114.2	37.7	943.3	0.020	6.651	0.00020	0.069	0.0018	0.617
3.4913	3.5066	3.499	228.7	65.3	0.286	0.0525	0.233	81.61	2444.4	37.4	696.4	0.027	8.697	0.00036	0.124	0.0032	1.112
3.9871	4.0045	3.996	229.6	74.6	0.325	0.0561	0.269	82.72	2617.7	35.1	533.9	0.036	9.847	0.00061	0.186	0.0055	1.655
4.9942	5.0135	5.004	259.3	93.4	0.360	0.0628	0.297	82.56	3112.5	33.3	340.5	0.056	13.377	0.00150	0.411	0.0134	3.596
5.9855	6.0068	5.996	281.5	111.9	0.398	0.0688	0.329	82.71	3550.3	31.7	237.1	0.080	16.731	0.00309	0.766	0.0277	6.515
6.9946	7.0207	7.008	268.5	130.8	0.487	0.0743	0.413	84.74	3748.3	28.7	173.6	0.110	18.298	0.00577	1.161	0.0517	9.593
8.5324	8.5674	8.550	244.3	159.6	0.653	0.0821	0.571	87.43	3949.2	24.7	116.6	0.163	19.911	0.01279	1.904	0.1146	14.918
10.048	10.098	10.073	201.5	188.0	0.933	0.0891	0.844	90.45	3892.8	20.7	84.0	0.227	19.456	0.02468	2.551	0.2207	19.124
11.991	12.046	12.019	218.5	224.4	1.027	0.0974	0.929	90.52	4428.5	19.7	59.0	0.322	23.816	0.04998	4.602	0.4473	30.344
14.187	14.268	14.227	180.1	265.6	1.475	0.1059	1.369	92.82	4373.9	16.5	42.1	0.452	23.369	0.09832	6.185	0.8762	37.322
Long twisted gamma match:-																	
1.9805	1.992	1.986	172.7	37.1	0.215	0.0396	0.175	81.56	1600.6	43.2	2160.9	0.009	3.923	0.00004	0.017	0.0003	0.155
2.4881	2.5012	2.495	190.4	46.6	0.245	0.0444	0.200	81.86	1883.5	40.4	1369.9	0.014	5.352	0.00009	0.038	0.0008	0.338
3.0009	3.0148	3.008	216.4	56.2	0.259	0.0487	0.211	81.23	2204.6	39.3	942.3	0.020	6.374	0.00020	0.075	0.0018	0.672
3.492	3.5071	3.500	231.8	65.3	0.282	0.0525	0.229	81.36	2461.0	37.7	696.1	0.027	8.804	0.00036	0.126	0.0032	1.128
3.9887	4.0057	3.997	235.1	74.6	0.317	0.0562	0.261	82.31	2649.2	35.5	533.6	0.036	10.062	0.00061	0.191	0.0055	1.695
4.9956	5.0157	5.006	249.0	93.4	0.375	0.0628	0.312	83.25	3051.0	32.6	340.2	0.056	12.921	0.00150	0.396	0.0135	3.463
5.9888	6.0105	6.000	276.5	112.0	0.405	0.0688	0.336	83.02	3519.5	31.4	236.8	0.080	16.490	0.00310	0.754	0.0278	6.417
7.0003	7.0251	7.013	282.8	130.9	0.463	0.0744	0.389	83.94	3848.1	29.4	173.4	0.110	19.097	0.00578	1.225	0.0518	10.071
8.5409	8.5738	8.557	261.7	159.8	0.610	0.0822	0.528	86.54	4089.3	25.6	116.4	0.163	21.046	0.01283	2.042	0.1150	15.847
10.058	10.105	10.082	214.5	188.2	0.877	0.0892	0.788	89.84	4018.5	21.4	83.9	0.227	20.472	0.02475	2.719	0.2215	20.153
12.013	12.065	12.039	231.5	224.8	0.971	0.0974	0.873	89.96	4562.2	20.3	58.8	0.323	24.913	0.05030	4.886	0.4504	31.690
14.214	14.296	14.255	173.841	266.122	1.531	0.106	1.425	93.07	4301.765	16.165	41.954	0.454	22.779	0.09915	6.018	0.885	36.640

Rho-Q Loop Efficiency Spreadsheet

- The spreadsheet automates the Rho-Q method.
- Loop dimensions are inserted in blue shaded boxes at top.
- The pairs of 3dB frequencies that are the Q measurements are put in the two blue shaded columns at the left.
- Un-shaded columns are calculated outputs.
- The formulas for these outputs are given in the top rows.
- The measurements shown are for the experimental 1m diameter loop of 10mm copper plumbing tube shown left.
- It has two twisted gamma matches of different lengths, switched at the bottom.
- There is no significant difference in efficiency η for a short twisted gamma feed (top measurements) or a long twisted gamma (bottom measurements).
- Other feeds also give the same efficiency.
- The measured loop efficiency is compared with the classical predictions. Note the large discrepancies!
- Included are (a) Tuning capacitance values (b) Capacitor voltage for given power input, and (c) loop current.
- *Qmode* is the estimated Q for a conducting material with zero resistivity. $Qmode = Qmeas/\eta$)

Rho-Q Loop Efficiency Spreadsheet - 2

f1 (3dB), in MHz	f2(3dB), in MHz	f0 in MHz	Measured Q	Loop Reactance Xl	Measured Rtot	Skin-effect loss = Rloss	Rrad=Total Radiation Resistance	Measured Efficiency = Eff %	Capacitor Voltage	Loop Current (amps)	Cap Value in pF	Estimated Mode Q
Short twisted gamma match:-												
1.9804	1.9916	1.986	177.3	37.1	0.209	0.0396	0.170	81.07	1621.6	43.7	2161.5	218.72
2.4876	2.5006	2.494	191.9	46.6	0.243	0.0444	0.198	81.72	1890.3	40.6	1370.5	234.76
2.9988	3.0139	3.006	199.1	56.1	0.282	0.0487	0.233	82.73	2114.2	37.7	943.3	240.67
3.4913	3.5066	3.499	228.7	65.3	0.286	0.0525	0.233	81.61	2444.4	37.4	696.4	280.23
3.9871	4.0045	3.996	229.6	74.6	0.325	0.0561	0.269	82.72	2617.7	35.1	533.9	277.63
4.9942	5.0135	5.004	259.3	93.4	0.360	0.0628	0.297	82.56	3112.5	33.3	340.5	314.02
5.9855	6.0068	5.996	281.5	111.9	0.398	0.0688	0.329	82.71	3550.3	31.7	237.1	340.38
6.9946	7.0207	7.008	268.5	130.8	0.487	0.0743	0.413	84.74	3748.3	28.7	173.6	316.84
8.5324	8.5674	8.550	244.3	159.6	0.653	0.0821	0.571	87.43	3949.2	24.7	116.6	279.40
10.048	10.098	10.073	201.5	188.0	0.933	0.0891	0.844	90.45	3892.8	20.7	84.0	222.73
11.991	12.046	12.019	218.5	224.4	1.027	0.0974	0.929	90.52	4428.5	19.7	59.0	241.41
14.187	14.266	14.227	180.1	265.6	1.475	0.1059	1.369	92.82	4373.9	16.5	42.1	194.02
Long twisted gamma match:-												
1.9805	1.992	1.986	172.7	37.1	0.215	0.0396	0.175	81.56	1600.6	43.2	2160.9	211.76
2.4881	2.5012	2.495	190.4	46.6	0.245	0.0444	0.200	81.86	1883.5	40.4	1369.9	232.63
3.0009	3.0148	3.008	216.4	56.2	0.259	0.0487	0.211	81.23	2204.6	39.3	942.3	266.40
3.492	3.5071	3.500	231.8	65.3	0.282	0.0525	0.229	81.36	2461.0	37.7	696.1	284.85
3.9887	4.0057	3.997	235.1	74.6	0.317	0.0562	0.261	82.31	2649.2	35.5	533.6	285.67
4.9956	5.0157	5.006	249.0	93.4	0.375	0.0628	0.312	83.25	3051.0	32.6	340.2	299.13
5.9888	6.0105	6.000	276.5	112.0	0.405	0.0688	0.336	83.02	3519.5	31.4	236.8	333.03
7.0003	7.0251	7.013	282.8	130.9	0.463	0.0744	0.389	83.94	3848.1	29.4	173.4	336.89
8.5409	8.5736	8.557	261.7	159.8	0.610	0.0822	0.528	86.54	4089.3	25.6	116.4	302.38
10.058	10.105	10.082	214.5	188.2	0.877	0.0892	0.788	89.84	4018.5	21.4	83.9	238.77
12.013	12.065	12.039	231.5	224.8	0.971	0.0974	0.873	89.96	4562.2	20.3	58.8	257.35
14.214	14.296	14.255	173.841	266.122	1.531	0.106	1.425	93.07	4301.765	16.165	41.954	186.78

Rho-Q Loop Efficiency Spreadsheet - 3

Efficiency of Tuned Loop Antennas by Q Measurement for:

f1 (3dB), in MHz	f2(3dB), in MHz	f0 in MHz	Rrad=Total Radiation Resistance	Measured Efficiency = Eff %	Capacitor Voltage	Dipole mode Resist.	Efficiency of Dipole mode %	Kraus Loop Resist.	Kraus Loop Eff %	Chu Resist.	Chu Efficiency %	Estimated Mode Q
Short twisted gamma match:-												
1.9804	1.9916	1.986	0.170	81.07	1621.6	0.009	4.023	0.00004	0.018	0.0003	0.159	218.72
2.4876	2.5006	2.494	0.198	81.72	1890.3	0.014	5.389	0.00009	0.038	0.0008	0.341	234.76
2.9988	3.0139	3.006	0.233	82.73	2114.2	0.020	6.651	0.00020	0.069	0.0018	0.617	240.67
3.4913	3.5066	3.499	0.233	81.61	2444.4	0.027	8.697	0.00036	0.124	0.0032	1.112	280.23
3.9871	4.0045	3.996	0.269	82.72	2617.7	0.036	9.847	0.00061	0.186	0.0055	1.655	277.63
4.9942	5.0135	5.004	0.297	82.56	3112.5	0.056	13.377	0.00150	0.411	0.0134	3.596	314.02
5.9855	6.0068	5.996	0.329	82.71	3550.3	0.080	16.731	0.00309	0.766	0.0277	6.515	340.38
6.9946	7.0207	7.008	0.413	84.74	3748.3	0.110	18.298	0.00577	1.161	0.0517	9.593	316.84
8.5324	8.5674	8.550	0.571	87.43	3949.2	0.163	19.911	0.01279	1.904	0.1146	14.918	279.40
10.048	10.098	10.073	0.844	90.45	3892.8	0.227	19.456	0.02468	2.551	0.2207	19.124	222.73
11.991	12.046	12.019	0.929	90.52	4428.5	0.322	23.816	0.04998	4.602	0.4473	30.344	241.41
14.187	14.266	14.227	1.369	92.82	4373.9	0.452	23.369	0.09832	6.185	0.8782	37.322	194.02
Long twisted gamma match:-												
1.9805	1.992	1.986	0.175	81.56	1600.6	0.009	3.923	0.00004	0.017	0.0003	0.155	211.76
2.4881	2.5012	2.495	0.200	81.86	1883.5	0.014	5.352	0.00009	0.038	0.0008	0.338	232.63
3.0009	3.0148	3.008	0.211	81.23	2204.6	0.020	6.374	0.00020	0.075	0.0018	0.672	266.40
3.492	3.5071	3.500	0.229	81.36	2461.0	0.027	8.804	0.00036	0.126	0.0032	1.128	284.85
3.9887	4.0057	3.997	0.261	82.31	2649.2	0.036	10.062	0.00061	0.191	0.0055	1.695	285.67
4.9956	5.0157	5.006	0.312	83.25	3051.0	0.056	12.921	0.00150	0.396	0.0135	3.463	299.13
5.9888	6.0105	6.000	0.336	83.02	3519.5	0.080	16.490	0.00310	0.754	0.0278	6.417	333.03
7.0003	7.0251	7.013	0.389	83.94	3848.1	0.110	19.097	0.00578	1.225	0.0518	10.071	336.89
8.5409	8.5736	8.557	0.528	86.54	4089.3	0.163	21.046	0.01283	2.042	0.1150	15.847	302.38
10.058	10.105	10.082	0.788	89.84	4018.5	0.227	20.472	0.02475	2.719	0.2215	20.153	238.77
12.013	12.065	12.039	0.873	89.96	4562.2	0.323	24.913	0.05030	4.886	0.4504	31.690	257.35
14.214	14.296	14.255	1.425	93.07	4301.765	0.454	22.779	0.09915	6.018	0.885	36.640	186.78

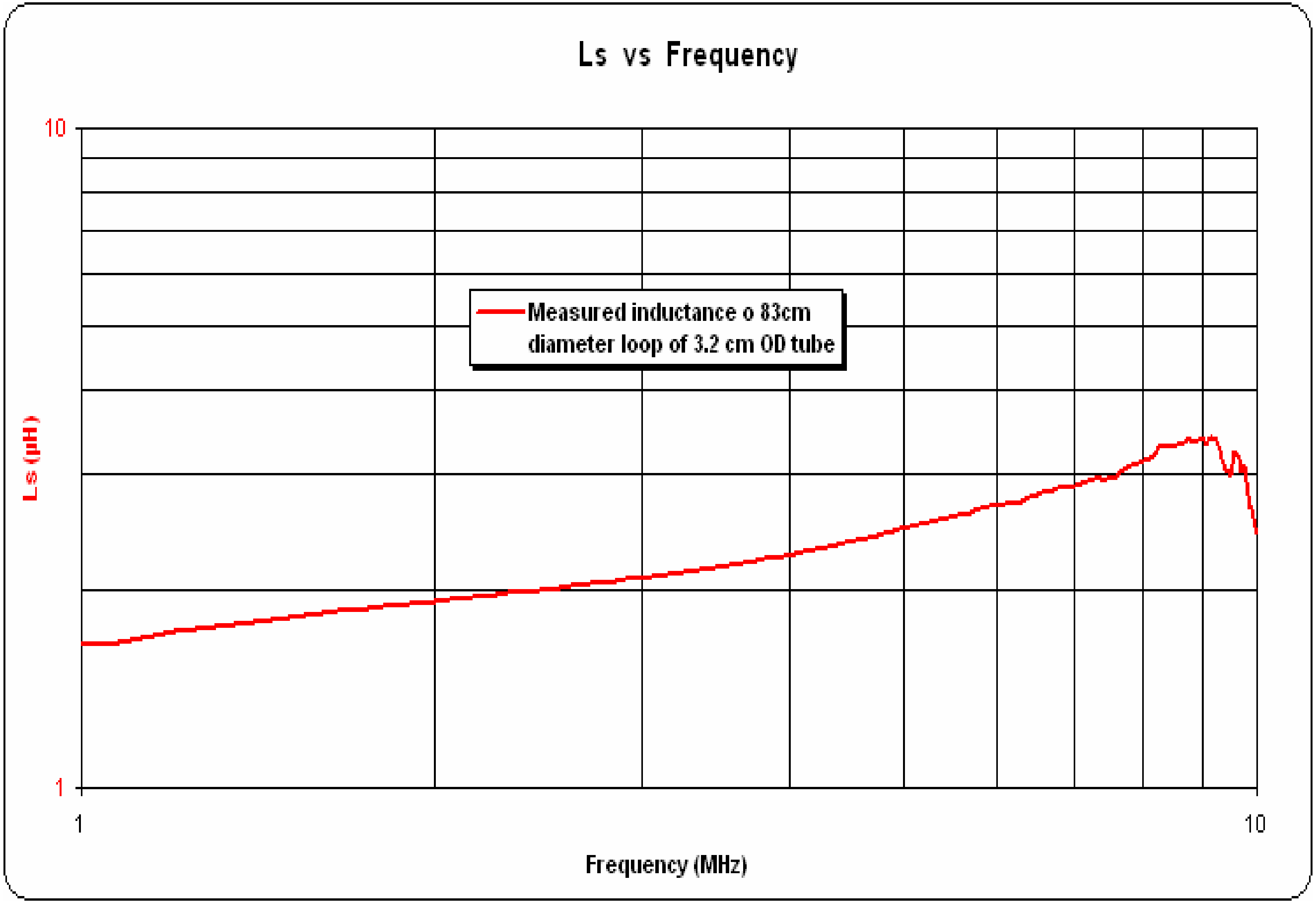
The importance of the simple Rho-Q Method for Antenna Efficiency

- Each Q measurement immediately provides an efficiency answer at each measurement frequency
- No formula for radiation resistance has to be assumed.
- No ground losses need be taken into account.
- No ground wave propagation formula is needed.
- The (loop) antenna pattern above ground is not needed.
- No field sensors have to be calibrated (at the point of use).
- The DC resistivity values of loop conductor materials are well established.
- **It shows that a copper loop of 10mm diameter (or aluminum tube of 17mm) will be 80% to 90% efficient, whatever its length! Much larger is a waste of copper (or aluminium).**

Wideband-Q ‘ Heuristic’ Method for Measuring All Radiation Resistance and Loss Components

- *Relies on measuring Q over as wide a tuning range as possible and fitting these measurements heuristically to a simple equivalent circuit model.*
- Components can be separated because each varies differently with frequency and, or antenna size.
- The value of the model parameters for each component are chosen to give the best fit of model and experiment. Accurate if Q > ~15.
- Inductance of loop or capacitance of dipole/monopole was originally assumed constant with frequency up to antenna self resonance.
  - The latest (miniVNA) measurements indicate that **loop inductance increases weakly with frequency**. An approximately $f^{1/2}$ law has been measured over a frequency decade. Thus loop Q appears to increase with frequency as $f^{1/2}$.
- Total combined series resistance is then given as reactance/Q = X_L/Q or X_c/Q.
- For the best fit to measurements we find (unexpectedly) that **the resistances** are “uncorrelated” and **have to be combined by a “root mean square” (RMS) operation.**
  - The explanation is that all resistance components are distributed and are not directly coupled to each other.

Inductance of single turn loop appears to vary with frequency!



Loop Radiation Resistance Components

The Wideband Q 'Method is a 'Heuristic' Method that extracts and separates from one set of more than n+1 measurements the following n radiation and loss resistance components:-

1. *Traditional loop radiation resistance*:-

$$R_{trad} = 31{,}171\ (A/\lambda^2)^2 = 20\pi^6\ (D/\lambda)^4 = 19{,}228(D/\lambda)^4$$

 – Only becomes appreciable near loop self resonance at f_{res}(MHz) ≈ 22/D.
 – Can be enhanced near ground or with connected or unconnected ground plane.

2. *New*ly discovered *loop radiation resistance – the Retarded Biot-Savart Mode*

$$R_{loop} = X_L/Q = X_L D/500.$$

where $X_L = 2\pi f L,\ L \cong 1\mu H \times \pi D$ in practice, and $Q \sim 500/D(metres)$

 – This is affected by presence of the ground image and ground resistance; it can be halved (and the Q doubled) in the extreme case.

3. *Dipole mode radiation resistance*.

$$R_{dip} \cong (\pi/2)^2 \times 20\ (ka)^2 = (\pi/2)^2 \times 20\ (\pi D/\lambda)^2 = 487 \times (D/\lambda)^2$$

 – Can also be enhanced by presence of ground or ground planes.

Loop Loss Resistance Components – continuation.

4. *Conductor losses for copper tube*

$$R_{loss} = 7.07 \times 10^{-6} \times \pi \, (D_{loop} / D_{tube}) \, (f_{MHz})^{0.5}$$

– Conductor loss resistance. Has a square root of frequency law because of "skin effect".

6. *Conductor losses in nearby walls etc*. Also has $f^{1/2}$ characteristic. Varies depending on distance from walls.

6. Losses from ground conductivity σ and dielectric ε. These have a cut-off frequency f_c when $\sigma = 2\pi f \varepsilon$. $f_c \sim$ 1-30MHz

– novel *observation*?

7. Ground (re-)radiation resistance. This is not ground reflection. It is radiation from the induced ground currents as if the ground were a patch antenna. It is most marked for highly conductive ground.

– novel *observation*?

Comments on the Various Radiation Mode and Loss Resistances found by the 'Heuristic' Wideband Q Method.

The Wideband Q 'Method is a 'Heuristic' Method that extracts and separates from one set of more than n+1 measurements the following n resistance parameters:-

1. **The traditional loop mode** - yes, it is there and is just detectable at the higher frequencies - Hooray! - honour is saved, and the reputations of the pundits and experts can remain intact!
2. **The (folded) dipole mode** - at least this is gaining grudging acceptance by the loop experts - it was my original attempt to explain the loop measurement discrepancy, but it was not a large enough effect to fully explain the results at low frequencies.
3. **The new 'Retarded Biot-Savart' (RBS) loop mode** - this is hotly disputed by those who have not performed any (suitable) measurements. The above Q technique is a suitable method of measurement.
4. **Conductor loss** - this is found to obey the "skin effect" square-root of frequency law as might be expected.

Comments on the Various Radiation Mode and Loss Resistances found by the 'Heuristic' Wideband Q Method. - continued.

5. **Wall loss** - adjacent walls and ceilings of buildings and anechoic chambers often give the same "skin effect" square-root of frequency ($f^{1/2}$)loss law as for the conductor loss. Steel re-inforced concrete walls give losses that are very significant even at a considerable distance.
6. **Ground resistance** - presumed to be a combination of *loss*, *ground current radiation* and creation of *ground wave* - the latter two can explain the differing behavior of the CFA over sand, muddy fields and seawater. We have used a loop to detect and measure the transition frequency of a muddy field, given by the soil constants (epsilon and sigma) quoted in the books. A low-pass cut-off law agrees with the results as expected and predicted.
7. **Height of a loop above ground** actually appears to enhance the square of frequency law followed by the dipole mode. Further measurements are needed to characterise and separate this effect.
8. **A Mathcad programme** models the input impedance of the loop, to separate the various effects and give the best possible parameter values for these. It is a very interesting multi-variable data analysis problem!

Tuned Loop Mathcad Worksheet Circuit Model – a simulation!

Features:

- Tuned Plots   e.g. Smith Chart & SWR.
- Envelope Plots e.g. SWR Envelope.
- Smith Chart Plot – 10K points.
- Choose tuning capacitor – plot match over frequency.
- Choose k_m Coupling(s) = $1/R_a$ = adjust gamma match.
- Choose input (gamma) inductance(s) (for SWR).
- Efficiencies.
- Capacitor Voltage and loop current.
- Actual Voltage Ratio (0.02 watts input).
- Q curves
- Operating Bandwidth.
- ***Compare with measurements to separate all resistance components***

MJU Mathcad Loop Worksheet - 1

Small Tuned Loop Design Worksheet

MJU - December 2001

Steps to plot $k := f_{min} \cdot f_{step}^{-1} .. f_{max} \cdot f_{step}^{-1}$ $f(k) := f_{step} \cdot k$ $\omega_k := 2 \cdot \pi \cdot f(k)$

Frequency; $f_{min} \equiv 1.8 \cdot 10^6$ to $f_{max} \equiv 30 \cdot 10^6$. in $f_{step} \equiv 10 \cdot 10^3$ linear steps.

Impedance Equation for Loop

$$Z_k := i \cdot \omega_k \cdot L_2 + r_a^{-2} \cdot \left[\left(i \cdot \omega_k \cdot L_1 + R_{tot}(k) \right)^{-1} + i \cdot \omega_k \cdot C_1 \right]^{-1}$$

r_a is the effective transformer ratio of the input (gamma) match .

$$\Gamma(k) := \frac{Z_k - 50}{Z_k + 50} \qquad VSWR(k) := \frac{1 + |\Gamma(k)|}{1 - |\Gamma(k)|}$$

Typical mode and loss weights:-
for R_{env} : k_e = 0.005 to 0.025
for R_{trad} : k_t = 1
for R_{ground}: k_c = 0.125 and f_g = 4MHz
dip :- for no dipole mode (e.g. multi-turn loop) : dip = 0
for dipole mode: dip = 1
for ground-plane mode: dip = ~1.5
for elevated g-p loop: dip = 2

$k_e \equiv 0.08$

$k_t \equiv 0.4$

$k_c \equiv 0.1$

$f_g \equiv 10 \cdot 10^6$

$k_{dip} \equiv 0.39$

a = 1 gives 100% coupling of modes. Larger a decouples the modes. Use a =2? $a \equiv 2$

Choose loop dimensions:-

$D_{loop.m} \equiv .68$ $D_{tube.mm} \equiv 8$

Cu = 0.0707
Al = 0.128

$Tube_{loss} \equiv 0.0707$

$$b \equiv \frac{\pi \cdot D_{loop.m}}{D_{tube.mm}} \cdot Tube_{loss}$$

Choose gamma coupling k_m. =l / r_a , where r_a is effective turns ratio. :

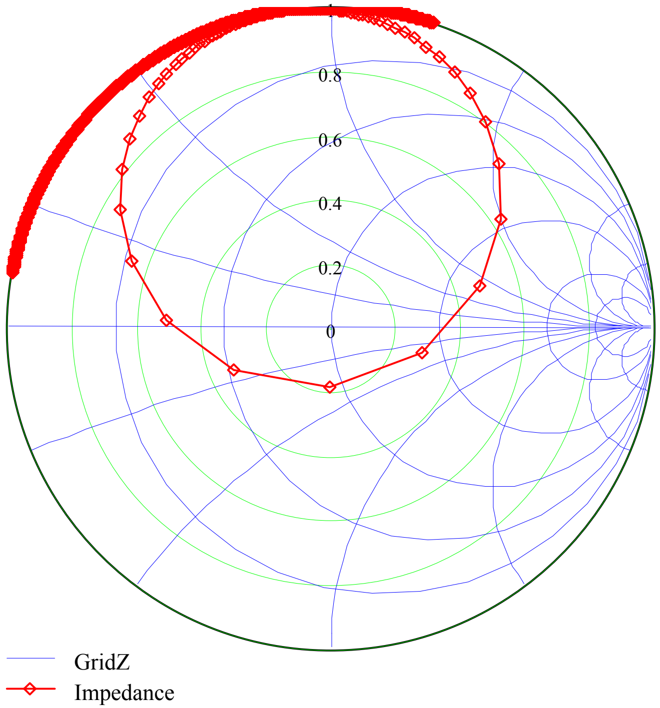
$$k_m \equiv \frac{1}{32}$$

$$r_a \equiv k_m^{-1}$$

Choose : $C_1 \equiv 40 \cdot 10^{-12}$

$$L_1 \equiv \frac{\pi \cdot D_{loop.m}^{1.25}}{\left(0.167 \cdot D_{tube.mm}\right)^{0.167}} \cdot 10^{-6}$$

Choose intrinsic loop Qil = 300 to 600 $Q_{il} \equiv 520$



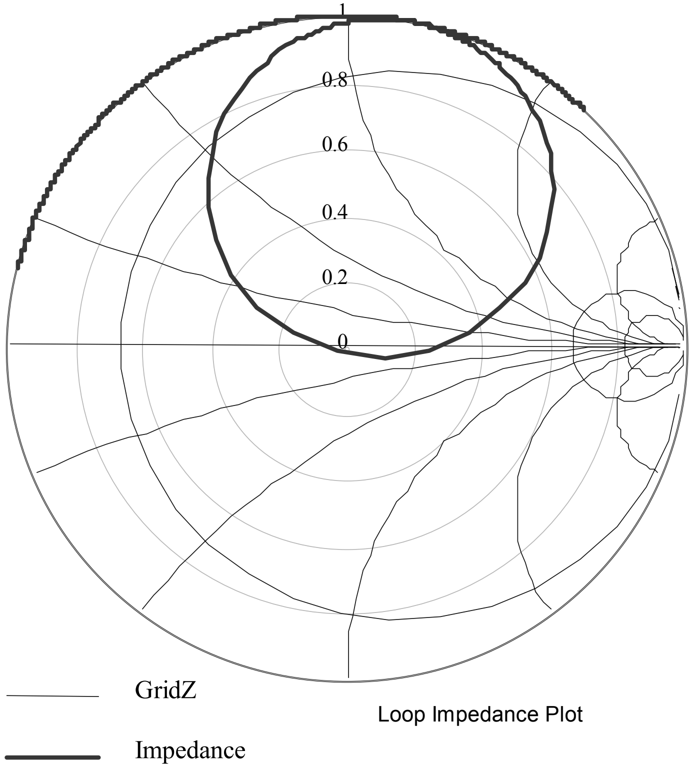
Smith Chart - (r = 0.2 is 1.5:1 SWR)

$$f_{res} := \left[2\pi \left(L_1 \cdot C_1 \right)^{0.5} \right]^{-1}$$

f_{res} is the loop resonant frequency $f_{res} = 1.851 \times 10^7$

G3LHZ

Fig 2. Comparison of measured and predicted input impedance at centre of loop tuning range 10.21MHz



Smith Chart - (r = 0.2 is 1.5:1 SWR)

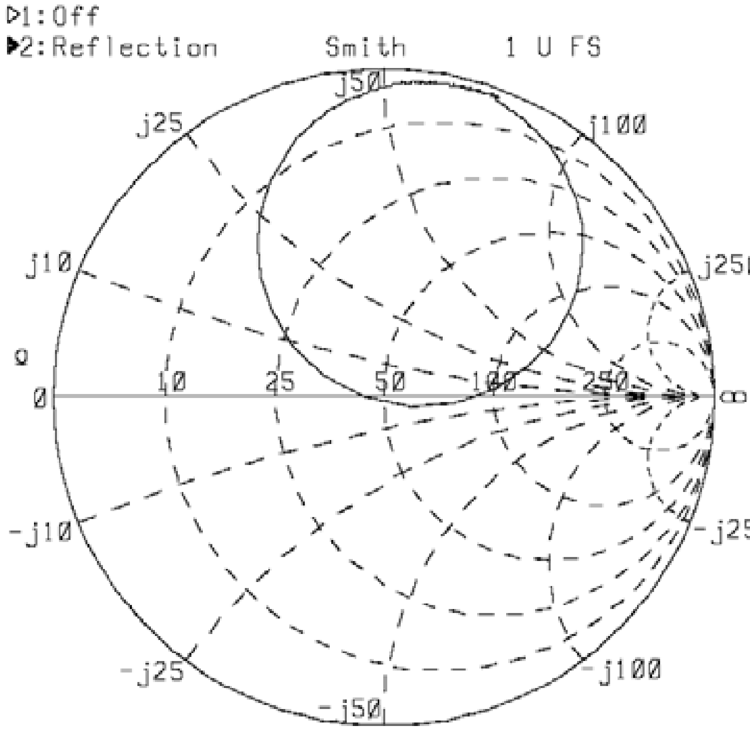
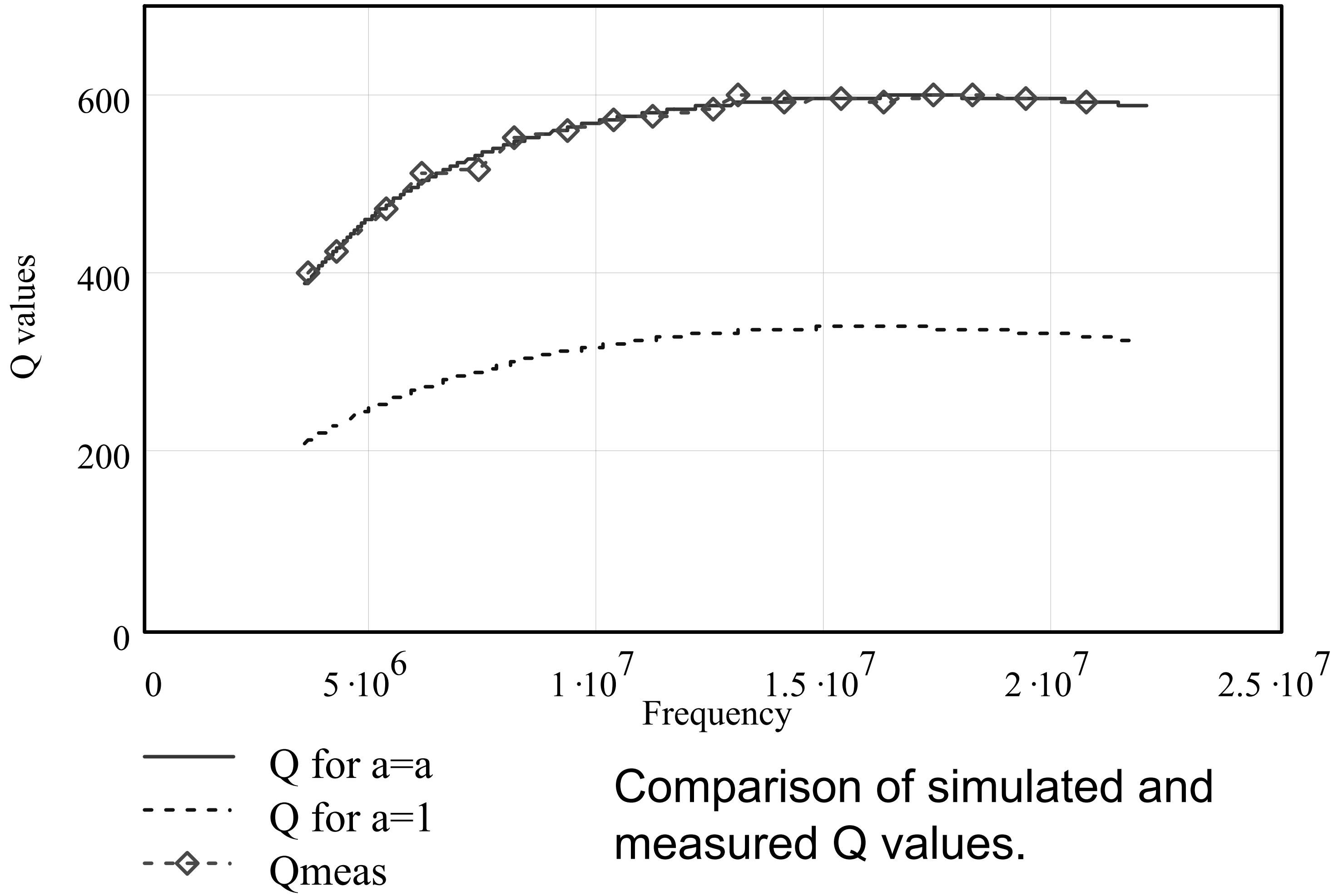


Fig 3. Comparison of measured Q values with model predictions over the loop tuning range.



Comparison of simulated and measured Q values.

MJU Mathcad Loop Worksheet - 2

$$R_{dip}(k) := \left(k_{dip} \cdot \frac{f(k) \cdot D_{loop.m}}{3 \cdot 10^{8}} \cdot \frac{\pi}{2}\right)^{2} \cdot 200$$

$$R_{loop}(k) := (\omega_{k} \cdot L_{1}) \cdot Q_{ml}^{-1}$$

$$R_{trad}(k) := \left[k_{t} \cdot \left(\frac{f(k) \cdot D_{loop.m}}{3 \cdot 10^{8}}\right)\right]^{4} \cdot 10\,\pi^{6}$$

$$R_{ground}(k) := k_{c} \cdot D_{loop.m}^{2} \cdot \left(1 + f(k)^{2} \cdot f_{g}^{-2}\right)^{-1}$$

$$R_{env}(k) := k_{e} \cdot \left(f(k) \cdot 10^{-6}\right)^{0.5}$$

Select Q table

$$Q_{f} := Q_{f2}$$

$$R_{loss}(k) := b \cdot \left(f(k) \cdot 10^{-6}\right)^{0.5}$$

$$R_{tot}(k) := \left(R_{loss}(k)^{a} + R_{ground}(k)^{a} + R_{loop}(k)^{a} + R_{env}(k)^{a} + R_{dip}(k)^{a} + R_{trad}(k)^{a}\right)^{\frac{1}{a}}$$

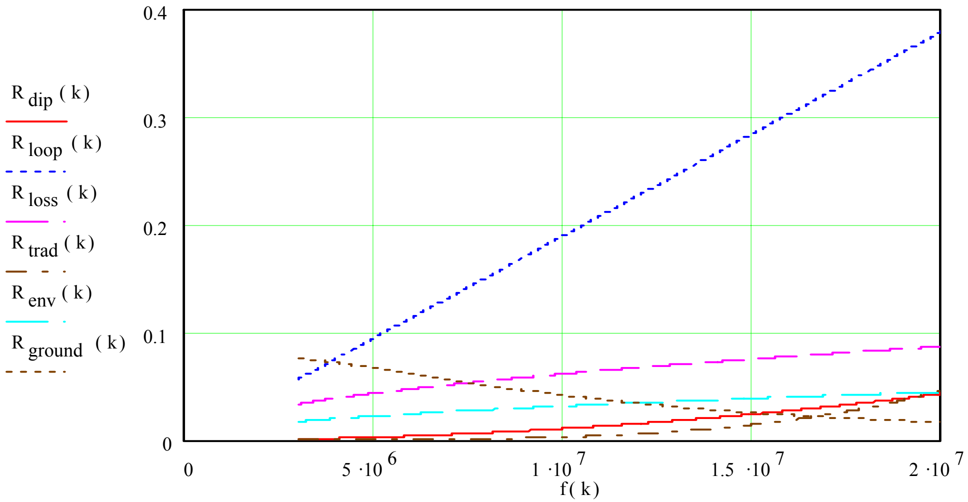
$$R_{tot1}(k) := \left(R_{loss}(k) + R_{ground}(k) + R_{loop}(k) + R_{env}(k) + R_{dip}(k) + R_{trad}(k)\right)$$

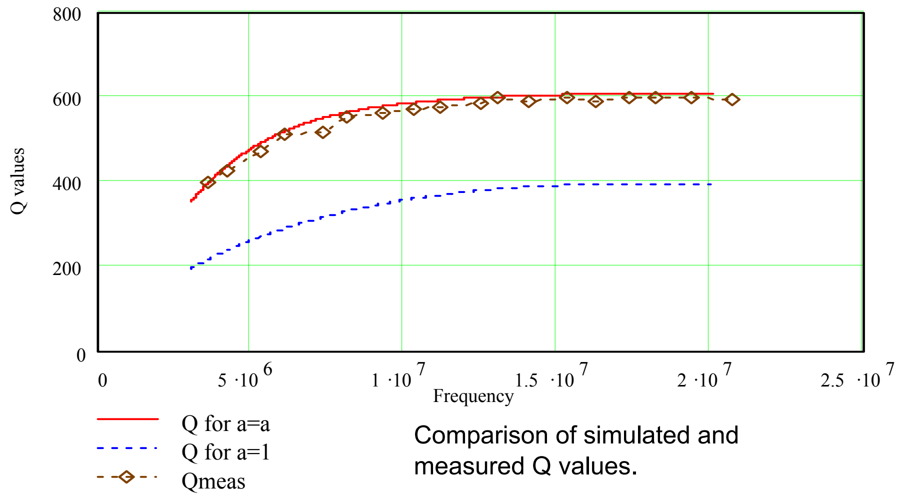
$$f_{m} := 10^{6} \cdot Q_{f}^{\langle 0 \rangle}$$

$$Q_{meas} := Q_{f}^{\langle 1 \rangle}$$

$$Q_{BW}(k) := \frac{\omega_{k} \cdot L_{1}}{\left(R_{tot}(k)\right)}$$

$$Q_{BW1}(k) := \frac{\omega_{k} \cdot L_{1}}{\left(R_{tot1}(k)\right)}$$





Comparison of simulated and measured Q values.

$$Eff(k) := \left[1 - \left(\frac{R_{loss}(k)}{R_{tot}(k)}\right)^{1}\right] \cdot 100$$

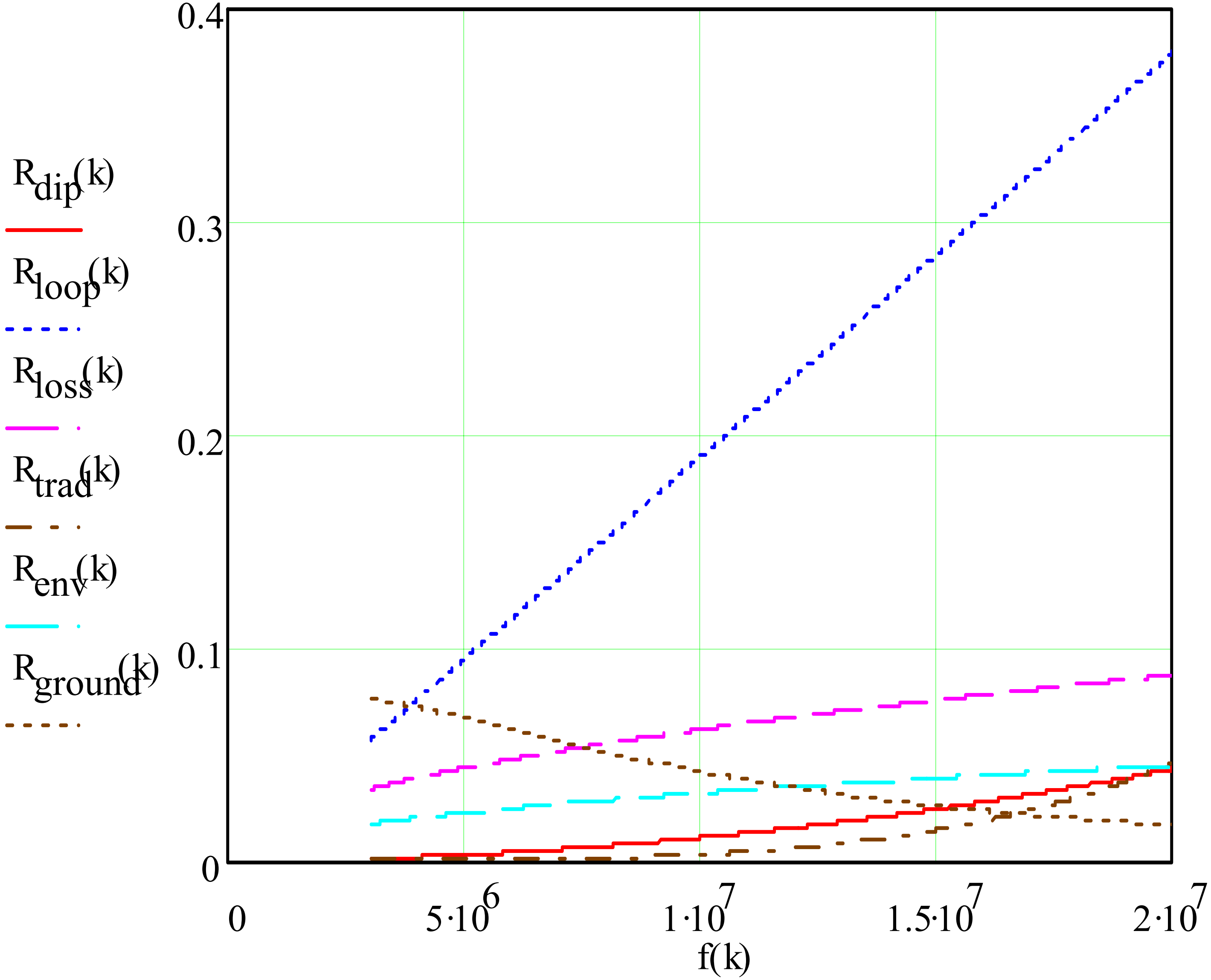
Operating Bandwidth for 1.5:1 SWR, BW(k) = 0.35BW(3dB)

$$BW(k) := \frac{0.35 \cdot f(k)}{Q_{BW}(k)}$$

MJU Mathcad Loop Worksheet - 3

Radiation Modes and Loss Resistances:

1. Folded Dipole Mode
2. New Loop Mode
3. Conductor Loss Resistance
4. Traditional (Kraus) Loop Mode
5. Detected Skin effect Environmental Loss
6. Ground Loss including cut-off frequency



The Chu-Wheeler Criterion for Small Antenna Q

- The ***original*** Chu-Wheeler criterion states that

$$Q_{min}(original) = (ka)^{-3}$$

  where a is the radius of the sphere just containing the small antenna and
  k = 2π/λ (the propagation constant).
  - **This criterion has been used to 'rubbish and condemn' many small antennas and to 'prove' that their inventors are 'charlatans'**
- From many plots of separate mode radiation and loss resistances (as in previous slide) we find an approximation for the ***real*** Chu-Wheeler criterion should be
  - for a one metre loop :

$$Q_{min}(reality) = [\{300/(ka)\}^2 + (ka)^6]^{0.5}$$

    this loop is typically 80% to 90% efficient.
  - For a 35cm loop

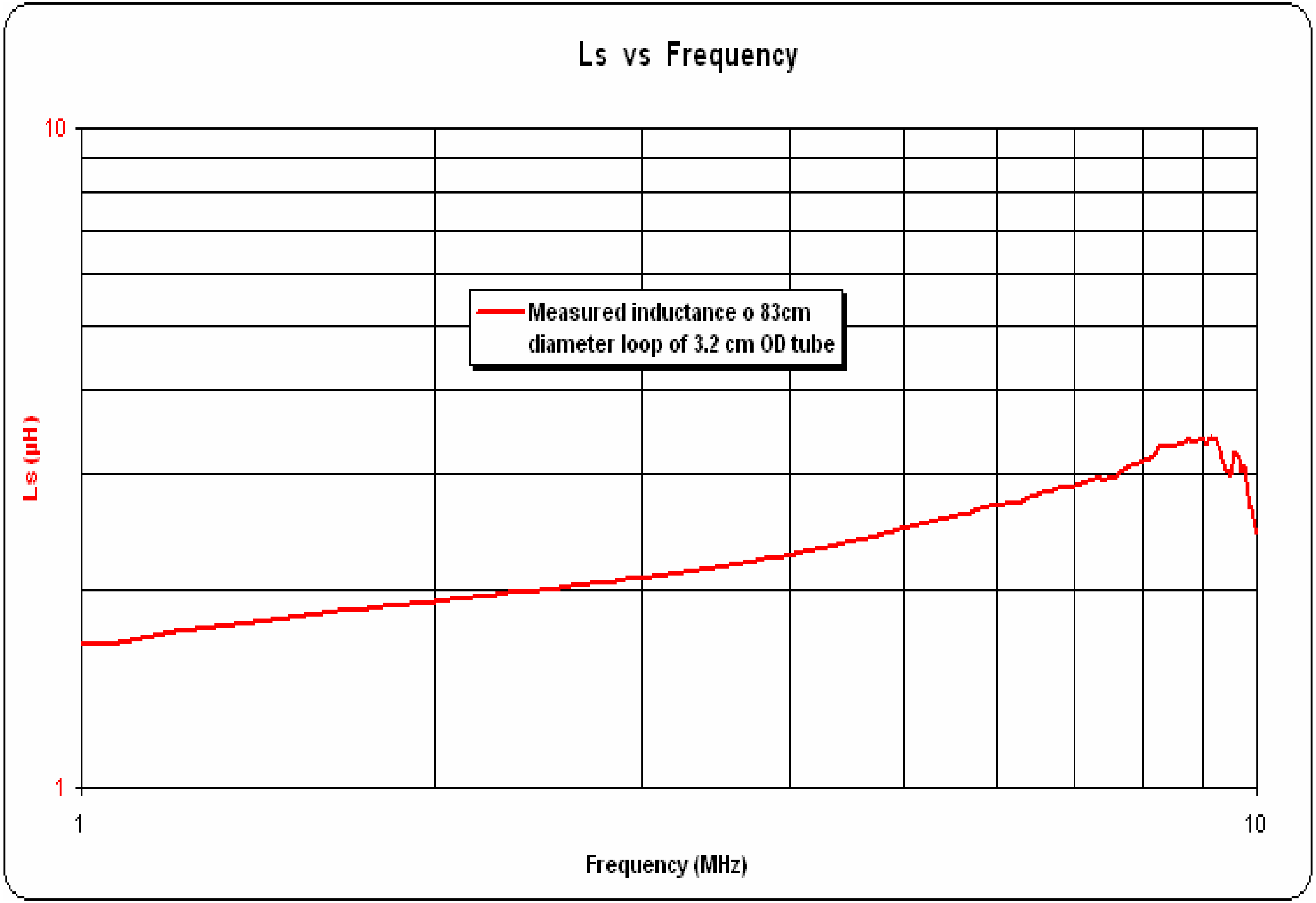
$$Q_{min}(reality) = [\{120\}^2/ka + (ka)^6]^{0.5}$$

  - ***Note that further measurements are needed to confirm the finding that the inductance of a 35cm loop varies as the square root of frequency!!!***
  - ***This has a major impact and means that loop efficiency drops very rapidly at smaller sizes than 35cm, but the measured Q does not.***
  - ***The loop radiation model needs further refinement***

Loop Design Formulas - Inductance

- The loop inductance defines the required capacitor values for the required tuning range.
- The loop diameter is D in metres. The wire/tubing diameter is d. C = loop circumference, and area = A. λ = wavelength.
- Traditional formula due to *Patterson* (of *Patterson* loop fame?)
  - $L(\mu H) = 0.00508A \times [2.303 \log (4A/d) - 2.451]$
  - This is not accurate for thin wires.
- A more complicated formula from *Grover* is more accurate.
- **New empirical formula** (- good for small loops):
  - $L(\mu H) = C(1.25D)^{1.6}/(160d)^{1/6}$
  - This is to be fine tuned when more measurements are available.
- **But beware, all is not what it seems when 'real' measurements are made – with an analyser, the miniVNA. See next slide:**

Inductance of single turn loop appears to vary with frequency!



68cm loop over wet field

$$R_{dip}(k) := \left(k_{dip} \cdot \frac{f(k) \cdot D_{loop.m}}{3 \cdot 10^8} \cdot \frac{\pi}{2}\right)^2 \cdot 200$$

$$R_{loop}(k) := (\omega_k \cdot L_1) \cdot Q_{ml}^{-1}$$

$$R_{trad}(k) := \left[k_t \cdot \left(\frac{f(k) \cdot D_{loop.m}}{3 \cdot 10^8}\right)\right]^4 \cdot 10\pi^6$$

$$R_{ground}(k) := k_c \cdot D_{loop.m}^{\;2} \cdot \left(1 + f(k)^2 \cdot f_g^{-2}\right)^{-1}$$

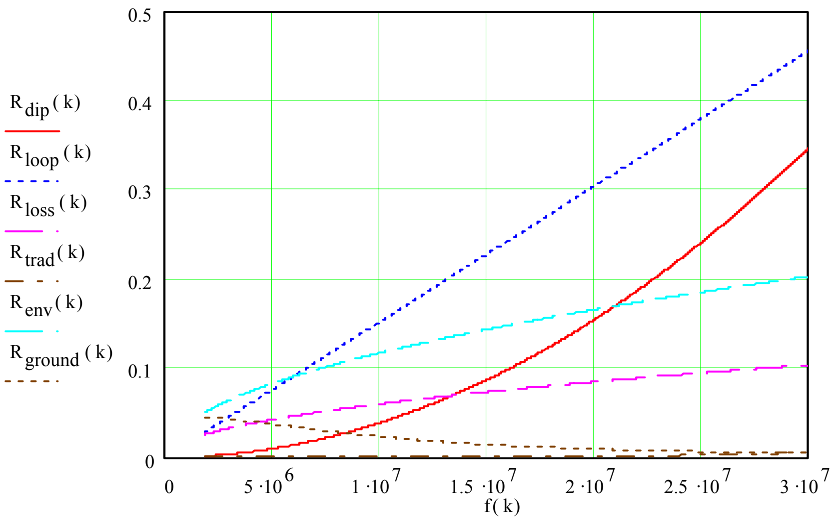
$$R_{env}(k) := k_e \cdot D_{loop.m}^{\;2} \cdot \left(f(k) \cdot 10^{-6}\right)^{0.5}$$

Select Q table

$$Q_f := Q_{f2}$$

$$R_{loss}(k) := b \cdot \left(f(k) \cdot 10^{-6}\right)^{0.5}$$

$$R_{tot}(k) := \left(R_{loss}(k)^a + R_{ground}(k)^a + R_{loop}(k)^a + R_{env}(k)^a + R_{dip}(k)^a + R_{trad}(k)^a\right)^{\frac{1}{a}}$$



$$R_{tot1}(k) := \left(R_{loss}(k) \ldots + R_{ground}(k) \ldots + R_{loop}(k) \ldots + R_{env}(k) \ldots + R_{dip}(k) \ldots + R_{trad}(k)\right)$$

$$f_m := 10^6 \cdot Q_f^{\langle 0 \rangle} \qquad Q_{meas} := Q_f^{\langle 1 \rangle}$$

$$Q_{BW}(k) := \omega_k \cdot L_1 \cdot R_{tot}(k)^{-1}$$

$$Q_{BW1}(k) := \omega_k \cdot L_1 \cdot R_{tot1}(k)^{-1}$$

$$Z_1(k) := \frac{1 \cdot k_m^{\;2} \cdot R_{tot}(k)^{-1} \cdot (\omega_k \cdot L_1)^2}{1 + (\omega_k \cdot L_2)^2 \cdot 50^{-2}}$$

In wet field

$D_{loop.m}$ = 0.68 $D_{tube.mm}$ = 8

for R_{env} : k_e =0.08

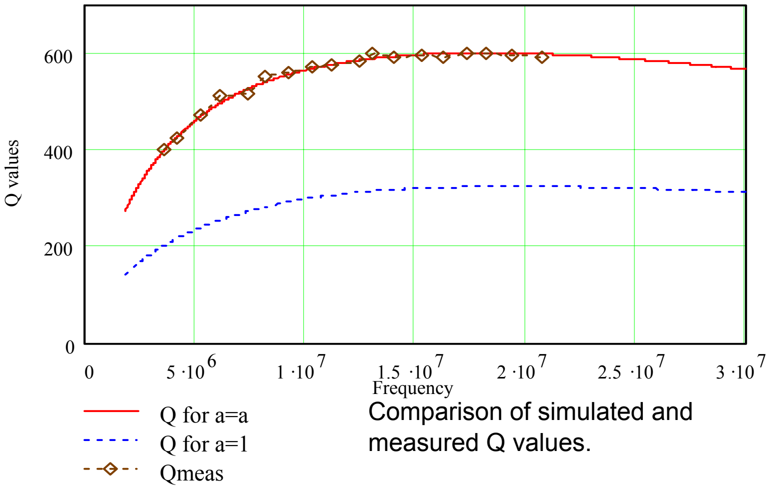
for R_{trad} : k_t = 0.4

for R_{ground}: k_c = O.1

and f_g =10MHz

k_{dip} = 0.39

k_m = 1/20 Q_{il} = 520



Comparison of simulated and measured Q values.

$$\Gamma_1(k) := (Z_1(k) - 50) \cdot (Z_1(k) + 50)^{-1}$$

$$SWR(k) := (1 + |\Gamma_1(k)|) \cdot (1 - |\Gamma_1(k)|)^{-1}$$

$$Eff_e(k) := \left[1 - \left(\frac{R_{loss}(k)^a + R_{env}(k)^a}{R_{tot}(k)^a}\right)^{\frac{1}{a}}\right] \cdot 100$$

$$Eff(k) := \left[1 - \left(\frac{R_{loss}(k)}{R_{tot}(k)}\right)^1\right] \cdot 100$$

Operating Bandwidth for 1.5:1 SWR, BW(k) = 0.35BW(3dB)

$$BW(k) := \frac{0.35 \cdot f(k)}{Q_{BW}(k)}$$

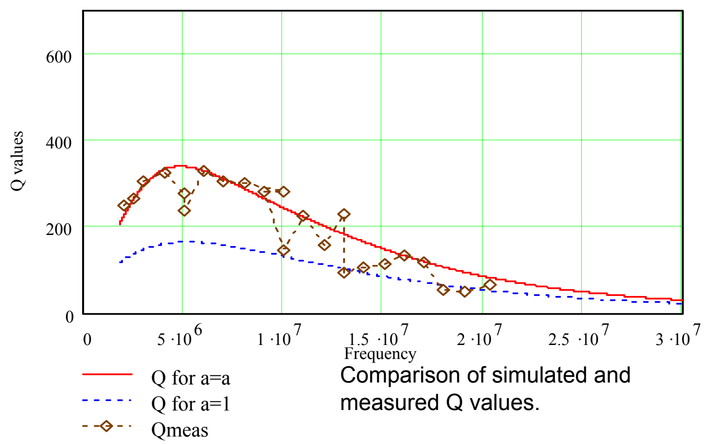
$1 + (\omega_k \cdot L_2)^2 \cdot 50$

$$\Gamma_1(k) := (Z_1(k) - 50)\cdot(Z_1(k) + 50)^{-1}$$

$$SWR(k) := (1 + |\Gamma_1(k)|)\cdot(1 - |\Gamma_1(k)|)^{-1}$$

$$Eff_e(k) := \left[1 - \left(\frac{R_{loss}(k)^a + R_{env}(k)^a}{R_{tot}(k)^a}\right)^{\frac{1}{a}}\right]\cdot 100$$

$$Eff(k) := \left[1 - \left(\frac{R_{loss}(k)}{R_{tot}(k)}\right)^1\right]\cdot 100$$



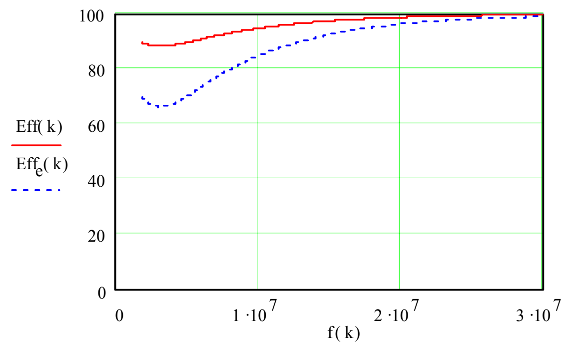
Comparison of simulated and measured Q values.

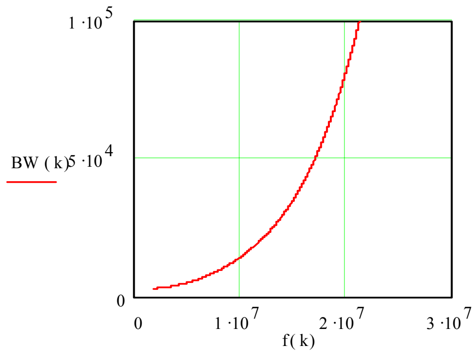
Operating Bandwidth for 1.5:1 SWR, BW(k) = 0.35BW(3dB)

$$BW(k) := \frac{0.35\cdot f(k)}{Q_{BW}(k)}$$

2 Turn Loop in Conservatory

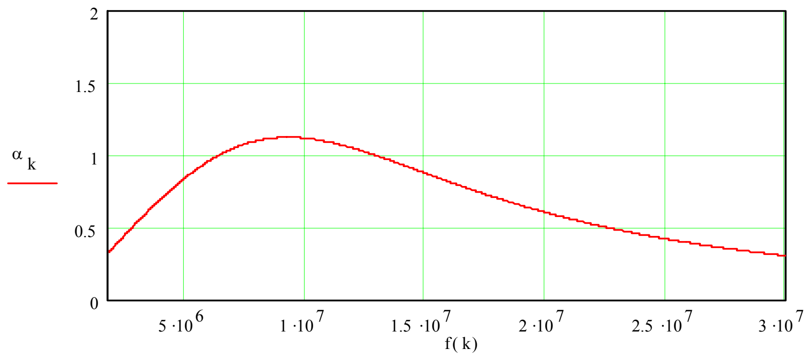
In conservatory
$D_{loop.m}$ = 1
$D_{tube,mm}$ = 2*10 =20
for R_{env} : k_e =0.03
for R_{trad} : k_t = 2.0
for R_{ground}: k_c = O.125
and f_g = 20MHz
k_{dip} = 1
k_m = 1/20
Q_{il} = 520





$$\alpha_k := \left(\frac{R_{dip}(k)}{R_{loop}(k) + R_{trad}(k)}\right)^1$$

α = dipole/ loop amplitude ratio. α = 1: means F/B ratio = ∞ and Dir = 3 (4.8dB). α = 2 or 0.5: means F/B ratio = 3 (9.5dB) and Dir = 2.7 (4.3dB). (Use α in AntPlotLoopDip)



Using Heuristics to resolve the 'Loop Controversy' once and for all time!

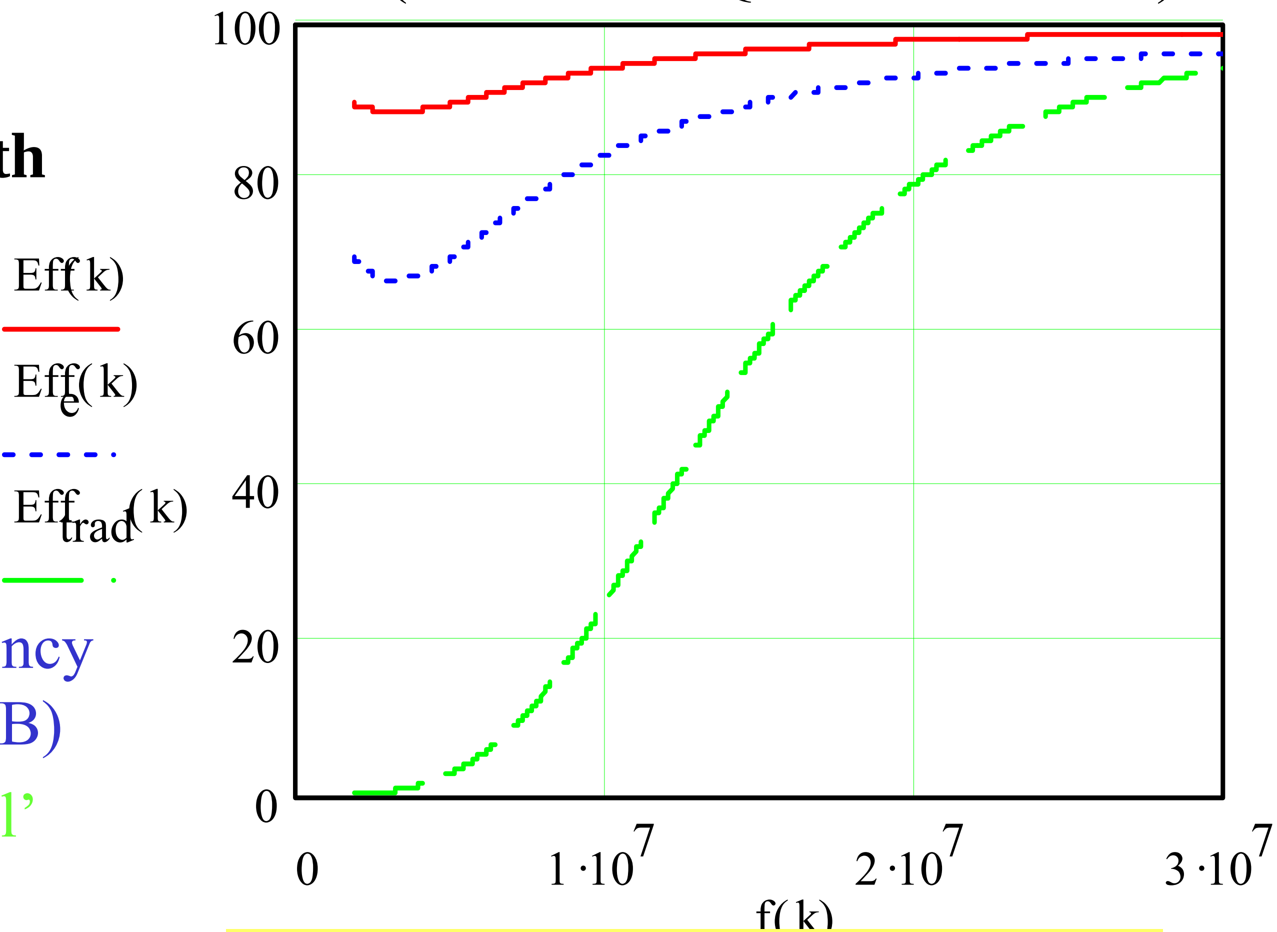
Method

- Four 'Heat Accounting' (heuristic) measurement methods based on the 'First Law of Thermodynamics' show that the small tuned loop of 10mm (or more) diameter copper tube is always 80% to 90% efficient
- The existing 'Chu-Wheeler Small Antenna Criterion' is firmly contradicted. It is in urgent need of revision to prevent it being used to do any more damage to small antenna design and invention .
- The 15 to 30dB discrepancy when efficiency measurements are made over 'real ground' needs further measurements and a 'heuristic' theory and explanation.
- **The loop critics have mistakenly included ground losses immediately under the loop and field sensor in their loop efficiency estimates.**
- **Note that the only 'safe' way of doing field strength measurements over ground, is between an identical pair of antennas.** The ground loss under both antennas is then easy to measure. The field at the half-way point can be calculated exactly and then used to calibrate any field sensor for further use.

Tuned Loop Efficiency – The Controversy is 'Classical Theory versus Practical Measurements' ('Wideband Q' measurements)

•**Two turn 1m loop with 10mm copper tube:**

1. Measured Intrinsic Efficiency = Eff(k) >88% (-0.6dB)
2. Measured Environmental Efficiency = $Eff_e(k)$ >66% (-1.8dB)
3. Traditional 'classical' prediction of Loop Efficiency = $Eff_{trad}(k)$. At 1.8MHz = 0.08% or -31dB !!!!

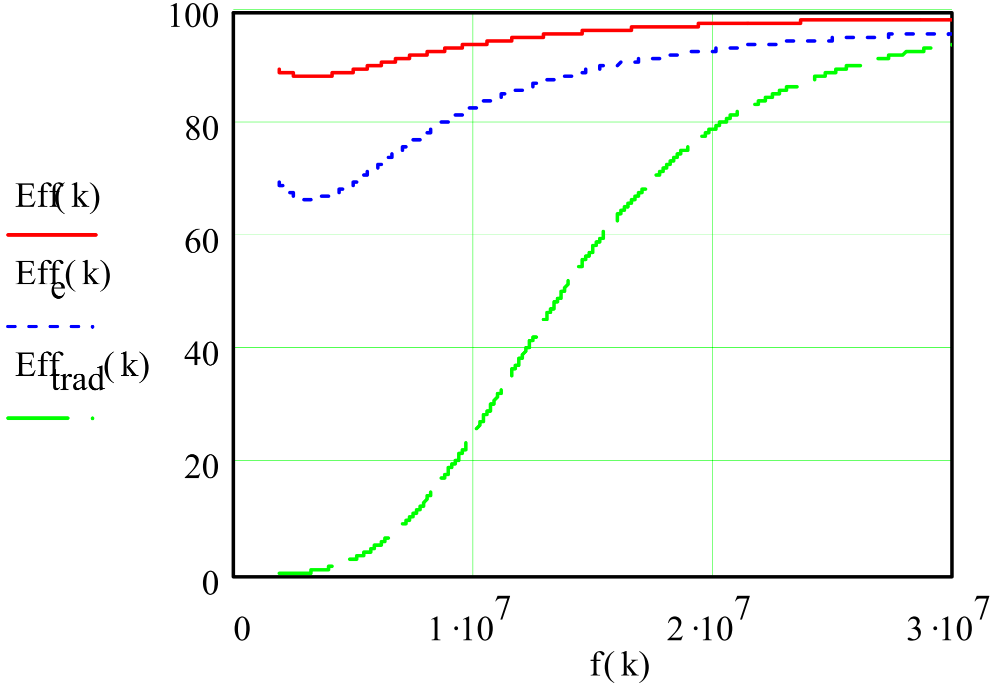


Classical	1.8MHz = -31dB
Theory:-	3.6MHz = -19dB
14MHz = -3dB	5MHz = -13dB
28MHz = -<1dB	7MHz = -6dB

Tuned Loop Efficiency – The Controversy

Definitions of Efficiency:

1. *Intrinsic Efficiency (in free-space)* – does the antenna get hot? The "Physics" efficiency.
2. *Near-field Environmental Efficiency* - as measured at antenna terminals.
3. *Ground-Wave Gain Efficiency* – in dBi or dBM, where M = Monopole.
4. *Sky-Wave Gain Efficiency* – at given elevation angle, in dBi or dBM



- Two turn 1m loop with 10mm copper tube:
  1. Measured Intrinsic Efficiency = Eff(k).
  2. Measured Environmental Efficiency = $Eff_e(k)$.
  3. Traditional predicted Loop Efficiency = $Eff_{trad}(k)$. At 1.8MHz = 0.08% or -31dB !!!!

DEFINITIONS OF ANTENNA EFFICIENCY AND EFFECTIVENESS

"Where does the power go?"

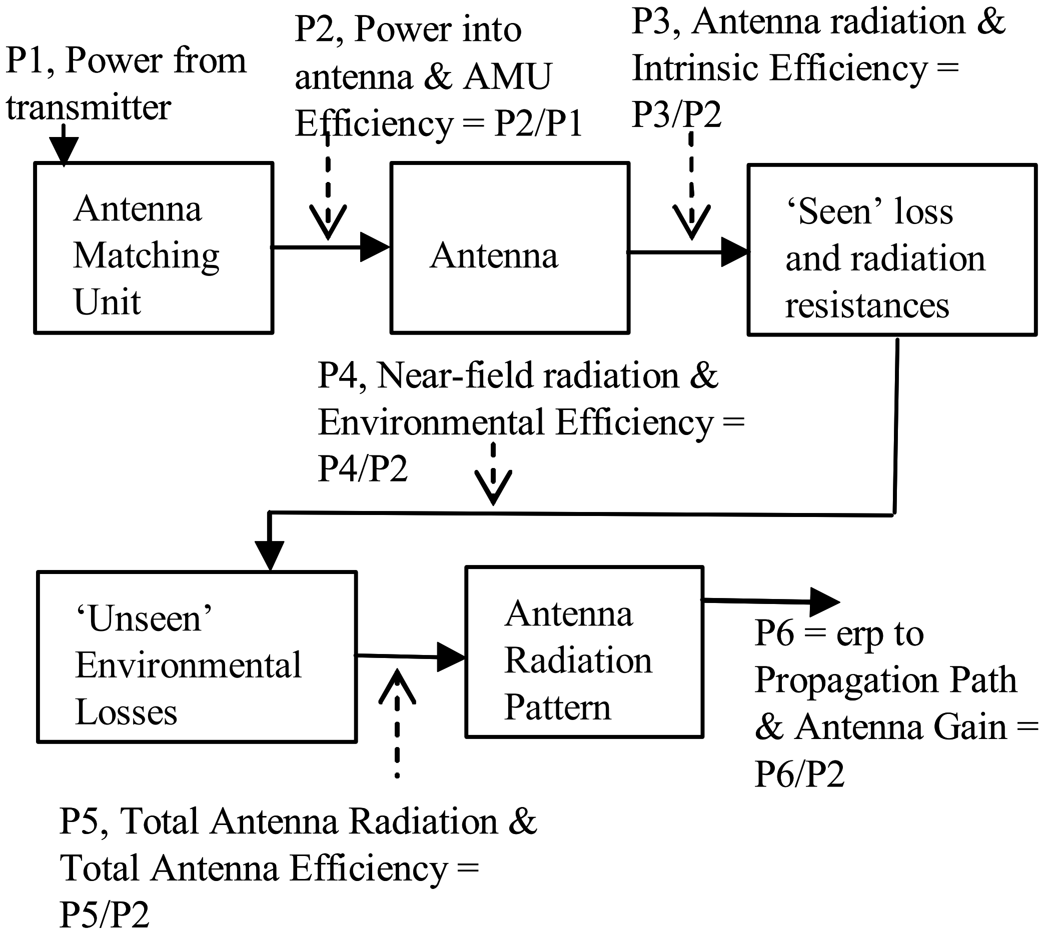


Figure: Various losses and antenna efficiencies

- 15 efficiency definitions = Pn/Pm
- P6 is power density in a given direction
- P6/P5 is the 'directivity' in that direction
- Important ratios are: 'intrinsic efficiency = P3/P2', 'total antenna efficiency = P5/P2' and 'antenna gain = P6/P2.
- '***Intrinsic efficiency***' is important because it is little affected by the environment and is essentially the *efficiency of the antenna in free space*.
- It is the proportion of the input rf that just escapes the surface of the antenna and has not been dissipated as heat in the antenna conductor surfaces.
- Effectiveness = (Antenna gain from transmitter) /(Cost etc). It is qualitative!
- We need agreed standard definitions validated by measurements. For many years there has been much confusion and misunderstanding. The IEEE-Std 145-1993 on antenna efficiency has not helped!

Heuristics for (Loop) Antennas with Propagation

Radiation mechanisms of a small antenna over ground (loop at bottom left):

1.Heat losses in antenna.

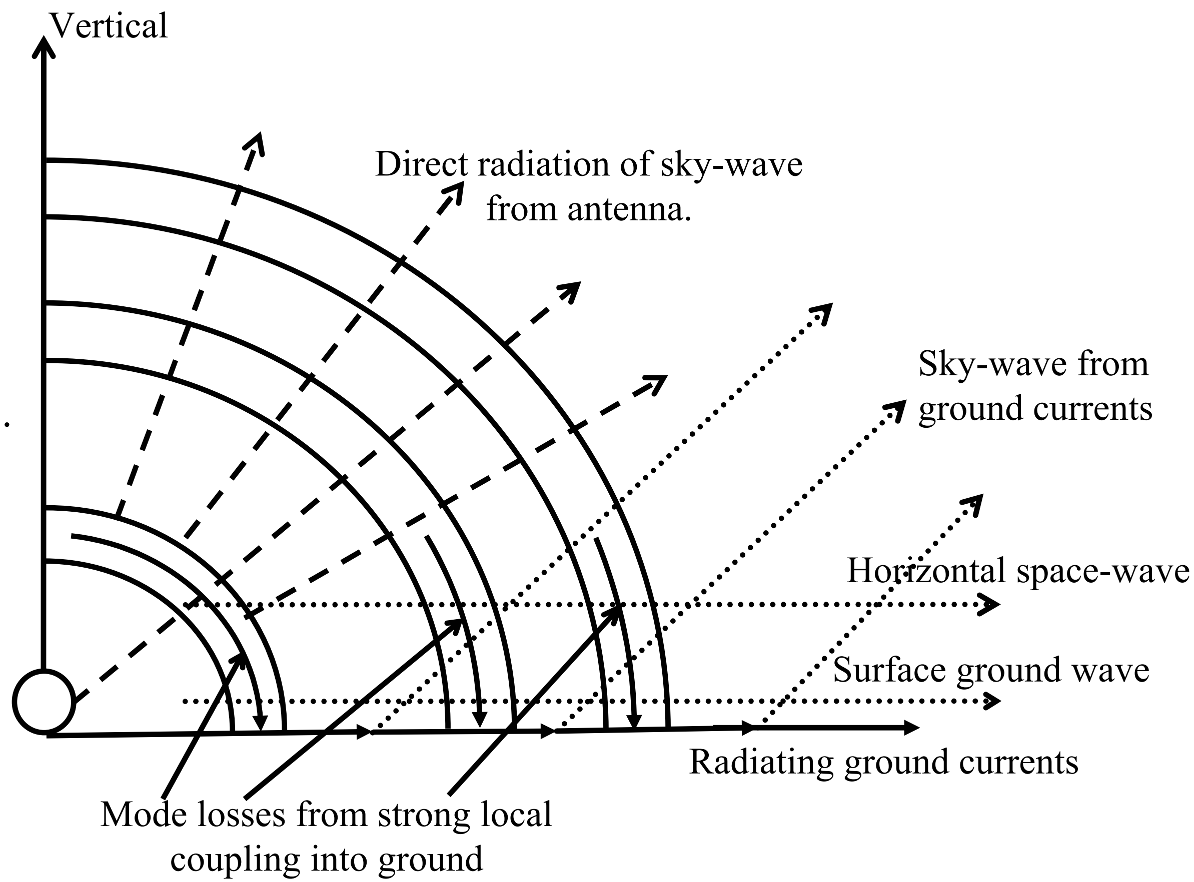
2. Direct radiation to sky-wave.

3. Antenna mode losses from strong local coupling into ground .

4. Launching of two types of surface wave:

    - Horizontal space-wave
    - Surface-ground-wave from ground currents.

5. Radiation of sky-wave from ground currents



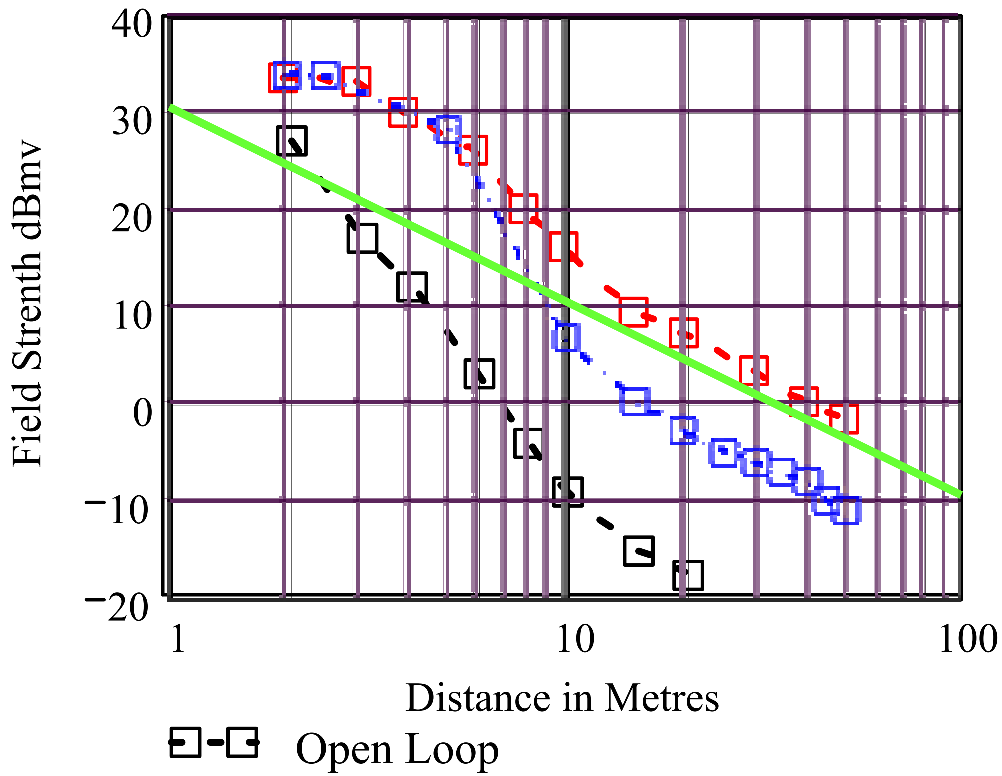
Where does the input power go? How much power couples straight into the ground under a small antenna? Does this propagate under the ground? What is the pattern and polarisation of the antenna when close to ground as compared to free space? How much surface/ground wave is launched, and of what type? Are there two or more surface wave layers.

Heuristics can answer all these questions – existing theory and simulations just cannot!

Close-in Ground Losses for Any Small Antenna Close to Ground

3.6 MHz path loss with distance from 2 to 50 metres for a pair of vertical 1m (tuned) loops with centres 1.5 metres above ground:

(a) Top red curve: ground-path loss for dry winter conditions (+2°C) with both loops resonated and matched.
(b) Middle blue curve: ground-path loss for wet winter conditions (+4°C) with both loops resonated and matched.
(c) Bottom black curve: Using one loop open and un-tuned as a 'field sensor' and using 'Faraday's Law of Induction' from Maxwell's Equations. Dry winter conditions as above in (a).
(d) Green Line: Inverse Square Law reference line.



Conclusions from these results:

1. Close-in ground losses occur in first 10 metres from an antenna close to ground.
2. Close-in ground losses for dry clay soil = 8dB
3. Close-in ground losses for wet clay soil = 16dB (but with 1/r surface wave further out?)
4. Field sensor sensitivity (single turn loop) can be up to 25dB in error if calculated and not calibrated.
5. The unpredictable and large ground losses under field sensors must also be calibrated out.
6. **Efficiencies of an identical pair of loops is found from the asymptotic path loss as the loops are brought together. This occurs at about 3m spacing for 1m loops as above**

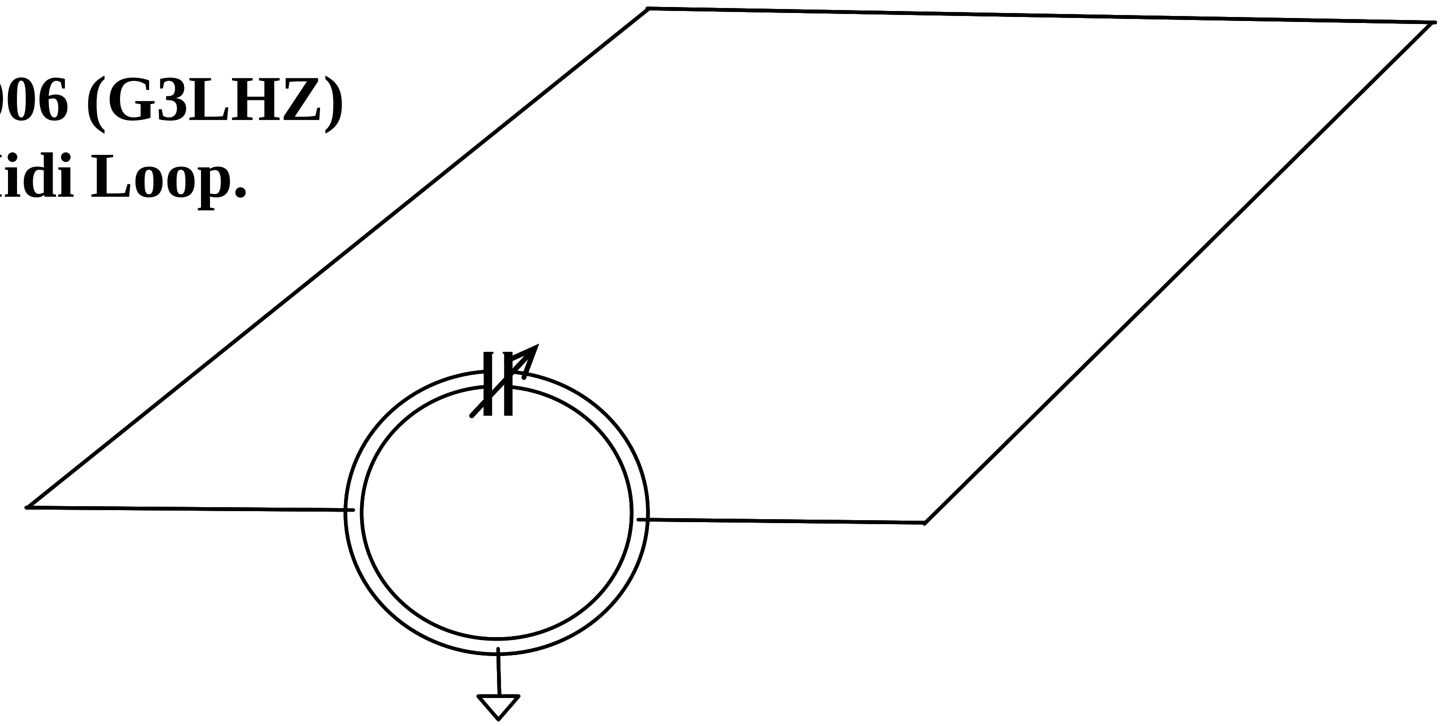
Using Heuristics to resolve the 'Loop Controversy' once and for all time!

- The so-called 'Loop Controversy' is now fully explained:
- Loop losses concentrated in the capacitor rotor connection is a demonstrably incorrect suggestion.
- The critics have mistakenly included ground losses immediately under the antenna and the field sensor in their (poor) loop efficiency estimates by field strength measurement.
- This led them to believe that NEC (and any other 'Method of Moments' (MoM) simulation programme) correctly predicts loop efficiency. NEC and MoM do not!
- The earth is no longer 'flat' – at least for most people!
- And that's the end of it! Or is it?

G3LHZ Mini-Midi Loop.

- Two loops combined: smaller one (mini-loop) is vertical and larger one (midi-loop) is horizontal.
- The smaller loop both radiates and acts as a matching unit for the larger loop
- It is a two radiation mode antenna
- Multi-path interference has been observed between the two modes giving rise to ‘selective fading phase distortion’

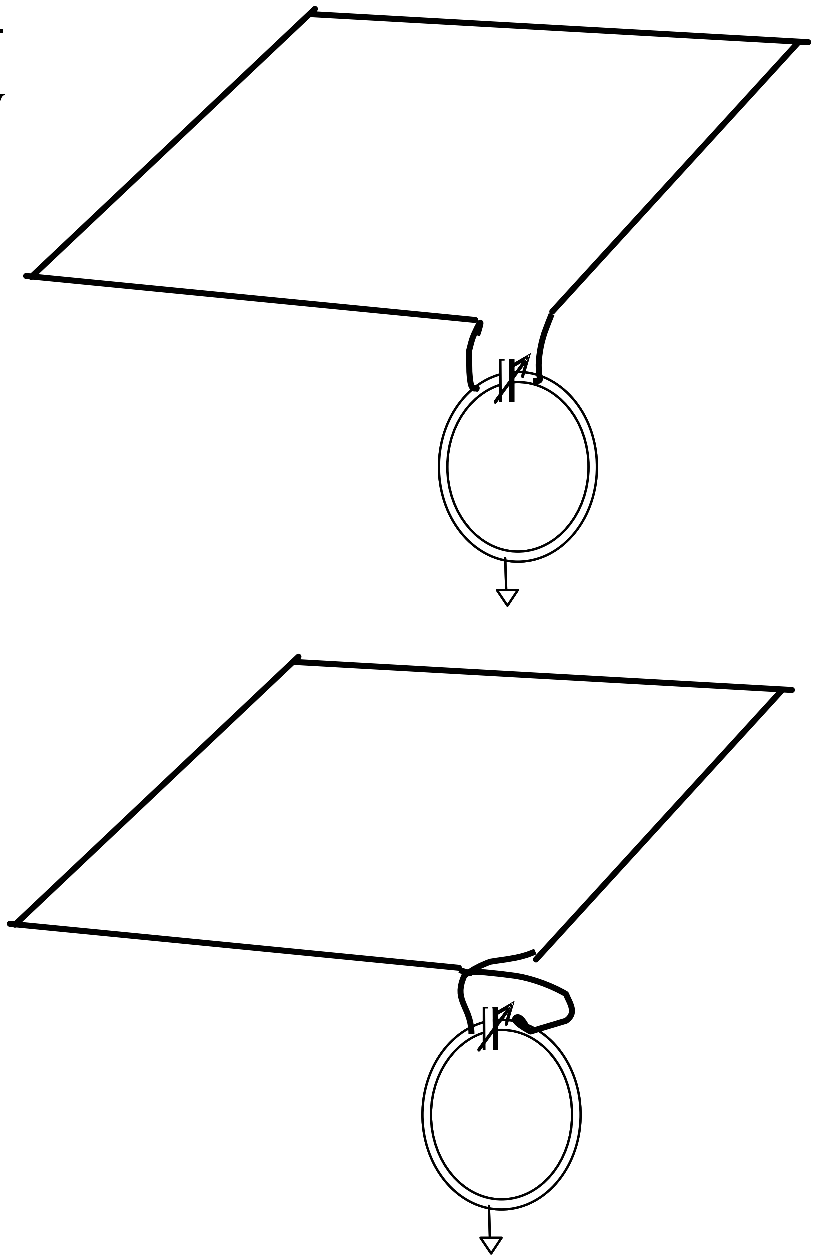
Original 2006 (G3LHZ) Mini-Midi Loop.



- The ‘mini-loop’ is vertical and the horizontal rectangular ‘midi-loop’ is 20 to 40m (0.25λ to 0.5λ) perimeter at about 2m above ground. (Midi-Loop size is as recommended for the (MFJ) ‘Loop Tuner’.
- Bandwidth can be improved to 3% corresponding to a Q of 30 as tapping points are moved towards the capacitor.
- Power handling is at least doubled.
- The SWR is raised towards 4:1 but any reasonable ATU can handle this without having to adjust the loop match.

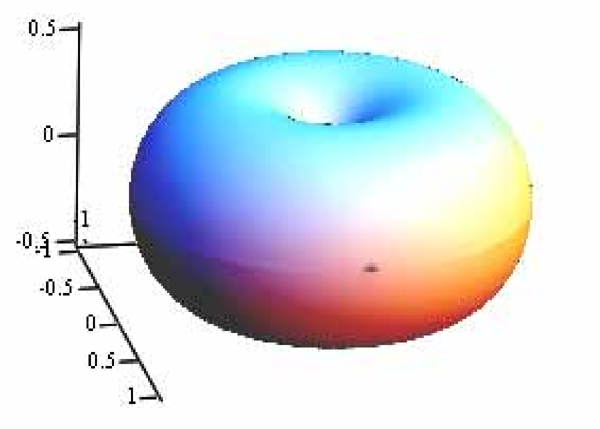
2007 Mini-Midi Loop Variants – 'heuristic discoveries' not yet fully explained

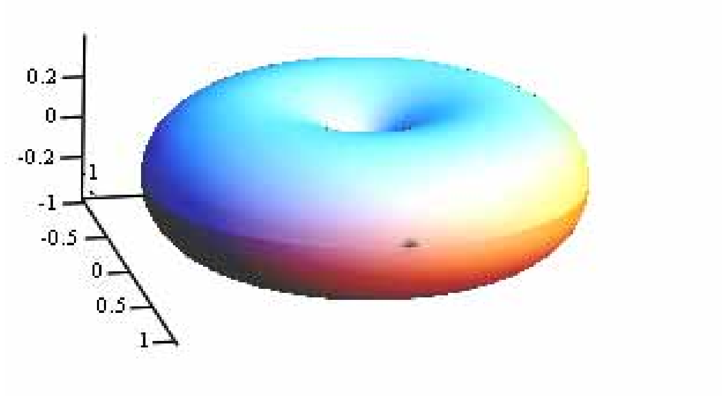
- Small loop orientation matters. If the loops make a right angle, then cross-over (180°) connections give 20dB more sky-wave than same phase (0°) connection, which appears to gives best ground wave in some directions.
- The SWR varies from 1:1 to about 1.5:1 as the small loop orientation is changed by 180°
- Power handling is not significantly affected. (Remains about 550 to 750 watts for either orientation).
- More *heuristic* work needed to work out and explain what is happening



Simulated Heuristic Loop Patterns –

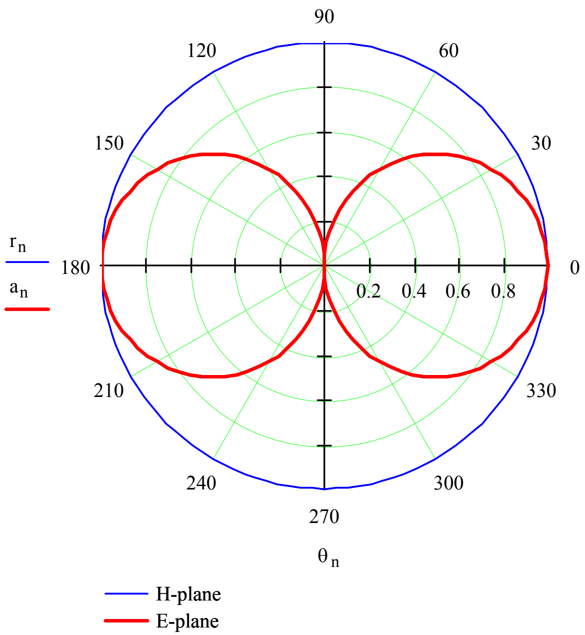
Mini-Loop on left. Midi-Loop on right

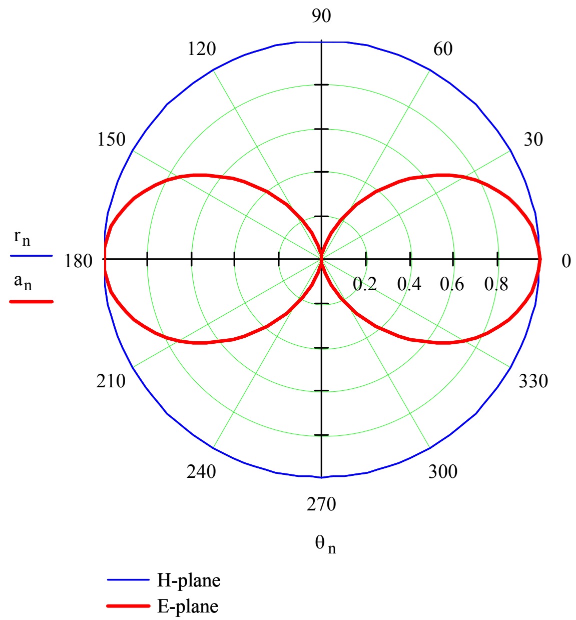




Mini-Loop Directive Gain = 1.5 = 1.76dBi

Midi-Loop Directive Gain = 1.87 = 2.7dBi





(G3LHZ) Mini-Midi Loop Example.

- The ‘mini-loop’ is an AMA5 vertical loop shown with two additional 1440pF Palstar capacitors to tune optionally to 160 m
- The horizontal rectangular ‘midi-loop’ is 20 to 40m (0.25λ to 0.5λ) perimeter at about 2m above ground in apple trees. It is attached across the capacitor at top of the mini-loop.
- Protection and insulation for the apple tree branches and bamboo support is provided by plastic foam pipe insulation as shown.

2007 Update on (G3LHZ) Mini-Midi Loop.

- This is now the work-horse antenna for 1.8 to 10MHz.
- On 80m it has a combined Q of about 40.
- On 160m the Q is about 70. But tuning the loop within this Q bandwidth does affect which loop radiates the most.
- The Mini- Midi loop takes at least 500watts over the range with 750 watts possible on 80m. The AMA5 (mini-loop) is rated at 150watts on its own.

The CFA – How Well Does It Work?

By Mike Underhill - G3LHZ

Extracts from a talk originally given to HFC 2005 and revised in 2006 for University of Surrey Antennas and Propagation Course

Declaration of Position and Viewpoint.

- I sit firmly ‘on the fence’ in the CFA controversy.
- I adopt a position of ‘neutrality’.
- I do not have a ‘vested interest’ in the CFA.
- I try to be ‘objective’.
- I try to be ‘scientific’.
- I am a seeker of ‘the truth’.

Why is the CFA so controversial?

- **Why has the debate been so unscientific,** i.e. dogmatic, acrimonious and based on personal reputations?
- Are the gurus and icons always right without question?
- Does a majority voting for a view make the view more true or less true?
- If ‘accepted theory’ says that the CFA does not work, can we safely say it does not work?
- If theory and simulation contradict repeated measurements, which of these should be changed?
- Can the results of a simulation or calculation be called measurements?
- If NEC (Method of Moments) simulation says that the CFA does not work, can we safely say it does not work?
- If NEC is substantially contradicted by measurements, should it not be up-graded?
- **If PVS (Poynting Vector Synthesis) is a ‘flawed’ concept do all antennas stop working, or only the CFA?**

What is the CFA?

- An *Aerial* is an English term and, perhaps sadly, is becoming a 'historical' term for an *Antenna*.
- CFA stands for "Crossed Field Antenna".
- The CFA was invented by Maurice Hateley and Fathi Kabbary and first patented in 1988. The British Patent was No. 2,215,524. There are also patents in Australia Europe, Japan, and the US.
- The CFA is a small antenna – 'Small' is when the antenna is inside a sphere or hemi-sphere of $\lambda/2\pi$ (~ $\lambda/6$) radius.
- I propose that the CFA is a *two element antenna* (like the Franklin Antenna?) that cannot be successfully analysed as a one element antenna. This is my 'neutral' contribution to the debate. See later.
- Perhaps both sides will make friends and join forces to dispute this?!
- **The EH Dipole antenna looks like a CFA with built in phasing, coupling and matching components. It behaves the same as the CFA.**
- **How does the CFA work.?**

Barrel-shaped CFA – the original(?) experimental model

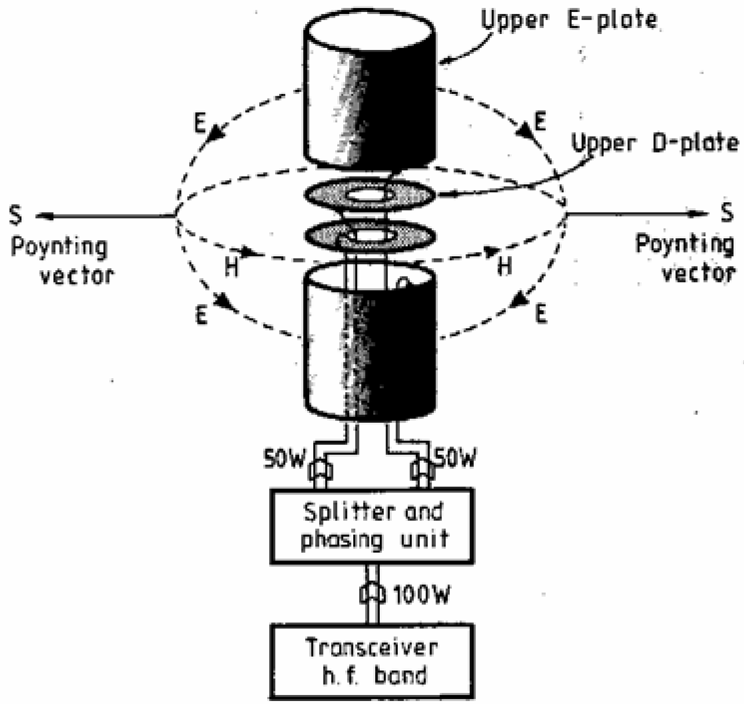


Fig.6. The "barrel-shaped" crossed-field-antenna (CFA).

Fig.7. A practical barrel-shaped CFA. The length of this particular structure is 70cm.

BASIC CFA DESIGN PRINCIPLES

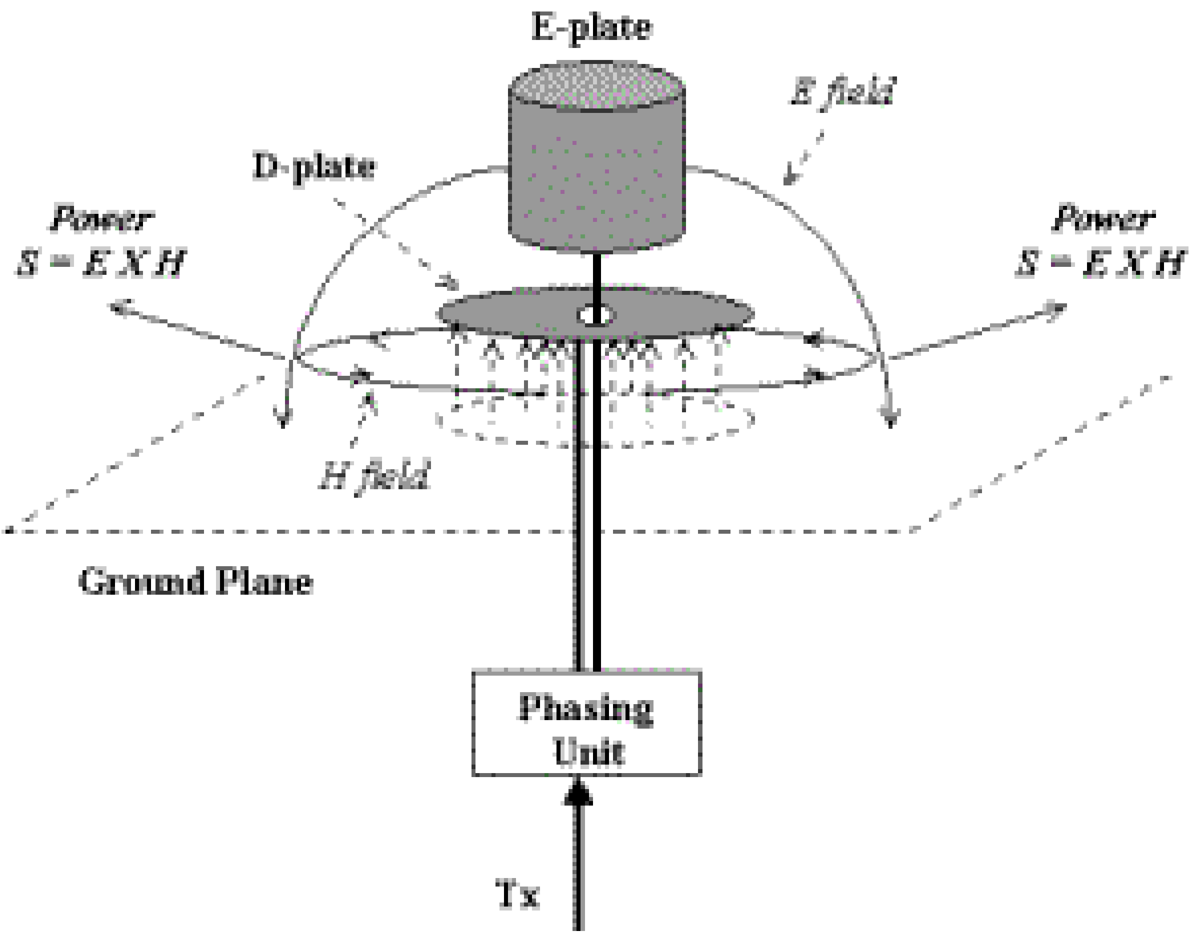
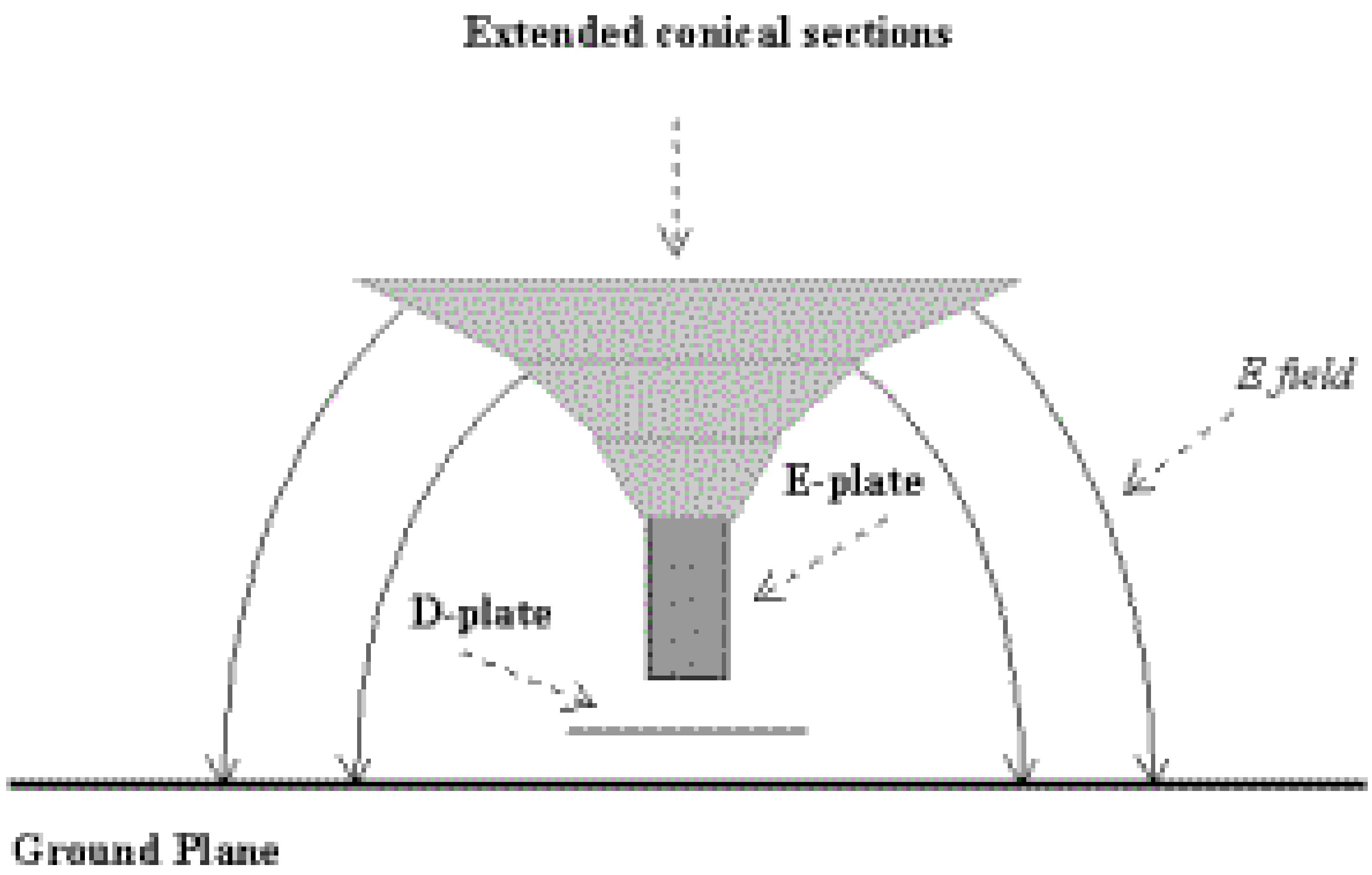


Fig. 1 The basic operation of a GP CFA

The fundamental principle underpinning CFA design is that electric and magnetic fields are produced from separate field stimuli, or field electrodes, and crossed-stressed in–phase within a small volume, called the *interaction zone*, close to the CFA structure.

Top-loading the CFA



- **Fig. 2 The addition of conic sections to the E-plate**

972 kHz CFA at Shifnal (Tong)

Shifnal CFA and Matching Network – 26 March 2002

Environment of CFA at Shifnal (Tong) – 972 kHz

Note: reservoir at left possibly leaking to give wet ground at front: oak tree on right higher than top of CFA; and raised ground-plane immediately under the 'D-plate' disc.

FOUR EGYPTIAN MW BROADCAST CROSSED-FIELD-ANTENNAS

F M Kabbary (*a*), M Khattab (*a*), B G Stewart (*b*), M C Hately *(c)* and A Fayoumi (*a)*
***(a)* Egyptian Radio and TV Union, Cairo; (*b)* Dept of Engineering, Glasgow Caledonian University; (*c)* Hately Antenna Technology, Aberdeen.**
(Paper Presentation at NAB99 ~ Reprint by Permission)

ABSTRACT

Crossed-Field-Antennas (CFAs) are novel, small, broadband, high power antennas commonly less than 2 to 3% of λ in height. Currently there are a number of MW broadcast CFAs in service in Egypt. Information relating to four of these broadcast antennas is presented. The paper details: the basic CFA design principles which result in their novel size-wavelength independent nature; near field measurements showing the existence of minimal induction field; vertical plane radiation field patterns; ***evidence of strong ground-wave and diminished sky-wave radiation***; input impedance and bandwidth evaluations of the four CFAs showing their broadband frequency characteristics; and finally, advantages and benefits of CFAs over conventional MW and/or LW antennas.

CFAs at Tanta in Egypt

- **Fig. 3 The 100kW and 30kW Tanta CFAs situated on the same rooftop, separated by 6m (19.5ft)**

Barnis CFA

- **Fig. 4 The 100kW Barnis CFA**

CFA Bandwidths

CFA	f (kHz)	λ	Height	% of λ
Tanta 30kW	1161	258.2m (840ft)	8.2m (26.7ft)	3.5%
Tanta 100kW	774	387.6m (1260ft)	9.0m (29.3ft)	2.3%
Barnis 100kW	603	497.5m (1617ft)	9.0m (29.3ft)	1.8%
Halaieb 7.5kW	882	340.1m (1105ft)	6.0m (19.5ft)	1.8%

CFA	2:1 SWR freqs (kHz)	Bandwidth (kHz)	% Bandwidth
Tanta 30kW (1161kHz)	1148 1175	27	2.3%
Tanta 100kW (864kHz)	759 814	55	7.1%
Barnis 100kW (603kHz)	579 627	48	8.0%
Halaieb 7.5kW (882kHz)	875 894	19	2.2%

SWR 2:1 CFA Bandwidth evaluations

FOUR EGYPTIAN MW BROADCAST CROSSED-FIELD-ANTENNAS

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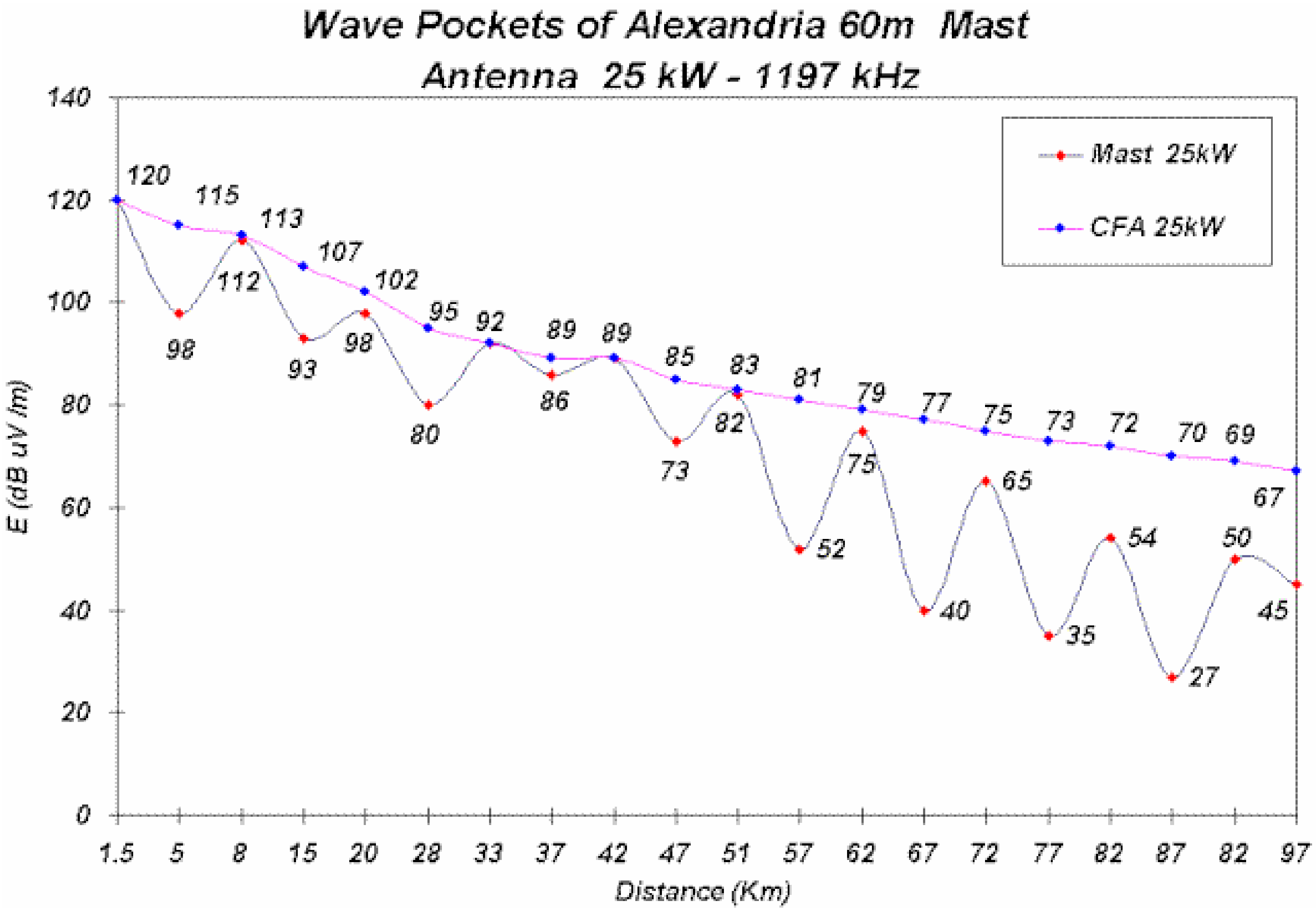
(Paper Presentation at NAB99 ~ Reprint by Permission)

ABSTRACT

Crossed-Field-Antennas (CFAs) are novel, small, broadband, high power antennas commonly less than 2 to 3% of λ in height. Currently there are a number of MW broadcast CFAs in service in Egypt. Information relating to four of these broadcast antennas is presented. The paper details: the basic CFA design principles which result in their novel size-wavelength independent nature; near field measurements showing the existence of minimal induction field; vertical plane radiation field patterns; evidence of strong ground-wave and diminished sky-wave radiation; input impedance and bandwidth evaluations of the four CFAs showing their broadband frequency characteristics; and finally, advantages and benefits of CFAs over conventional MW and/or LW antennas.



KABBARY, F.M., 'Daytime Wave Pockets of Medium Wave Mast Antennas' Antennex on-line Issue #59, March 2002

- Why is the CFA better than the 60m mast. particularly at larger distances?
- Why does the 60m mast create 'wave pockets' and not the CFA?
- If it was ionospheric sky-wave interference would not the packets be much closer spaced near the transmitter and be prone to fading? Do they exist at night time.
- It looks like two horizontal waves travelling at 3.1% different velocities? Why? Are there two ground waves?
- Would a loop receiving antenna fill in the nulls? Or an antenna presenting a different load impedance to free space? (Does the folded dipole differ from the ordinary dipole in this respect?)

Where does the input power go? What are the patterns of the CFA and EH antennas?

Radiation mechanisms of a small antenna over ground (loop at bottom left):

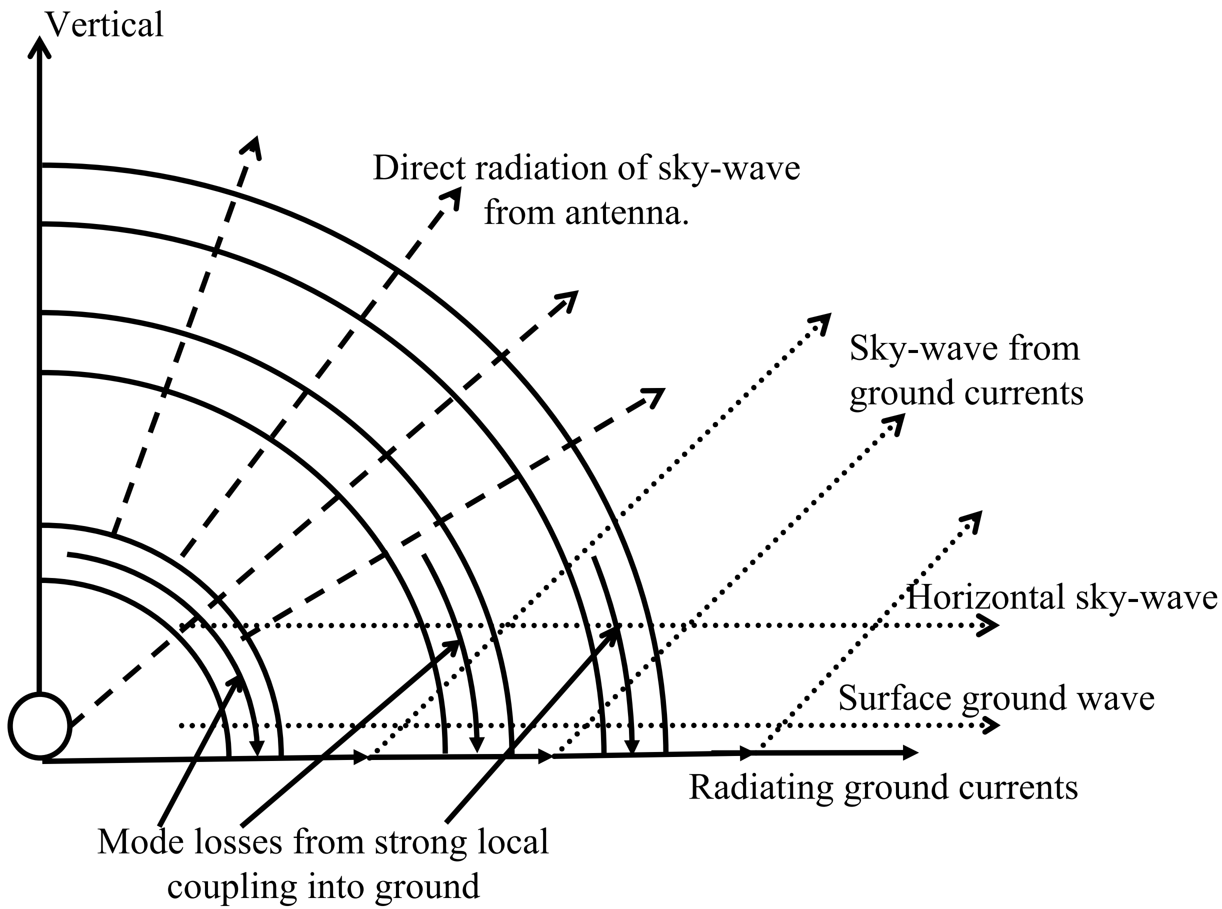
1.Heat losses in antenna.

2. Direct radiation to sky-wave.

3. Antenna mode losses from strong local coupling into ground .

4. Launching of two types of surface wave:
   - Horizontal Sky-wave
   - Surface-ground-wave from ground currents.

5. Radiation of sky-wave from ground currents



How can we possibly define the efficiency of any small antenna on an absolute basis without knowing all these? Is simulation good enough?

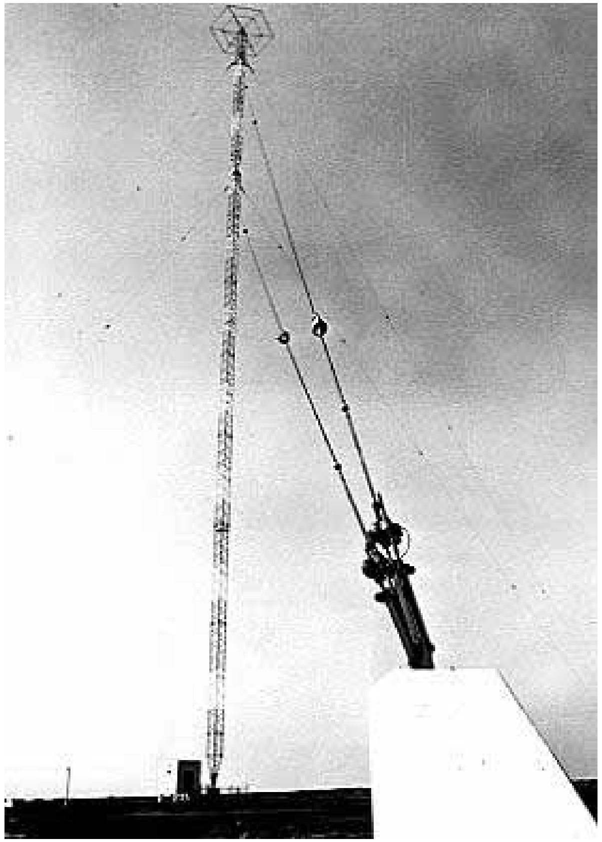
Comments on the CFA and Poynting Vector Synthesis (PVS)

1. The CFA is probably the best (short-fat) monopole that you can get.
2. The CFA performance and matching are sensitive to the ground, weather and environmental conditions. A Tracking Automatic ATU is highly to be recommended.
3. The CFA is usefully improved if placed on top of a tallish building.
4. In the desert the CFA is about 3dB better than a much taller vertical. Probably this is because the low-height CFA launches an effective ground-wave in the low-loss dielectric of the desert sand.
5. If PVS 'works' for one antenna it works for all antennas.
6. The difference between stored energy and power flow is always a 90° phase difference in at least one component of the electromagnetic field no matter how you feed the antenna.
7. The debate about PVS is all about semantics. It does not make the slightest difference to the question of whether a particular antenna works or not!
8. **But there is Coupling between the two elements of a CFA that considerably improves the bandwidth. Perhaps it should be called a 'Coupled Field-mode Antenna (CFA)'?!**
9. The EH Dipole is a CFA with the matching and phasing network built inside it.

THE EH DIPOLE ANTENNA - MORE INFORMATION ON HOW IT WORKS AND HOW IT HAS PERFORMED

By Lloyd Butler VK5BR

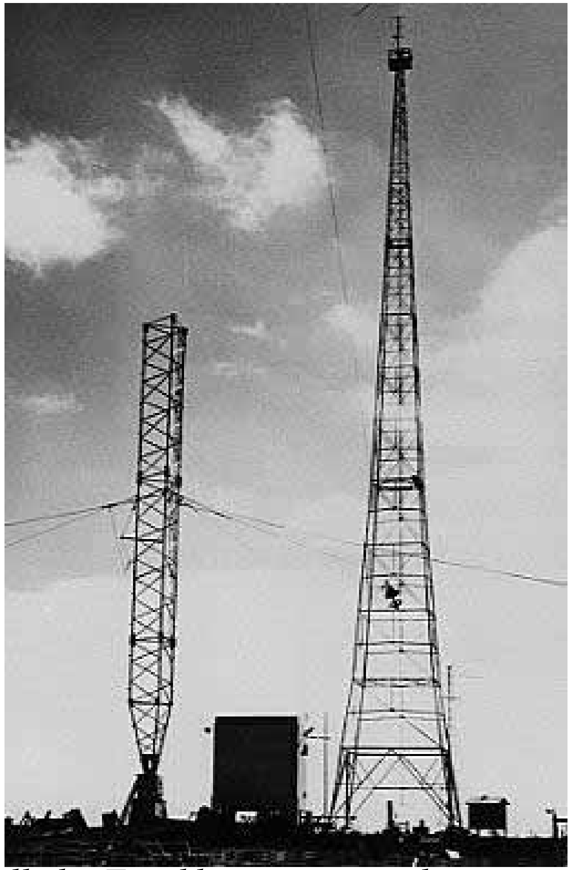
- **The article was originally published in Amateur Radio, November 2003 and follows on from the previous article published in the April 2003 issue of the journal.**
- **Some Background:-**



The Franklin Medium Wave AM BC Antenna

The CFA and EH antenna patterns can be derived as if they were Franklin antennas that are much reduced in size.

In the photo at left, the old east tower is visible in the background, with the KNBC-FM antenna on top.



KNBC (KPO)'s present 550 ft. tower was completed in 1949. This type of antenna is called a Franklin antenna, a design used by only a few AM stations in the U.S. The antenna is easily recognized by the porcelain insulator in the middle of the structure.

A traditional Franklin antenna consists of two half wave antennas stacked end-to-end and fed in phase. At 680 kc, this would require a tower 1,500 ft. tall, an obvious impracticality. The KNBC tower measures 400 ft. to the midpoint insulator. The upper portion of the tower is shortened to only 150 ft., and this is compensated for by a 50 ft. diameter capacitive top loading "hat" at the top of the structure. The top section is fed from a shunt tap on the lower section. There is a copper tube that runs up from the tap on insulated stand-offs, where it connects to the upper section just above the insulator.

The Franklin Antenna is used as a means to lower the radiation angle of the signal. This increases the ground wave coverage of the station, and reduces the night time interference at the fringes of the ground wave signal, caused by sky wave signals originating from the same tower.

About the 'Franklin Antenna' from "Tall AM Towers" by John Battison in Radio Magazine (downloaded Oct 2005)

Figure 1. The effect of antenna height on the angle of lobe radiation.

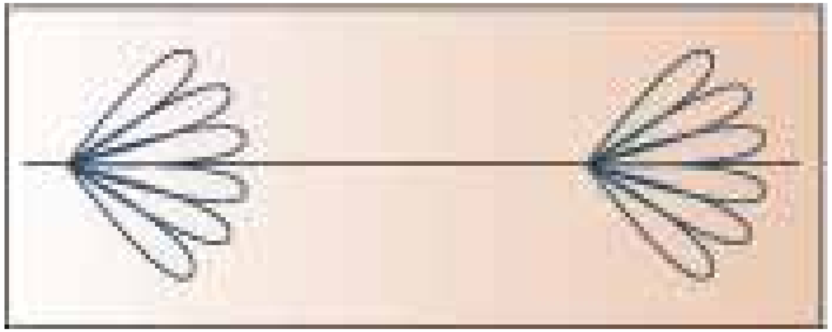


Figure 2. Radiation pattern of an antenna longer than one wavelength.

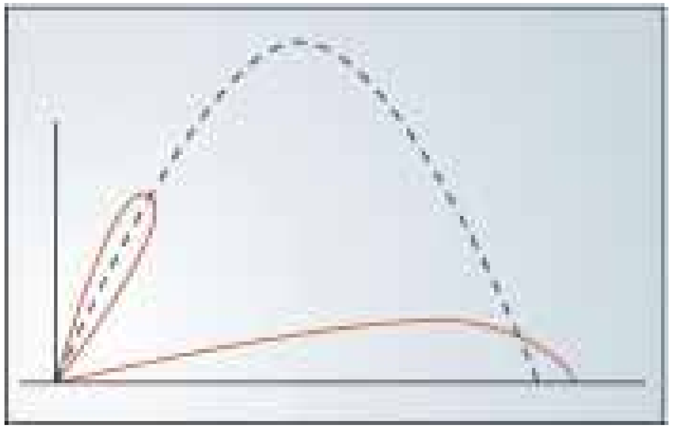


Figure 3. High angel signales cause skywave interference to the groundwave

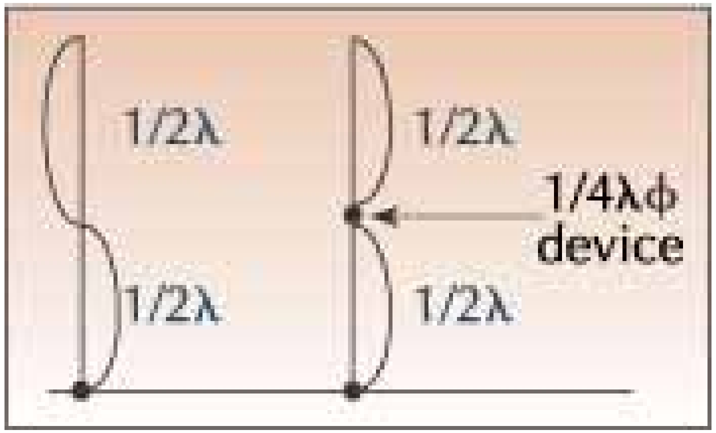


Figure 4. Stacking two half-wavelength radiators normally produces a phase-cancelled signal.
(This is the Franklin Antenna)

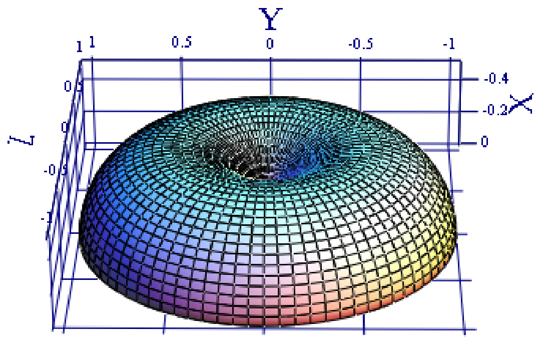
CFA and EH Mode patterns

Small vertical radiation pattern. For CFA and EH monopole

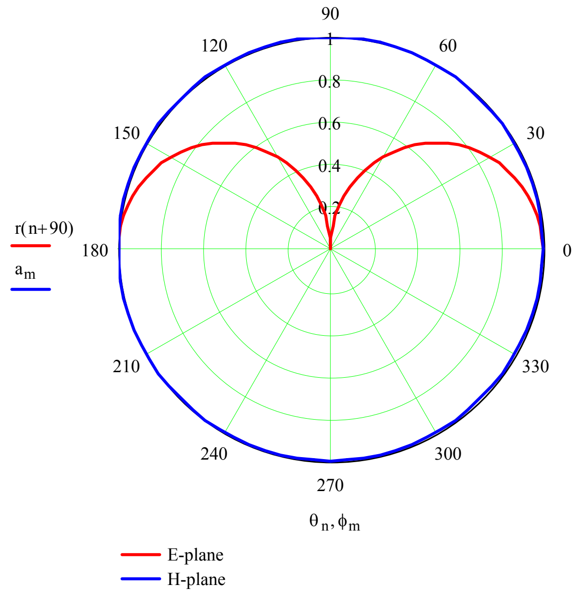
= EH anti-symmetric mode pattern?

Directivity Gain at horizon = 4.771dBi = - 0.389dBQ

(dBQ = gain relative to a Quarter-Wave Vertical. dBQ = dBi - 5.16dB)



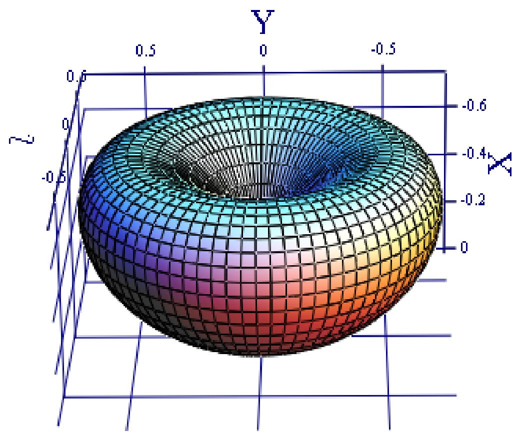
Antenna 3D Plot (E field is vertical)

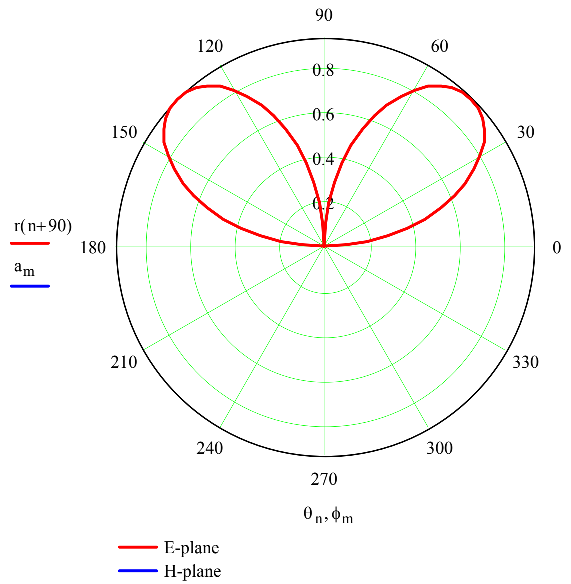


CFA D-plate radiation pattern.

= EH anti-symmetric mode pattern?

Directivity Gain at 45°
= 5.74dBi = 0.58dBQ

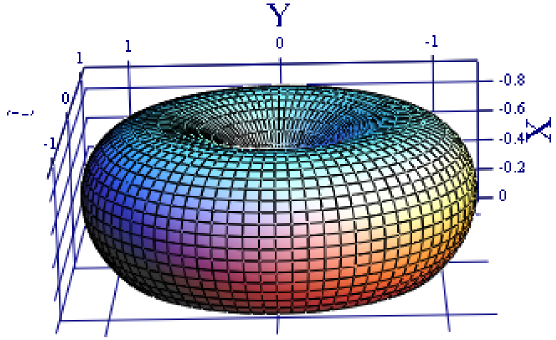


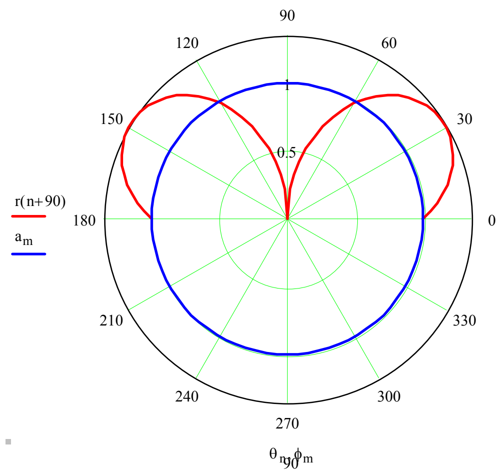


Antenna 3D Plot (E field is vertical)

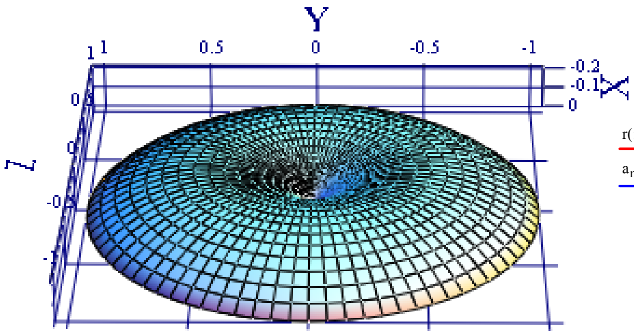
Combined Mode Patterns of the CFA and EH

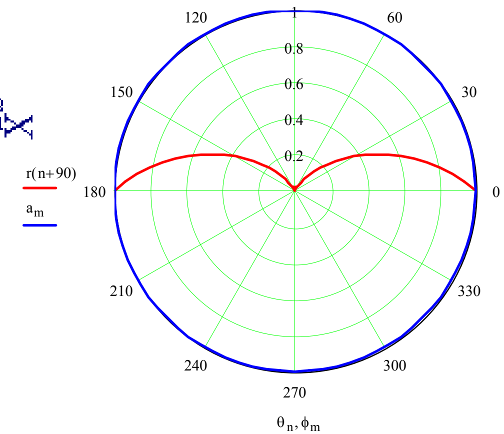
Modes in-phase and with equal power gives directivity = 1.574dBi = -3.586dBQ along the horizon, and = 4.045dBi = -1.115dBQ at 32°



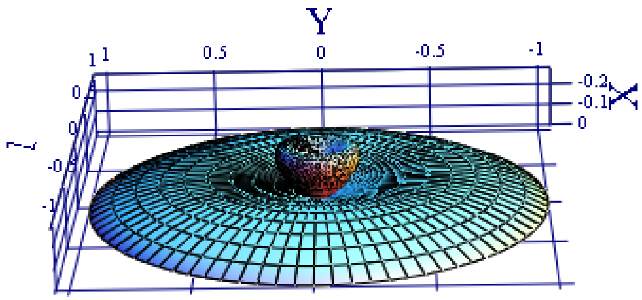


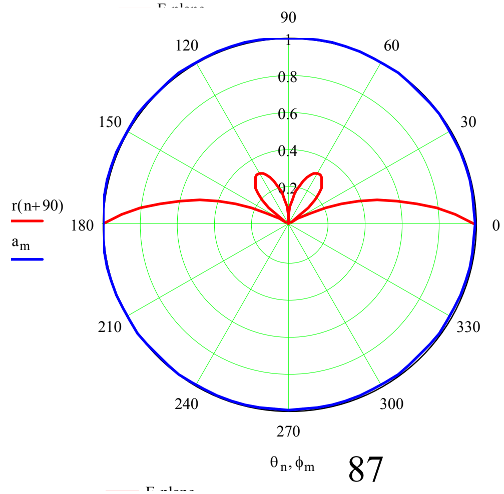
Modes 180° out-of-phase and with equal power gives directivity = 8.62dBi = 3.46dBQ along the horizon.



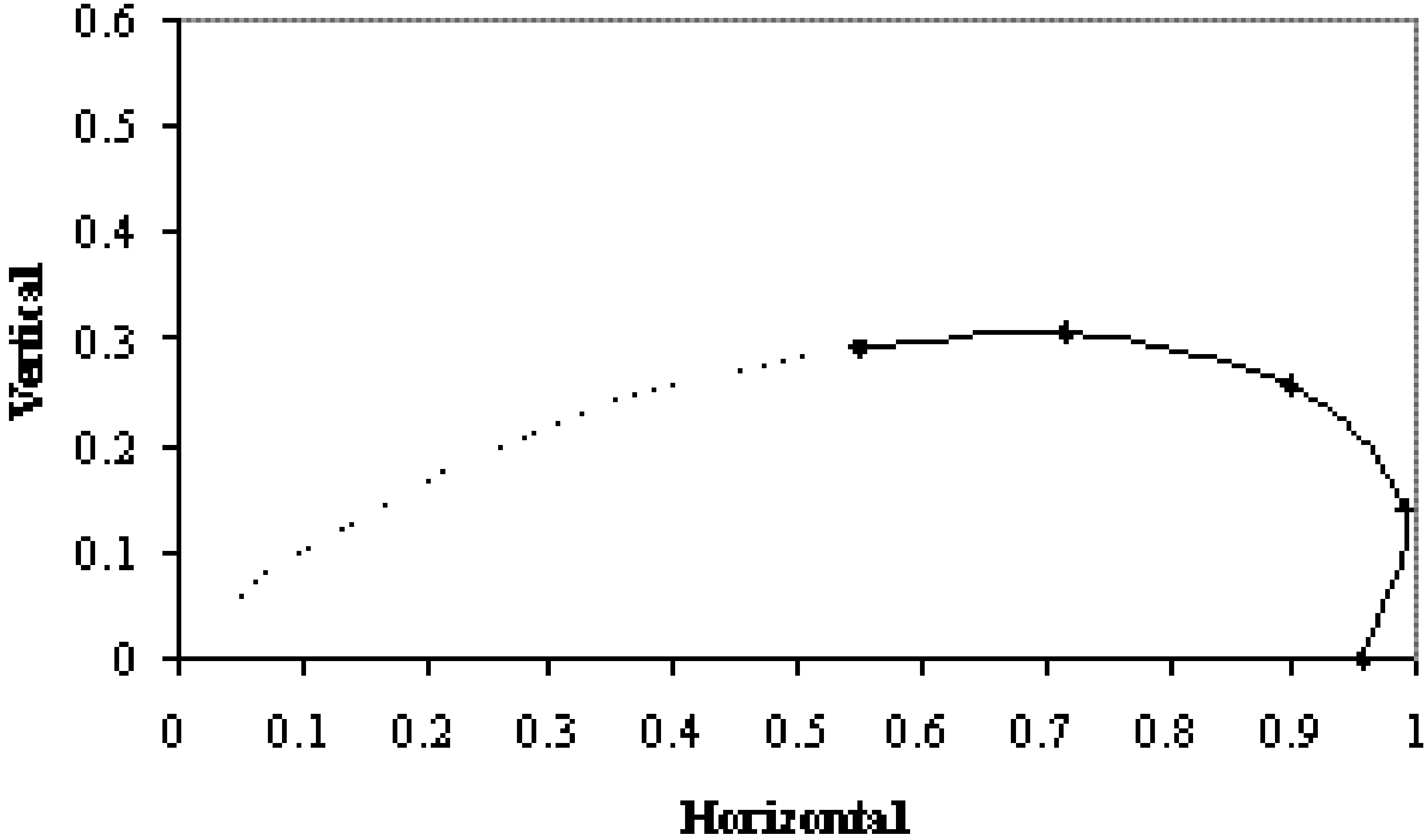


180 degrees phase shift and mode ratio B/A = 1.875 gives directivity gain = 10.03dBi = 4.87dBQ along the horizon.



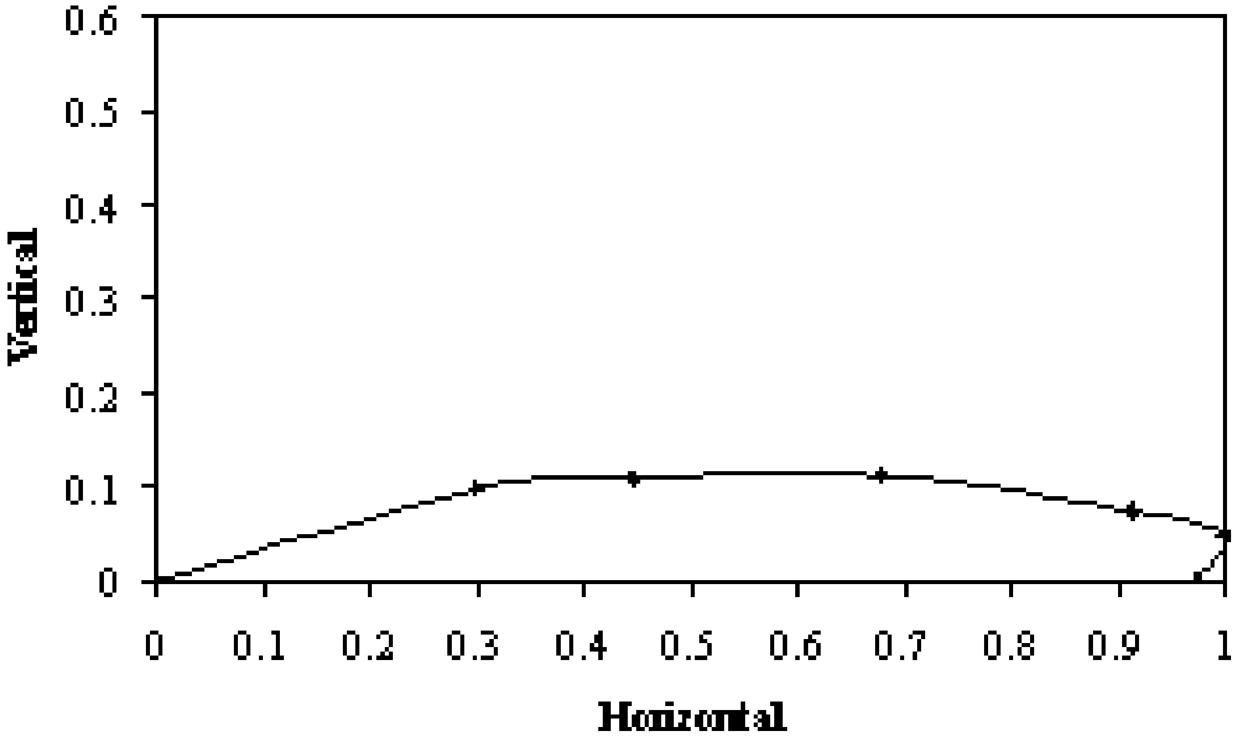


Barnis CFA Vertical Pattern



- **Fig. 7 Barnis 100kW relative vertical plane radiation field pattern measured in the vertical direction at a distance of 70m**

Measured CFA Vertical Radiation Pattern at Tanta



- **Fig. 6 Tanta 30kW relative vertical plane radiation field pattern measured in the vertical direction at a distance of 610m**

<u>Arnos EH Dipole</u> - efficiency measured by heat generated – the only correct way of measuring antenna efficiency – It does not include ground loss!

Arno Venus 160 EH Dipole: copper 'tuning band' shorted turn temperature increased from 13°C to 25°C using a non-contact thermometer (centre picture) after 15 minutes of 80 watts input to antenna. Rough estimate of no worse than 50% antenna efficiency from this. Needs more refinement.

The way forward in the CFA controversy?

- **Perhaps both sides in the CFA dispute are half right and half wrong?** – or thereabouts?
- Will either or both sides accept this?
- Can both sides stop using the words "everybody (or anybody) knows that…."
- Or; "I have been in antennas longer than you, so I know why you are wrong and everybody will see this."
- Dogmatism does a lot of damage to 'the truth'.

And on a more scientific level:

- Can the two sides agree to separate *environmental losses* from *antenna losses* and to measure these separately?
- Can the two sides avoid claming that that there is only one way to measure *antenna efficiency* and theirs is the only way?
- **Can the two sides agree a set of measurements that will settle the controversy once and for all?**

The CFA – How Well Does It Work? –

- **The EH (Dipole) Antenna is a CFA with the power splitting, phasing, and matching network components inside it.**
- The CFA is probably the best short fat vertical that you can have. It can launch a good surface wave given the right earth conditions.
- The most important CFA and EH effect is cancellation and reduction of the stored energy around the antenna, that shows itself as a major reduction in the Q and increase in the bandwidth; typically 2 to 10 times? 2 times is easy to 'explain', 10 times is not!
- Typical CFA and EH Qs are 12 to 30. This is remarkably low, not predicted classically, and not yet fully explained.
- It is not helpful to understanding what is going on, to call this effect "PVS (Poynting Vector Synthesis)". My opinion is that PVS is a 'red herring' !
- Does adjusting the phasing for best bandwidth give the most favourable antenna pattern?
- The CFA could be called 'Coupled Field-mode Antenna'?!
- Lower Q means higher power handling when antenna resistive losses are low.
- The EH antenna will take up to 2kW. It could not do this if it was not efficient!
- **On most counts the CFA and EH antennas work well!**
- **Caution:** No small antenna can overcome a poor, low height, environment. Ground losses are traditionally severely underestimated.

From the Original G3LHZ IP-Quad to Novel Multi-tuned Loops

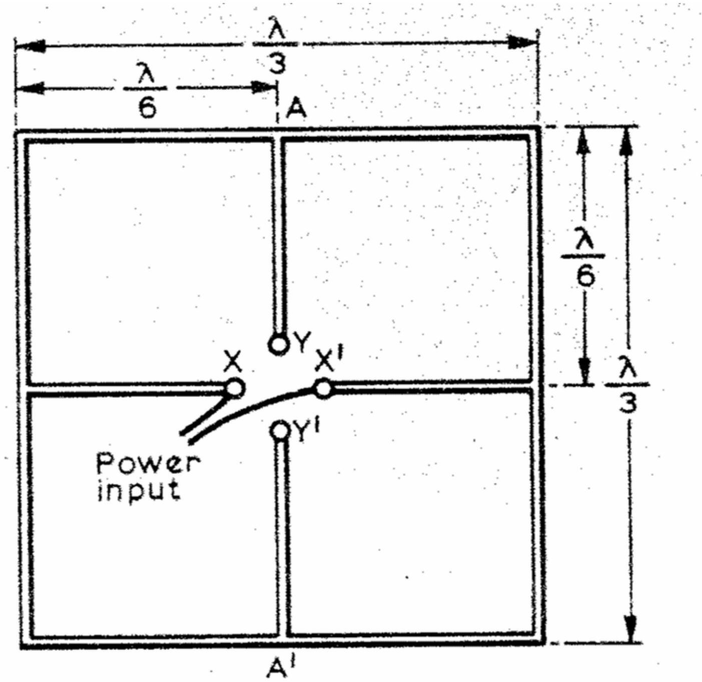
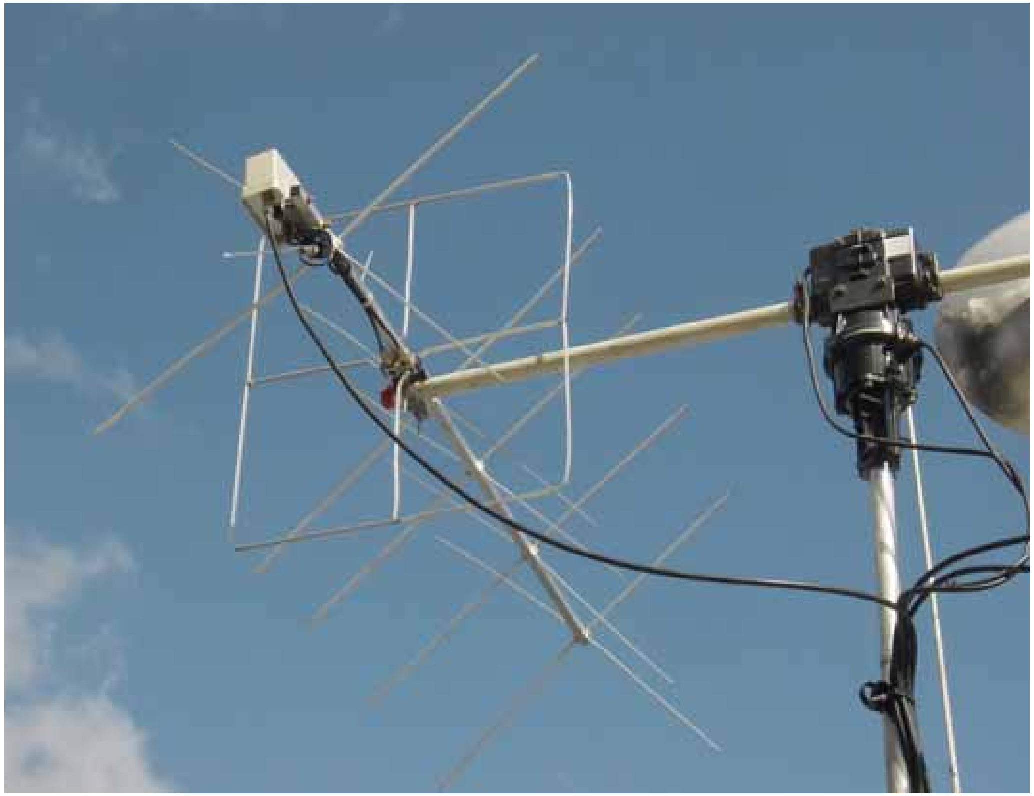


Fig 3. Isolated inputs of the new quad element

'The ip quad – a new versatile quad driven element'
by M. J. Underhill, G3LHZ,
Radio Communication,
September 1976



WiMo 2m Cross-polarised Antenna as on the GB4FUN Vehicle on 6/5/06 in Belfast.
Note the Driven Element!

G3LHZ Diagonal IP-Quad

First Reported in
Technical Topics
November 1976

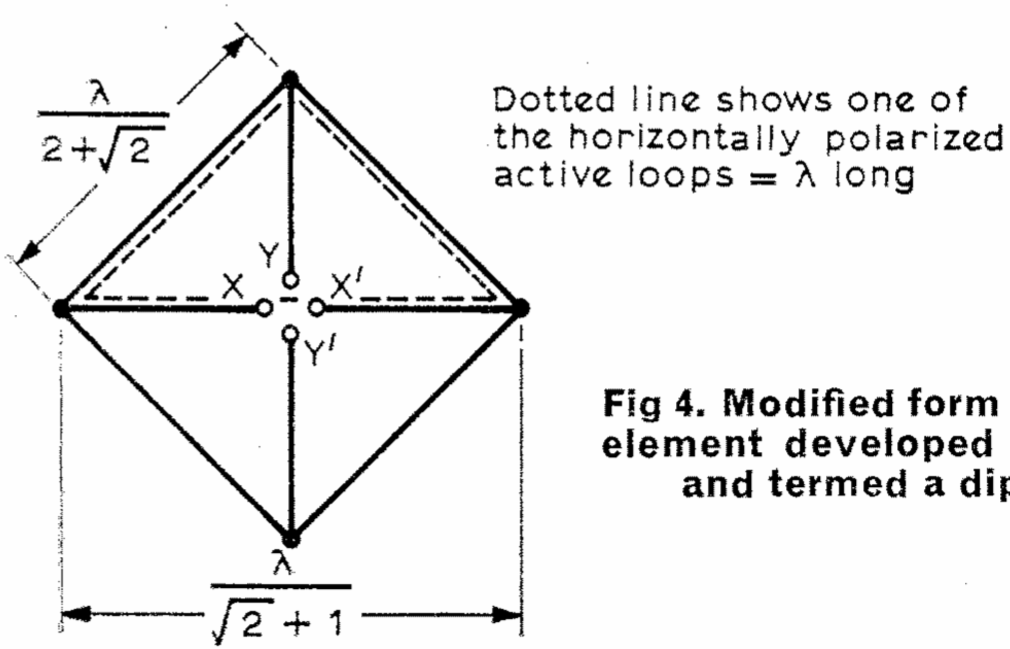


Fig 4. Modified form of ip quad element developed by G3LHZ and termed a dip quad

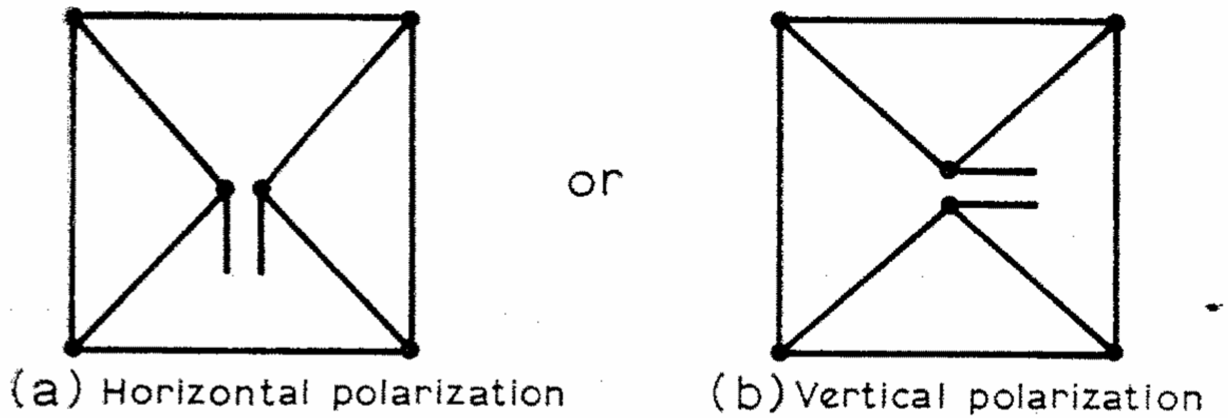
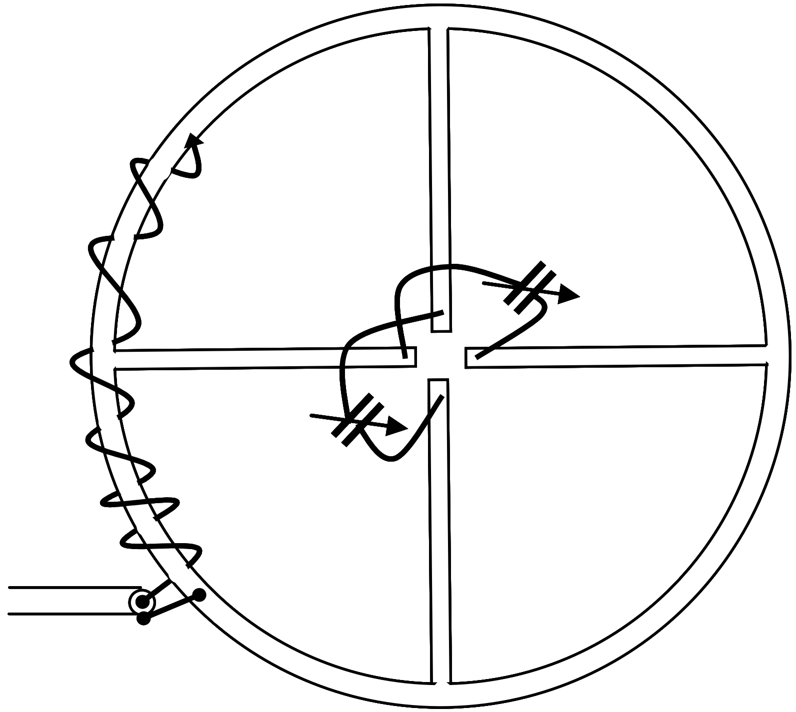


Fig 5. Showing how either ip quad or dip quad elements can be rotated through 45° and both input ports fed together. This provides choice of horizontal or vertical polarization (as in original element) if switching at the feed points is used

Centre-Line Tuned Loops



- Based on IP quad structure but much ‘smaller’ with respect to a wavelength.
- Independent two frequency tuning.
- Polarisation can be changed from horizontal to vertical by varying the tuning.
- When both ‘ports’ tuned to the same frequency the bandwidth is nearly doubled.
- 1.7 m diameter loop of 10mm tube handled 550 watts on 160m. >3000pF needed!

Reasons for Corner Fed Square Loop

- Above1m ‘Egg-beater’ for LF, with ‘figure-of-eight’ loop inside for HF is too complicated. However both work well
- Parallel loops double the bandwidth and reduce inductance.
- Reduced inductance gives greater power handling at the cost of a larger tuning capacitor. Q is also about $1/\sqrt{2}$ lower.
- Corner fed square loop (at right) does all that combined loops above do.
- Connected in parallel improves bandwidth about two times.
- Can be simultaneously tuned at up to four frequencies in a 10:1 (or more) range.
- All home-made loops shown use 10mm plumbing copper tube
- 1m square fits in a Laguna with the seats down!

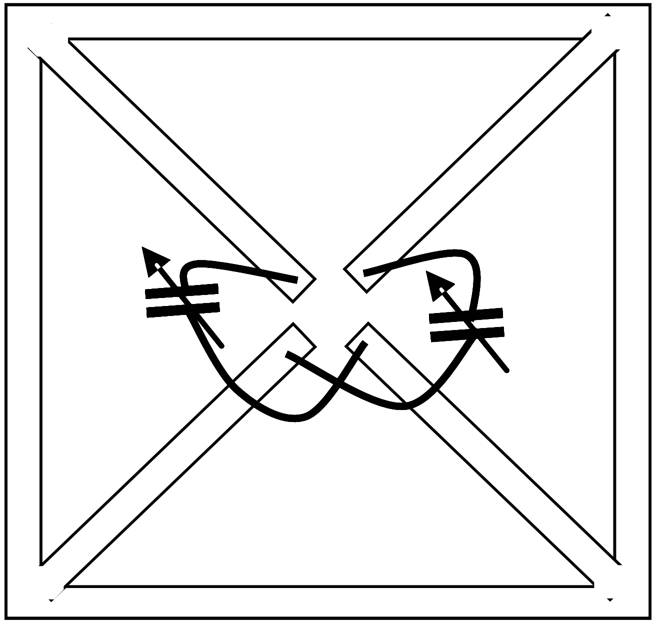
Corner Fed Square Loop

G3LHZ

Corner Fed Square Loop – reverse

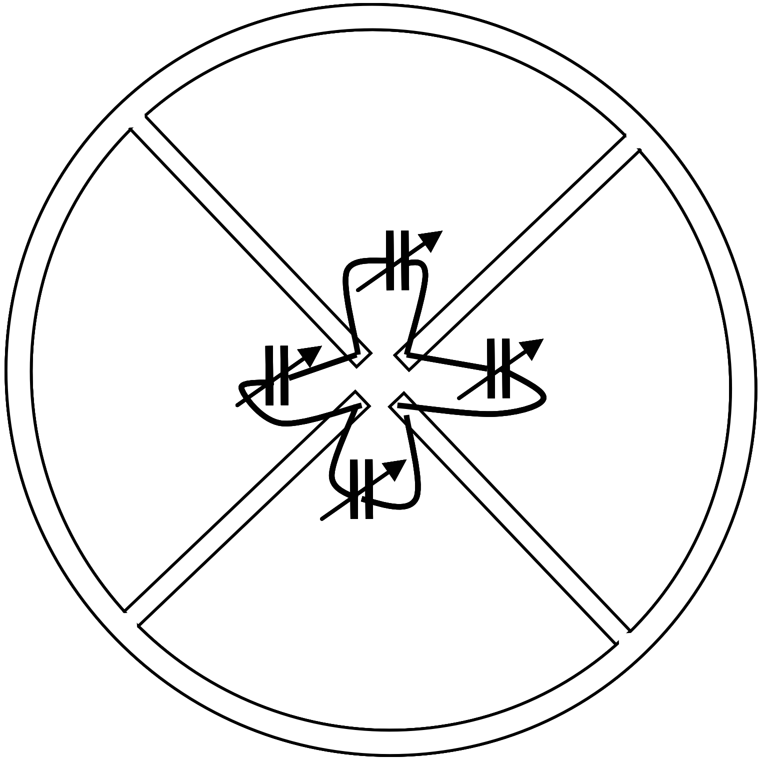
G3LHZ

One Diagonal Square Loop Arrangement



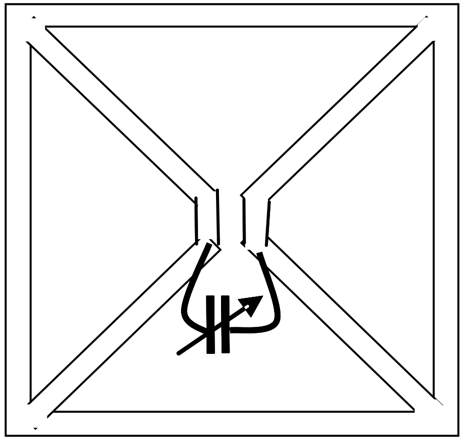
- Diagonal Square has same antenna patterns as Square or Circular Loops.
- It is a more compact shape, all else being equal.
- Easy to construct
- With capacitors as shown it is two frequency tuning and 'variable polarisation'
- With one diagonal tuned high and one low, in principle circular polarisation can be achieved at one frequency.

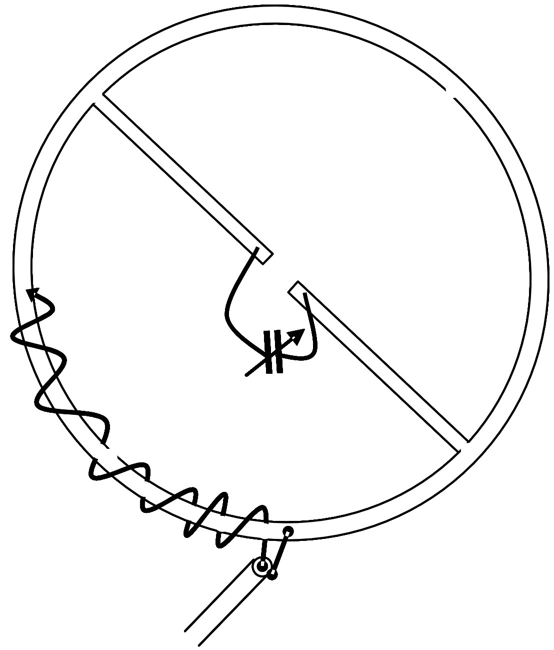
Four-frequency Loop



- The four frequencies do interact.
- Best if spaced to different bands.
- Uses one or more long twisted gamma matches empirically adjusted.

Wider-Band High Power Loops

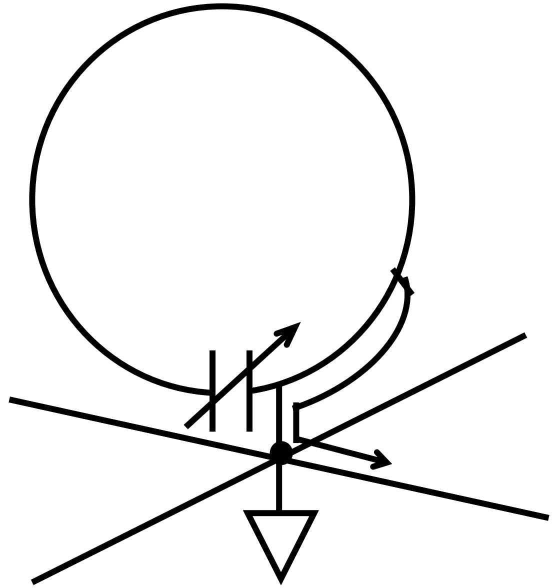




- 1m square loop of 10mm copper plumbing tube with about 2000pF capacitance to tune to 80m took 750 watts before flashover. (Used 2 Palstar 1440pF caps.)
- Did not self-destruct with this power!
- Q is about 140 which is typical for this kind of loop arrangement. (Allows 3 to 4 times the power.)

- 1.7m diameter loop of 10mm copper plumbing tube with about 3300pF capacitance to tune to 160m took 550 watts with no sign of flashover or overheating.
- BW = 9.2 kHz
- Q =215 which is typical for this connection. (Allows about double the power)

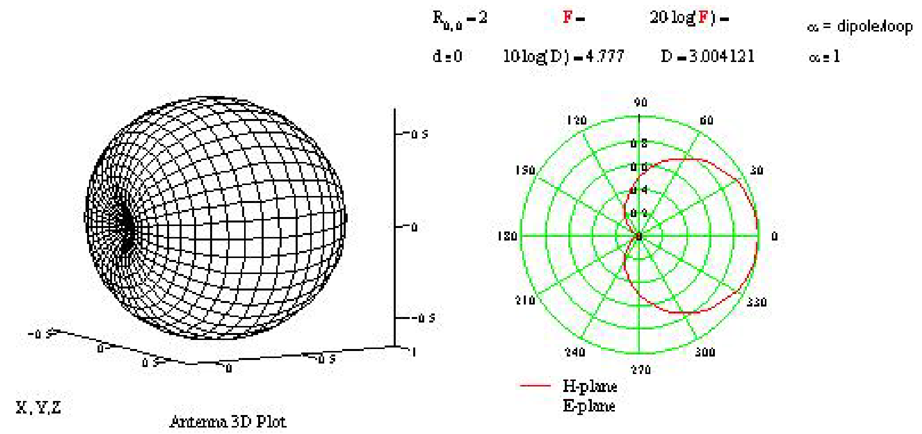
The G3LHZ loop-monopole arrangement

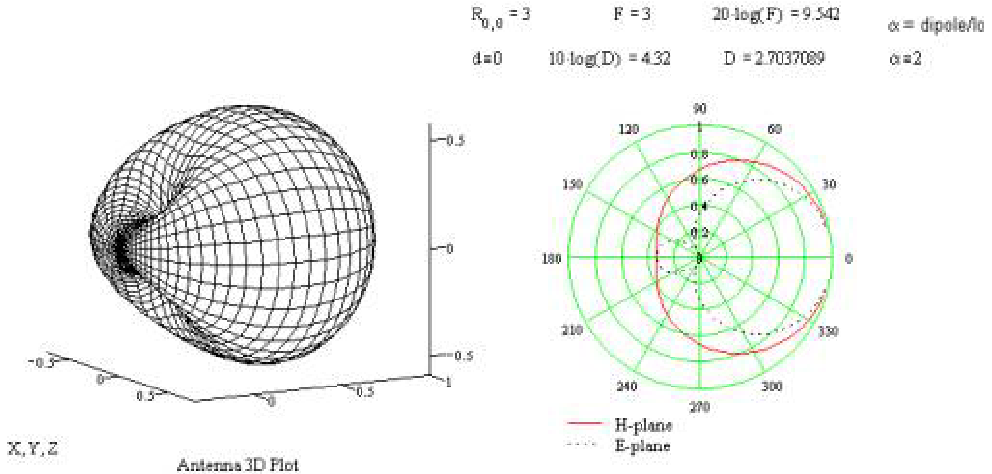


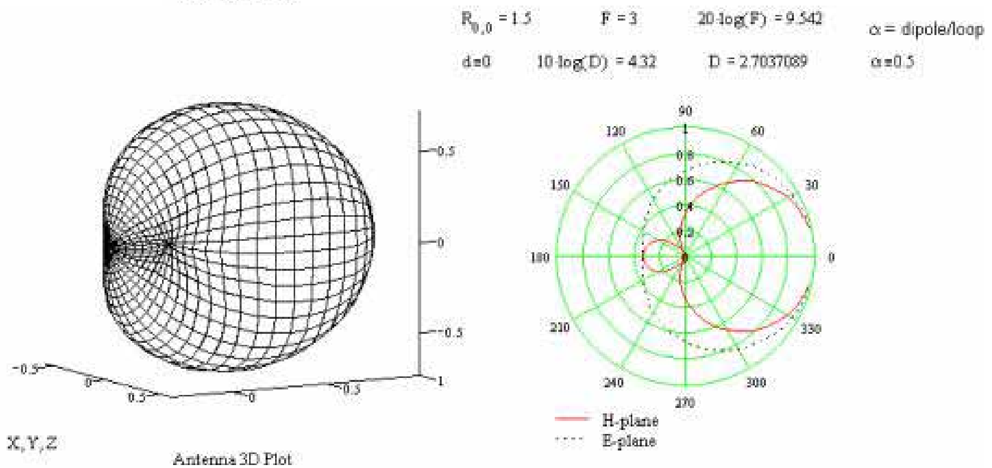
- Gamma-fed Grounded Monopole-Loop with small ground plane.
- The ground-plane can be a ‘bowtie’ about twice or three times the loop size
- An attic ground-plane much reduces EMC interference to and from house wiring
- The pattern is of a vertical monopole combined with a vertical loop.
- It is directional towards the capacitor. Null away from the capacitor
- It is like a DF antenna with the ‘sense’ vertical switched on.
- Good directionality only occurs with the antenna at the right height above ground; higher for ‘poor’ ground and lower for ‘good’ ground.
- The Q is about halved at the highest tuning frequencies, then giving wider bandwidth and higher power operation.

Unidirectional Loop Directivity – a ‘heuristic’ approach

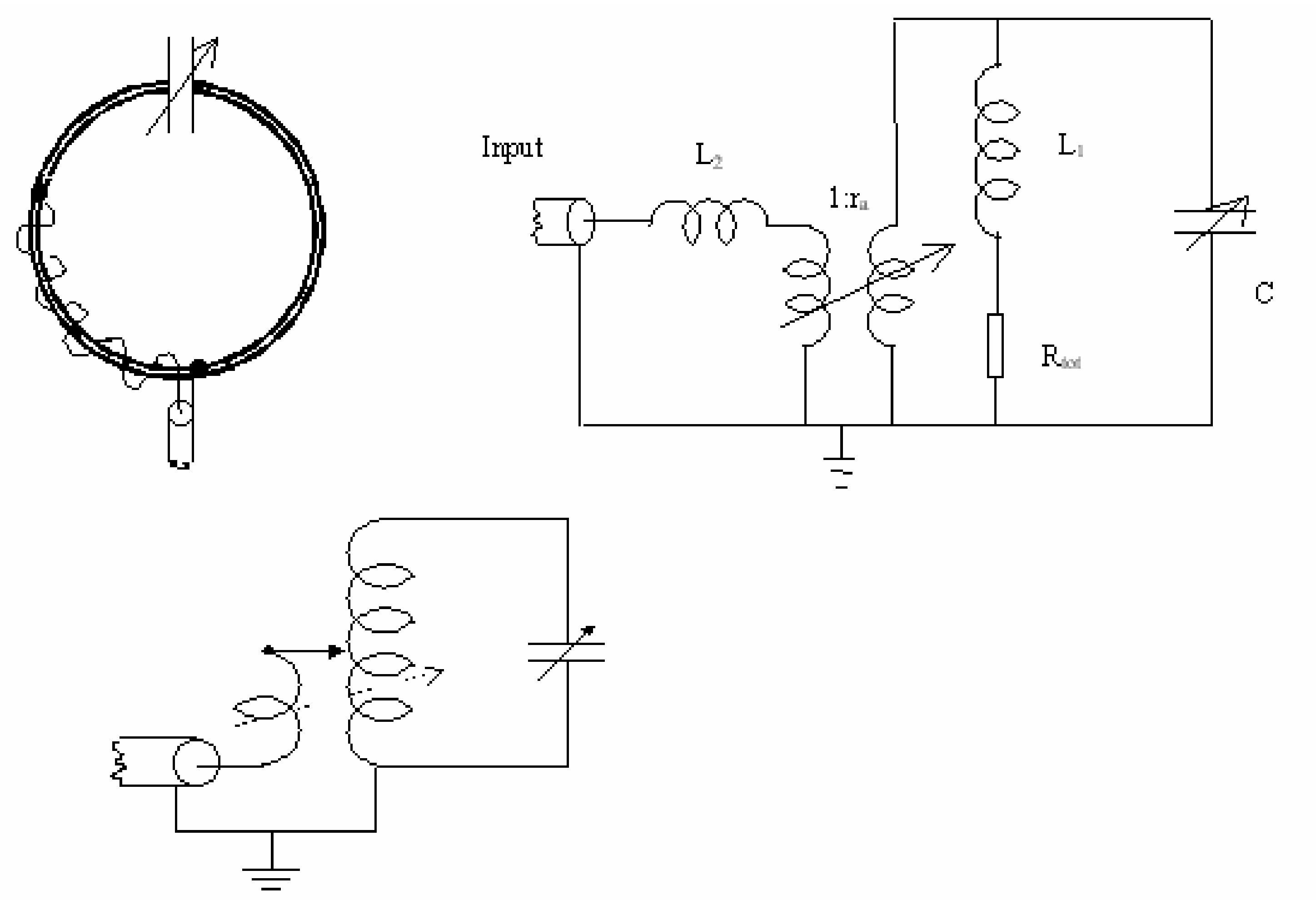
- Two loop modes are assumed (electric and magnetic dipole modes).
- They combine with an unknown ratio and phase.
- to give a unidirectional pattern. We measure a few points o
- Directivity in forward (boresight) direction depends on the total shape of the antenna pattern only.
- Directivity D = Gain, if antenna is 100% efficient. Gain = Directivity × Efficiency.
- Maximum Directivity occurs when the the modes are equal. It is 3 (4.78dBi), relative to an isotropic antenna. There is then a perfect backward null. D = 1.64 for a λ/2 dipole.
- Nulls are no longer at right angles to the antenna.







Loop Matching and Equivalent Circuits

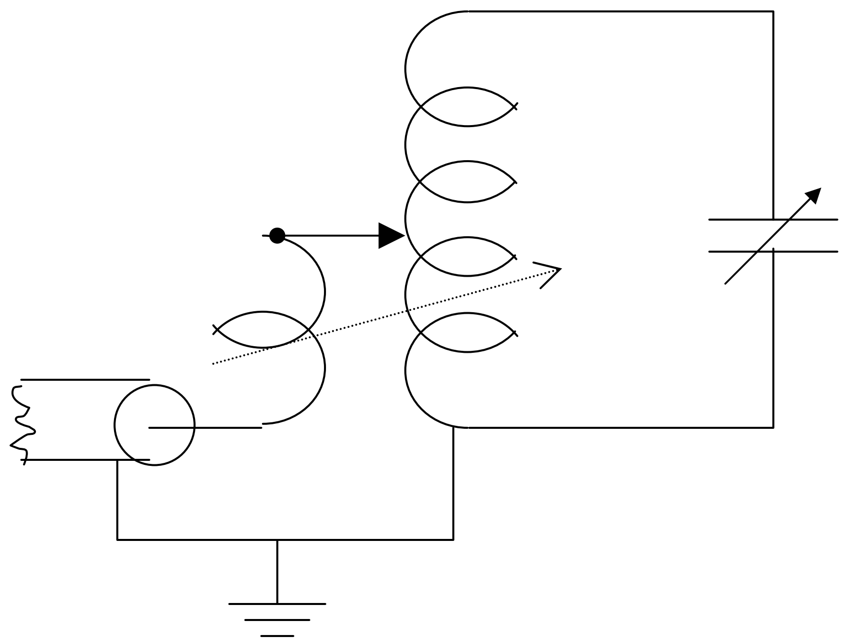


The Twisted Gamma Match - 1

- The “twisted gamma match” (or mu-gamma, or G3LHZ gamma match) consists of a long insulated wire wound loosely or tightly around the main loop starting from a chosen ground point.
- It combines three coupling modes:-
  - Inductive coupling - as by a small loop.
  - Travelling wave coupling - as in directional couplers.
  - Tapping along main loop - as in conventional gamma match.
- The loop coupling is achieved by pulling out a small loop at a desired point along the gamma wire.
- The travelling wave coupling is weak and it allows the point of maximum coupling to be moved to practically any point around the loop (for optimising directionality).
- The best tapping point can be found using a large crocodile clip and then replacing this by a soldered joint, permanent clamp, or large “jubilee” clip.

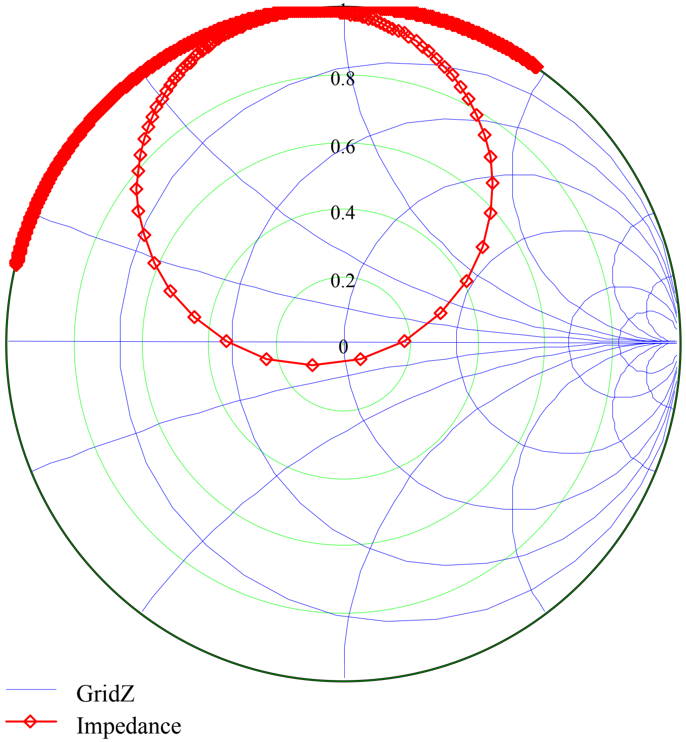
The Twisted Gamma Match - 2

- There are usually two essentially open-circuit points of practically zero coupling on the main loop, at approximately 90° and 270° away from the tuning capacitor. Practical coupling points can be found on either side of these “null” points.
- An equivalent lumped circuit shows how the inductive coupling can cancel the tapping point voltage at certain places.



W-Q predicted SWR over 1m. loop tuning range.

(lower picture)

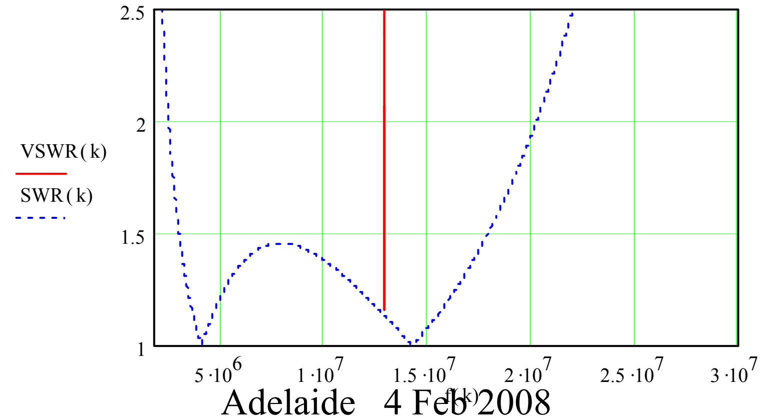


Smith Chart - (r = 0.2 is 1.5:1 SWR)

$f_{res} := \left[2\pi\left(L_1 \cdot C_1\right)^{0.5}\right]^{-1}$

f_{res} is the loop resonant frequency

$f_{res} = 1.282 \times 10^{7}$



Adelaide 4 Feb 2008

dip

a = 1 gives 100% coupling of modes. Larger a decouples the modes. Use a =2?

$a \equiv 2$

Choose loop dimensions:-

$D_{loop.m} \equiv 1$ $D_{tube.mm} \equiv 20$

Cu = 0.0707
Al = 0.128

$Tube_{loss} \equiv 0.0707$

$$b \equiv \frac{\pi \cdot D_{loop.m}}{D_{tube.mm}} \cdot Tube_{loss}$$

Choose gamma coupling k_m. =l / r_a, where r_a is effective turns ratio. :

$k_m \equiv \frac{1}{20}$

$r_a \equiv k_m^{-1}$

Choose : $C_1 \equiv 60 \cdot 10^{-12}$

$$L_1 \equiv \frac{\pi \cdot D_{loop.m}^{1.25}}{\left(0.167 \cdot D_{tube.mm}\right)^{0.167}} \cdot 10^{-6}$$

Choose intrinsic loop Qil = 300 to 600

$Q_{il} \equiv 520$

Proposed basic loop Q formula:

$Q_{ml} \equiv Q_{il} \cdot D_{loop.m}^{-1}$

Thus: $Q_{ml} = 520$

and: $L_1 = 2.569 \times 10^{-6}$

Choose extra input inductance factor:

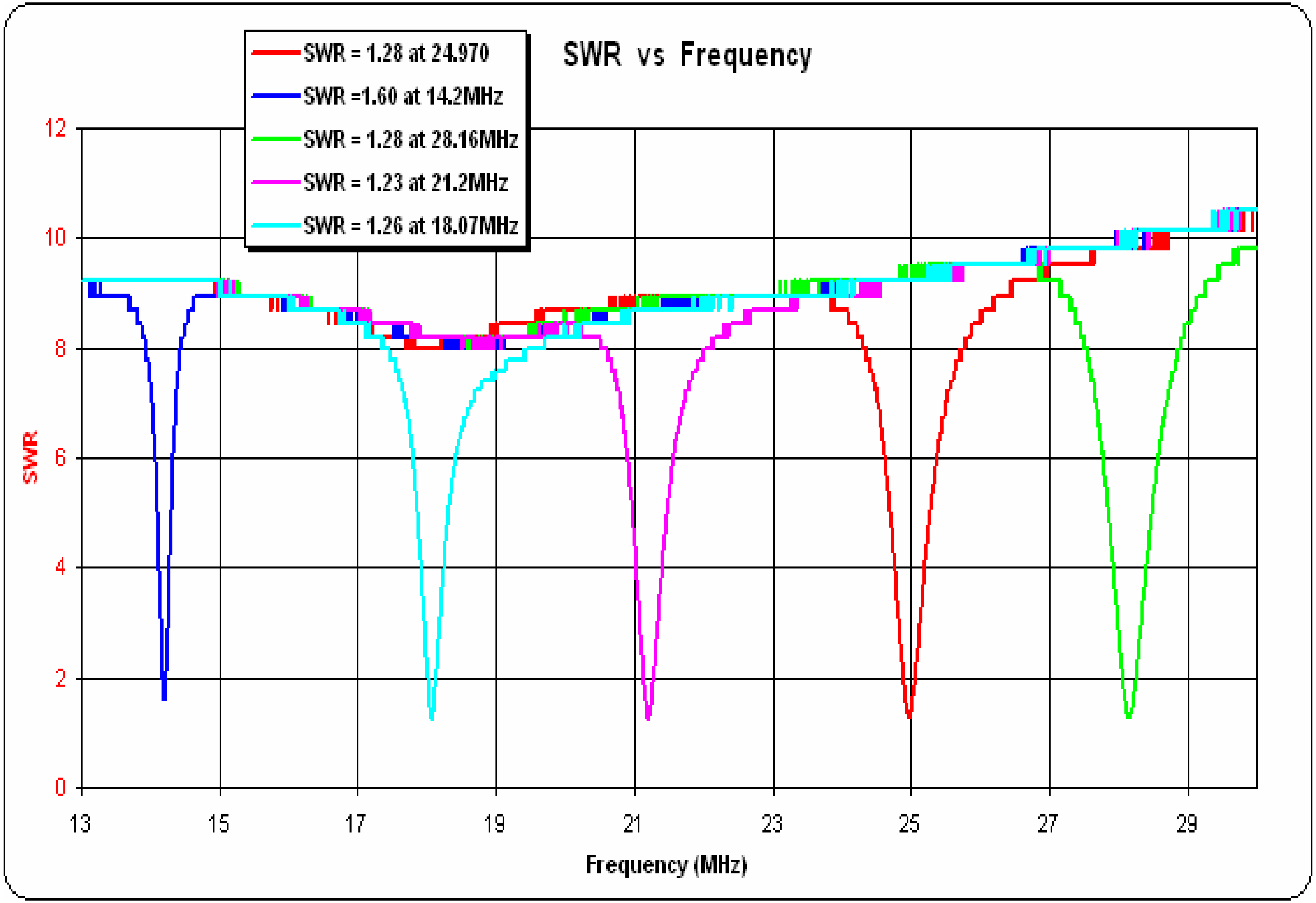
$\alpha_{Lgam} \equiv .2$

Input inductance L_2: $L_2 \equiv L_1 \cdot \alpha_{Lgam}$

$L_2 = 5.137 \times 10^{-7}$

G3LHZ

5 band < 2:1 SWR of AMA3 83cm diameter loop with 'twisted gamma match' – as seen on miniVNA



How antennas transmit *and* receive –the heuristic approach and process

- What can we observe?
- What can we deduce from this?
- Derive the theory and model – without pre-conceptions
- Calibrate the model by measurements
- Find consequences, make predictions, and inventions
- Validate theory and inventions by further measurements

‘Qualitative’ heuristic theory of electromagnetic radiation

1. Antenna surfaces create one or more (magnetic or electric) ‘energy storage modes’ surrounding the antenna. The modes are ‘distributed impedances’ in the space around the antenna. (The modes are present even when no power is being transmitted or received.)
2. Transmitted *or* received power P fills these modes with stored energy

$$U = PQ/2\pi f,$$

where Q is the total antenna Q and f is the frequency.

3. On receive, the stored energy creates the ‘capture area’ of the antenna. It focuses the received power onto the antenna surfaces, which convey it to the antenna terminals.
4. On transmit, the stored energy redirects the transmitted power to form the antenna pattern.
5. The stored energy matches the antenna to free space. (The match condition on receive is the same as on transmit.)
6. In (phased) arrays and Yagis, the power to-and-from each element is redirected by further ‘mutual energy’ stored in the ‘coupling impedance distribution’.

(“And that’s all there is to it!?”)

Qualitative heuristic theory – outcomes and validation

Consequences

- Once the RF power is launched (1mm) from the surface of the antenna it does not return. The field/energy distribution surrounding the antenna re-directs power (by the generation of large displacement currents) to form the antenna pattern. It does *not* suppress the emission of the power in the first place.
- Small transmit antennas are therefore *fundamentally* very efficient.
  (The Chu-Wheeler criterion is seriously damaging. It needs urgent revision.)
- There is a very wide range potential new designs for small antennas.
- A small antenna needs sufficient stored energy to form its pattern. It therefore has a high Q and narrow bandwidth.
- Stored energy *can be partially* cancelled to give lower Q. Lower Q antennas are more efficient and handle higher powers.

Validation

- If the predictions of a theory are correct *qualitatively*, it is *partially* validated.
- If the predictions of a theory are correct *quantitatively*, it is *fully* validated.
- Calibration measurements (of antenna Q, input impedance, pattern, efficiency etc.) validate heuristic theory. The theory then predicts accurately.

Preliminary 'quantitative' heuristic theory of electromagnetic radiation – based on energy and power considerations – 1

Observations and questions:

- Sources create fields. But what field distributions are created?
- Oscillating power sources can radiate power. But how much from a source of a given strength?
- If sources can radiate they can also receive power. The 'source' is then a 'sink'.
- Each and every field stores energy. The total energy is U_{tot} =
- Fields can convey power. What are the lines of power flow on transmit *and* on receive?

Definitions:

- Q_{ant} is the antenna (source/sink) Q. For a total antenna stored energy E_{ant} and total radiated or received power P_{tot},, at angular frequency $2\pi f$ we have

$$Q_{ant} = U_{tot}/2\pi f P_{tot}$$

- But what is the 'local Q' value Q_{loc} at any point in (near-field) space?

$$Q_{loc} = U_d/P_d \, \lambda$$

Note: in the far field $Q_{loc} = 1$ by definition.

'Quantitative' heuristic theory of electromagnetic radiation – based on energy and power considerations – 2

Impact of Q:

1. Q_{ant} is the antenna (source/sink) Q. For a total antenna stored energy E_{ant} and total radiated or received power P_{tot},, at angular frequency $2\pi f$ we have
$$Q_{ant} = U_{tot}/2\pi f P_{tot}$$
2. The 'local Q' value Q_{loc} at any point in (near-field) space can be
$$Q_{loc} = U_d/P_d \lambda$$
   – Note: in the far field $Q_{loc} = 1$ by definition.
3. The distribution of Q_{loc} appears *not* to scale with frequency
   – *This leads to a 'quantum' theory*
   – *It means 'radio-photons' are not stable much below terahertz frequencies at room temperature*
4. The group velocity of a wave can be said to be
$$v_g = c_{em}/Q_{loc}$$
5. A total group delay of Q_{ant}/f has to be added to the normal propagation delay.

Novel Small Tuned Antennas derived from the Tuned Loop – How do they work?

- Traditional theory says that none of these antennas should work. But they do!
- Q and heat measurements once again show efficiencies of 80% to 90% or more.
- Can we use heuristics to find out why?
- What can we observe from these 'impossible' antennas?

Twisted Tuned Folded Dipole – how can it radiate at all?

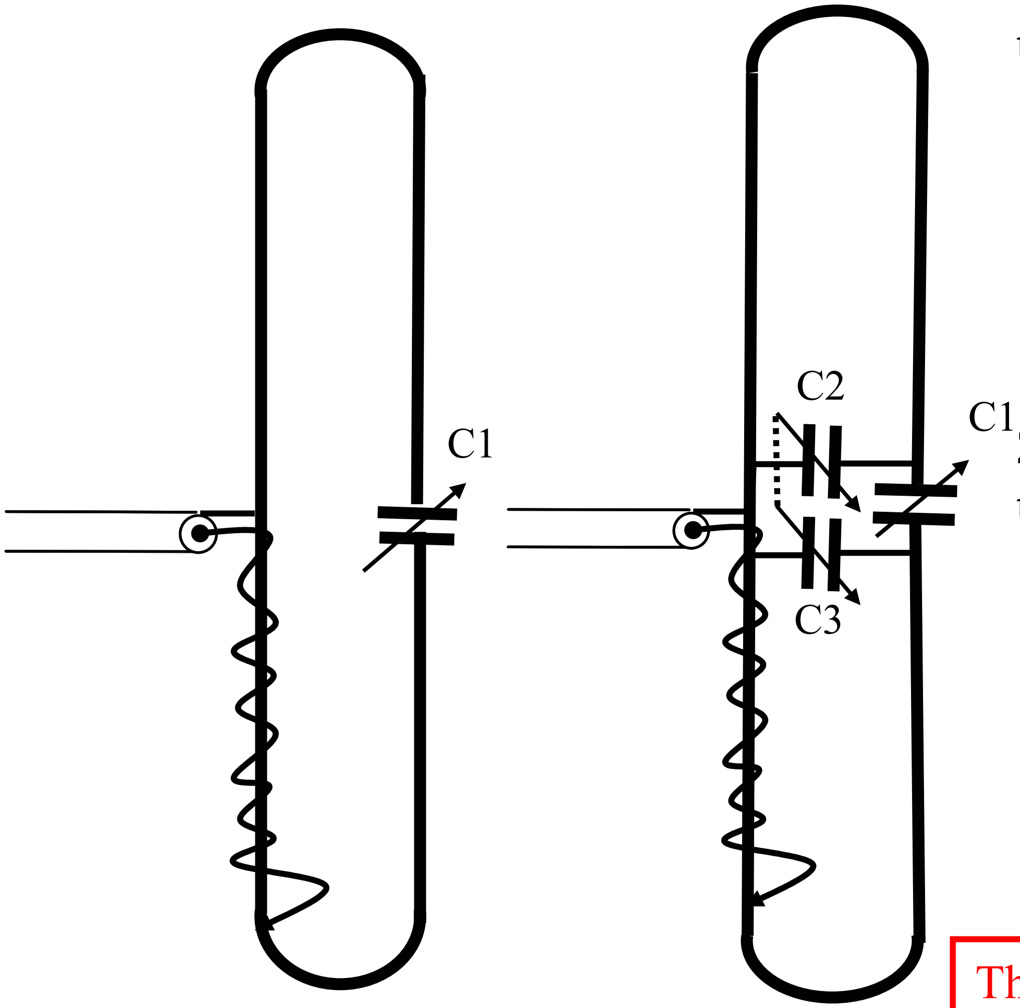
Single Capacitor Twisted Folded Dipole-measured in a Conservatory

Efficiency of Tuned Loop Antennas by Q Measurement for:		Twisted folded dipole 4m perimeter 10mm copper tubed	
One loop circumference in metres, Cir =	4.06	Conductor diameter, metres, d =	0.01
Measured inductance value in uH, Lm =	3.09	Calculated Inductance, Le in uH =m×O.52 Cir/(d)^0.13 =	3.84
Chosen inductance value in uH, L =	3.09	Loop reactance Xl = 2π f0 L	Rtot = Xl/Q
Copper resistivity at DC, ρ =	2.00E-08	Skin-effect Rloss = 2m×√(0.1×f0×ρ)×Cir/d	Rrad = Rtot-Rloss
Chu radius in metres, a =	1	Loop Eff % = 100%×(Rrad/Rtot)	C = Capacitor Value = 1E6/(2πf0Xl)
Half dipole mode length in metres z =	1	Cap volts = √(WQXl)	Loop current = √(WQ/Xl)
Kraus loop radius in metres r =	0.5	Dipole Efficiency = 100%/(1+Rtot/Rdip) where Rdip =m^2× 4×800(z f0/300)^2	
W =Power Input in watts =	400	Kraus Efficiency = 100%/(1+Rtot/Rkraus) where Rkraus = m^2×20×π^2×8(π r f0/150)^4	

f1 (3dB), in MHz	f2(3dB), in MHz	f0 in MHz	Measured Q	Loop Reactance Xl	Measured Rtot	Skin-effect loss = Rloss	Rrad=Total Radiation Resistance	Measured Efficiency = Eff %	Capacitor Voltage	Loop Current (amps)	Cap Value in pF	Efficiency of Dipole mode %	Kraus Loop Eff %	Chu Efficiency %	Estimated Mode Q	Mode Q=300 Effic %
Horizontal 1.7m agl in conservatory																
2.0896	2.1051	2.097	135.3	40.7	0.301	0.0526	0.248	82.52	1484.6	36.5	1863.5	11.499	0.015	1.134	163.97	72.07
2.4651	2.4886	2.477	105.4	48.1	0.456	0.0572	0.399	87.47	1423.9	29.6	1336.2	10.676	0.020	1.450	120.49	73.72
3.0563	3.0759	3.066	156.4	59.5	0.381	0.0636	0.317	83.29	1930.0	32.4	872.0	18.006	0.055	3.978	187.82	75.73
3.4292	3.4422	3.436	264.3	66.7	0.252	0.0673	0.185	73.33	2655.5	39.8	694.5	29.364	0.131	8.964	360.40	76.76
3.6904	3.7045	3.697	262.2	71.8	0.274	0.0698	0.204	74.49	2744.0	38.2	599.6	30.744	0.162	10.856	352.02	77.41
4.3912	4.4106	4.401	226.9	85.4	0.377	0.0762	0.300	79.77	2784.5	32.6	423.3	31.369	0.236	15.084	284.37	78.90
5.0179	5.0391	5.029	237.2	97.6	0.412	0.0814	0.330	80.22	3043.5	31.2	324.2	35.320	0.367	21.696	295.69	79.99
7.0774	7.1034	7.090	272.7	137.7	0.505	0.0967	0.408	80.84	3875.1	28.1	163.1	46.957	1.175	47.176	337.32	82.60
10.188	10.223	10.206	291.6	198.1	0.680	0.1160	0.564	82.93	4807.3	24.3	78.7	57.670	3.651	74.008	351.61	85.06
14.121	14.198	14.160	183.9	274.9	1.495	0.1366	1.358	90.86	4496.8	16.4	40.9	54.382	6.000	82.747	202.39	87.02
18.414	18.464	18.439	368.8	358.0	0.971	0.1559	0.815	83.94	7266.9	20.3	24.1	75.688	22.038	95.504	439.35	88.44
21.828	21.899	21.864	307.9	424.5	1.378	0.1698	1.209	87.68	7230.9	17.0	17.1	75.505	28.237	96.728	351.20	89.29
1	2	1.500	1.5	29.1	19.415	0.0445	19.371	99.77	132.2	4.5	3643.3	0.103	0.000	0.005	1.50	68.58
1	2	1.500	1.5	29.1	19.415	0.0445	19.371	99.77	132.2	4.5	3643.3	0.103	0.000	0.005	1.50	68.58
Vertical 0.1m agl in conservatory																
2.1195	2.1313	2.125	180.1	41.3	0.229	0.0529	0.176	76.89	1724.2	41.8	1814.7	14.913	0.021	1.564	234.25	72.21
2.4754	2.4894	2.482	177.3	48.2	0.272	0.0572	0.215	78.95	1848.9	38.4	1330.3	16.772	0.033	2.431	224.59	73.74
3.0045	3.0191	3.012	206.3	58.5	0.283	0.0630	0.220	77.77	2196.6	37.6	903.7	22.146	0.069	4.923	265.26	75.57
3.4212	3.4395	3.430	187.5	66.6	0.355	0.0673	0.288	81.07	2234.7	33.6	696.6	22.744	0.092	6.500	231.22	76.75
3.694	3.7148	3.704	178.1	71.9	0.404	0.0699	0.334	82.69	2263.5	31.5	597.4	23.198	0.111	7.679	215.37	77.43
4.3977	4.4147	4.406	259.2	85.5	0.330	0.0762	0.254	76.91	2978.1	34.8	422.2	34.334	0.270	16.923	337.02	78.91
5.0225	5.0428	5.033	247.9	97.7	0.394	0.0815	0.313	79.33	3112.8	31.9	323.7	36.355	0.385	22.499	312.51	79.99
7.0412	7.0655	7.053	290.3	136.9	0.472	0.0964	0.375	79.56	3987.4	29.1	164.8	48.383	1.230	48.340	364.84	82.56
9.9496	9.9777	9.964	354.6	193.4	0.546	0.1146	0.431	78.99	5238.0	27.1	82.6	61.795	4.112	76.315	448.89	84.91
14.168	14.202	14.185	417.2	275.4	0.660	0.1368	0.523	79.28	6779.4	24.6	40.7	73.042	12.709	91.625	526.24	87.03
18.201	18.254	18.228	343.9	353.9	1.029	0.1550	0.874	84.93	6977.3	19.7	24.7	74.160	20.296	95.033	404.92	88.38
21.834	21.895	21.865	358.434	424.500	1.184	0.170	1.015	85.66	7801.423	18.378	17.148	78.204	31.416	97.177	418.43	89.29
1	2	1.500	1.5	29.1	19.415	0.0445	19.371	99.77	132.2	4.5	3643.3	0.103	0.000	0.005	1.50	68.58
1	2	1.500	1.5	29.1	19.415	0.0445	19.371	99.77	132.2	4.5	3643.3	0.103	0.000	0.005	1.50	68.58

Basic and Double Tuned Folded Dipoles Compared

(can be twisted or straight)



1. Single Tuned – one main resonance

2. Double Tuned – two main resonances

1.Single Tuned - 4m length 10mm tube:

- Tuning range 1.9 to 19MHz
- With some capacitor switching
- Q about 200 to 350 – higher at HF end
- Compromise gamma position if ATU used

2.Double Tuned - 4m length 10mm tube:

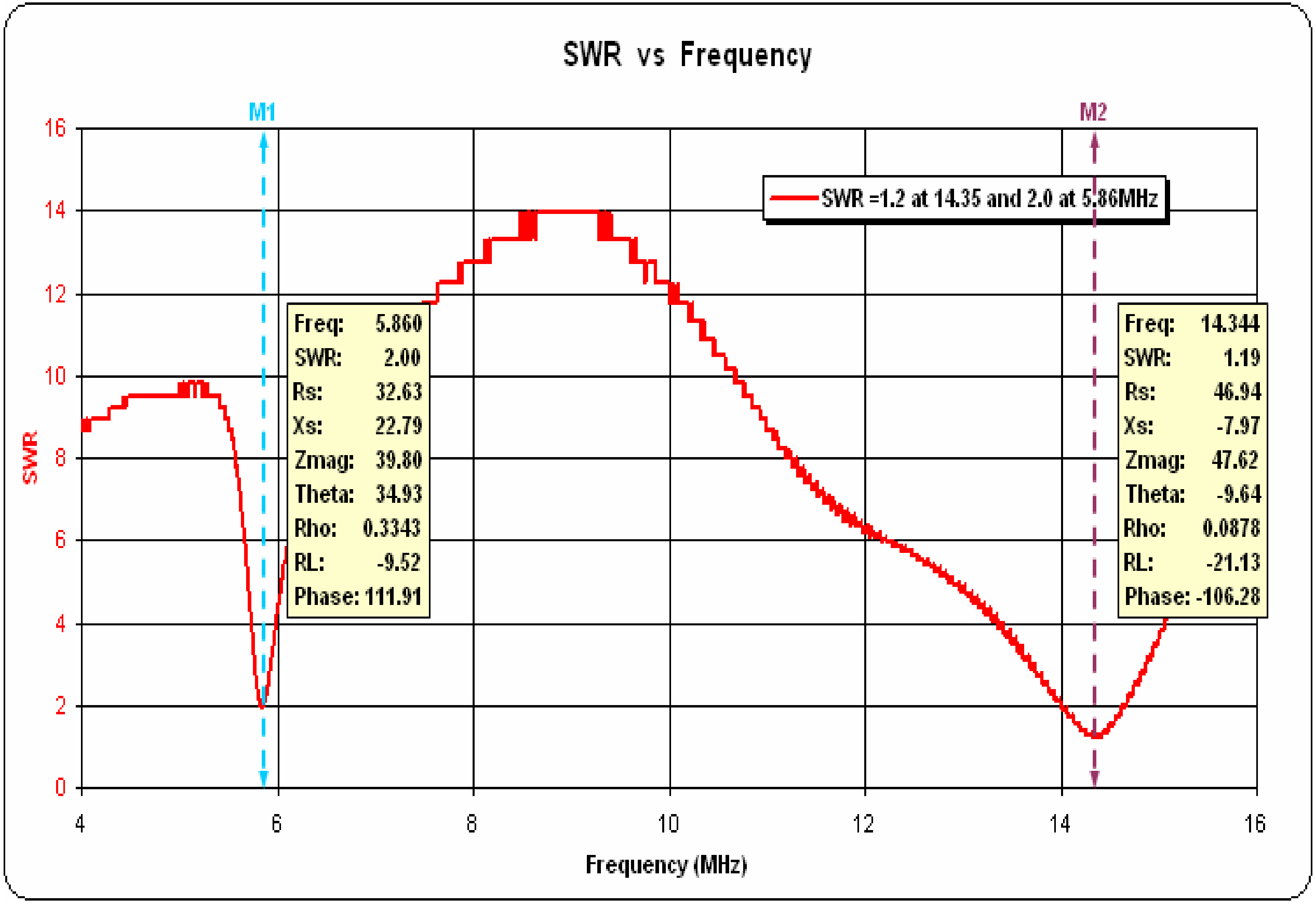
- Tuning ranges 1.8 to 11MHz and 5 to 45MHz
- Without capacitor switching
- Q about 150 over both ranges
- Two switched gamma matches recommended

The 'radiating currents' cancel out.

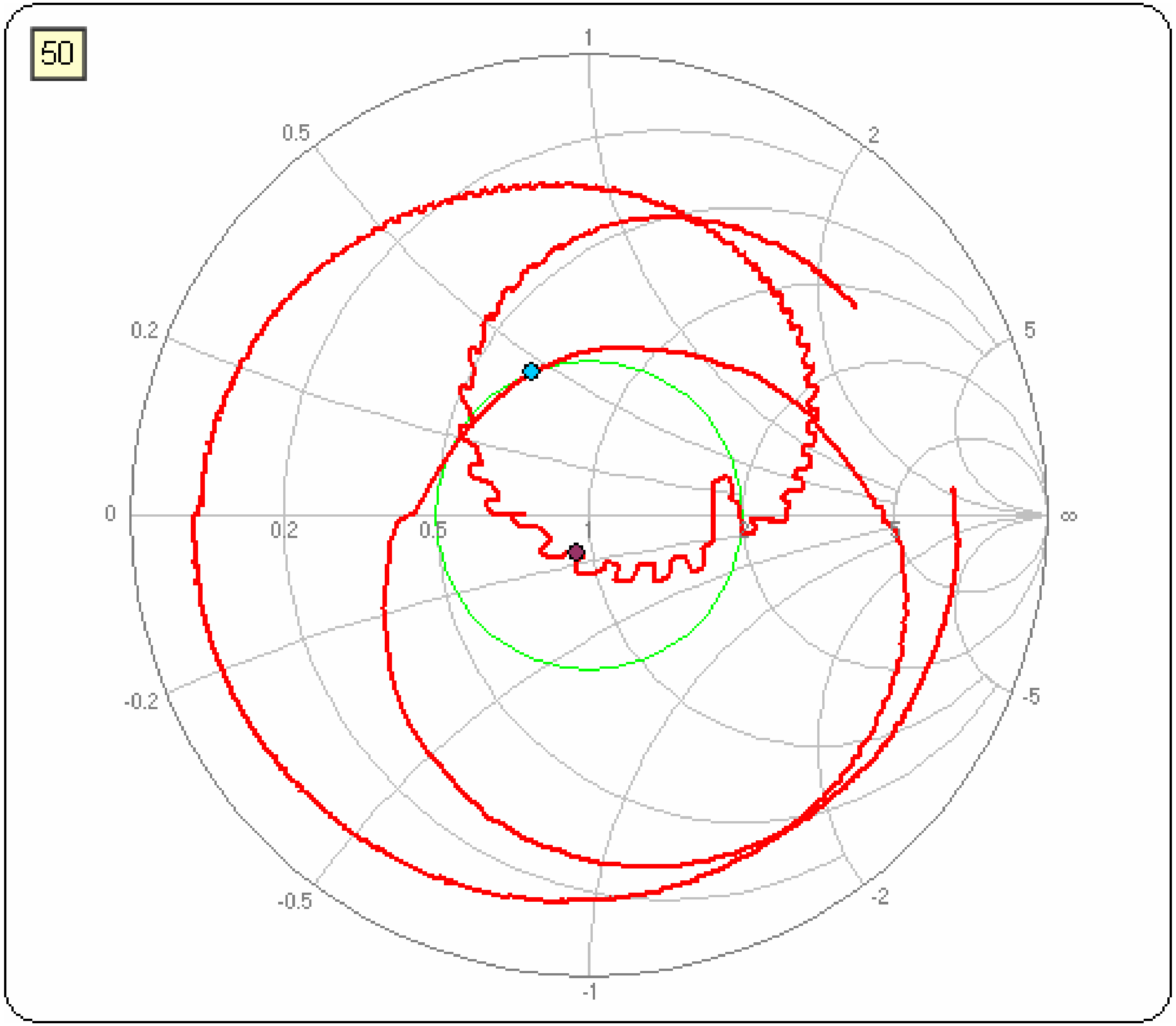
Therefore Old EM theory and NEC say that these antennas cannot possibly work!

2m length horizontal double-tuned folded dipole

2m length horizontal double-tuned folded dipole



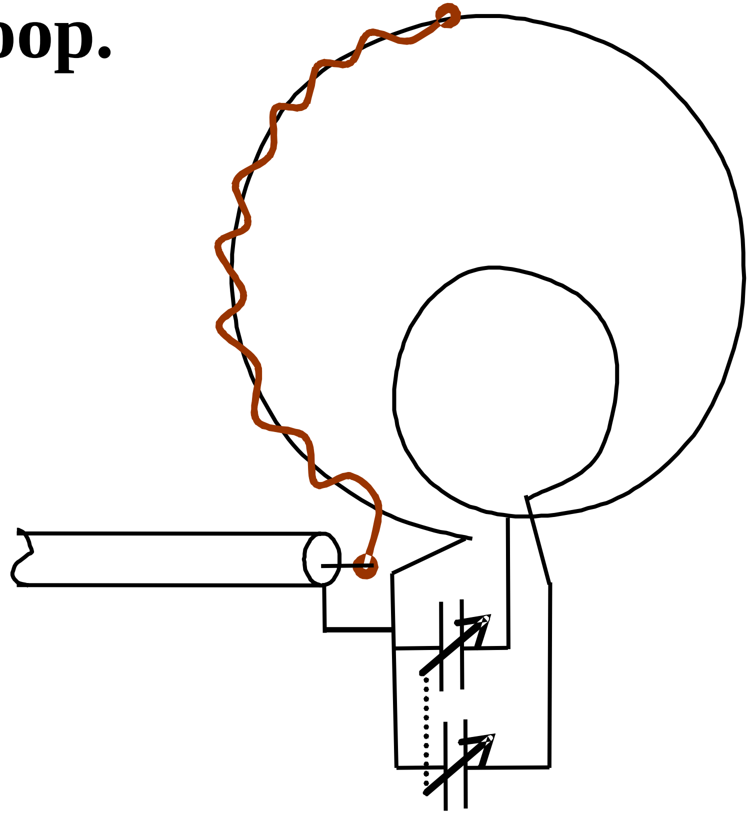
2m length horizontal double-tuned folded dipole



Twisted Folded Dipole Outcomes

- For the single tuned TFD vertical, 500 watts for 1.5 min on 80m gave temperature rise from 16°C to 68°C, a rise of 52°C. The tube length is 4.06m as compared with 1m reference loop of 3.14m. The 1m reference loop gave a rise of 86°C for 150 watts. From this we can estimate the dissipated heat power as $150 \times 52 \times 4.06/(86 \times 3.14) = 117$ watts
- The efficiency is therefore 1- 117/500 = 0.765 or 76.4%
- This compares with 76.9% from the Rho-Q method.
- Note that the inductance measured at 3.7MHz at 3.09uH is significantly less than a loop of the same length of tube, being 3.84uH.
- It means that an opened out loop having higher inductance is more efficient at 86.4% estimated from the Rho-Q method using the same Q value.
- Note that a temperature rise of 52°C meant that the loop tuning changed by about 0.2%.
- The Q of this antenna increases from about 150 to 350 as frequency rises.
- The Double Tuned TTFD version has a Q of down to 150 over most the tuning range

My original 1 metre diameter 1.8 + 3.5 - 30MHz experimental transmitting GP-loop.



- Two resonant frequencies, each with about 4:1 tuning range
- Twisted gamma match on small loop only
- Additional capacitor connected for 160m

2.2 m high 'Double Dustbin Antenna' with internal tuned folded dipole of 5×2m = 10m total length.

- Does it work?
- Yes it does! It has been tested on 3722kHz
- How does it work?
- What modes are there at different frequencies?
- Is it a bit like a CFA? Does it have the same radiation modes?
- Q is measured at 20 to 140
- Efficiency >80 or 90%
- More measurements and optimisation to be done:
- See how Q varies with ground conditions (as found by loop ground sensor)?

Tuned Hairpin Antenna

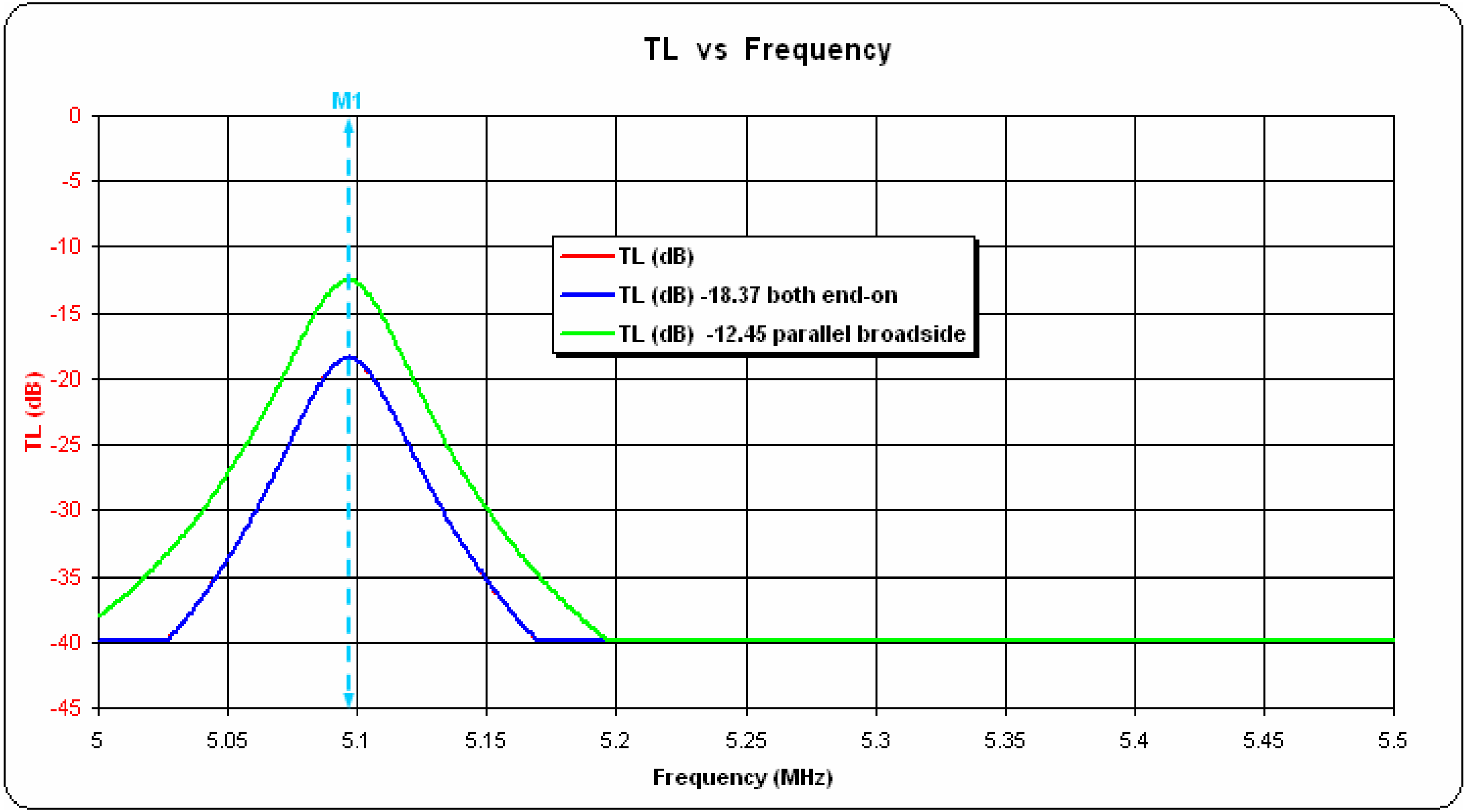
Twisted loop-gamma feed →

- 2m height hairpin
- \>200watts 2 to 10MHz
- Can be double tuned to go to 30MHz
- Efficiency >80 to >90%
- *How can it possibly radiate? – The currents well and truly cancel!*

Pair of Tuned Hairpin Antennas

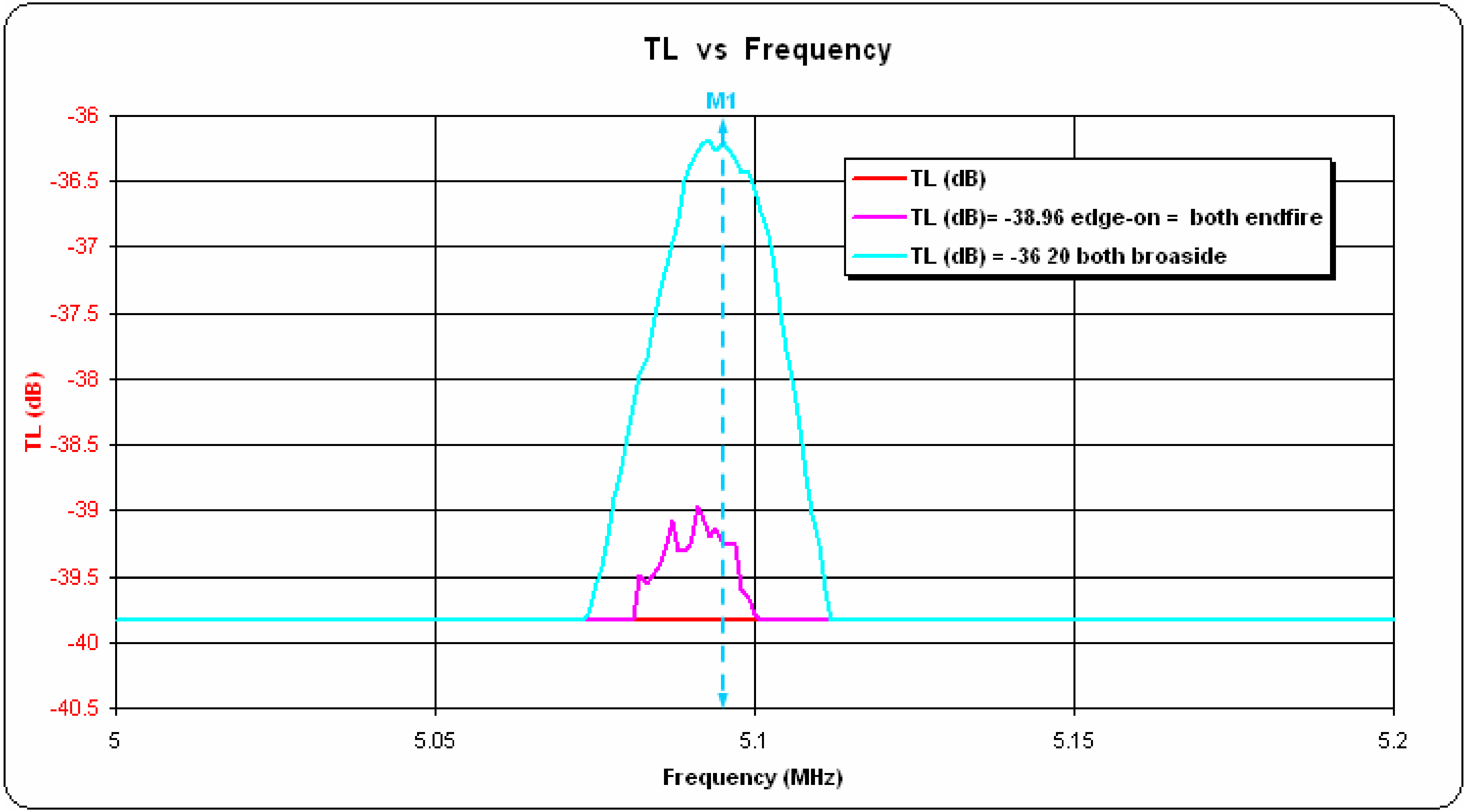
- **Antenna patterns under investigation:**
  - ***Depends on type and orientation of field sensor!***
  - **An *identical pair* of antennas is the only safe way to sort this out!**
  - **This is the heuristic approach:**
  - **Do the measurements!**
- **First results:**
  - **There are two dipole patterns**
  - **The horizontally polarised pattern is max at 'broadside'**
  - **The vertically polarised pattern is max at 'end-on'. It is a magnetic dipole pattern like a loop. It is 3dB down on the other mode**

Coupling between two 2m length vertical tuned hairpins spaced 1.5 metres apart (using MiniVNA)



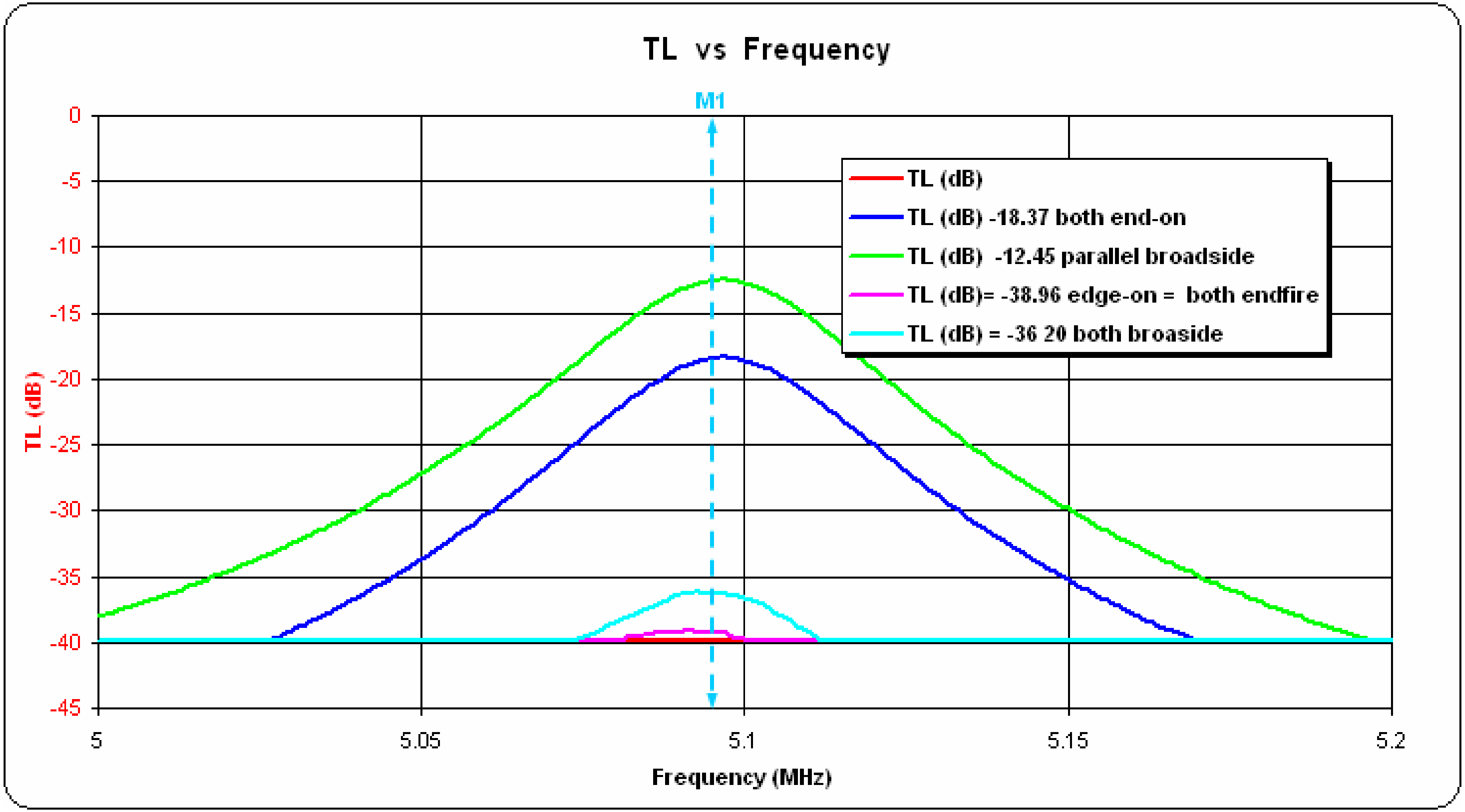
Also note that there are deep nulls if either hairpin is rotated by 90°

Coupling between two 2m length vertical tuned hairpins spaced 4.2 metres apart (using MiniVNA)



Also note that there are deep nulls if either hairpin is rotated by 90°

Coupling between two 2m length vertical tuned hairpins spaced 1.5 and 4.2 metres apart (using MiniVNA)



- **Also note that there are deep nulls if either hairpin is rotated by 90°**
- ***But how can there be two <u>independent</u> patterns for each hairpin?***

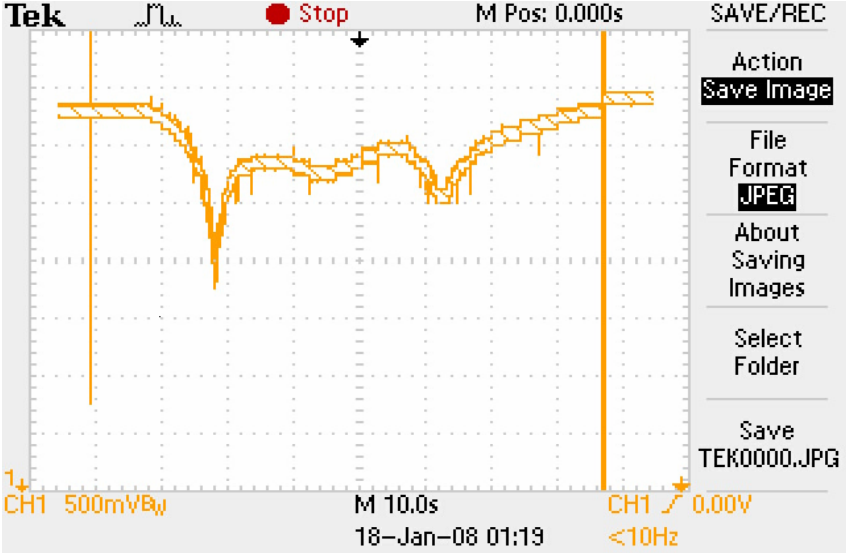
Coiled Tuned Hairpin

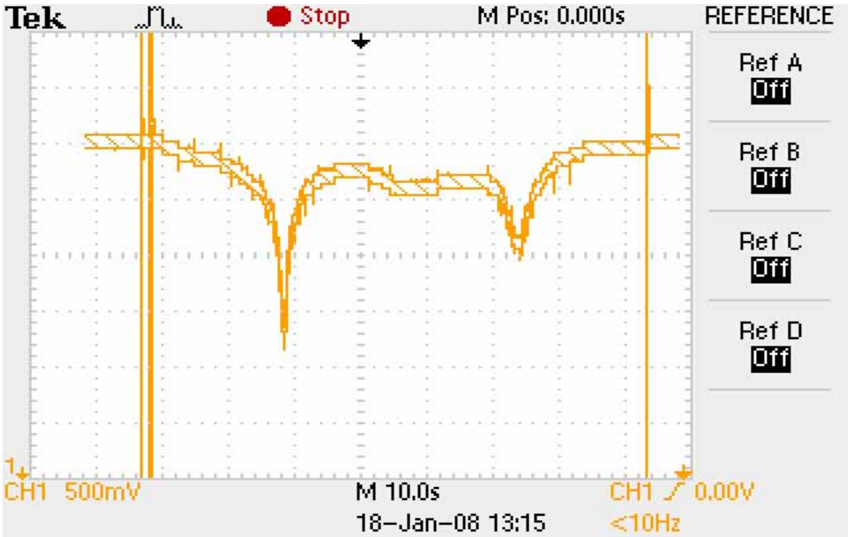
- **80cm diameter coiled**
- **>200watts 2 to 10MHz**
  - **Can be double tuned to go to 30MHz**
- **What is the pattern? – under investigation – heuristically!**

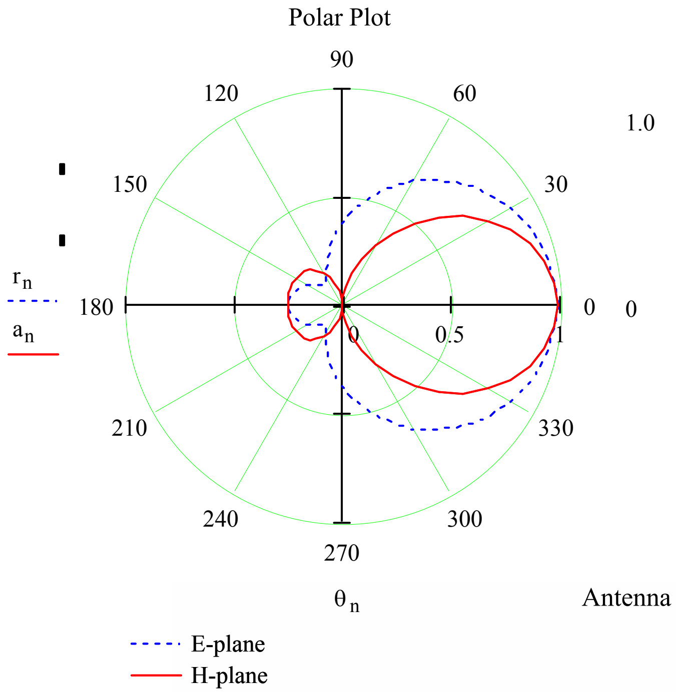
Coiled Double-Tuned Hairpin

- **80cm diameter when coiled**
- **>200watts 1.8 to 30MHz double tuned**
- **May need switched twisted gamma matches**
- **What is the pattern? – under investigation – heuristically!**

Heuristically Derived Antenna Pattern of Coiled Hairpin







Antenna 3D Plot

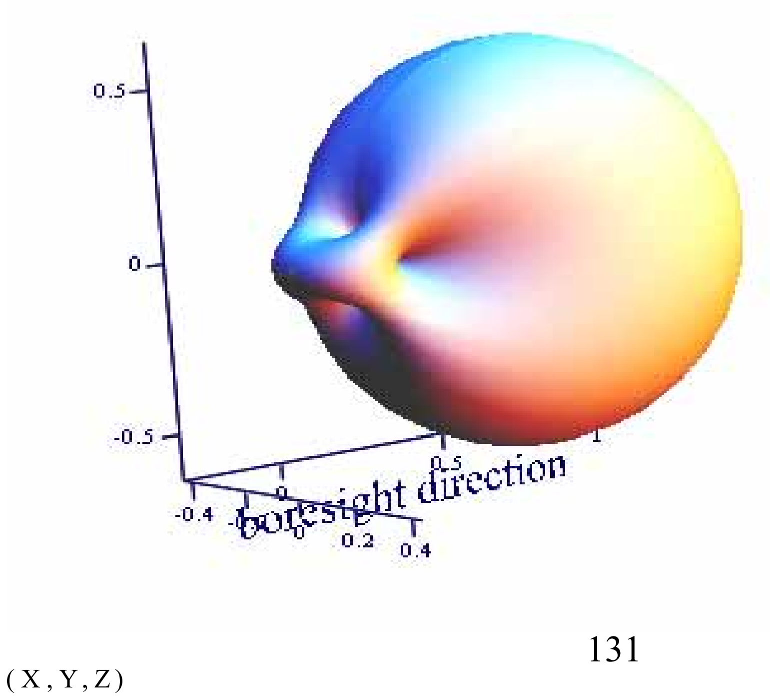


Figure 1: Pair of Candidate 'Tuned Coiled Hairpins' in front of UR Labs at one end of UR Open Range for Small Antenna Measurement. (Antennas 5m apart)

Figure 3: Original Open Range Arrangement of Equipment.

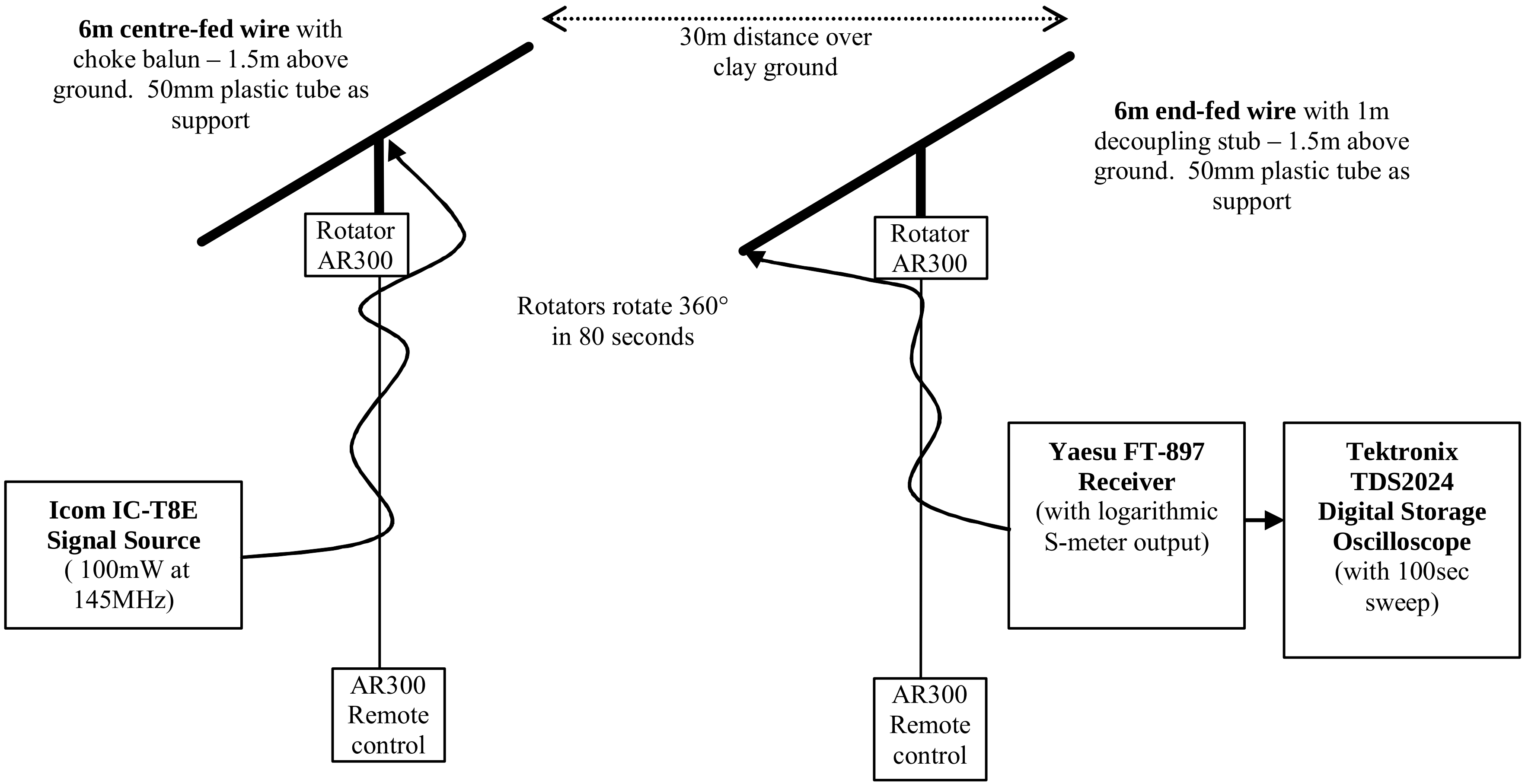


Figure 2: Underhill Research Open Range for Small Antenna Measurement. (Illustrating Rotatable 6.1m End-fed Horizontal Wire (inside plastic pipe) at 16m Distance with UR 35cm Receiving Loop in Foreground.)

The New Theory – derived heuristically from observations of 'impossible' antennas

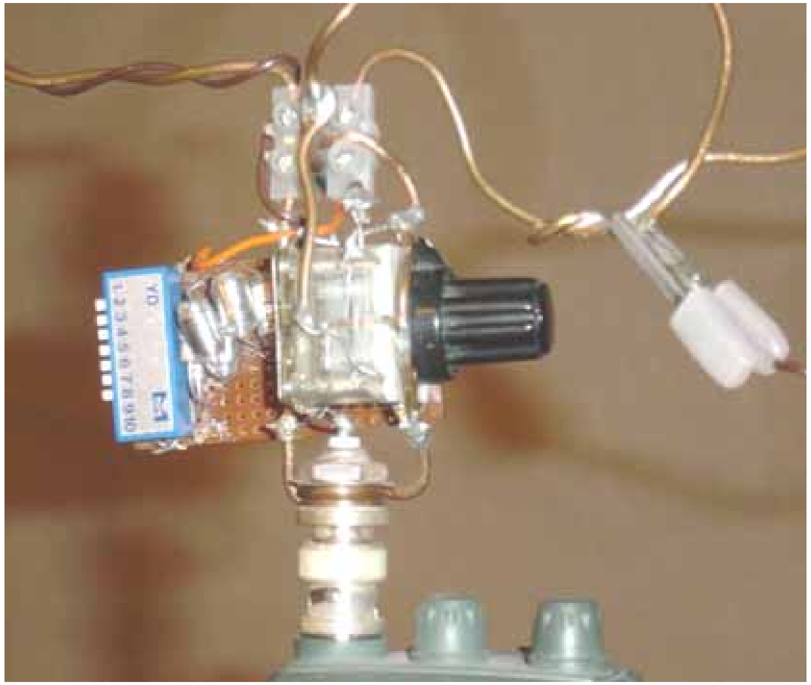
- We find: once the RF escapes a conductor diameter or so it just keeps on going.
- The 'real currents' do not cancel. How then do the antenna patterns form?
- From heuristics is that cancelling real currents generate large 'magnetic displacement currents' in the 'cancellation space' in the antenna near field.
- It is the displacement currents that radiate, receive and store the antenna energy.
- Displacement currents form in regions of 'high energy capacity'= novel concept!
- The coiled hairpin antenna shape is such that the magnetic displacement currents also cancel.. Then the cancelling 'magnetic displacement currents' create radiating 'electric displacement currents'. And so on ad infinitum!
- We find in general that the original polarisation of the waves is preserved.
- Received signals generate exactly the same displacement current distributions
- The stored energy divided by the transmitted or received energy per cycle is the measured antenna Q. A local Q at any point in space can be similarly defined.
- **In essence that's all there is to the radiation theory of antennas!**
- **It's simple really!**

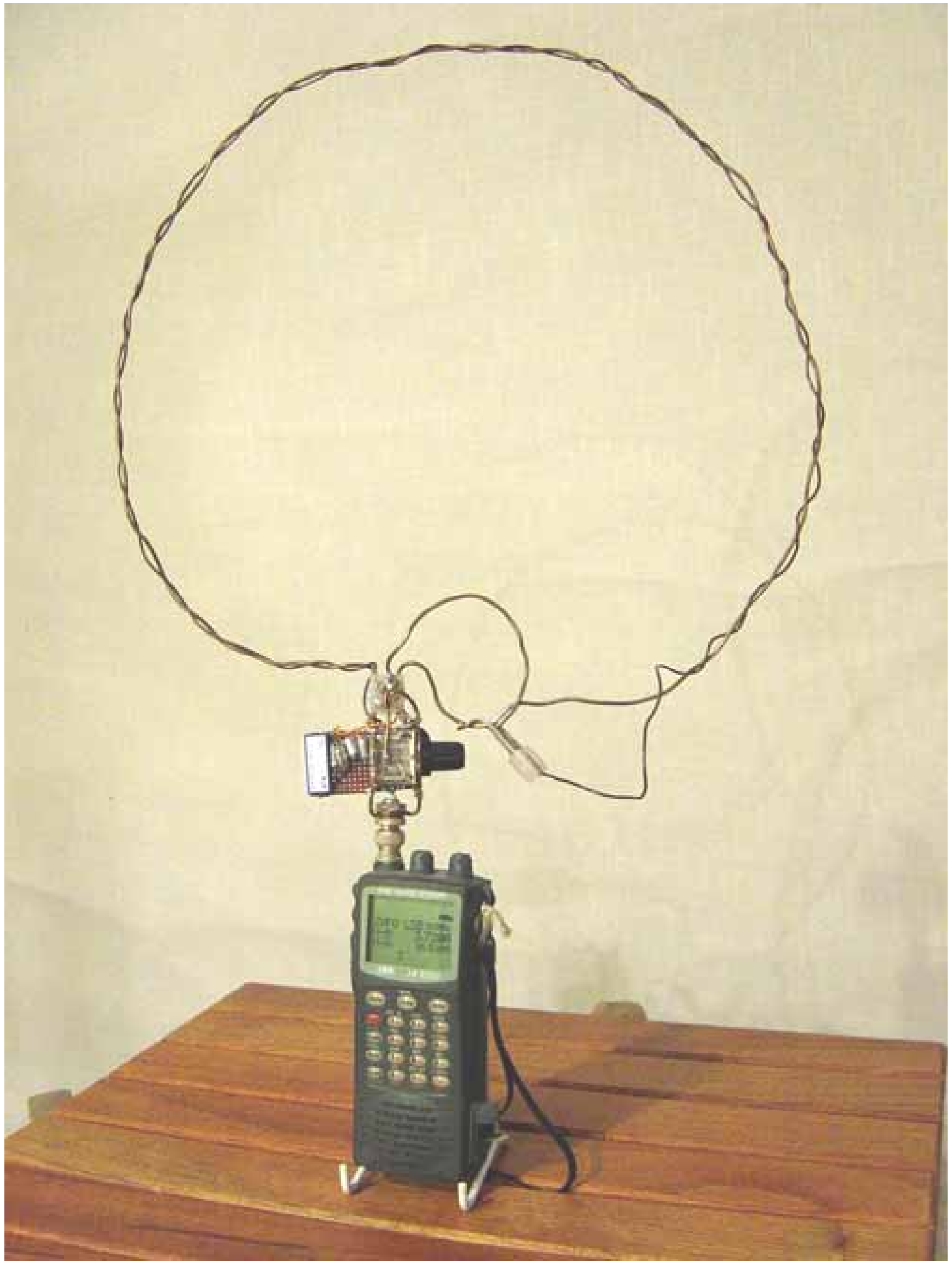
Small Tuned Antenna and Loop Construction

- 10mm diameter 'mini-bore' 'semi-flexible' copper tubing is recommended for loop and other small antenna conductors. It is available from 'Plumb Centre' in 10m lengths at about £20.
- It does not have to be cleaned. A tarnished copper loop works just as well as a cleaned and polished one. Paints are probably best avoided.
- For the loop support 50mm grey plastic down-pipe is recommended. (You could fix a loop to an existing plastic drain-pipe!). For extra strength a length of (square) timber can be inserted.
- The 50mm pipe support clips are ideal for supporting the loop on the pipe and for attaching the (motor tuned) tuning capacitors.
- To attach the loop to the support clips, 'No. 4' black plastic cable cleats are ideal. Try TLC or similar electrical suppliers. A bag of 100 cleats should be less than £10.
- The clips may be attached using the same type of 'roofing bolts' as used for the down pipe clips. Longer bolts are needed for attaching two cleats to one down-pipe support clip.
- Water-proof white plastic boxes for tuning capacitors may be cut to length from square electrical trunking. 'Stop-ends' complete the boxes. The useful standard sizes are 75×75mm or 100×100mm, available from TLC or similar electrical suppliers . Bath sealant can complete the water-proofing if felt necessary. Otherwise white insulating tape may be used.
- For remote tuning, motors with gearboxes and 6mm shafts are available from MFA/Como Drill. Remember that higher ratio gear boxes in general have more backlash. Lower ratio ones introduce more motor control 'overshoot'.

Doubly Resonant 35 cm Receiving Loop 1.5 to 150 MHz.

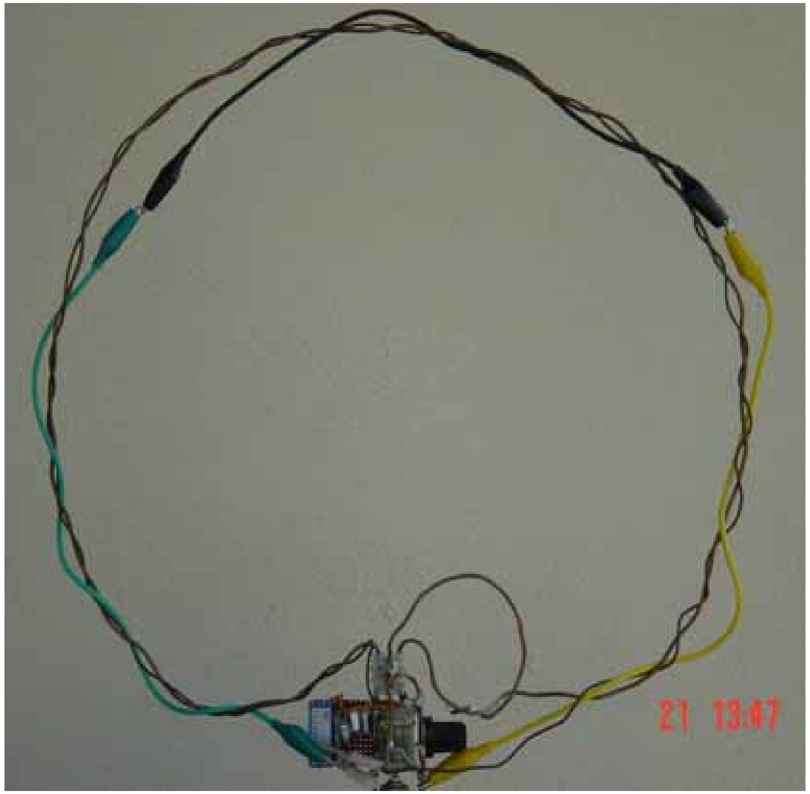
- **Example of long twisted gamma match coupling to two loops**
- **Added switched capacity to tune down to 1.5MHz**





Wide-band Un-tuned Receiving Loops (Field Sensors)

- 35cm and 50cm diameter examples for 100kHz to >100MHz
- Multi-turn for LF performance, switched single turn for HF
- But what field is sensed, H or B? Suggestions are:
- At low frequencies H field is sensed (by ‘Reciprocal Biot-Savart law’)?
- At high frequencies B field is sensed (by induction)?



Local Ground Sensing by 50cm Loops

Principle: Loop SWR or Rho (Gamma) is plotted by a miniVNA in a sub-range of frequencies in the 2 to 50MHz region or around selected spot frequencies for the loop horizontally and vertically on the ground, The values for ground permittivity and conductivity are extracted *heuristically* from the differences between the plots.

Ground Sensing

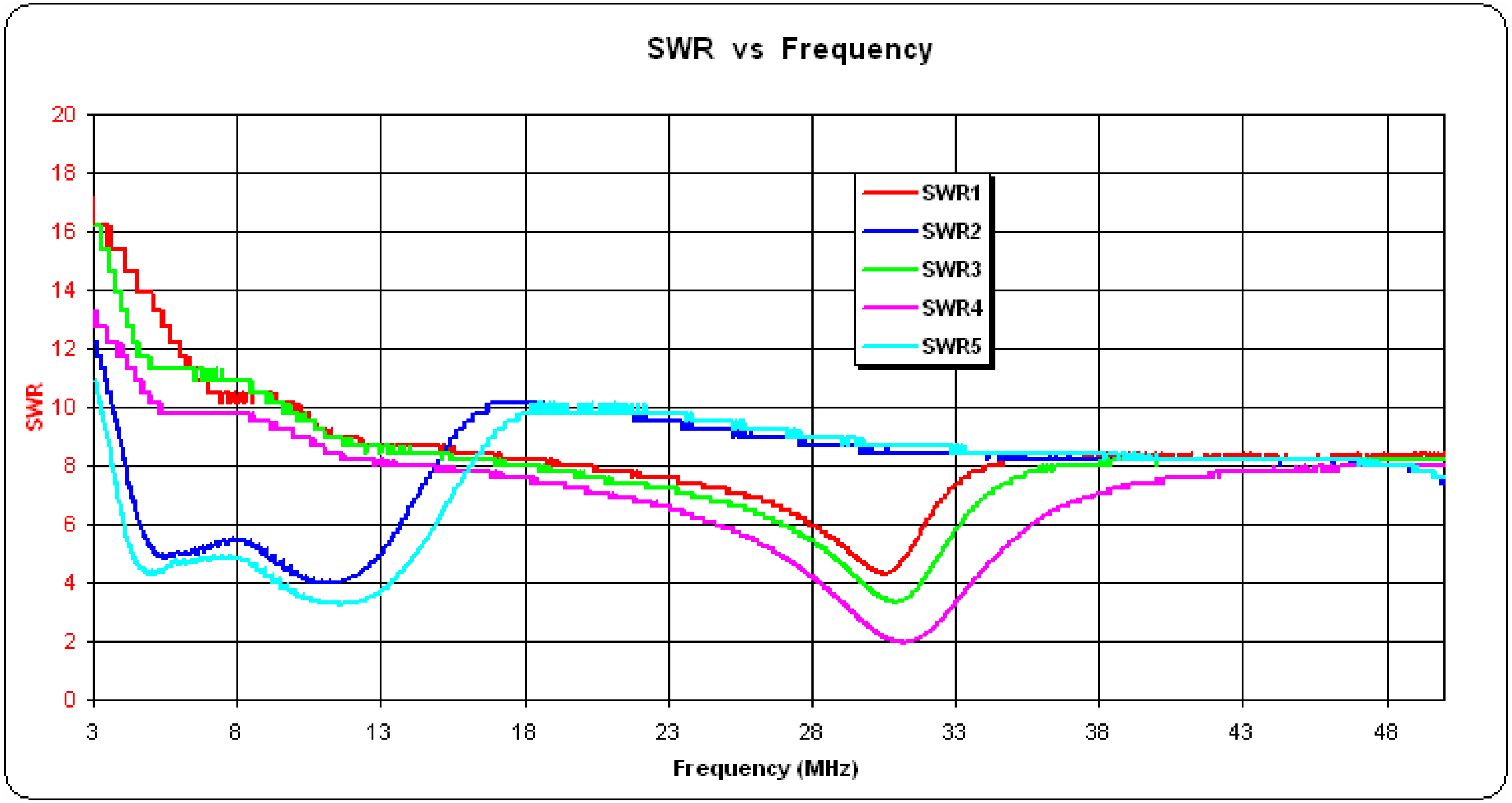


Figure 24: Two sets of comparisons over wet clay ground. The lower curves on the left were for a three turn loop. Those curves that are lower on the right were foe a ingle turn with the two turns shorted. SWR 2 and 3 are for the three turn loop vertical and horizontal on the ground respectively. SWR4, 5 and 1 are for the one turn loop vertical and horizontal on the ground and then horizontal and raised 30cm above ground, respectively

Ground Sensing

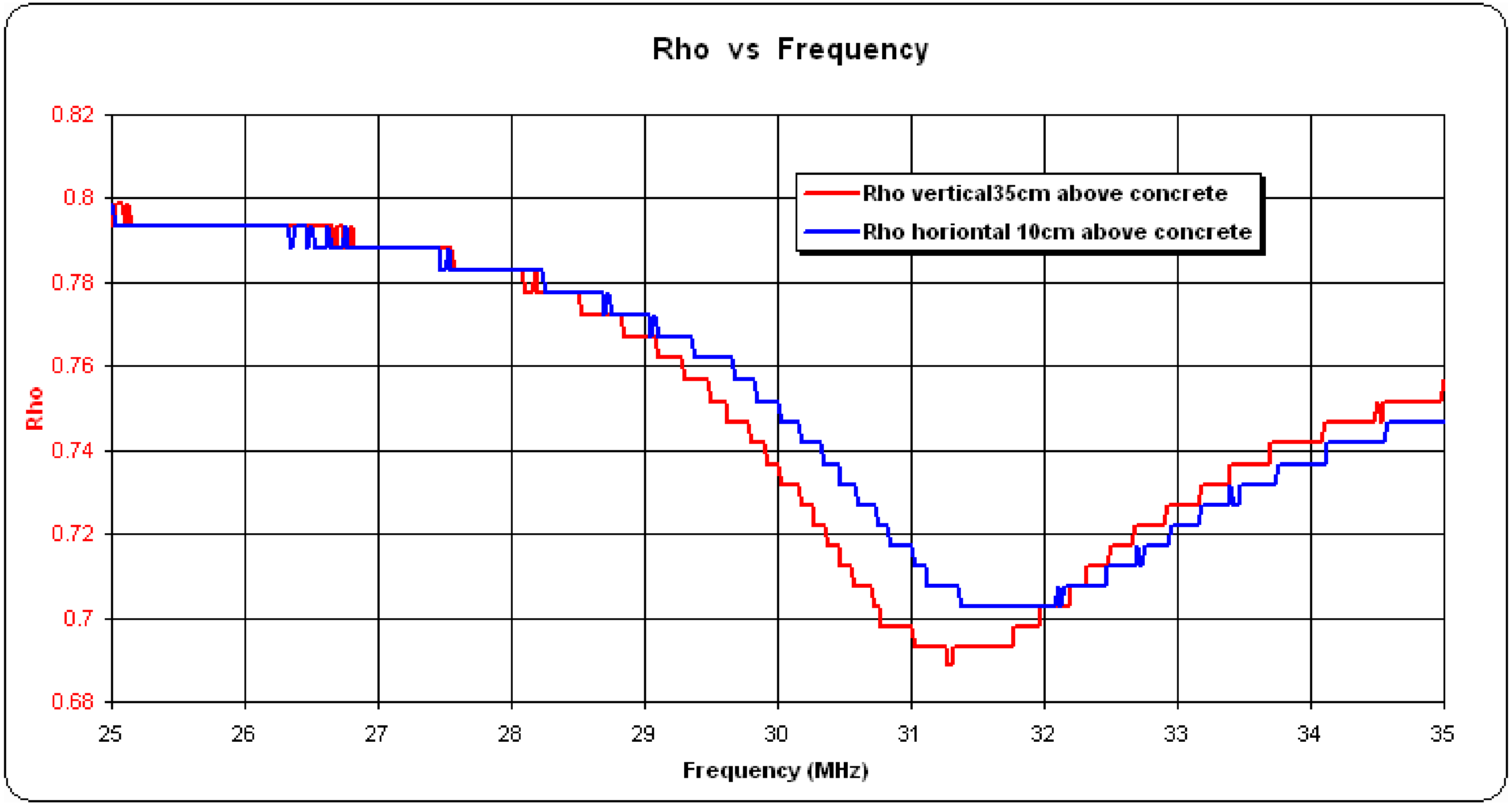


Figure 25: Dry concrete vertical/horizontal comparison showing resonant absorption at about 31MHz using three turn loop with two turns shorted.

Conclusions and Findings (Spring 2006)

- Small Loops are 80 to 95% efficient for copper tube >10mm (with any feed type).
- Losses decrease inversely proportional to tube diameter. Double the diameter means half the loss. This is irrespective of loop size.
- High power loops are >90% efficient – to prevent self-destruction by self-heating.
- Two loops in parallel nearly double the bandwidth and at least double the power handled before flashover.
- The novel (G3LHZ) diagonal fed square or circular loops give 3 to 4 times the bandwidth and power handling before capacitor flashover.
- The novel (G3LHZ) 'mini-midi loop' reduces Q from about 300 typically down to about 30 to 40. A 3% bandwidth is achievable (and double this with an ATU).
- A 500 watt 1.7m top-band loop has been made (with single centre line tuning).
- A 1m square loop has been made which can handle 750watts on 80m.
- The ground losses under a loop limit its performance. At 15m height or morethese become minimal.
- The patterns (and polarisation) of the centre-line and diagonal loops are unusual and are being investigated.

Additional Conclusions (Autumn 2006)

- Old Theory and NEC say that the ‘Twisted’ and the ‘Flat’ Tuned Folded Dipole’ Antennas cannot possibly work!
- The Rho-Q and ‘Heat Lost’ Efficiency measurements show efficiencies of 80% for the ‘Single- Tuned’ version and 90% for the Double tuned versions . The efficiency appears to be the same whether the dipole is twisted or not.
- Surely Old Theory and NEC should therefore now be upgraded to comply with these measurements?
- A 4m total length of 10mm copper tubing, if doubly tuned, can provide a ‘tuned folded dipole’ covering 1.8 to 45MHz with 90% efficiency and with a Q not exceeding 150.
- What is the polarisation of the ‘twisted’ version?
- Power handling of 500 watts or more is now a practical proposition for small HF antennas. Vacuum capacitors are not required.
- All the materials for such efficient loops are available from most counter-sales building suppliers

Latest Conclusions (Early 2008)

- Old Theory and NEC say that almost all old and new Small Tuned Antennas cannot possibly work! Heuristics (measurements) show that they do!
- Unexpected ground losses under any small antenna explain the misunderstanding
- Surely Old Theory (Chu-Wheeler) and NEC *must* now be upgraded to comply?
- The 'loop *controversy*' is 'dead'– it must be buried. (For CFA also?)
- Any small antenna made of 10mm copper tube of any length will be 80% to 90% efficient. Much larger than this is a waste of copper!
- Splitting a loop into 2 or 4 segments reduces Q by √2 or 2 respectively and increases power handling by 2 or 4 times.
- Small antenna powers of 0.5 to 1kW are now practical without vacuum capacitors.
- All the materials for such efficient small antennas are available from most counter-sales building suppliers
- New Heuristic EM theory explains simply why antennas transmit and receive.
- New and 'novel' antenna types can now be invented
- Local ground losses can be found with small 50cm loops,