Impossible Antennas and Impossible Propagation

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Contents – 1. (Talk is selected topics from these slides)

1. **Some History since 2nd Feb 2008** – The ‘futile’ controversy rages on! But hopefully the ‘truth’ will eventually prevail, no matter how ‘impossible’!
2. **What does ‘impossible’ mean?** – In theory? In practice?
3. **Thermal Efficiency** – the common-sense measure for antennas. Does the (small) antenna get hot or self-destruct? (**‘First Law of Thermodynamics**’ = conservation of energy and power.)
4. **Antenna Effectiveness** – is an antenna with good propagation on transmit or good Signal-to-Noise-Ratio (SNR) on receive.
5. **How do we discover new antennas and new modes of propagation?** – We follow Archimedes. **Experiment**→ Concept→ Theory→ Mathematics→ Simulation→ Design→ Make→ Optimisation by **Experiment**. Radio amateurs are experimenters!
6. **The Inductance of Small Loops of all Shapes and Sizes.** Demo measurements. **RSS (root-Sum of-the Squares) combining** of inductance components is discovered to be essential.
7. **Ground Assessment with Small Loops** – (EM) coupling found to be a maximum of $\kappa = 1/2\pi$. This is of fundamental importance. Demo of basic Ground Assessment.

Contents – 2

8. **Optimum Small Tuned Loop Design** – not too big and not too small. Small Loops do not scale! Use of two or more modes.
9. **Optimum Antenna Conductor Size.** – An active spreadsheet will be shown.
10. **The Impossible Loop-Monopole opens our eyes**. Eureka! It will be demonstrated.
11. **How Antennas Transmit *and Receive*. –** It is the coupling that transmits *and receives*. The coupling forms a lens around the antenna.
12. **Low Noise Receive Antennas –** what has to be done?
13. **The Discovery of 'Anomalous Wave Tilt' –** Impossible propagation?
14. **The Coupled Transmission Line Model of all Electromagnetics, Antennas and Propagation –** is all the theory we need for the future?
15. **Simple Plotting of Antenna Patterns –** using FunCubePro, will be demonstrated.
16. **The Future of Simulation for all Electromagnetics, Antennas and Propagation is 'Analytic Region Modelling' (ARM)? –** Examples for long wires, large loops and effects of lossy ground on antenna patterns will be

1.1 Some History since the 2nd Feb 2008 AHARS talk.

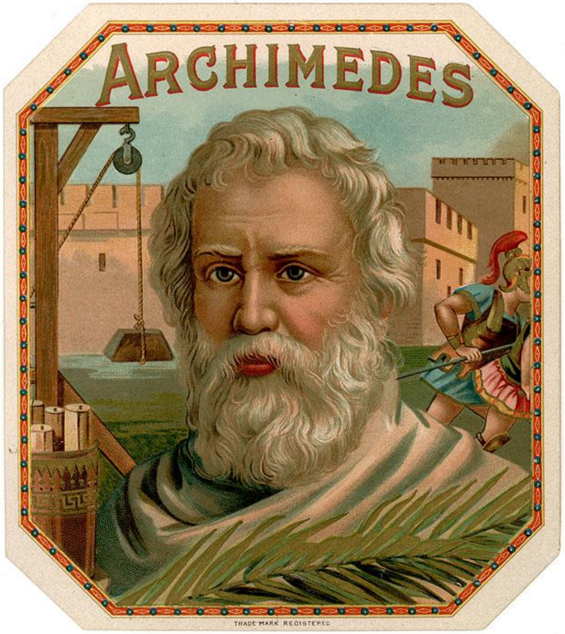
- The last AHARS talk (2/2/08) and the first [1] of my now ten PIERS (Progress In Electromagnetic Research) papers came to the attention of some of 'the critics' through website postings on the Antennex Discussion Group in November 2011.
- This re-ignited 'The Loop and Small Antenna Controversy'. I conveyed the view to the moderator that the debate had become actionable according to European Libel Law, and so any reference to me should be removed from the Antennex Archives. Not surprisingly any reference to me and my work is now apparently prohibited.
- I was also advised to use 'The Small Antenna Handbook' by Hansen and Collin if I was to continue short course lecturing lecture at Surrey University without further complaints being made about me and the University. (It is a very pessimistic book!)
- To put *a positive take* on this rather unsavoury episode I have studied all this book and all the available critical remarks *to find out what has been causing the critics to show such great fear*. (Fear causes irrational actions?)
- This has been very instructive because it flags up what has to be changed if we are going to 'make progress' once again in the field of Antennas and Propagation, as we shall see.

1. Underhill, M. J., "A Physical Model of Electro-magnetism for a Theory of Everything", PIERS Online,Vol.7, No, 2, 2011, pp: 196 -200.

1.2 Some History – Controversy?

- Scientific Controversy is only about Theory. The experiment always decides what is the truth.
- Why has there been any controversy about Small Antennas?
  - The (observed and measured) facts always speak for themselves!
- The ‘loop controversy’ has been conducted in a very unscientific way. How and why?
  - Ignoring uncomfortable facts?
  - Fear of change and progress?
  - Too much unjustified belief in gurus, experts, and the scientific establishment?
  - Too much belief in Theory, Mathematical Analysis and Simulation?
  - Too much use of ridicule and attacks on personal credibility.
- **What is the way forward from here? Is it Archimedes? Eureka?**

"Eureka" and Practical Theory



- Archimedes, a Greek living in Sicily, used *observation and experiment* to form his theory and to confirm it:
- 'A floating body displaces its own weight in water'.
- This is 'Heuristics'. It is how all Science and Theory should be done.
- Archimedes is now my only Guru. He represents progress.
- Current 'Guru Science' ensures stagnation. No guru is allowed to change his mind!
- Personally I'd rather stay a heretic. Today's heretic is tomorrow's guru? Galileo?
- Sadly Archimedes was killed by a Roman soldier against the orders of General Marcellus, for showing disrespect to him by continuing to work on a maths diagram.

Theory, “Eureka” and “Heuristics”

- Heuristic theory is practical theory, derived from experiment, measurements and observation.
- Heuristic theory is ‘hindsight’ theory.
- Eureka’, and ‘heuristics’ both come from the same Greek word, ‘heurisko (ηευρισκω)’—“I find out”.
- ‘Pure theory’ without experimental verification is ‘pure speculation’.
- It only takes one experiment to destroy or modify a theory.
- Theory without practical confirmation is worthless.
- Theoretical physicists should not deceive themselves or others: How many practical string theories are there?
- **Heuristics is Progress!**

5. Discovering New Antennas and Propagation Modes

- *We follow Archimedes:*
- **Experiment**→Concept→Theory→Mathematics→Simulation→ Design→Make→Optimisation by **Experiment**. And repeat again?
- Radio Amateurs are Experimenters!
- Reminder:
  - Theory is totally subservient to Experiment and Concepts.
  - It only takes one experiment to destroy a theory
  - Theory without experimental validation is speculation with no utility value.
  - Mathematics is totally subservient to Theory. It has to be chosen to comply with the theory.
  - Mathematics cannot prove or disprove a physics theory. It can only prove its own assumptions are self-consistent.
- You can now choose better mathematics and better simulation. Do not be held back by mathematical orthodoxy and by over-hyped Finite Element simulation methods.
- The future is **Analytic Region Modelling (ARM)**. (It used here.)

Mathematics – a help or a barrier?

- Mathematics is only a language to describe scientific concepts.
- The power of mathematics is often overhyped.
- The power (of proof) of Mathematics is no better than its declared or hidden ‘assumptions.’
- Mathematics cannot prove or disprove any physics theory. This can only be done by experiment.
- Mathematics should be devised and chosen for the physics task in hand. *It is a tool.* It is the servant , not the master.

Simulation – a help or a barrier?

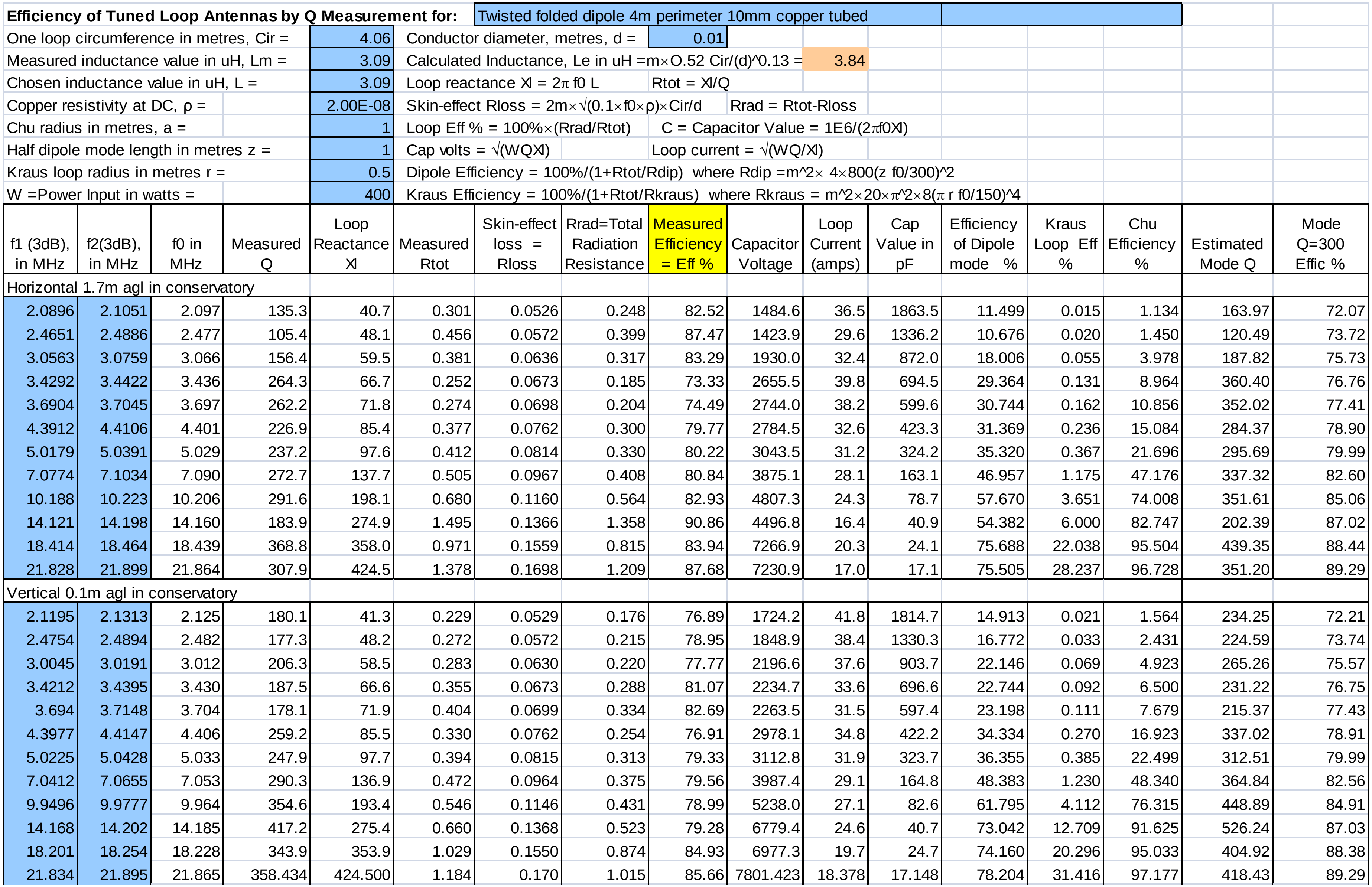
- Good well chosen mathematics is a useful tool for making extrapolations and predictions. Simulation is automation of the chosen mathematics.
- Beware of an extrapolation too far. Any formula or simulation has a limited (parametric) *region* of applicability.
- Each Physics 'process' has its own spatial region where it dominates.
- **Even if simulation and theory agree, it can be that both are wrong. "Caveat emptor—buyer beware"**
- Big Business now demands simulations to 'confirm performance'. Can it really? Simulation itself is now 'big business'!
- Finite Element (FE) methods are inefficient, untrustworthy and fundamentally limited by the number of elements. E.g. NEC etc.
- **Analytic Region Modeling (ARM)** is a very efficient new way forward – each region is modeled analytically and then combined in source to sink order (i.e. Transmitter to Receiver via Antennas and Propagation). It is the future! But when is the issue?

2.1 What does ‘impossible’ mean?

- Any antenna that theory proves is impossible and then can be shown to work in practice is an **‘impossible antenna’.**
- Any mode of propagation that theory proves is impossible and then can be shown to work in practice is an **‘impossible propagation mode’**.
- ‘Shown to work’ means that the antenna is **thermally efficient** as shown by **real, not simulated, experimental measurements.**
- Then Science demands that **the theory should be changed to comply with the measurements**.
- The **truth of real measurements** should never be denied.
- **Rejecting measurements that do not fit established theory is not honest science.**
- **Presenting simulated results as real measurements is not honest science.**

Small Tuned Antennas that are *Impossible* according to Chu sphere radius $a<\lambda/2\pi$

Single Capacitor Twisted Folded Dipole-measured in a Conservatory – Q is <400and Eff>75% . How can it work? It has no area and all currents cancel!



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
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

Demo of Inductance Measurement of Various Loops using MiniVNApro

3. Antenna *Thermal* Efficiency – Using the First Law of Thermodynamics (conservation of energy law)

- Antenna efficiency is its ***thermal efficiency***

= (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 sensor. (Total 10 to 30dB.)
- Inefficient small antennas can self-destruct with high power.
- **High power small tuned loops do not self-destruct. Thus they are efficient!** They may not be effective for some other reason!
- We shall see that the novel **Loop-Monopole** has an effective Q that is ~40 times less than a tuned loop. Thus in theory its loss is 40 times less. In practice it is probably 5 to 10 times less, because the coax cable required for the counterpoise will be an extra source of loss.

The Inductance of Wire Loops and Coils

- Inductance Measurement Demonstration Using MiniVNA Pro.
- Existing formulas are not satisfactory for small (tuned) loop design.
- From recent measurements we combine inductance processes and existing formulas into proposed inductance formulas, which are still under development as more measurements are being made:

1. For single turn or straight wire with total length of wire, l_{wire} we have

   $\mathbf{L1 \sim l_{wire}\ \mu H}$

2. Wire with diameter D_{wire} modifies L_1 to give the empirical formula

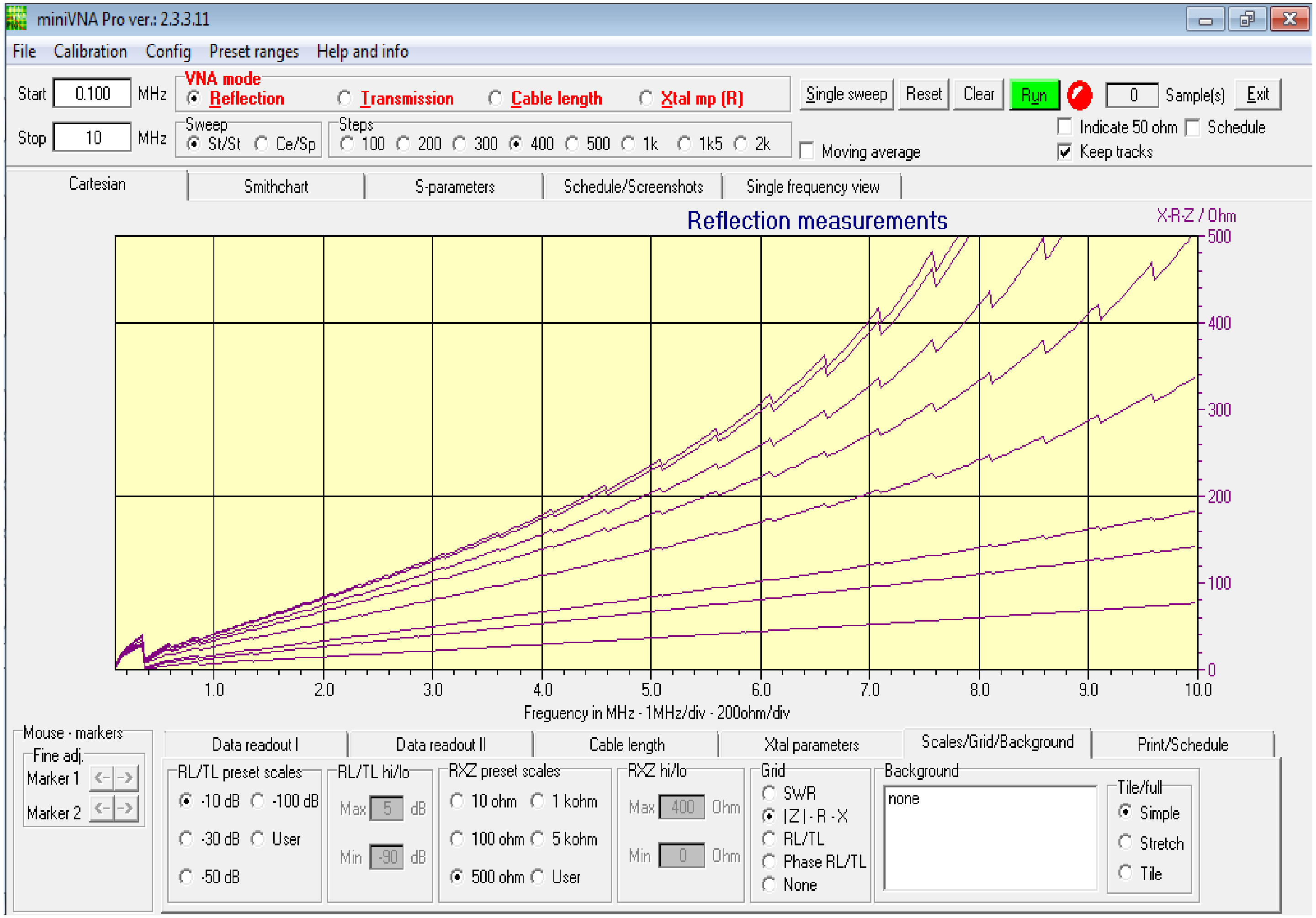
   $\mathbf{L1 = l_{wire} \times (0.006/ D_{wire})^{0.16}\ \mu H}$ with dimensions in metres.

3. Above a critical frequency fc the N-turn coil with area A, wire length l_{wire} coil length l_{coil} and n turns per unit length, has inductance

   $\mathbf{L_2 = L_1 \times \sqrt{\{(An)^2 + 1\}}}$

4. For short coils where $l < D$, n above becomes N, the total number of turns.
5. Below a critical frequency f_c the N-turn coil has its Area A reduced to be effective area $A_e = A / \sqrt{\{1 + (f_c/f)^2\}}$

Inductances of a 2.1m wire loop of fixed length as a single round turn, hairpin, folded dipole, and various multi turn loops



miniVNA Pro ver.: 2.3.3.11

Start 0.100 MHz

Stop 10 MHz

VNA mode: ● Reflection ○ Transmission ○ Cable length ○ Xtal mp (R)

Sweep: ● St/St ○ Ce/Sp

Steps: ○ 100 ○ 200 ○ 300 ● 400 ○ 500 ○ 1k ○ 1k5 ○ 2k

☐ Moving average

0 Sample(s)

☐ Indicate 50 ohm ☐ Schedule

☑ Keep tracks

Mouse - markers: Fine adj. Marker 1, Marker 2

RL/TL preset scales: ● -10 dB ○ -100 dB ○ -30 dB ○ User ○ -50 dB

RL/TL hi/lo: Max 5 dB, Min -90 dB

RXZ preset scales: ○ 10 ohm ○ 1 kohm ○ 100 ohm ○ 5 kohm ● 500 ohm ○ User

RXZ hi/lo: Max 400 Ohm, Min 0 Ohm

Grid: ○ SWR ● |Z| - R - X ○ RL/TL ○ Phase RL/TL ○ None

Background: none

Tile/full: ● Simple ○ Stretch ○ Tile

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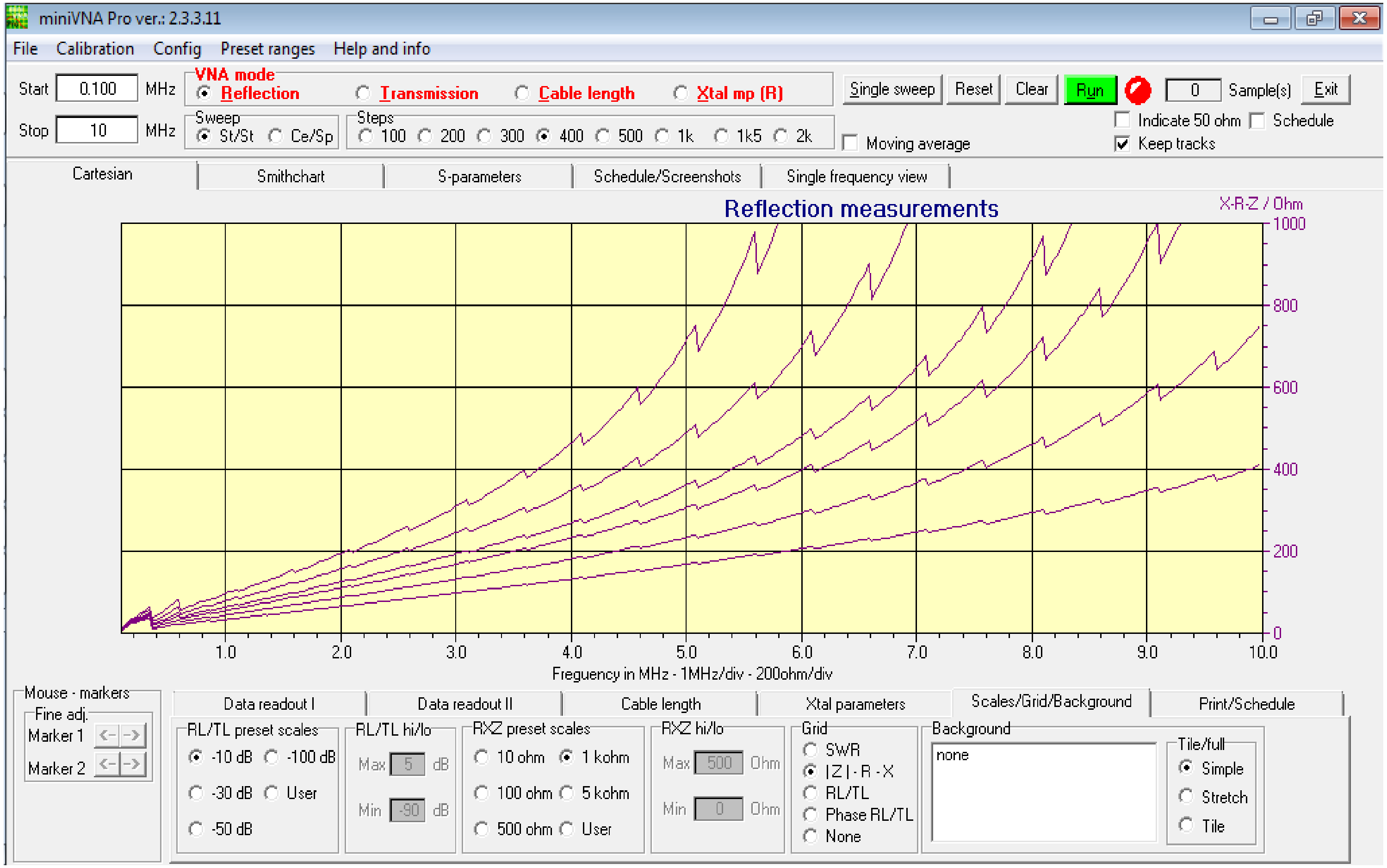
Inductances of a wire loop of 4.2m fixed length as a single round turn, hairpin, folded dipole, and various multi turn loops



Start 0.100 MHz

Stop 10 MHz

VNA mode: ● Reflection ○ Transmission ○ Cable length ○ Xtal mp (R)

Sweep: ● St/St ○ Ce/Sp

Steps: ○ 100 ○ 200 ○ 300 ● 400 ○ 500 ○ 1k ○ 1k5 ○ 2k

☐ Moving average

0 Sample(s)

☐ Indicate 50 ohm ☐ Schedule

☑ Keep tracks

RL/TL preset scales: ● -10 dB ○ -100 dB ○ -30 dB ○ User ○ -50 dB

RL/TL hi/lo: Max 5 dB, Min -90 dB

RXZ preset scales: ○ 10 ohm ● 1 kohm ○ 100 ohm ○ 5 kohm ○ 500 ohm ○ User

RXZ hi/lo: Max 500 Ohm, Min 0 Ohm

Grid: ○ SWR ● |Z| - R - X ○ RL/TL ○ Phase RL/TL ○ None

Background: none

Tile/full: ● Simple ○ Stretch ○ Tile

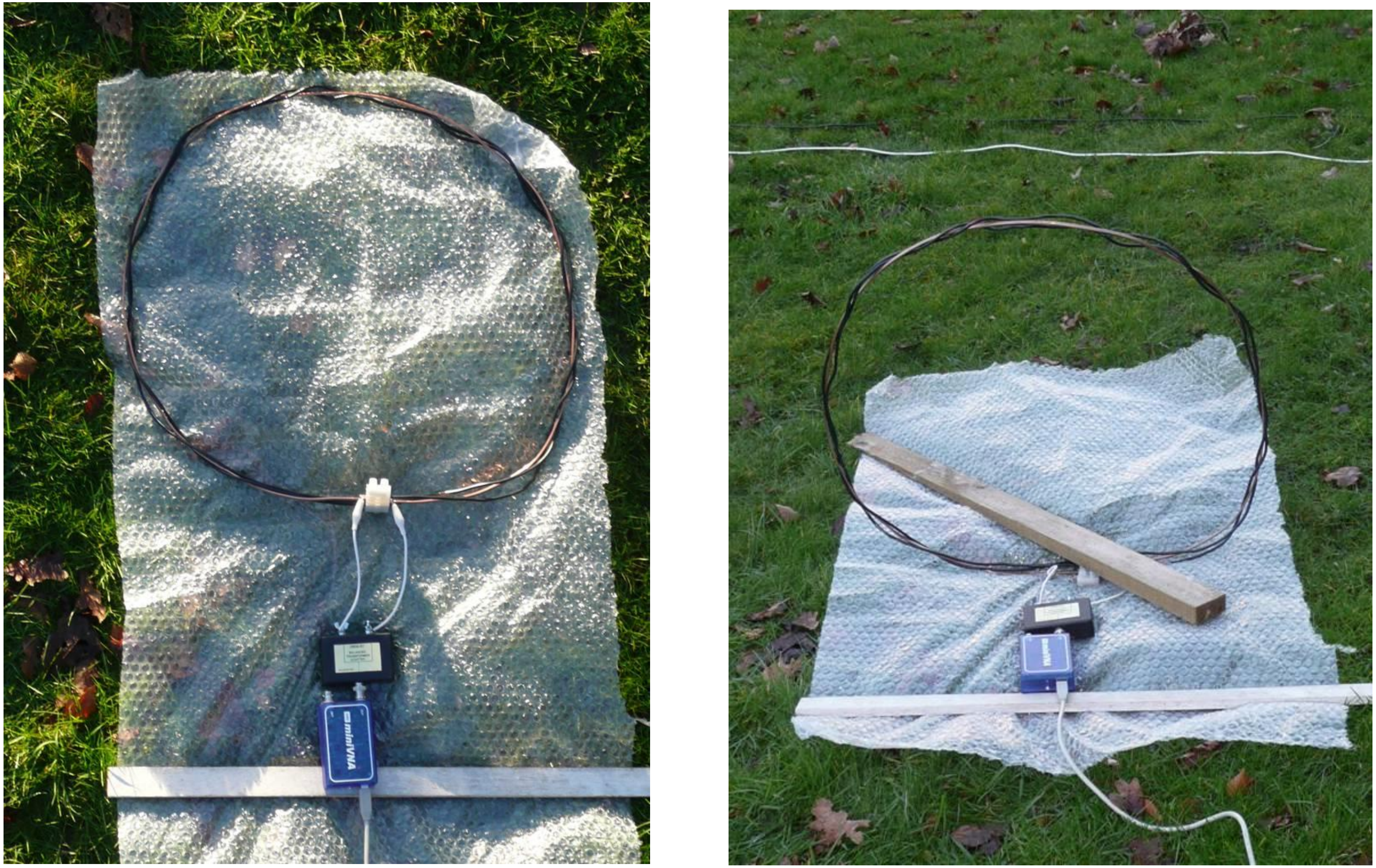
Demo of Inductance Measurement of Various Loops using MiniVNApro

Impact of the ground and environment on antenna ‘effectiveness’

- Absorption height (Goubau Height) – discovered to be square root wavelength dependent.
- Loss in dB increases linearly from this height down to the ground value
- Resonant absorption of real ground with main peak between 5.3 and 7MHz.
- Peak ground value absorption can be 25 to 30dB
- Tree noise and absorption loss – temperature dependent!

Ground Sensing by Loops

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

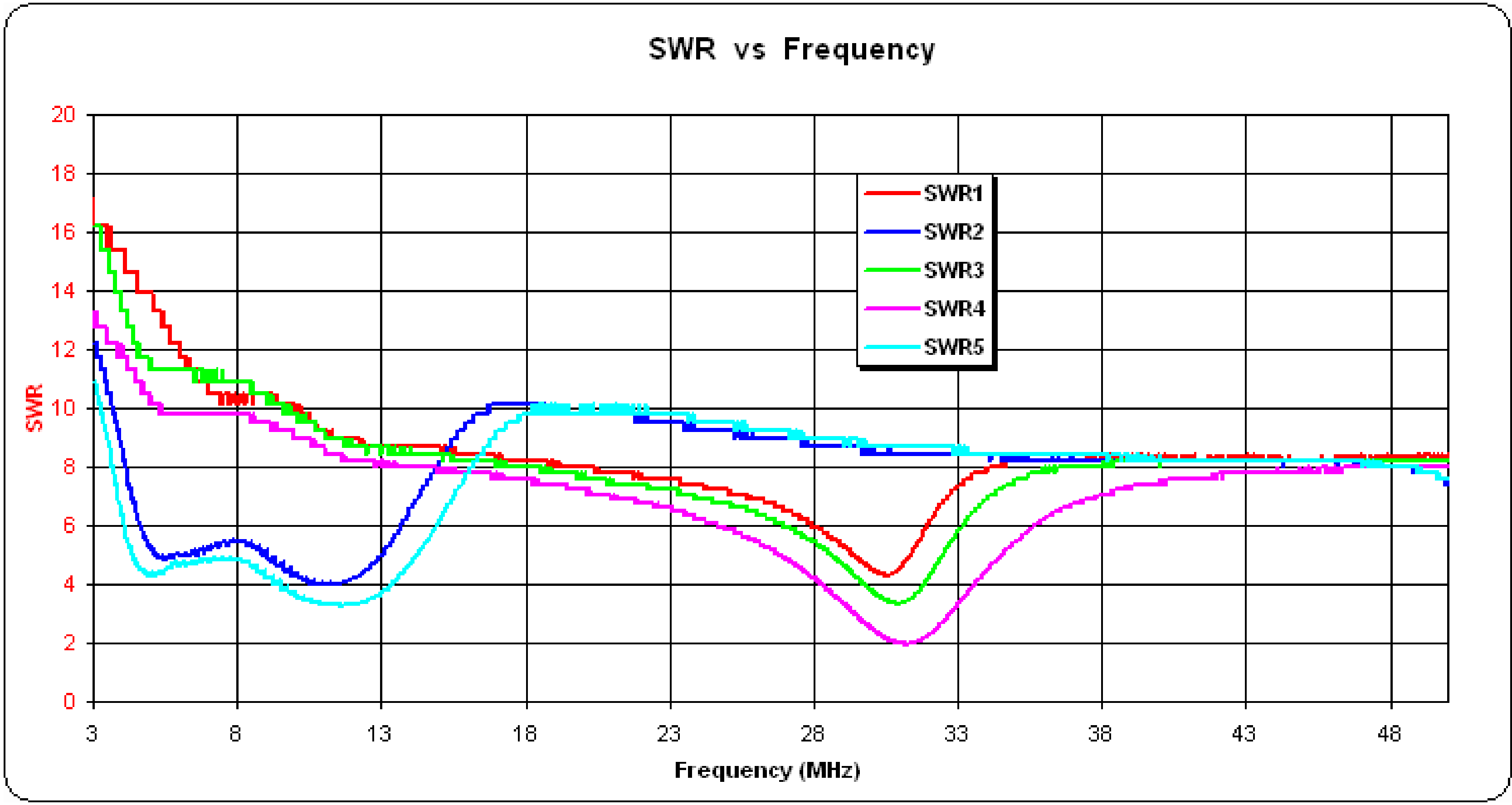


Figure 24: Two sets of comparisons over wet clay ground. The lower curves on the left were for a three turn loop. Those curves that are lower on the right were foe a ingle turn with the two turns shorted. SWR 2 and 3 are for the three turn loop vertical and horizontal on the ground respectively. SWR4,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

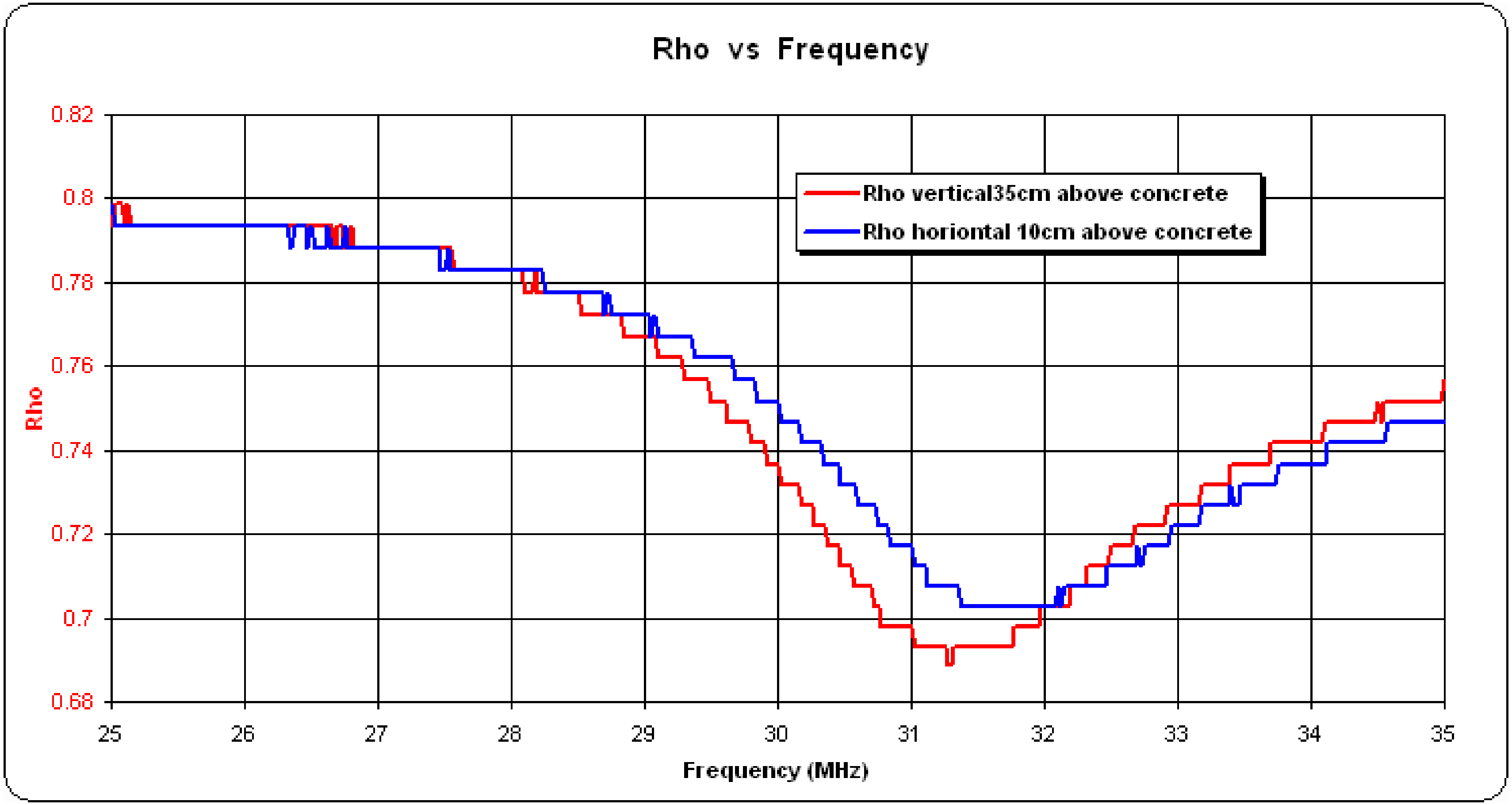


Figure 25: Dry concrete vertical/horizontal comparison showing resonant absorption at about 31MHz using three turn loop with two turns shorted.

Water Sensing: Figure 3.2.2 URGA1 H-field untuned loop in inflatable boat on Heath House Lake.

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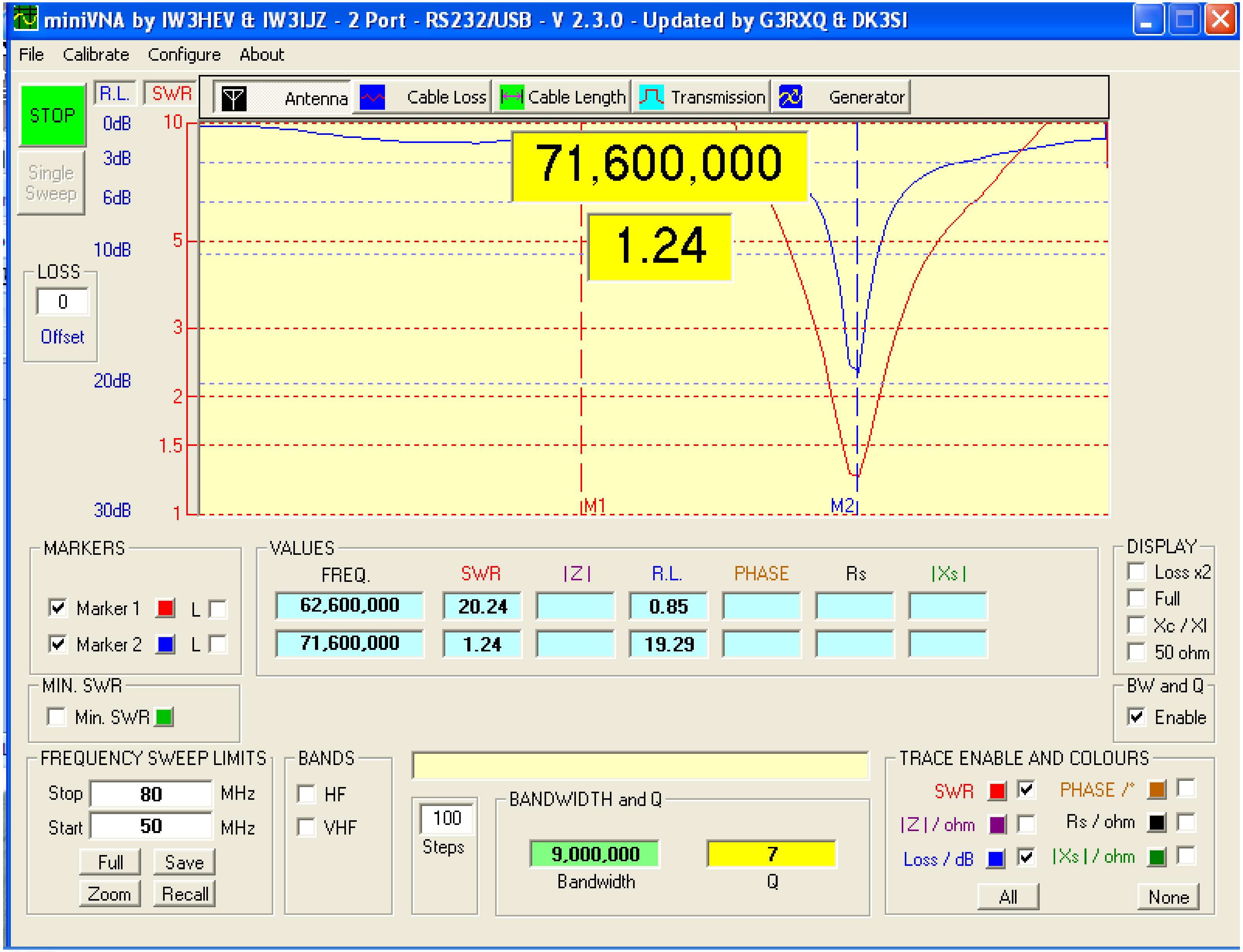
Use of Tuned Loops for Ground/Water Sensing

Figure 4.4. VHF mode free space reference setting



miniVNA by IW3HEV & IW3IJZ - 2 Port - RS232/USB - V 2.3.0 - Updated by G3RXQ & DK3SI

LOSS: 0 Offset

MARKERS
☑ Marker 1 🟥 L ☐
☑ Marker 2 🟦 L ☐

VALUES

FREQ.	SWR	|Z|	R.L.	PHASE	Rs	|Xs|
62,600,000	20.24		0.85			
71,600,000	1.24		19.29			

DISPLAY
☐ Loss x2
☐ Full
☐ Xc / Xl
☐ 50 ohm

BW and Q
☑ Enable

MIN. SWR
☐ Min. SWR 🟩

FREQUENCY SWEEP LIMITS
Stop 80 MHz
Start 50 MHz

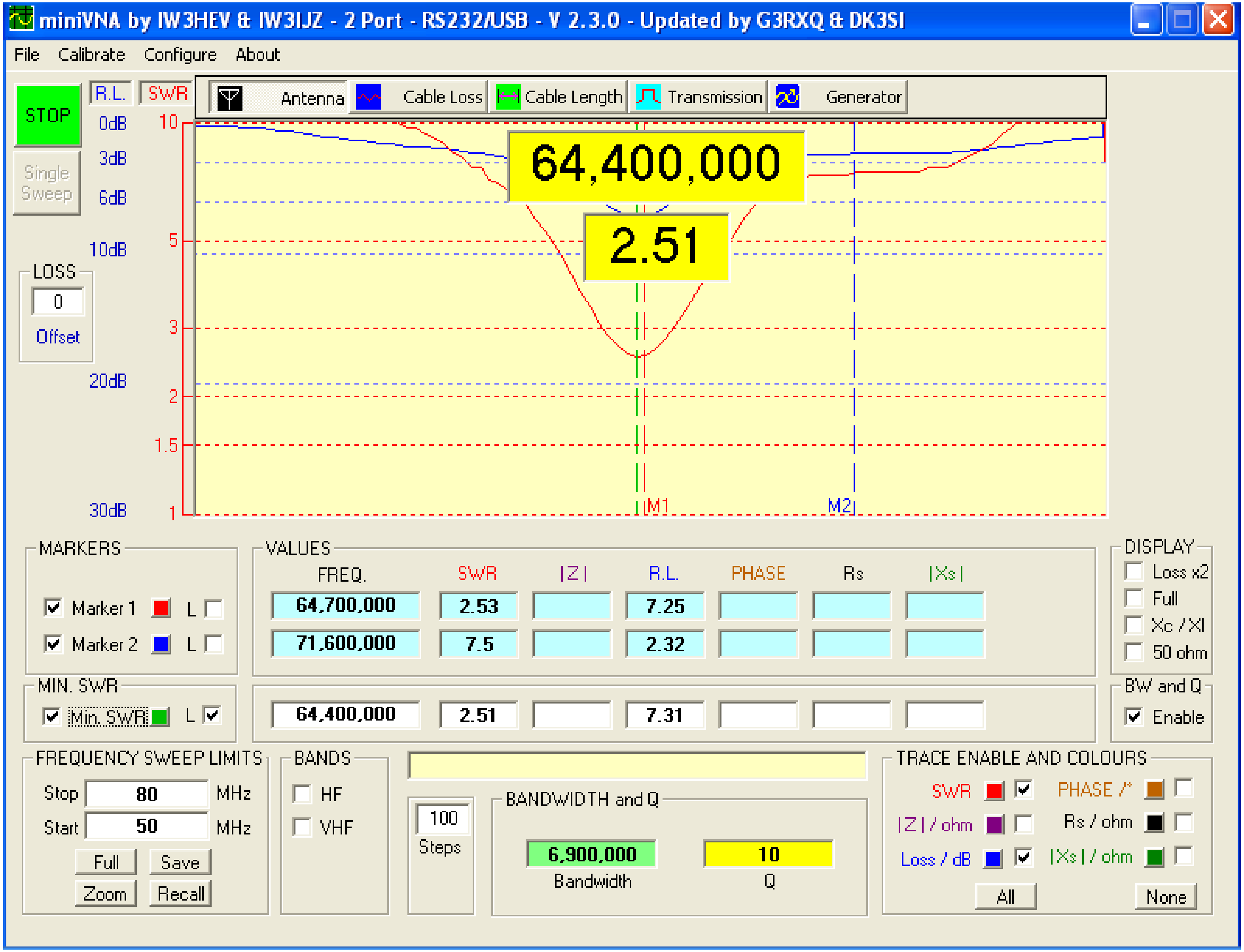
BANDS
☐ HF
☐ VHF

100 Steps

BANDWIDTH and Q
Bandwidth 9,000,000
Q 7

TRACE ENABLE AND COLOURS
SWR 🟥 ☑
PHASE /° 🟧 ☐
|Z| / ohm 🟪 ☐
Rs / ohm ■ ☐
Loss / dB 🟦 ☑
|Xs| / ohm 🟩 ☐

Figure 4.5. VHF-Horizontal measurement showing dielectric shift of frequency on car roof



LOSS: 0
Offset

MARKERS
- ☑ Marker 1 🟥 L ☐
- ☑ Marker 2 🟦 L ☐

MIN. SWR
- ☑ Min. SWR 🟩 L ☑

VALUES

FREQ.	SWR	|Z|	R.L.	PHASE	Rs	|Xs|
64,700,000	2.53		7.25			
71,600,000	7.5		2.32			
64,400,000	2.51		7.31			

DISPLAY
- ☐ Loss x2
- ☐ Full
- ☐ Xc / Xl
- ☐ 50 ohm

BW and Q
- ☑ Enable

FREQUENCY SWEEP LIMITS
Stop 80 MHz
Start 50 MHz

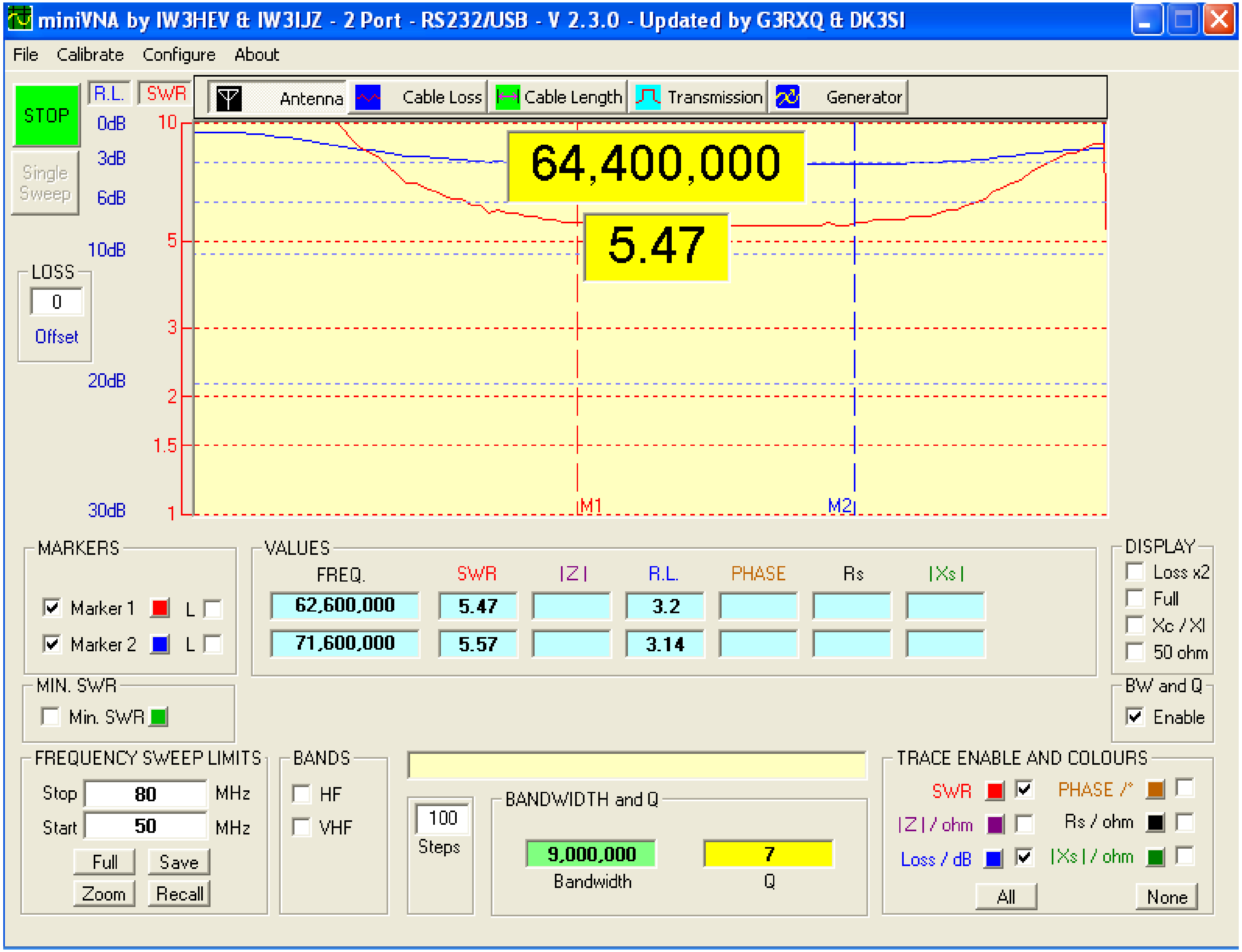
BANDS
- ☐ HF
- ☐ VHF

100 Steps

BANDWIDTH and Q
Bandwidth: 6,900,000
Q: 10

TRACE ENABLE AND COLOURS
- SWR 🟥 ☑
- PHASE /° 🟧 ☐
- |Z| / ohm 🟪 ☐
- Rs / ohm ■ ☐
- Loss / dB 🟦 ☑
- |Xs| / ohm 🟩 ☐

Figure 4.6. VHF-Vertical measurement showing large change of SWR with sensor flat on aluminium sheet.



64,400,000

5.47

LOSS: 0

MARKERS
- ☑ Marker 1 🟥 L ☐
- ☑ Marker 2 🟦 L ☐

VALUES

FREQ.	SWR	|Z|	R.L.	PHASE	Rs	|Xs|
62,600,000	5.47		3.2			
71,600,000	5.57		3.14			

DISPLAY
- ☐ Loss x2
- ☐ Full
- ☐ Xc / Xl
- ☐ 50 ohm

BW and Q
- ☑ Enable

MIN. SWR
- ☐ Min. SWR 🟩

FREQUENCY SWEEP LIMITS
Stop 80 MHz
Start 50 MHz

BANDS
- ☐ HF
- ☐ VHF

100 Steps

BANDWIDTH and Q
9,000,000 Bandwidth
7 Q

TRACE ENABLE AND COLOURS
- SWR 🟥 ☑
- PHASE /° 🟫 ☐
- |Z| / ohm 🟪 ☐
- Rs / ohm ■ ☐
- Loss / dB 🟦 ☑
- |Xs| / ohm 🟩 ☐

Aiming for Antenna Effectiveness – considerations:

- Antenna (thermal) **efficiency.**
- All external **environmental losses.**
- Antenna **pattern and directivity in the desired direction** including **the effects of ground and other reflections**
- **Horizontal/Vertical polarisation losses** depending on desired propagation mode.
- Selection of **optimum propagation mode**
- **Operational Convenience:**
  - **Antenna size**
  - **Easy/Optimum placement** in the available environment
  - **Broadbanding** the bandwidth
  - **Multi-banding**
- **Receive SNR** (Signal-to-Noise Ratio). Reduction of coupling to local noise. Noise Nulling.
- *Perhaps enough for a book on* ***Antenna Effectiveness****?*

The Loop-Monopole – summary of PIERS Taipei 2013 paper

1. **The Original Requirement – for Wave-Tilt Measurements.**
2. **The Development Path from The Small Tuned Loop.**
3. **The Preferred Design (so far).**
4. **Showing How Antennas Work both on Receive and Transmit:**
   - “It is the *coupling* that receives and transmits”
5. **Impact on the Chu Small Antenna Q Criterion – Destruction?**
6. **Coupling to Ground Losses – underestimated?**
   - **“**What if Jack Belrose and Mike Underhill are both correct?”
7. **Impact on Maxwell’s Equations – Modification?**
   - and move to Coupled Transmission Line (CTL) Model?
8. **Pattern Measurement and Simulation.**
9. **The Future – new designs and new propagation modes?**

This talk was given at the Progress In Electromagnetic Research Symposium (PIERS) on 27th March 2013 in Taipei, Taiwan.

Wideband Small Loop-monopole HF Transmitting Antenna with Implications for Maxwell's Equations and the Chu Criterion

Michael J (Mike) Underhill
Underhill Research Ltd, UK

CONTENTS

1.1 INTRODUCTION – Need for new antenna

- A small highly portable wideband transmitting antenna was needed for ‘anomalous’ wave-tilt measurements in the HF band [4].
- Over fresh water or wet ground the wave-tilt direction was found to be reversed, hence ‘anomalous’, below about 5.3MHz. *This is a new and unexpected discovery.*
- The measurements were made for 40 to 70m paths over wet ground and a freshwater lake for frequencies from 1.8 to 52MHz.

- **Over 40 measurements, each taking about 20 minutes, were made.**
- The transmitting antenna was a 80cm diameter two turn multi-mode tuned loop with operating Q typically 170 at the lower frequencies (at right [4]).

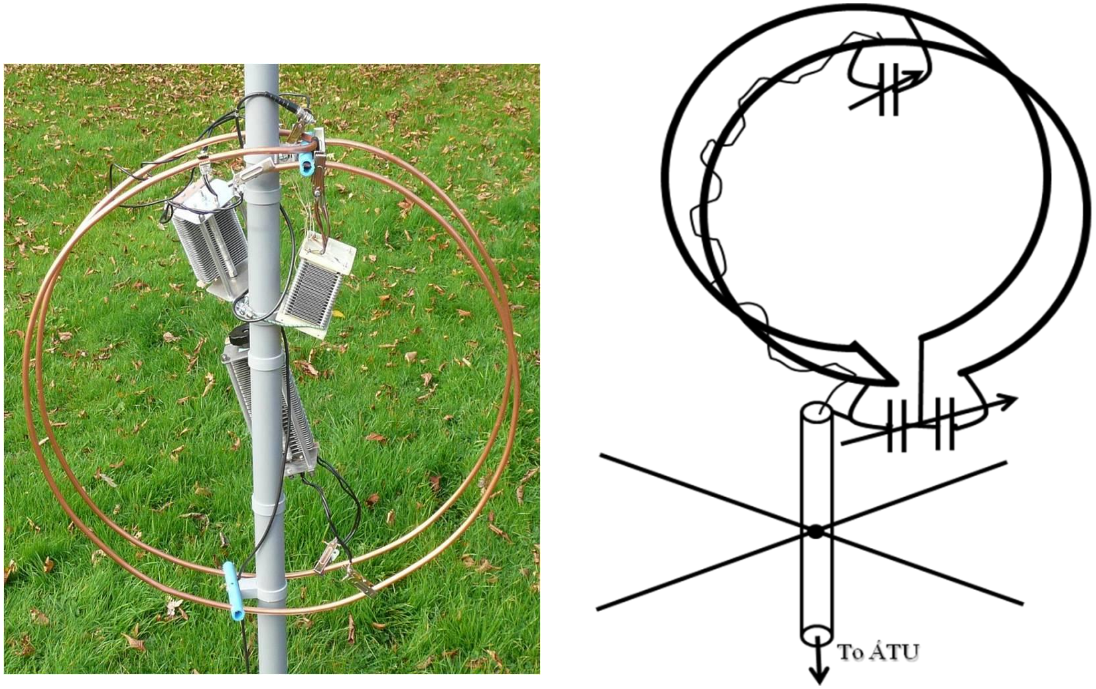
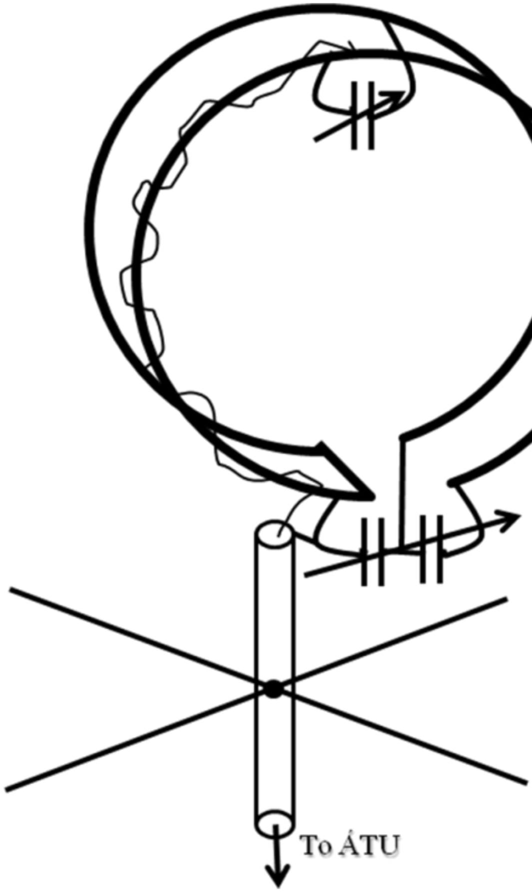


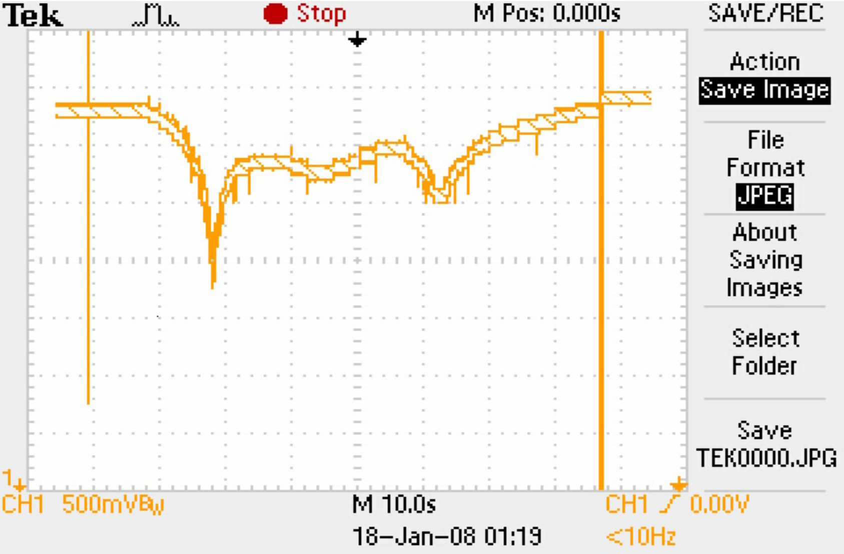
Figure 4 from [4]: 80cm two opposing turns double tuned coupled multi-mode loop transmit antenna 1.8 to 70MHz. Top-fed on left, and bottom fed schematic on right

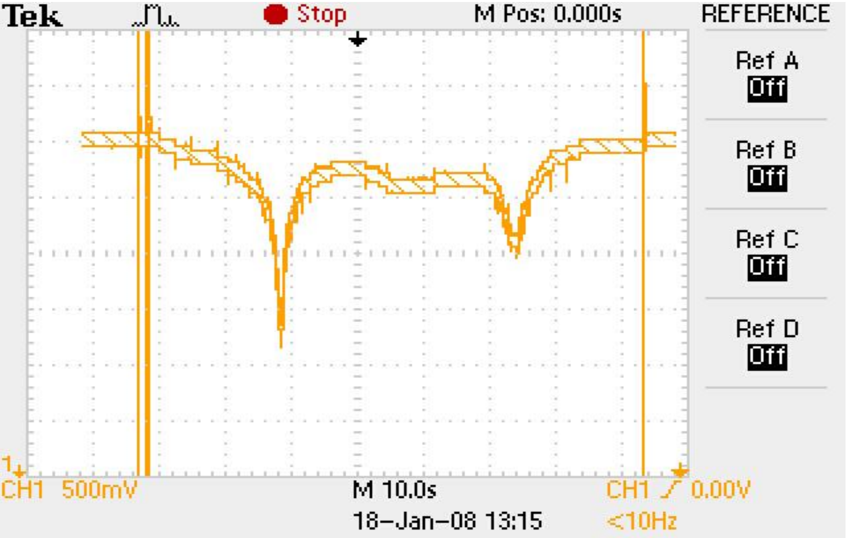
The Best (most effective) Small *Tuned* Loop so far discovered?

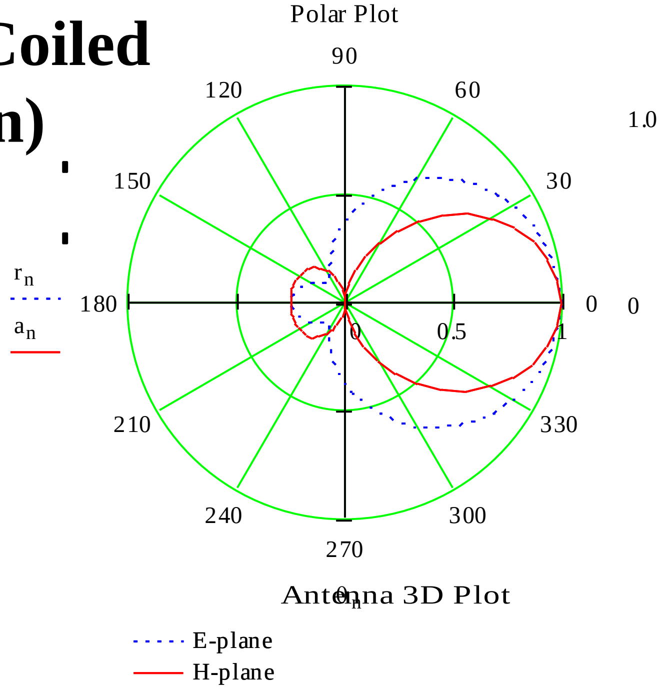
- The 80cm diameter two-turn loop shown in the figure can handle 300watts on top band (160m) and 400 to 700watts up to 70MHz. The limitation is tuning capacitor voltage flashover not self-heating
- The efficiency is measured at ~90 to 95% by bandwidth Q measurements The Q is typically 170 at the lower frequencies

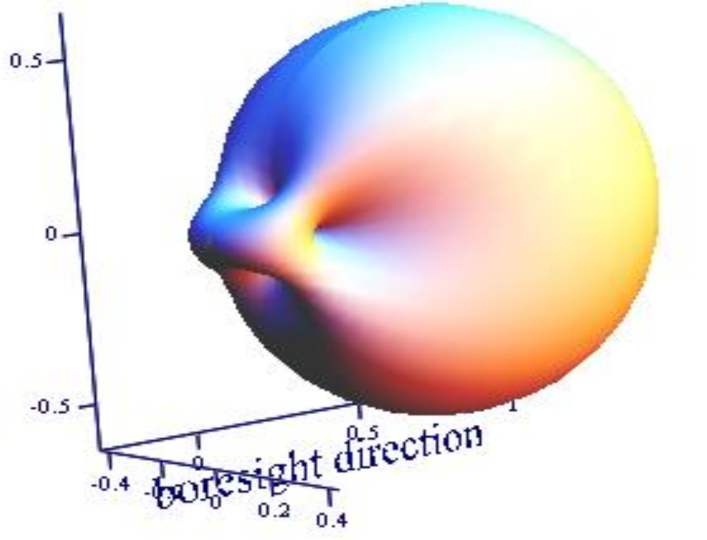


Heuristically Derived Antenna Pattern of Coiled Hairpin (See again in Modelling Section)

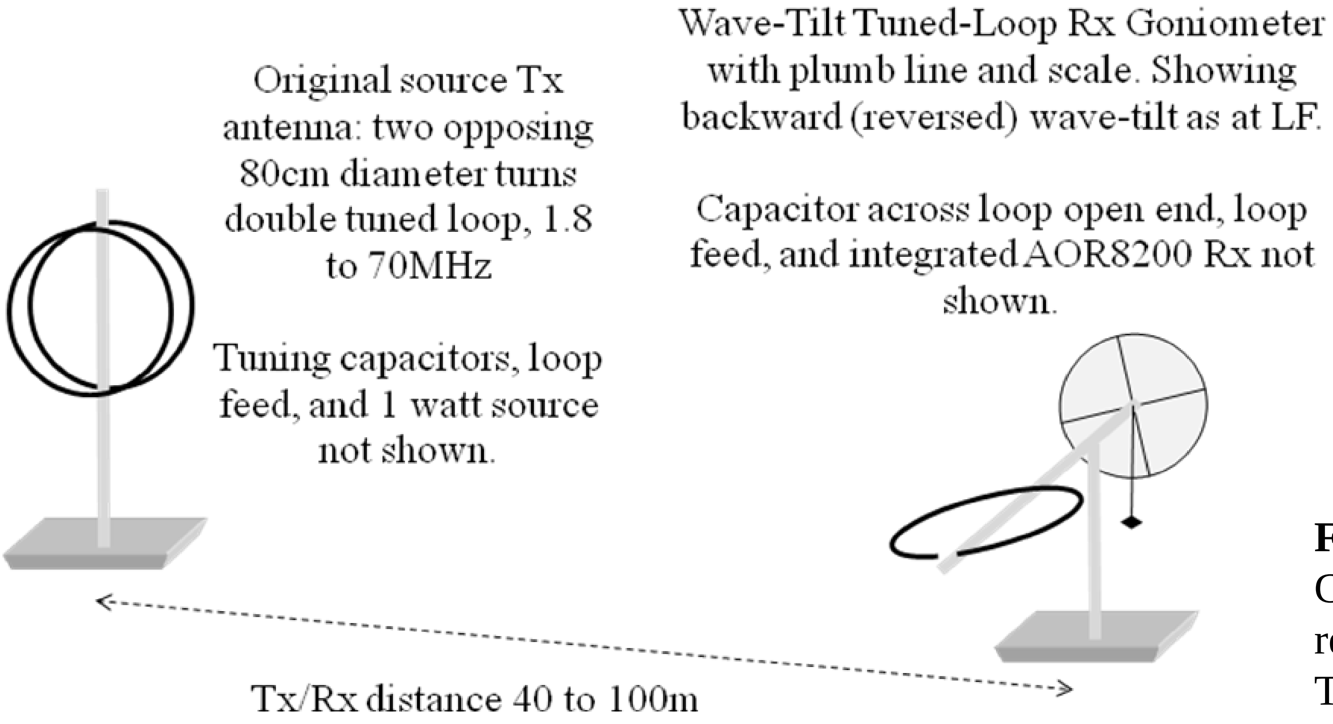








Extract from Underhill, M. J., “Anomalous Ground Wave Tilt Measured Over Wet Ground”, IET Conf. On Ionospheric Radio Systems and Techniques 2012, 15-17 May 2012,| York, UK



Original source Tx antenna: two opposing 80cm diameter turns double tuned loop, 1.8 to 70MHz

Tuning capacitors, loop feed, and 1 watt source not shown.

Wave-Tilt Tuned-Loop Rx Goniometer with plumb line and scale. Showing backward (reversed) wave-tilt as at LF.

Capacitor across loop open end, loop feed, and integrated AOR8200 Rx not shown.

Tx/Rx distance 40 to 100m

Figure 3: Wave tilt measurement setup

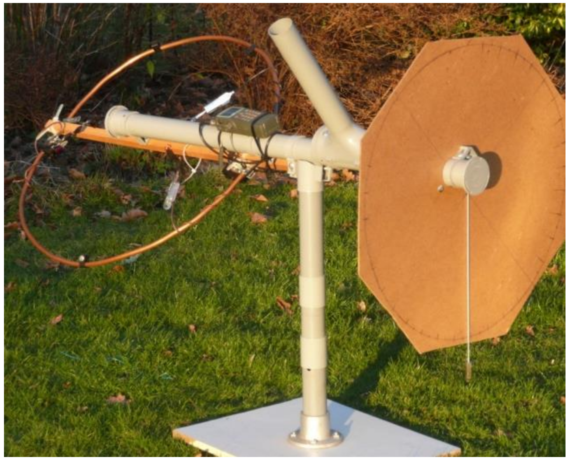


Figure 1: Tuned-Loop Goniometer with plumb-line reference and AOR8200 receiver. Tuning capacitors are on far left end of loop. Carefully balanced subsidiary segment shaped loop to receiver partially twisted around main loop conductor.

Wave-Tilt Measurement Site adjacent to the G3LHZ QTH at Hatchgate

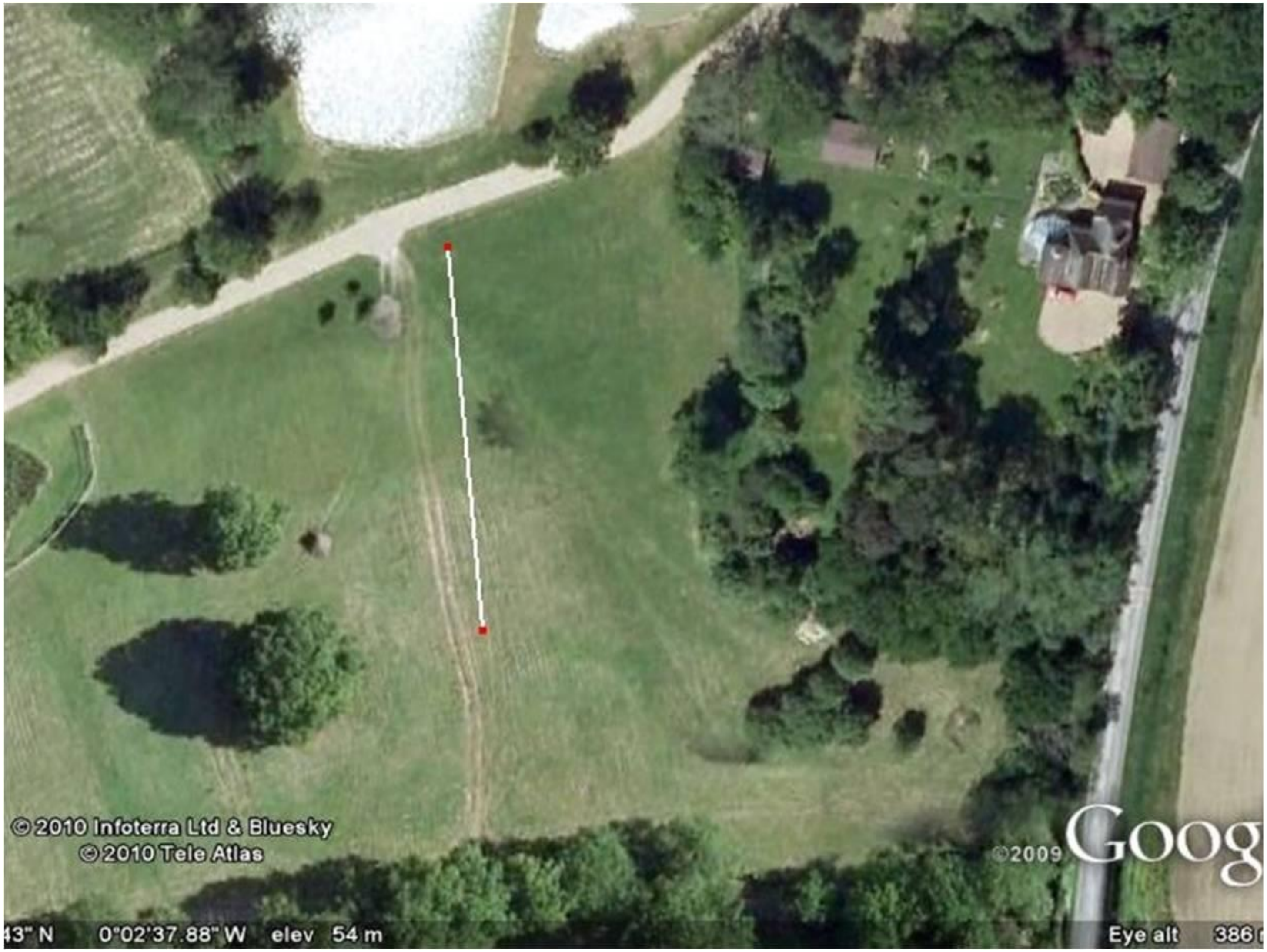


Figure 5: Summer picture of Heath House ‘main’ site. The 65m N-S (170°) path is shown. The clay soil was almost waterlogged for the winter-time measurements. The lake of site 2 is at the top of the picture. Underhill Research Laboratory is 40m to the left of the house (Hatchgate) at the right.

<u>Wave Tilt over Fresh Water:</u> Figure 3.2.1 Photograph of Heath House Lake & measurement setup. Tx in blue bag on far side of lake. AOR8200 receiver on goniometer base.

Extract from Underhill, M. J., “Anomalous Ground Wave Tilt Measured Over Wet Ground”, IET Conf. On Ionospheric Radio Systems and Techniques 2012, 15-17 May 2012,| York, UK

Measurements of anomalous wave tilt

Frequency (MHz)	Wave Tilt deg. f is forward b is back	Ellipticity difference angle deg	Notes/Comments
3.000	3b+5b→4b	2	70m path on land drain?
4.000	3b+3b→3b	0	70m path on land drain?
5.000	4b+6b→5b	2	At 57m
6.000	5f+11f→8f	6	At 57m
5.500	11f+1f→6f	10	At 57m
5.000	2b+15f→6.5f	17	57m Rx moved 8m W to place 2 at 57m
4.000	6f+11b →2.5b	17	Place 2 at 57m
4.500	0+1b→0.5b	1	Place 2 at 57m
30.900	12f+8f→10f	4	Place 2 at 57m
50.500	10f+25f→17.5f	15	Place 3 at 30m
50.500	8f+22f→15f	14	Place 2 at 57m

Table 5: Heath House field on 07/12/2009 from 1300 to1530. 10°C sunny then overcast. Session terminated by drizzle. 70m, 57m, and 30m N to S paths. Shorter paths to avoid trees and a land drain. The aim was to locate the critical frequency of changeover to anomalous tilt.

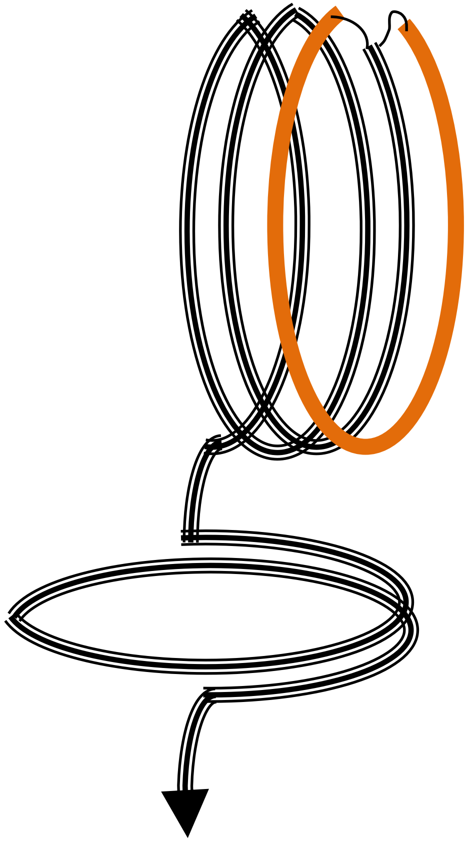
1.2 INTRODUCTION – The Loop-Monopole Solution

- So A portable wideband small transmitting antenna covering 1.8 to 52MHz was required.
- The √2 increased bandwidth found for a pair of coupled magnetic loop modes gave an indication of how to proceed.
- The postulate was that if small antenna electric and magnetic modes could be could be tightly coupled together a further increase in bandwidth could be obtained.
- The results exceeded all expectations.
- And fundamental revision of antenna theory was now required.

2.1 DESCRIPTION OF NEW LOOP-MONOPOLE - Construction

Figure 1 (on left): Picture of 90cm loop-monopole with MiniVNApro (Bluetooth connected) vector network analyser at bottom.

Figure 2 (on right): Schematic of loop-monopole seen in Figure 1. There is Transformer Coupling between the copper loop and the 2.5 turns in the coaxial cable



- The loop-monopole consists of a vertical copper loop of 1cm diameter tubing that is top fed directly by a 50m long 50 ohm coaxial cable. Two or three turns of the coaxial cable are loosely twisted around the copper loop.
- The lowest usable frequency is obtained with the copper loop connected to the coaxial cable as shown. But it depends mainly on the total length of the cable.

2.2 THE NEW LOOP-MONOPOLE - Operation

- We observe that the coupled coaxial cable turns launch a travelling wave on the outside of the feeder cable even when it is coiled under the loop part of the antenna as shown in Figure 1.
- The two turns of cable and the copper loop act as the upper part of the monopole with the rest of the feeder cable, whether coiled or not, acting as the ground or counterpoise for the upper monopole.
- The loop is a vertically polarised magnetic mode antenna. The monopole is a vertically polarised electric mode antenna as a vertical dipole.
- For two turns of the 50 ohm line and cable wound around the 90cm loop of 10mm copper tube, the antenna SWR varies from 11:1 at 1.7MHz to ~ 6:1 at twice this frequency (3.4MHz) and <6:1 at higher frequencies, measured up to 200MHz.
- Such SWR values are easy to match at any frequency with a standard Antenna Tuning Unit (ATU) to give at least a 16% operating bandwidth.

2.3 NEW LOOP-MONOPOLE - Explanation

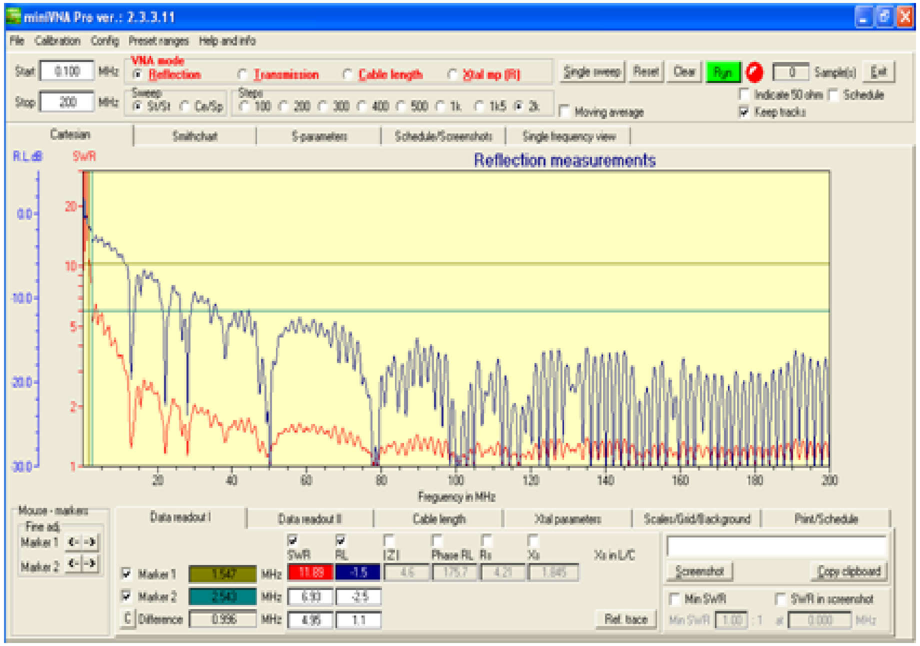
- An equivalent antenna Q can be estimated from the stored energy on a mismatched transmission line for a given SWR and Return Loss ρ. In this case we have $Q < 6.6$ from the following equations.

$$\mathrm{SWR} = (1 + \rho)/(1 - \rho) \quad \text{with} \quad Q = 2/(1 - \rho^2) \qquad (1)$$

- A useful reduction of the SWR at the lower frequencies was subsequently found by winding one more turn of the feeder cable onto the copper loop to give three wound turns without altering the total cable length of 50m.

- The 11:1 SWR frequency is lowered by about 10% and the 6:1 SWR by 25%, as seen in Figure 3. This is now the recommended design for any size or diameter of loop.

2.4a NEW LOOP-MONOPOLE – SWR and Return Loss

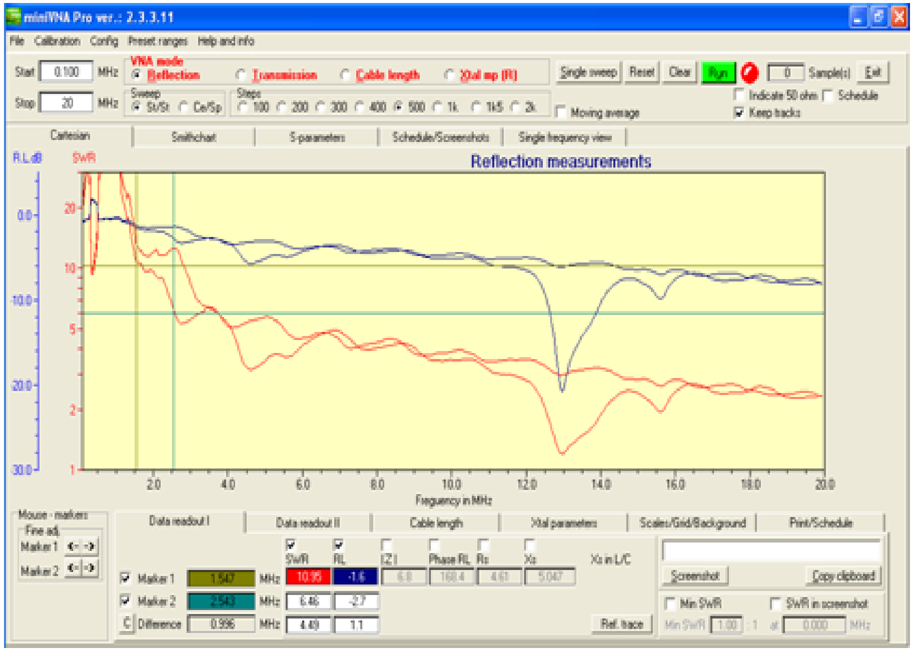


Start 0.100 MHz, Stop 200 MHz; ● Reflection; Sweep ● St/St; Steps ● 2k; ☑ Keep tracks

			☑ SWR	☑ RL	☐ |Z|	☐ Phase RL	☐ Rs	☐ Xs
☑ Marker 1	1.547	MHz	11.89	-1.5	4.6	175.7	4.21	1.845
☑ Marker 2	2.543	MHz	6.93	-2.5				
Difference	0.996	MHz	4.95	1.1				

☐ Min SWR Min SWR 1.00 : 1 at 0.000 MHz ☐ SWR in screenshot

Figure 3: For 0.1 to 200MHz the SWR (lower red plot) and Return Loss (upper blue plot) for loop-monopole of 3 turns on loop of a total feeder length of 50m.



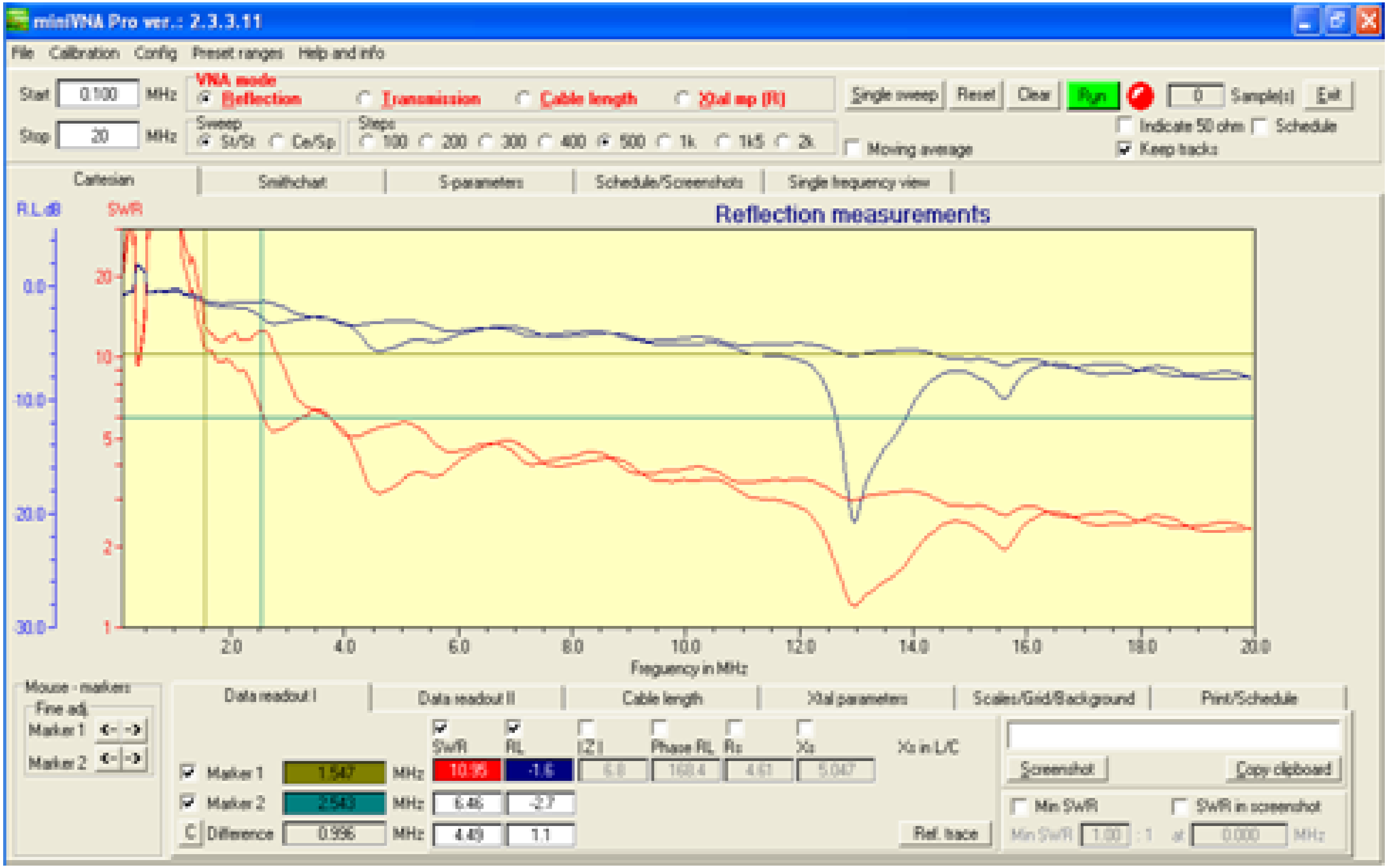
Start 0.100 MHz, Stop 20 MHz; ● Reflection; Sweep ● St/St; Steps ● 500; ☑ Keep tracks

			☑ SWR	☑ RL	☐ |Z|	☐ Phase RL	☐ Rs	☐ Xs
☑ Marker 1	1.547	MHz	10.95	-1.6	6.8	168.4	4.61	5.047
☑ Marker 2	2.543	MHz	6.46	-2.7				
Difference	0.996	MHz	4.49	1.1				

☐ Min SWR Min SWR 1.00 : 1 at 0.000 MHz ☐ SWR in screenshot

Figure 4: As in Figure 3 but for frequency range 0.1 to 20MHz and showing effect of reversing the coaxial cable connection to the copper loop.

2.4b NEW LOOP-MONOPOLE – SWR and Return Loss



Start 0.100 MHz
Stop 20 MHz

VNA mode: ● Reflection ○ Transmission ○ Cable length ○ Xtal imp (R)

Sweep: ● St/St ○ Ce/Sp

Steps: ○ 100 ○ 200 ○ 300 ○ 400 ● 500 ○ 1k ○ 1k5 ○ 2k

0 Sample(s)

☑ Keep tracks

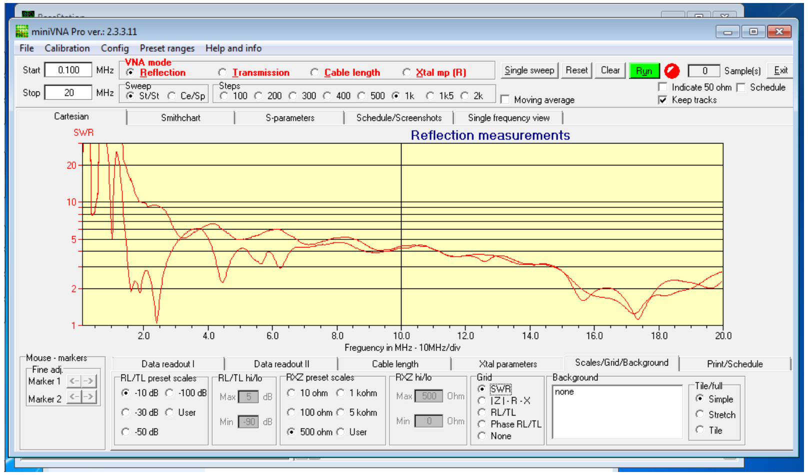
			☑ SWR	☑ RL	☐ |Z|	☐ Phase RL	☐ Rs	☐ Xs
☑ Marker 1	1.547	MHz	10.95	-1.6	6.8	168.4	4.61	5.047
☑ Marker 2	2.543	MHz	6.46	-2.7				
Difference	0.996	MHz	4.49	1.1				

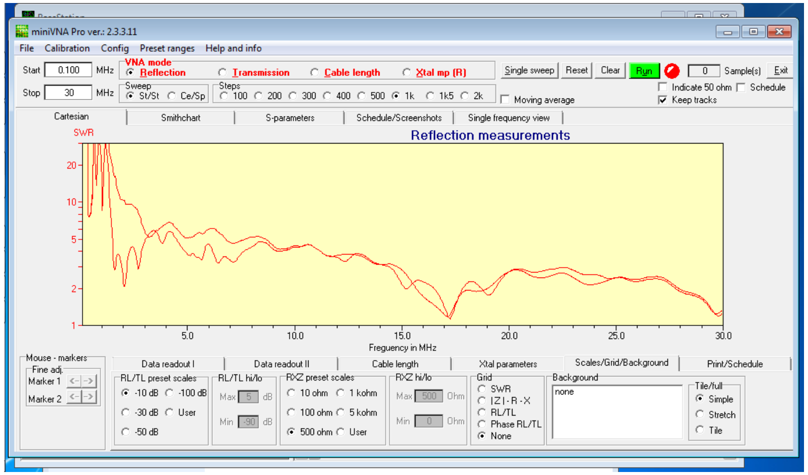
☐ Min SWR ☐ SWR in screenshot

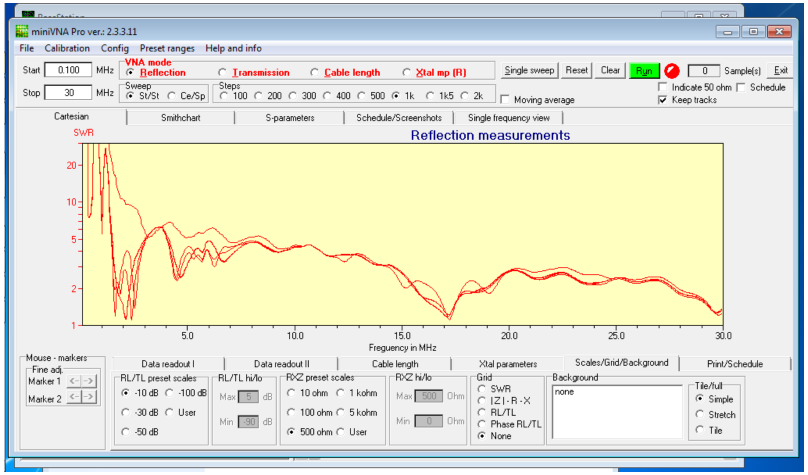
Min SWR 1.00 : 1 at 0.000 MHz

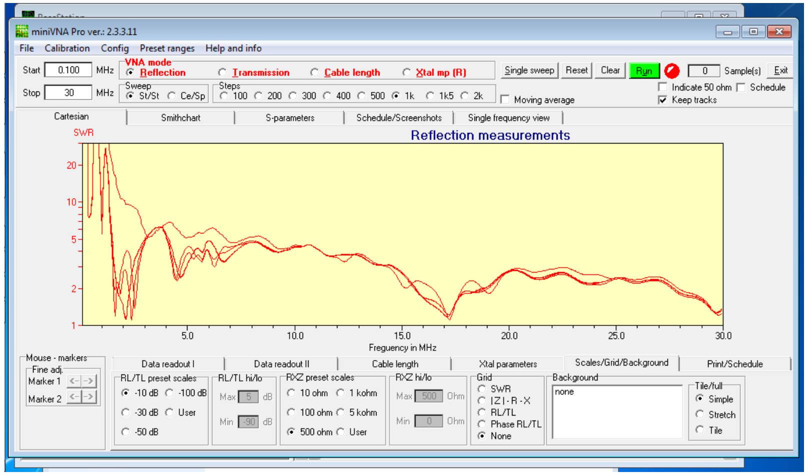
Figure 4: As in Figure 3 but for frequency range 0.1 to 20MHz and showing effect of reversing the coax connection to the copper loop.

Loop – Monopole as a Ground Sensor









Note that ground is not sensed between 3.5 and 4MHz. Why?

2.5 NEW LOOP-MONOPOLE – Conclusions from Measurements

- Figures 3 and 4 were obtained from a mRS ‘miniVNA pro’ Vector Network Analyser (blue) at the bottom of Figure 1. Particular features are small size, self contained battery power and a Bluetooth, electrically isolated, connection to the control and display computer.
- Any explanation that small antennas can only radiate efficiently from the feeders outside the small antenna volume can thereby be discounted.
- The total feeder length determines the lowest frequency of operation. In Figure 4 the SWR steps down to ~10:1 when the total coaxial cable length is a quarter wave $\lambda/4$, and steps down to ~6:1 when the cable length is $\lambda/2$.
- A surprising discovery was that coiling the feeder cable as shown in Figures 1 and 2 makes practically no difference to the lowest frequency of antenna operation. SWR and impedance changes were insignificant.
- When the cable is coiled the loop-dipole is a true *small* antenna.
- It follows that the main part of the surface wave energy on a cable or wire is confined to no more than about two or three conductor diameters distance outside the conductor (confirming n=3 in Equation 1 of [1])

3. IMPACT ON THE CHU SMALL ANTENNA Q CRITERION - 1

- The original Chu-Wheeler small antenna Q criterion [3] states that for antennas completely contained inside a sphere of radius a, where k is the propagation constant $2\pi/\lambda$, the Q cannot be less than $1/(ka)^3$ unless the antenna is inefficient and has a significant loss resistance.
- The new loop-monopole design can for example be contained in a sphere of radius a = 0.75m and it can be considered to be small below 64MHz.
- It has been measured to be efficient (> ~90%), in terms of power lost as heat and discounting internal cable losses, between 1.8MHz and 200MHz.
- The antenna can radiate 700watts continuous power at 3.7MHz without appreciable heat being generated. This was tested first by hand and then confirmed by a Protek IR camera.

3. IMPACT ON THE CHU SMALL ANTENNA Q CRITERION – 2

- For an antenna Q value of 6.6 as calculated from Equation 1, the practically measured performance contradicts the Chu-Wheeler small antenna Q criterion by four orders of magnitude (~11,000) at the lowest frequency of operation.
- At the test frequency of 3.7MHz the Q is about 4.5 and thus the discrepancy with respect to the Chu Wheeler Q is about 1,100.
- **The above Q and antenna efficiency results firmly contradict the Chu Small Antenna Q Criterion. References [5] and [6] are now confirmed as valid and not to be challenged.**
- **The Chu criterion has no credibility and should never be used.**
- **The claim is that the Chu criterion is derived directly from Maxwell's Equations. It follows that Maxwell's Equations should now be modified and improved to agree with the measured facts, for example as shown in reference [2].**

2. Underhill, M. J., "Maxwell's Transfer Functions", *Proc. PIERS 2012* Kuala Lumpur.

4. THE GENERALISED POYNTING VECTOR – 1

- The Poynting Vector (PV) can be modified to become a Generalised2) Poynting Vector (GPV), S, where its in-phase or 'real' ($\Re$) component represents travelling wave energy per unit volume and its quadrature or 'imaginary' ($\Im$) component the stored energy density per unit volume.
- For convenience the components may be expressed as power and standing wave power per unit surface [2].
- In either representation the *Q* is the ratio of the quadrature component to the in-phase component.
- We can also represent the Poynting Vector in terms of like pairs of potentials Φ and currents I [7,8]. For potential Φ and current I we thus have:

$$S = E \times H = \Phi \times I \qquad \text{with} \qquad Q = \frac{\Im[E \times H]}{\Re[E \times H]} = \frac{\Im[\Phi \times I]}{\Re[\Phi \times I]} \tag{2}$$

4. THE GENERALISED POYNTING VECTOR – 2

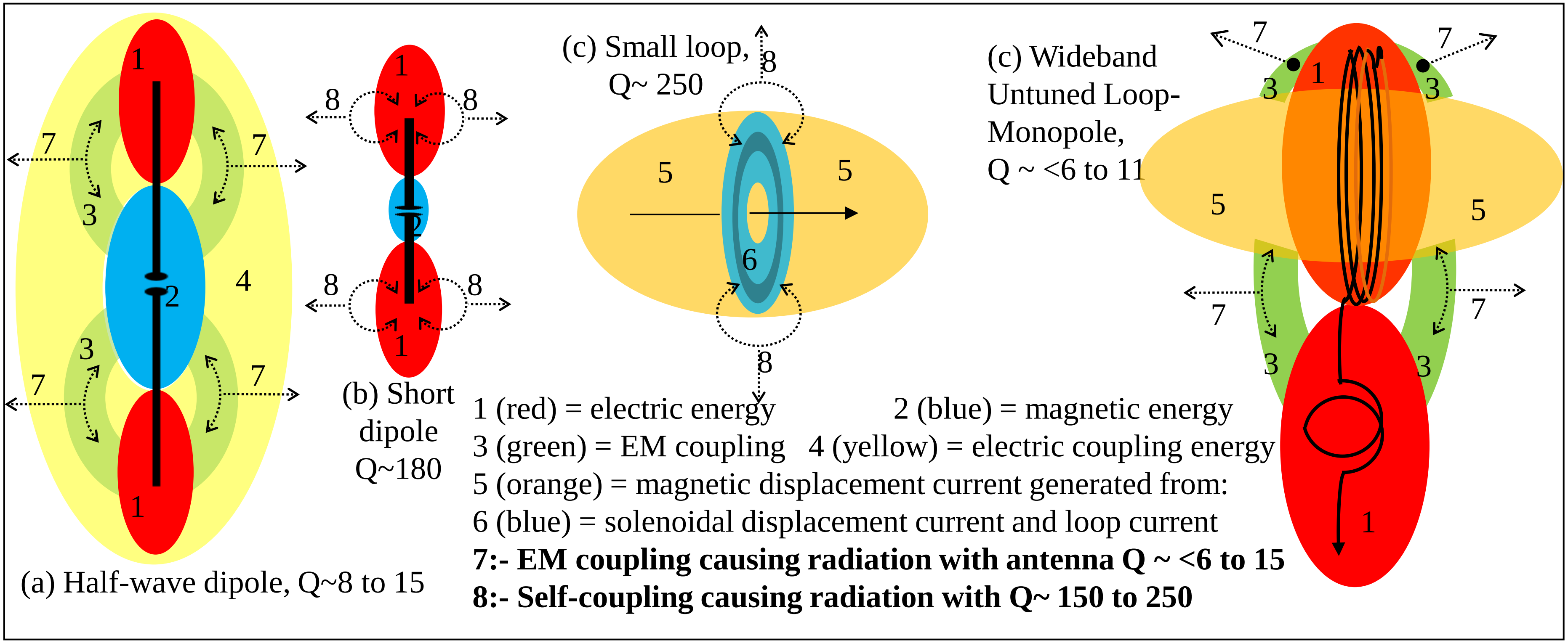
- Because the antenna is small it is contained within a region in which the EM coupling is strong so the potentials and induced energy densities are essentially uniform in the ‘coupled’ region of space.
- Also by observing that along a transmission line the peak energy densities of charge and current per unit length are the same, we can define charge per unit length q as quadrature current $-ji$.
- We can also define the respective potentials Φ_i and Φ_q as being in quadrature.
- In this way we find that radiation from charges and currents are separate processes that can take place in different parts of an antenna, as seen in Figures 5a and 5d. Thus we have:

$$\Phi_q = j\Phi_i\,, \qquad i = jq\,, \qquad \Phi = \Phi_i - j\Phi_q\,, \qquad I = i + jq \qquad (3)$$

5. THEORY OF RADIATION AND RECEPTION – 1

- A simple physical theory of (small) antenna operation is: “it is the *coupling* in the antenna that radiates or receives”. This concept is in agreement with the ‘Ether Lens’ model [7].
- Figure 5 shows two types of coupling. Self-coupling causes radiation in electric or magnetic single mode small antennas and it typically gives antenna Qs between 180 and 250. EM or mixed mode coupling between two modes of different types, electric and magnetic, gives Qs between ~6 and ~ 15.
- An equivalent explanation of the new ‘radiation and reception’ theory is: “an antenna conductor surface is transmitting when the external potential has a component that is in-phase with the current, and the antenna surface is receiving when the external potential has a component that is out of phase with the current induced in the antenna surface”. This can be deduced from the properties of the Generalised Poynting Vector.

5. THEORY OF RADIATION AND RECEPTION – 2



1 (red) = electric energy

2 (blue) = magnetic energy

3 (green) = EM coupling

4 (yellow) = electric coupling energy

5 (orange) = magnetic displacement current generated from:

6 (blue) = solenoidal displacement current and loop current

7:- EM coupling causing radiation with antenna Q ~ <6 to 15

8:- Self-coupling causing radiation with Q~ 150 to 250

Figure 5: Electric and magnetic antenna radiation mechanisms in (a) half-wave dipole, (b) short dipole, (c) small loop, and (d) wideband untuned loop-monopole.

“It is the *coupling* that radiates and receives”

5. THEORY OF RADIATION AND RECEPTION – 3

- The half wave dipole (a) in Figure 5 can be seen to be a mixed mode antenna, because the ends of the antenna can radiate from the oscillating charges and the centre of the antenna radiates from the oscillating current. In fact most of the radiation comes from the EM coupling of the two mode types.
- In this respect the loop-monopole (d) is similar. Both antennas are found to have low Qs, $\sim 2\pi$ to 5π, or ~6 to 15.
- The two small antennas (b) and (c) radiate by 'self-coupling', which is weaker, and are found to have Qs of $\sim(1/\surd 2)(2\pi)^3 \approx 175$ and $(2\pi)^3 \approx 250$ respectively.
- The $(1/\surd 2)$ reduction of Q is found when two modes of the same type are strongly coupled as for the ends of a short dipole (b). A thin half-wave dipole has less coupling from the ends to the centre and thus a higher Q, up to about 5π.

5. THEORY OF RADIATION AND RECEPTION – 4

- **To justify the stated antenna Q values:**
- For convenience we temporarily define currents and potentials in units that give them equal energy.
- We have $\kappa_0 = 1/(2\pi)$ as the limiting or asymptotic EM coupling factor at a point.
- Also for antennas we find that Q is the reciprocal of the total coupling factor.
- We observe that self-coupling is 3 step coupling process with induced displacement current around the conductor as an intermediary. Its basic Q is thus expected to be $(1/\kappa_0)^3 = (2\pi)^3 \approx 250$.
- The coupling between different mode types that are simultaneously excited with the correct phase is single step, and a Q of about $1/\kappa_0 = 2\pi \approx 6$ is to be expected.

5. THEORY OF RADIATION AND RECEPTION – 5

- **Existence of Process Regions:**
- Note that potentials combine according to the classical rules of vector addition.
- Whereas displacement currents combine according to the RSS (Root-Sum-of-the- Squares) vector addition rule [2].
- We also find that radiation and loss resistances of a ‘multi-mode’ antenna all combine according to the RSS rule [5,6].
- As a consequence ‘process capture’ occurs where the strongest antenna mode with highest radiation resistance dominates and partially suppresses all other modes and any loss resistances.
- Process capture creates ‘process regions’ where one process dominates.
- Partially coupled process regions can overlap. This is the basis of Analytic Region Modelling (ARM) [10] used for modelling the pattern of the loop-monopole below.

6. ANTENNA PATTERN OF LOOP-MONOPOLE

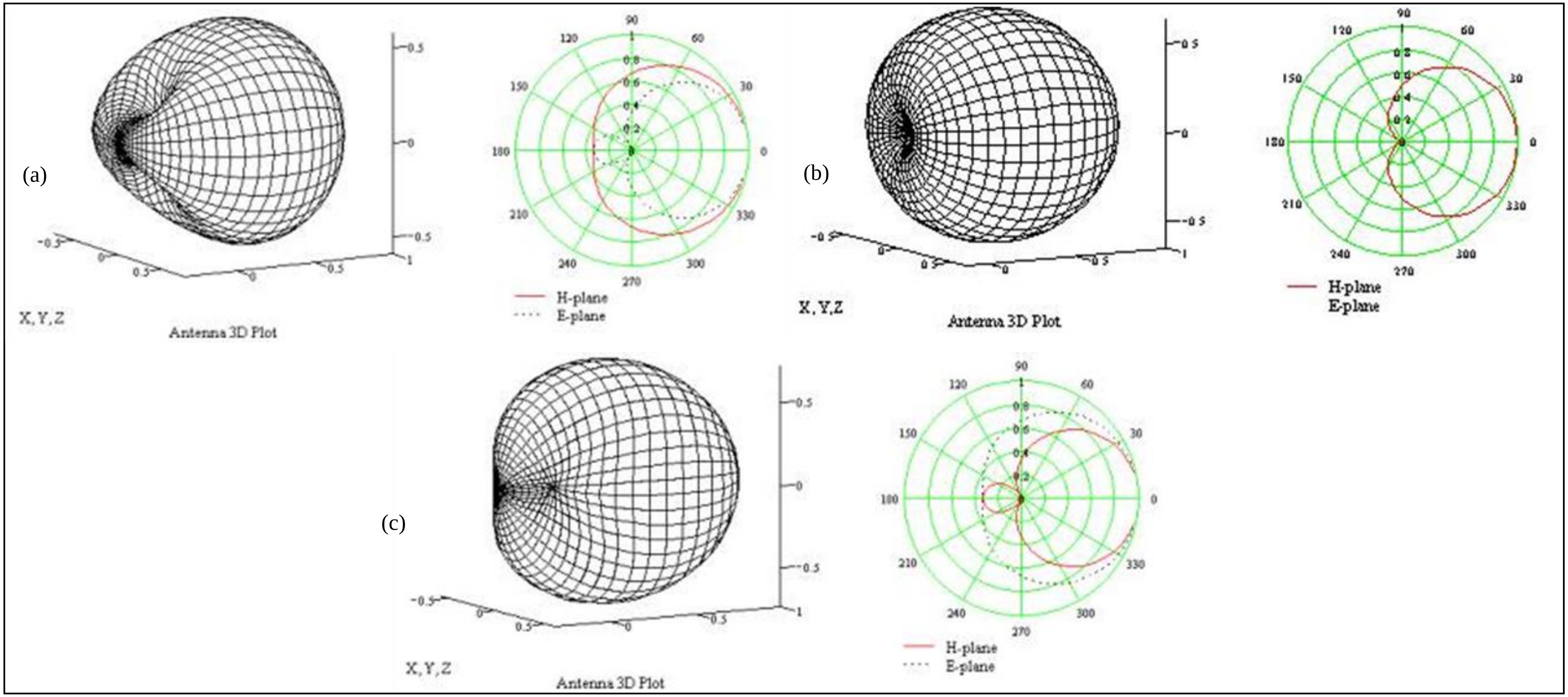


Figure 6. Loop-Monopole antenna patterns for ratios of **electric E mode to magnetic M mode:** (a) E/M = 2, (b) E/M = 1, and (c) E/M = ½

- The loop-monopole is usefully uni-directional (3 to 12dB) over significant parts of the operating frequency range. The pattern depends on the proportion of the electric monopole mode to the magnetic loop mode.
- The simulation methodology is that of ‘Analytic Region Modelling, ARM’ [10].

7. CONCLUSIONS

- A novel small high power wideband loop-monopole emphatically contradicts the Chu small antenna Q criterion. This criterion can no longer safely be used as a small antenna design rule.
- The classical Maxwell equations need to be revised and extended to include ‘electromagnetic coupling’ and ‘energy conservation’.
- The unexpectedly low value of effective antenna Q is the result of strongly (electromagnetically) coupled and nearly equally excited electric and magnetic modes occupying the same near-field volume.
- Thus the importance of ‘electromagnetic coupling’ has once again been demonstrated [1,2].
- New antenna theory: “It is the coupling that radiates *and* receives”.
- The polar diagram of the loop-monopole antenna has been found to be usefully uni-directional at some frequencies (3 to 12dB).
- Improved variants of the loop-monopole appear to be feasible.

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3. Chu, L. J., “Physical Limitations of Omni-Directional Antennas”, J. *Appl. Phys.*, Vol. 19, December 1948 pp. 1163-1175.
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5. Underhill, M. J., and Harper, M., ‘‘Simple Circuit Model of Small Tuned Loop Antenna Including Observable Environmental Effects’, *IEE Electronics Letters*, Vol.38, No.18, pp. 1006-1008, 2002.
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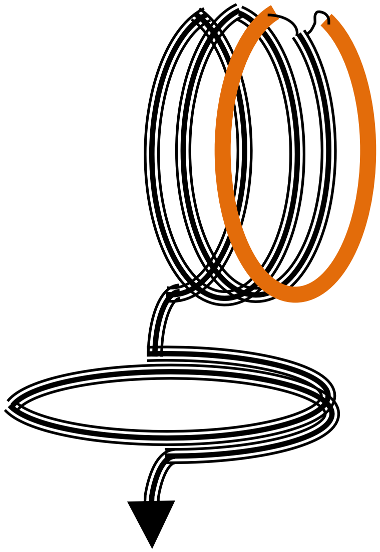
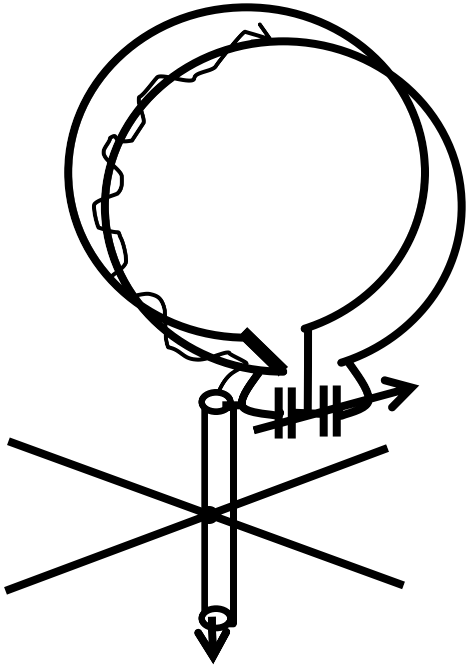
7. Underhill, M. J., “A Local Ether Lens Path Integral Model of Electromagnetic Wave Reception by Wires”, *Proc. PIERS 2012* Moscow.
8. Underhill, M. J., “Antenna Pattern Formation in the Near Field Local Ether”, *Proc. PIERS* 2012 Moscow.
9. Underhill, M. J., Blewett, M. J., “Unidirectional tuned loop antennas using combined loop and dipole modes”, *8th Int. Conf. on HF Radio Systems and Techniques*, 2000. (IEE Conf. Publ. No. 474).
10. Underhill, M. J., “Novel Analytic EM Modelling of Antennas and Fields”, *Proc. PIERS 2012* Kuala Lumpur.

Transportable 1.2m Square Loop-Monopole

Antenna Pattern Measurement

- The ‘Two Identical Antenna’ is the only scientifically sound and safe method of measuring (small) antenna patterns.
- It is applicable to mixed mode antennas like the loop-monopole, below left.
- It is applicable to multi-mode antennas like the double/triple-tuned coiled hairpin antenna., below right.

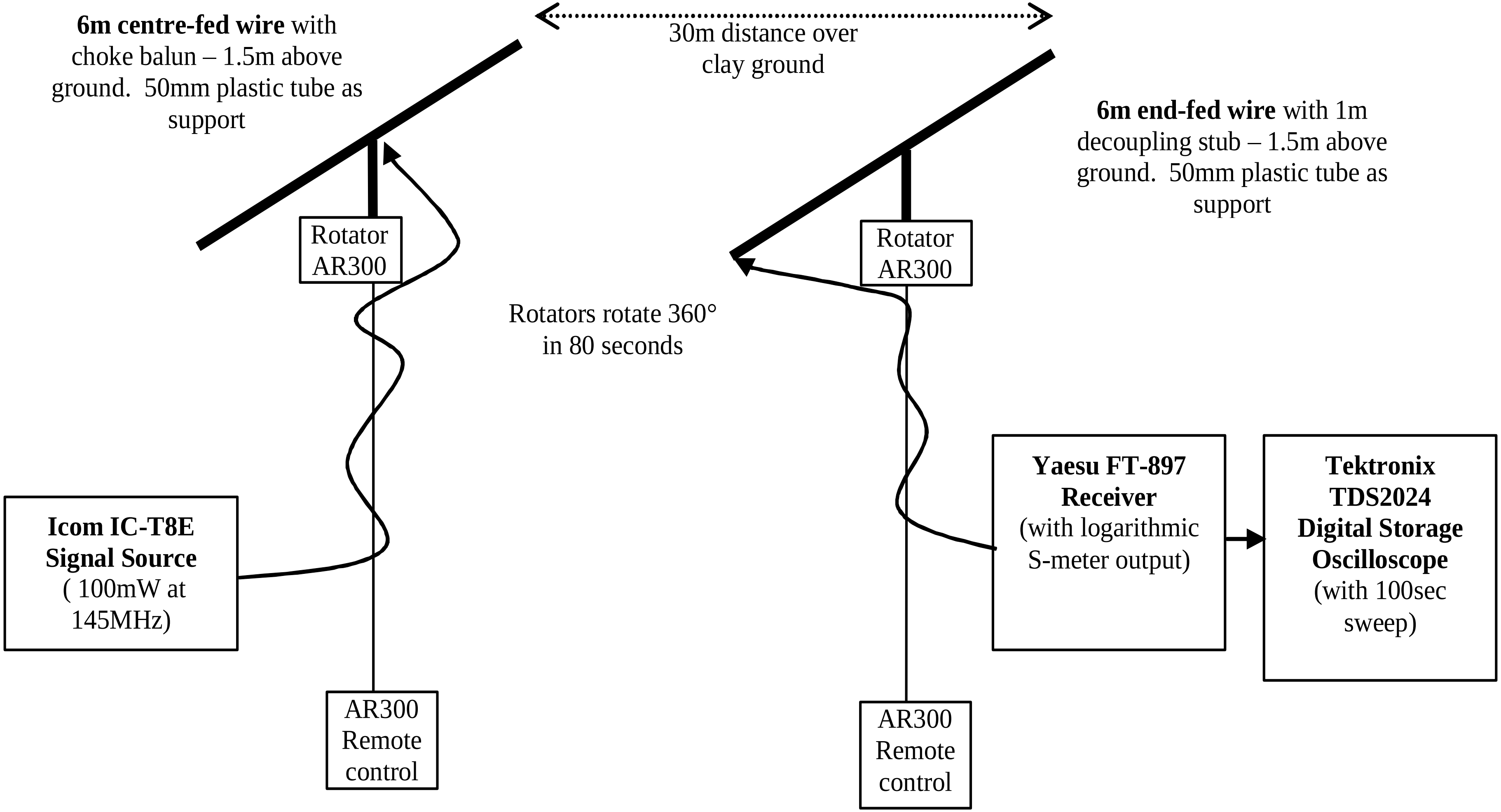




The ‘Two Identical Antenna Method’ for Accurate Path Loss and Field Strength Measurements over Ground

- The ‘two identical antenna method’ gives accurate measurements over any ground .
- The method uses two identical (small) antennas spaced at a distance *x*.
- Both antennas are impedance matched (to 50 ohms).
- One antenna is supplied with a measured power P1.
- The power P2 received in the matched load of the second antenna is measured. (The voltage across the 50 ohm load can be measured using a high impedance oscilloscope. The Tektronix TDS 310 has an FFT spectrum display that has selectivity and can be used to reject interference.)
- The path loss is calculated as L = P2/P1.
- The field strength power intensity at *x/2* is then P1/√L. (You can use dBs for this.)
- E-field and H-field probes can the be placed at *x/2* and calibrated accurately in the presence of the ground immediately below the sensor.
- Note that the measured sensitivities of these probes will in general be different from their sensitivities in free space. The differences are a measure of the effect that ground permittivity and conductivity have on the fields above ground.

The ‘Two Identical Antenna Method’ Antenna for Accurate Path Loss and Field Strength Measurements over Ground



6m centre-fed wire with choke balun – 1.5m above ground. 50mm plastic tube as support

30m distance over clay ground

6m end-fed wire with 1m decoupling stub – 1.5m above ground. 50mm plastic tube as support

Rotator AR300

Rotator AR300

Rotators rotate 360° in 80 seconds

Icom IC-T8E Signal Source (100mW at 145MHz)

Yaesu FT-897 Receiver (with logarithmic S-meter output)

Tektronix TDS2024 Digital Storage Oscilloscope (with 100sec sweep)

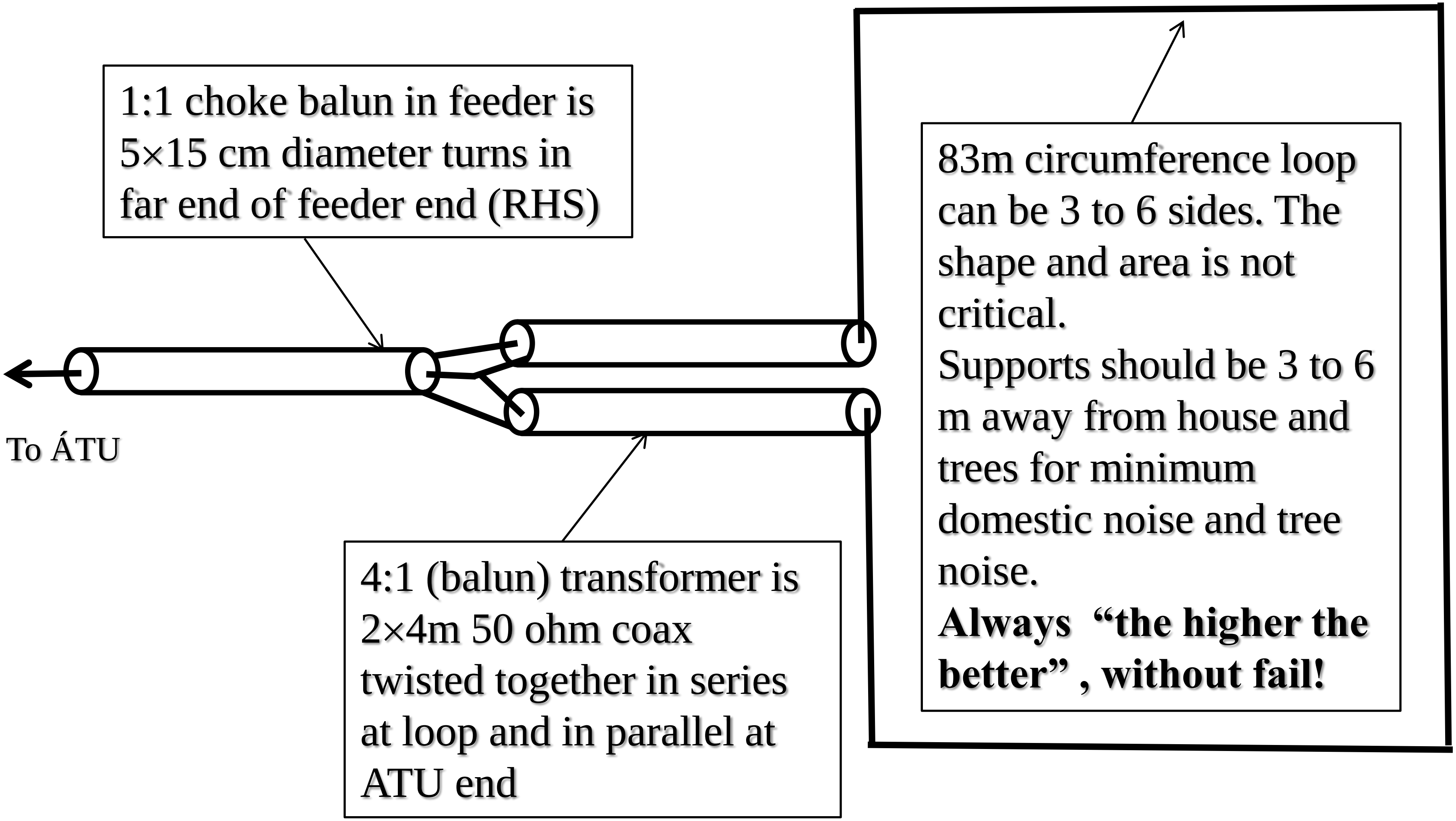
AR300 Remote control

AR300 Remote control

Two G3LHZ Horizontal Reference Loops at 15m and 2m Heights

- Usable on all bands from 0.1 to >200MHz with an ATU for lower frequencies.
- No deep nulls >~6dB are observed
- Travelling wave antenna at higher frequencies?
- SWR Plot also indicates this.

Original Reference Antenna at G3LHZ = 83m circumference horizontal loop for 1.8 to 60 MHz



1:1 choke balun in feeder is 5×15 cm diameter turns in far end of feeder end (RHS)

To ÁTU

4:1 (balun) transformer is 2×4m 50 ohm coax twisted together in series at loop and in parallel at ATU end

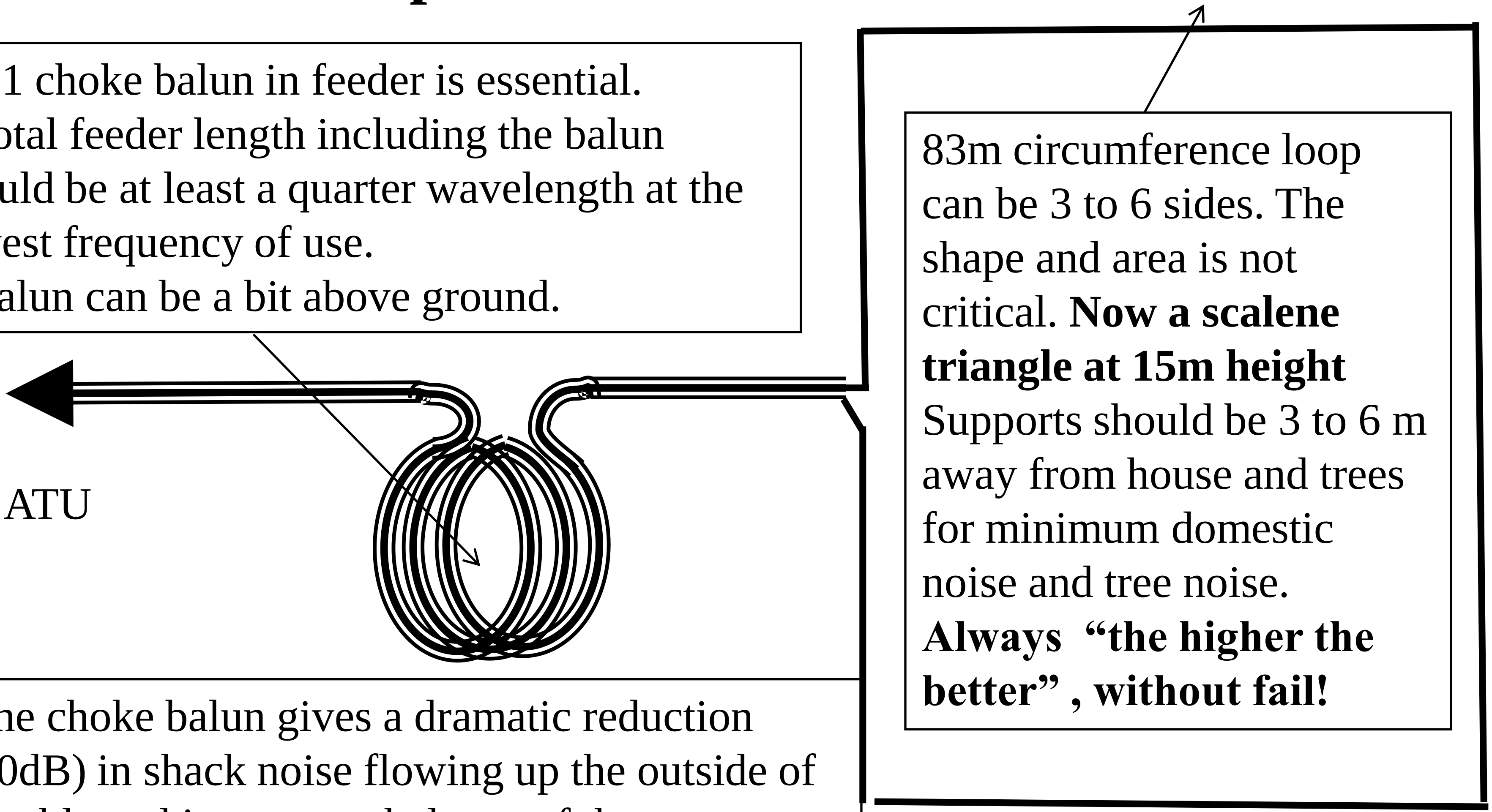
83m circumference loop can be 3 to 6 sides. The shape and area is not critical.

Supports should be 3 to 6 m away from house and trees for minimum domestic noise and tree noise.

Always “the higher the better” , without fail!

New Reference Antenna at G3LHZ = 83m circumference horizontal loop for 1.8 to 60 MHz with coax balun.

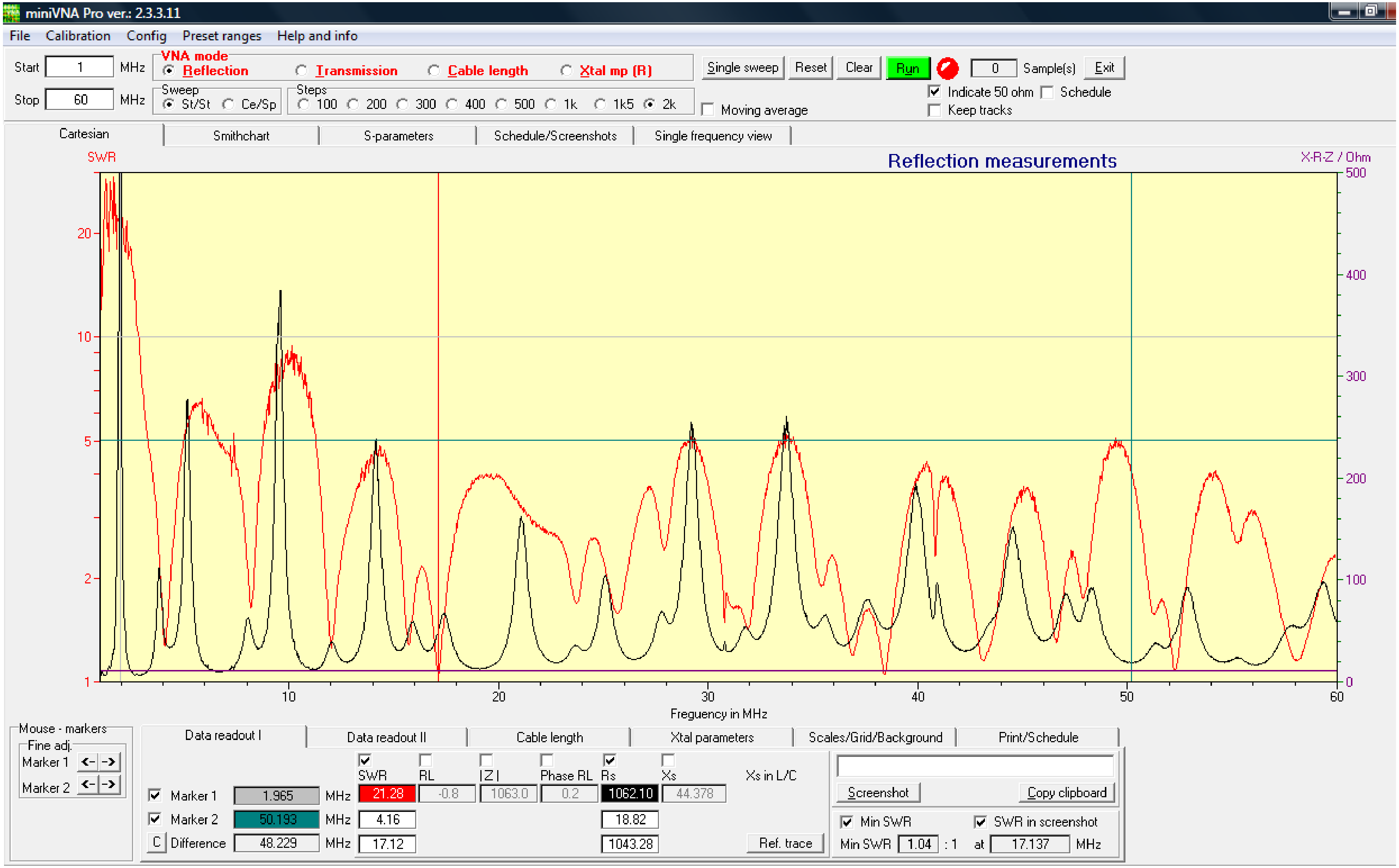
- 1:1 choke balun in feeder is essential.
- Total feeder length including the balun should be at least a quarter wavelength at the lowest frequency of use.
- Balun can be a bit above ground.



83m circumference loop can be 3 to 6 sides. The shape and area is not critical. **Now a scalene triangle at 15m height** Supports should be 3 to 6 m away from house and trees for minimum domestic noise and tree noise. **Always “the higher the better” , without fail!**

- The choke balun gives a dramatic reduction (>20dB) in shack noise flowing up the outside of the cable and into any unbalance of the antenna.
- Also supplying all rigs in shack through 25 or 50 m of coiled mains cable gives further reduction of house mains noise.

SWR of Original 83m Loop



miniVNA Pro ver.: 2.3.3.11

Start 1 MHz

Stop 60 MHz

VNA mode ● Reflection ○ Transmission ○ Cable length ○ Xtal mp (R)

Sweep ● St/St ○ Ce/Sp

Steps ○ 100 ○ 200 ○ 300 ○ 400 ○ 500 ○ 1k ○ 1k5 ● 2k

☐ Moving average

0 Sample(s)

☑ Indicate 50 ohm ☐ Schedule

☐ Keep tracks

			☑ SWR	☐ RL	☐ |Z|	☐ Phase RL	☑ Rs	☐ Xs	Xs in L/C
☑ Marker 1	1.965	MHz	21.28	-0.8	1063.0	0.2	1062.10	44.378	
☑ Marker 2	50.193	MHz	4.16				18.82		
C Difference	48.229	MHz	17.12				1043.28		

☑ Min SWR ☑ SWR in screenshot

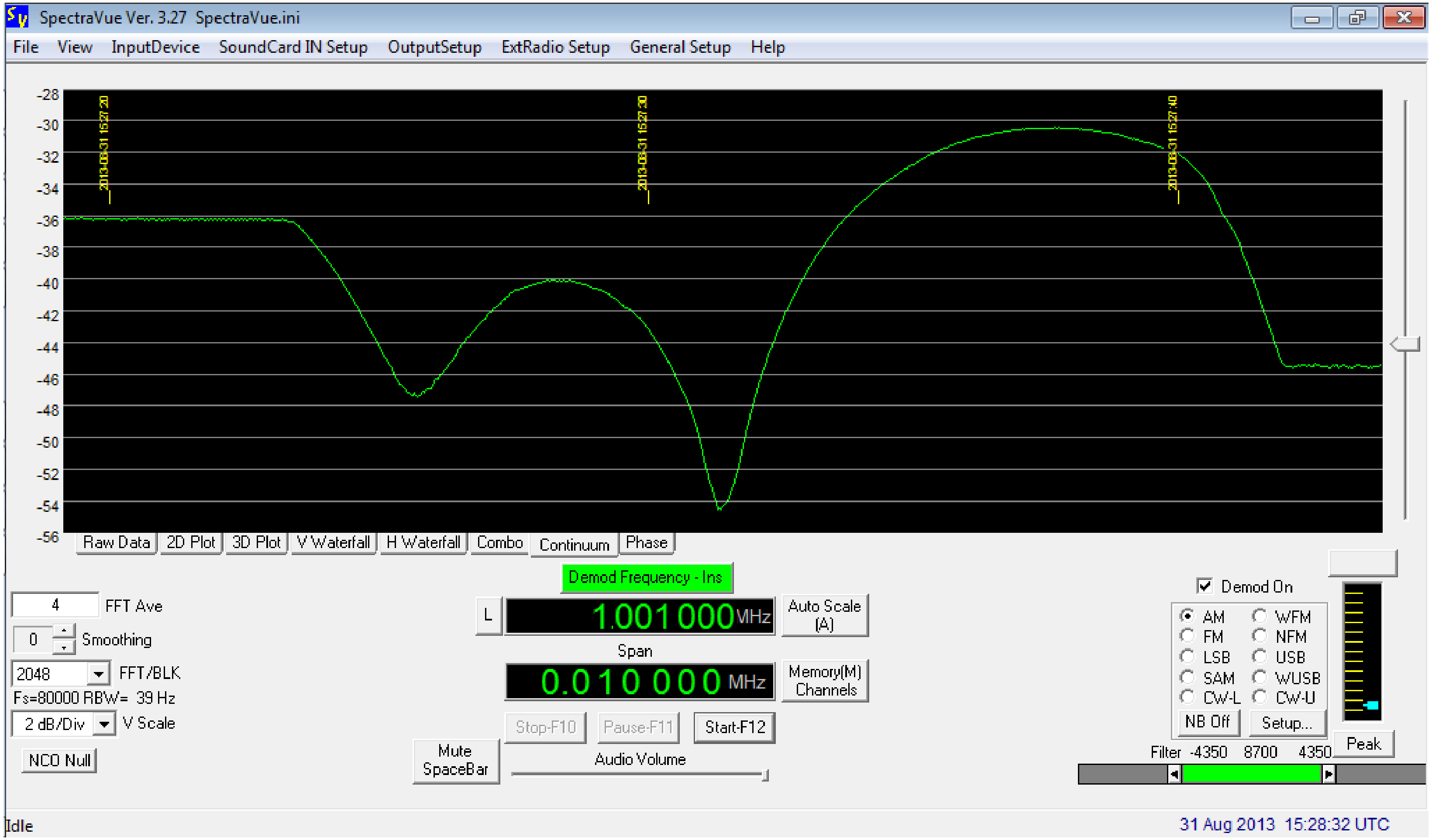
Min SWR 1.04 : 1 at 17.137 MHz

G3LHZ

Demo of Antenna Pattern Measurement

- Signal Source is battery-powered Elecraft KX3 with up to ~0dBm output.
- Calibrated receiver with ~0.2db pattern resolution is the FunCube Pro+ with SpectraView software. In 'Continuum' mode.
- A constant velocity rotator then gives storable scope time trace of the antenna pattern over 360^0. ('Print Screen' command stores the data as a graph.)
- Important to use a pair of identical antennas wherever possible

Antenna Patterns of a Pair of Loop-monopoles, one at 180^0 to the other.



SpectraVue Ver. 3.27 SpectraVue.ini

4 FFT Ave

0 Smoothing

2048 FFT/BLK

Fs=80000 RBW= 39 Hz

2 dB/Div V Scale

Demod Frequency - Ins

L 1.001 000 MHz

Span 0.010 000 MHz

☑ Demod On

● AM ○ WFM
○ FM ○ NFM
○ LSB ○ USB
○ SAM ○ WUSB
○ CW-L ○ CW-U

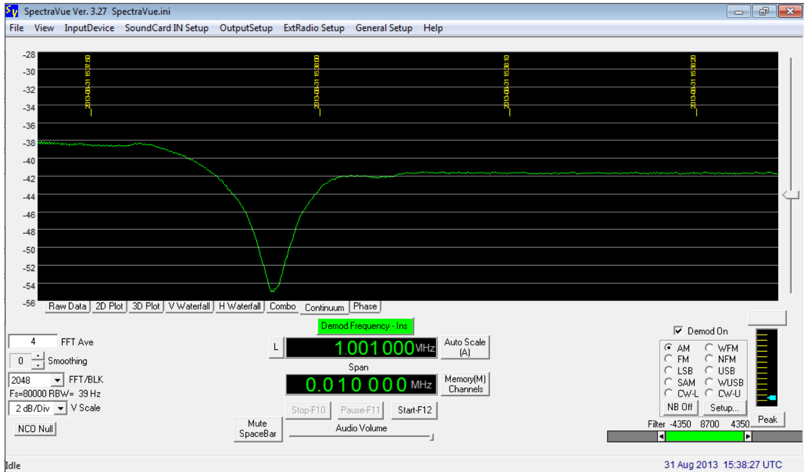
Filter -4350 8700 4350

Idle

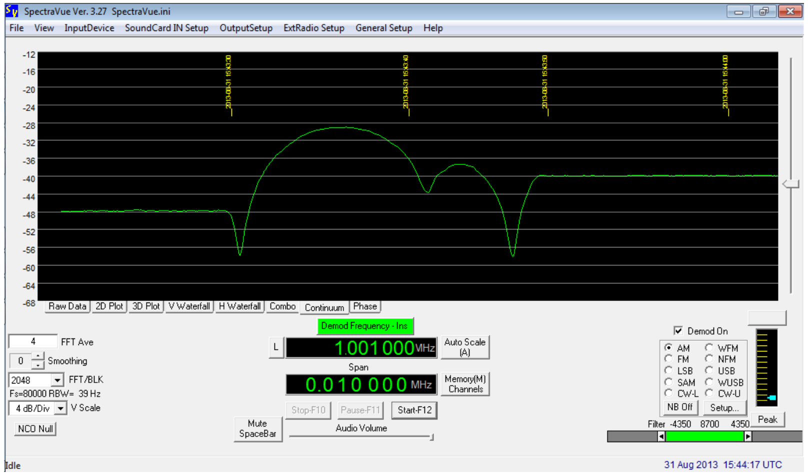
31 Aug 2013 15:28:32 UTC

- Measured on FunCubePro + with SpectraVue processing and display software
- Note Front-to-Back ratio of 24dB

Antenna Patterns of a Pair of Loop-monopoles, one at 90^0, 180^0, 270^0 and 0^0 to the other.



4 FFT Ave
0 Smoothing
2048 FFT/BLK
Fs=80000 RBW= 39 Hz
2 dB/Div V Scale
1.001 000 MHz
Span 0.010 000 MHz
☑ Demod On
● AM ○ WFM ○ FM ○ NFM ○ LSB ○ USB ○ SAM ○ WUSB ○ CW-L ○ CW-U
Filter -4350 8700 4350
Idle
31 Aug 2013 15:38:27 UTC



4 FFT Ave
0 Smoothing
2048 FFT/BLK
Fs=80000 RBW= 39 Hz
4 dB/Div V Scale
1.001 000 MHz
Span 0.010 000 MHz
☑ Demod On
● AM ○ WFM ○ FM ○ NFM ○ LSB ○ USB ○ SAM ○ WUSB ○ CW-L ○ CW-U
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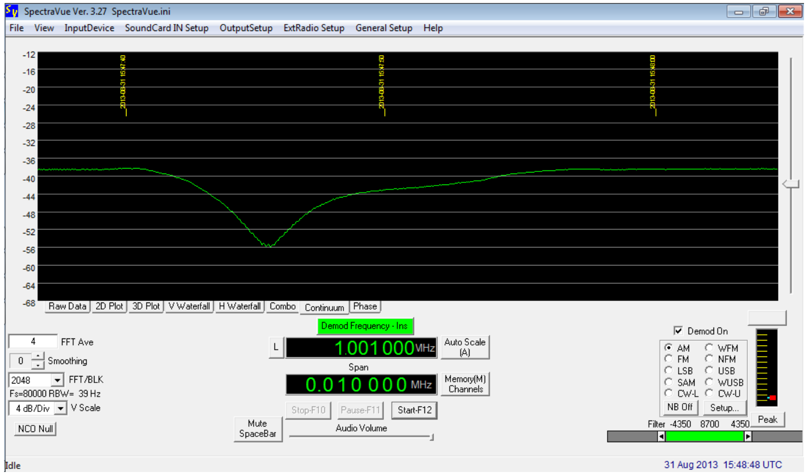


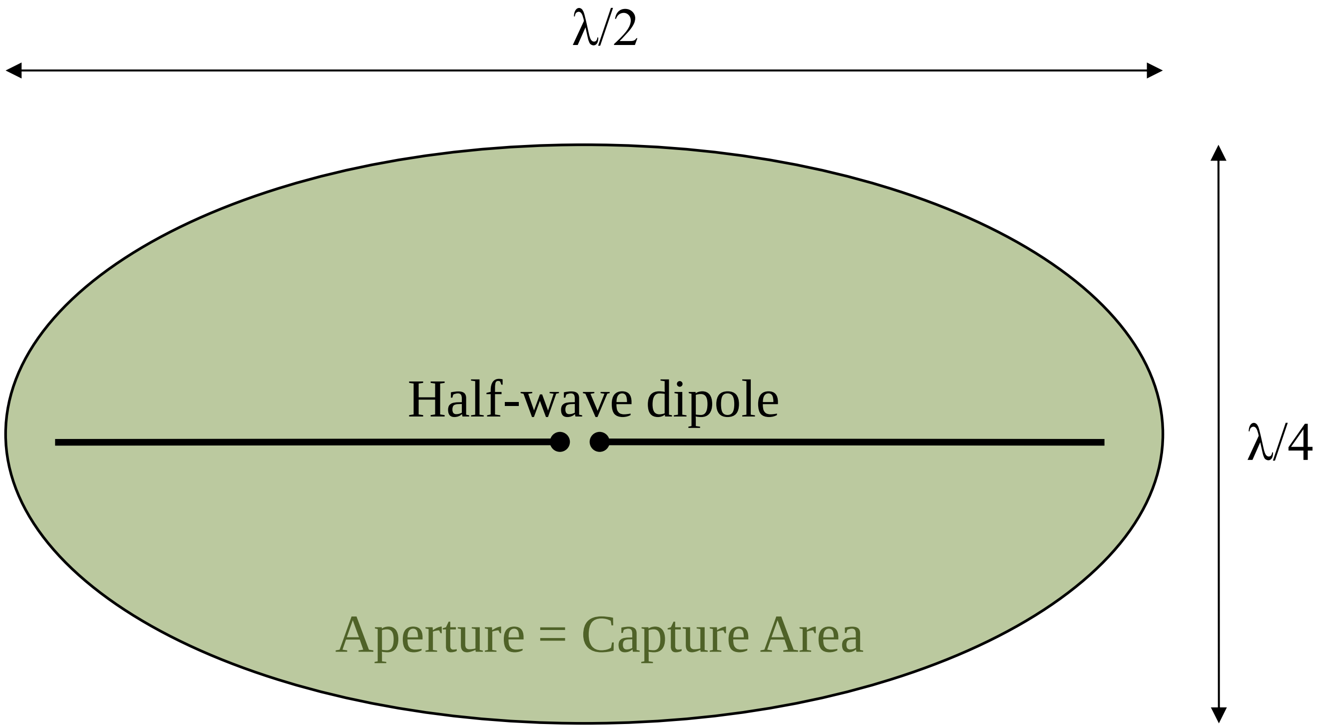
4 FFT Ave
0 Smoothing
2048 FFT/BLK
Fs=80000 RBW= 39 Hz
4 dB/Div V Scale
1.001 000 MHz
Span 0.010 000 MHz
☑ Demod On
● AM ○ WFM ○ FM ○ NFM ○ LSB ○ USB ○ SAM ○ WUSB ○ CW-L ○ CW-U
Filter -4350 8700 4350
Idle
31 Aug 2013 15:48:48 UTC

4 FFT Ave
0 Smoothing
2048 FFT/BLK
Fs=80000 RBW= 39 Hz
4 dB/Div V Scale
1.001 000 MHz
Span 0.010 000 MHz
☑ Demod On
● AM ○ WFM ○ FM ○ NFM ○ LSB ○ USB ○ SAM ○ WUSB ○ CW-L ○ CW-U
Filter -4350 8700 4350
Idle
31 Aug 2013 15:47:11 UTC

How Does a Wire Antenna Receive?

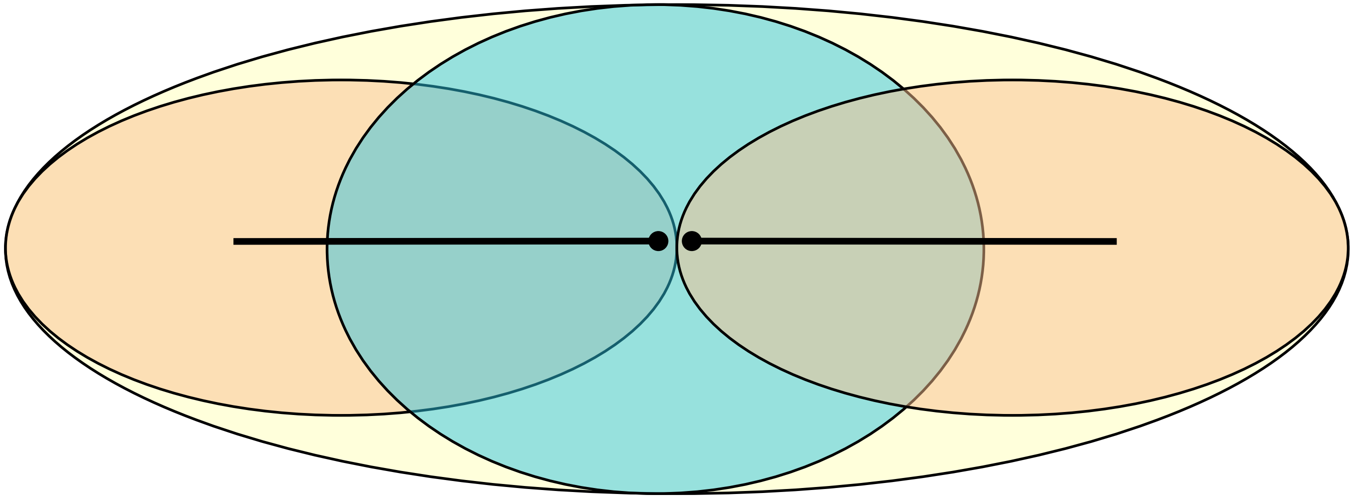
- The Physics of *reception* is an unsolved problem in Antenna Theory.
- There is a mathematical theory but it has to use the ‘principle of reciprocity’.
- Is it a focussing effect by a local ether lens?

The Problem: Antenna Aperture and Capture Area Much Larger than Physical Cross-section Area of a Wire Dipole.



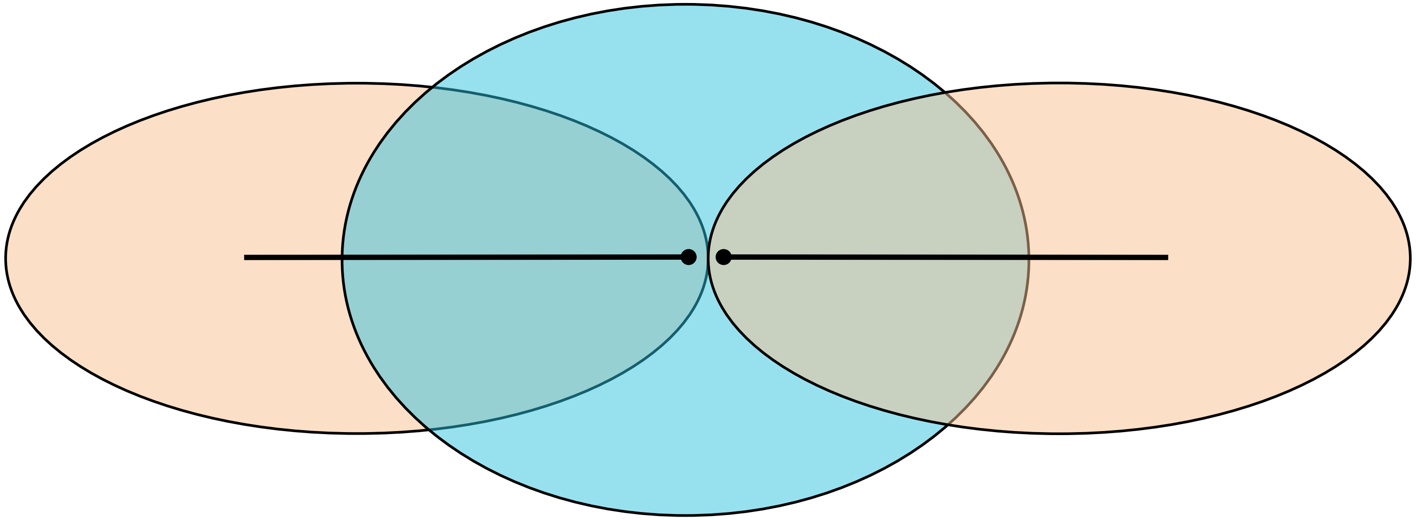
- Why is the receiving aperture and capture area so large? Is it a focussing effect like a lens? (Yes!)
- Also viewed from a few wavelengths do we see the wire magnified to the size of the aperture? (Arguably—Yes!)

<u>Antenna with two types of stored energy</u>. Is the lowered space impedance 'local ether' energy store the lens that does the focussing?



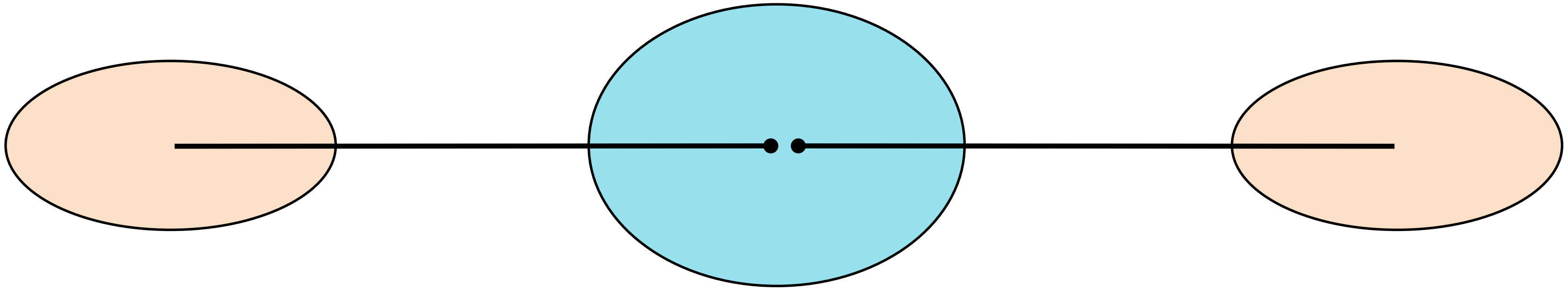
- **Electric, Magnetic and Total Energy of a (Short) Dipole at UHF**

Where does the radiation come from on the antenna?



- Radiation per unit length of a half-wave dipole at about 5 to 10MHz.

Where does the radiation come from on the antenna?



- Radiation per unit length of a half-wave dipole at about 1 to 2MHz.

Power Flow Trajectories for Reception by a Wire

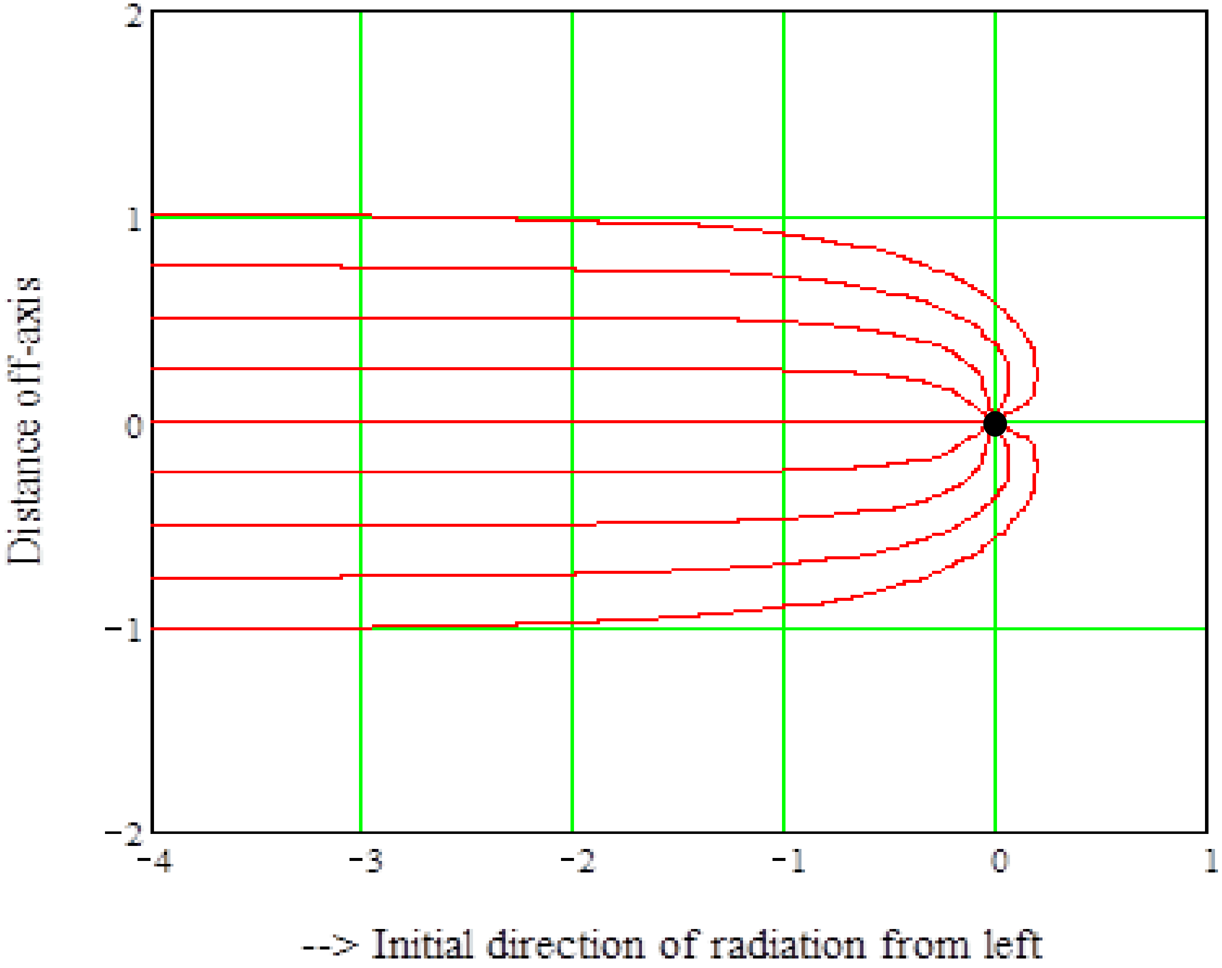


Figure1: Power flow trajectories from aperture left to all angles on a wire dipole at 0,0 on right.

POWER FLOW TRAJECTORY DEPENDENCE ON FREQUENCY

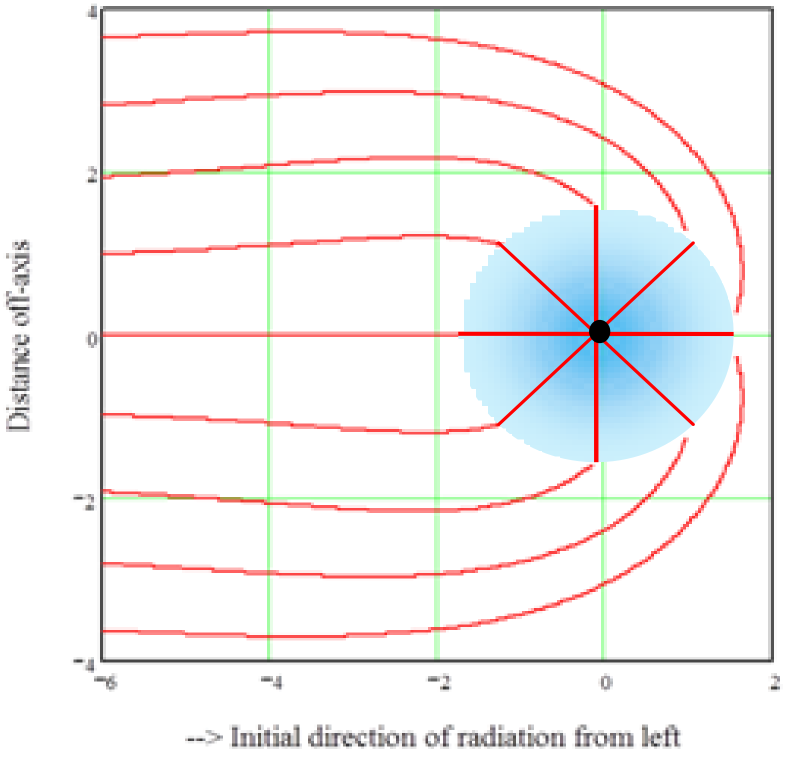


Figure 4: Power flow trajectories from aperture left to all angles on a wire dipole at 0.0 on right. Shaded blue lens region is finite but less than the capture aperture size for a frequency below about 90MHz.

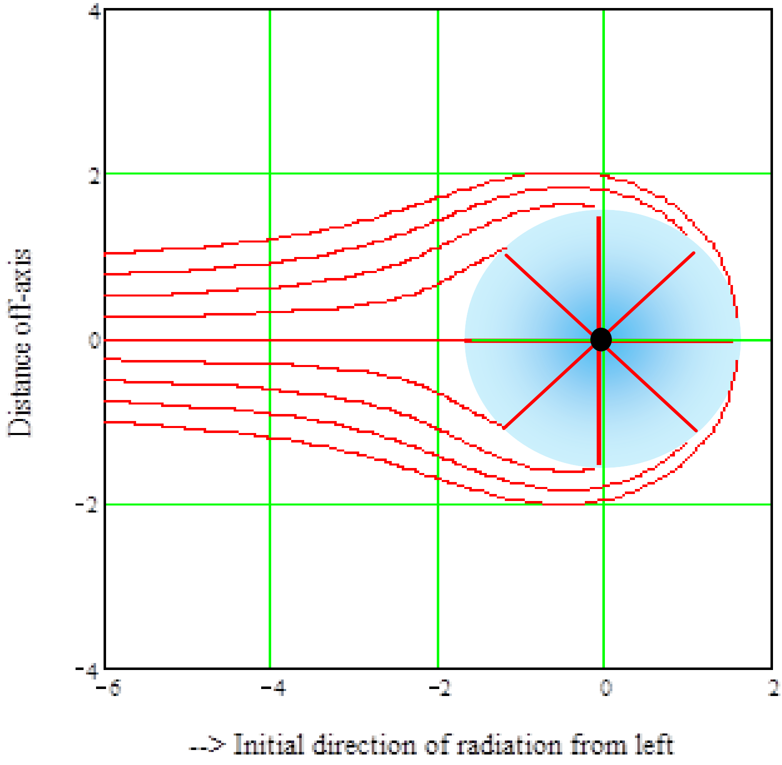


Figure 5: Shaded blue lens region is finite and larger than less than the capture aperture size, as is the case above about90MHz.

7. CONCLUSION

- This is a first attempt at representing the focussing process of a wire dipole. It is based on dividing the problem into ‘process regions’.
- At present not enough is known or has been measured for this newly elucidated focussing mechanism.
- Approximate power flow trajectories have been found which satisfy the constraints of the known capture aperture area of a dipole and the assumption that the local ether lens is a region of high EM self-coupling.
- A Feynman Path Integral process is assumed for EM coupling. ‘Coupling’ replaces Wave Function ‘probability’.
- The size of the local ether lens is taken to be the (Goubau) EM coupling distance [2], which is proportional to 1/√(frequency).
- Further measurements and more exact solutions to the trajectory equations are needed to refine the heuristic power flow trajectories obtained so far.

- This talk was given at the Progress In Electromagnetic Research Symposium (PIERS), 27th to 30th March 2012 in Kuala Lumpur.
- This selection of slides will be covered very quickly, picking out important points.
- A fuller version is in the Additional Slides at the end

Maxwell's Transfer Functions

Michael J (Mike) Underhill
Underhill Research Ltd, UK

2. The Modified Classical Maxwell's Equations

$$divD = \nabla \cdot D = \rho_E \qquad (1) \qquad\qquad divB = \nabla \cdot B = \rho_M \qquad (2)$$

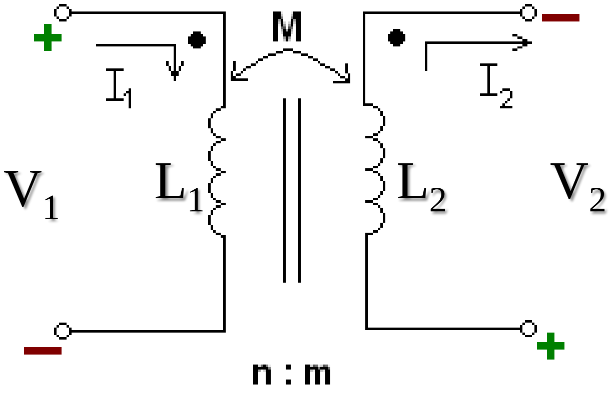
$$curlH = \nabla \times H = + \frac{\partial D}{\partial t} + J_R + J_E \qquad (3) \qquad\qquad - curlE = - \nabla \times E = \frac{\partial B}{\partial t} + J_M \qquad (4)$$

$D = \varepsilon E$ where generally in the near-field $\varepsilon > \varepsilon_0$ (5)

$B = \mu H$ where generally in the near-field $\mu > \mu_0$ (6)

- **The fundamentally important *modification* is that ε and μ are allowed to increase over ε_0 and μ_0 and become functions of position in near field space in the 'constitutive relations' (5) and (6). ε_0 and μ_0 effectively define the 'ether'**
- This removes a 100 years old dogma that there is no ether and now allows progress.
- Separately it can be shown that this is not contradicted by the Michelson-Morley Experiment.
- So ε and μ now can define the 'local ether' that surrounds any antenna or physical object [1].
- $\partial B/\partial t$ is defined as the magnetic displacement current as in (3) .
- $\partial D/\partial t$ is defined as the electric displacement current as in (4).

Partial EM Coupling Model is a transformer.



Coupling factor, $\kappa = M/\sqrt{(L_1 L_2)} \le 1$

Also we have $nL_2 = mL_1$

$V_2 := \kappa\,(m/n)\,V_1$ $\qquad$ $V_1 := \kappa\,(n/m)\,V_2$

$I_1 := \kappa\,(n/m)\,I_2$ $\qquad$ $I_1 := \kappa\,(m/n)\,I_2$

- **The transformer is a model of magnetic/inductive EM coupling.**
- The ‘capacitance transformer’ is used for electric/capacitative EM coupling .
- In the coupling equations the sources are on the right and the sinks are on the left. *The coupling equations are not reversible.*
- The symbol ‘ := ’ means ‘depends on’.
- In general sink strengths are less than source strengths.

Local Coupling of Fields

- ***For reasonably uniform local space anywhere away from the surface of the antenna we find that the asymptotic (causal) coupling between the fields in Maxwell's equation is not the 100% that*** **has *implicitly been assumed since the equations were originally constructed*.**
- In fact a value of around $\kappa_0 = 1/2\pi$ is what has been found experimentally. Thus experimental measurement validates any theory that predicts $\kappa_0 = 1/2\pi$.
- This value can be used both for local points away from any sources or for plane waves in space.
- It means that the sensitivity of simple field detectors in practice is less than expected by $\kappa_0 = 1/2\pi$ or -16dB.

Supporting Evidence for $\kappa_0 = 1/2\pi$.

- Some of the supporting evidence in addition to evidence in reference [2] are the findings:
- (a) that small tuned loop size scales inversely as the square root of frequency,
- (b) that the small tuned loop asymptotic antenna Q is about 248 = $(2\pi)^3$ and
- (c) small tuned loops can easily have measured efficiencies of >90%, as predicted by (b) and
- (d) by observation that high power small tuned loops do not overheat and self-destruct as they would if they were inefficient.

Maxwell’s Transfer Functions (MTFs)

- **Thus Maxwell’s equations should be converted to be causal (cause and effect) transfer functions.**
- We find that only the constitutive relations in equations 5 and 6 need to be made into two pairs of unidirectional causal equations as given in equations 9a to10b.
- This enforces causality into all the Maxwell equations.
- The ‘becomes equal to’ sign ‘:=’ is unidirectional and is used in equations 9 and 10.

$$D := \kappa\varepsilon E \qquad \text{(9a),} \qquad E := \kappa\frac{D}{\varepsilon} \qquad \text{(9b)}$$

$$B := \kappa\mu H \qquad \text{(10a),} \qquad H := \kappa\frac{B}{\mu} \qquad \text{(10b)}$$

5. Imposition of Conservation of Energy on Maxwell’s Equations –2

- We therefore conclude that E and H are essentially potentials and are fundamentally different from D and B.
- **As a consequence we have to redefine the div operator as the square root of the Laplacian:**

$$(\nabla\cdot)=(\nabla^2)^{1/2}=\left[\left(\frac{\partial}{\partial x}\right)^2+\left(\frac{\partial}{\partial y}\right)^2+\left(\frac{\partial}{\partial z}\right)^2\right]^{1/2} \qquad (11)$$

6. The Causal Maxwell's Equations

With $\kappa = \kappa_0 = 1/2\pi$ we can now set out the causal Maxwell equations as:

$$divD = \nabla \cdot D = \rho_E \qquad (12) \qquad\qquad divB = \nabla \cdot B = \rho_M \qquad (13)$$

$$-curlE = -\nabla \times E = \frac{\partial B}{\partial t} \oplus J_M \qquad (14) \qquad\qquad curlH = \nabla \times H = \frac{\partial D}{\partial t} \oplus J_R \oplus J_E \qquad (15)$$

$$D := \kappa_0 \varepsilon E \qquad (16a), \qquad\qquad E := \kappa_0 \frac{D}{\varepsilon} \qquad (16b)$$

$$B := \kappa_0 \mu H \qquad (17a), \qquad\qquad H := \kappa_0 \frac{B}{\mu} \qquad (17b)$$

- In (12) to (17b) sources are on the right and sinks are on the left.
- As before these equations describe the physics of what is happening with sources and sinks at the same point in space.
- **The field pairs are not 100% coupled. The coupling is $\kappa_0 = 1/2\pi$.**
- **This is an important discovery with far-reaching consequences.**

7. Maxwell's Transfer Functions (MTFs) – 3

$$divD = \nabla \cdot D = j\left(k_z^2 + k_r^2\right)^{1/2} D = 0 \qquad (18), \qquad\qquad divB = \nabla \cdot B = j\left(k_z^2 + k_r^2\right)^{1/2} B = 0 \qquad (19)$$

$$curlE_x = \frac{\partial E_x}{\partial y} = jkE_x \text{ and } \frac{\partial B_y}{\partial t} = j\omega B_y = j\kappa\mu H_y \text{ to give:} \qquad -jk\delta E_x = j\kappa\mu H_y \qquad (20)$$

$$curlH_y = \frac{\partial E_x}{\partial y} = jkE_x \text{ and } \frac{\partial B_y}{\partial t} = j\omega B_y = j\kappa\mu H_y \text{ to give:} \qquad -jk\delta E_x = j\kappa\mu H_y \qquad (21)$$

$$\delta D_x := \kappa\varepsilon E_x \oplus \qquad (22a), \qquad\qquad \delta E_x := \kappa\frac{D_x}{\varepsilon} \qquad (22b)$$

$$\delta B_y := \kappa\mu H_y \oplus \qquad (23a), \qquad\qquad \delta H_y := \kappa_0\frac{B_y}{\mu} \qquad (23b)$$

- **(19) to (23) are Maxwell's Transfer Functions in terms of impedances and admittances. The sinks are on the left and sources on the right.**
- The δ sign shows that these equations can be integrated to sum all the contributions to the parameter on the left.
- The coupling κ is now a dyadic and therefore a function of the distance between two relevant points in space.
- The ⊕ sign warns where *RSS integration* should be used.

Conclusions

- **Maxwell’s Equations have been converted into Maxwell’s Transfer Functions (MTFs), by redefinition of the mathematical operators and the EM fields in the original equations.**
- **And by defining and quantifying the Fundamental Concept of *ElectroMagnetic (EM) Coupling* or *Physics Coupling*.**
- MTFs are ‘causal’ equations with frequency and time responses provided by Laplace Transform structures.
- MTFs are thus engineering tools for solving practical problems in electromagnetics, antennas and propagation.
- MTFs naturally fit with the ‘Physical Model of Electro-magnetism’ (PEM) [1].
- MTFs can provided the underlying analytic equations for the method of ‘Analytic Region Modelling (ARM) [4]

Discovered Properties and Uses of *Physics EM Coupling* – 1

In Physics and Electromagnetics:

1. **The chosen 'Meromorphic' mathematical form removes all 'singularities'** from all Physics. No point sources or infinitely thin wires need be defined.
2. **Partial coupling κ with a maximum of 1/2π for (cylindrical) wire sources or 1/4π for spherical sources.** Applies for inductive coupling (as in a transformer), for capacitative coupling and for angular momentum and spin.
3. **Time delay τ in the coupling** creates **particle inertial mass equal to gravitational mass,** and accounts for **dark matter** low inertia properties.
4. EM coupling is the basis for the **Physical Electromagnetic model for a Theory of Everything** based on coupled transmission lines. It gives models for all particles and fields. It explains anomalous **EM Wave Tilt** and **Surface Waves.**
5. **A Local Ether** is a consequence . Also a **Cosmic Ether** based on (gravitational) potential, gives rise to the **Hubble Red Shift** by weak scattering.
6. **Maxwell's Transfer Functions** are Maxwell's equations modified to be causal from sources to sinks. They include the **RSS Process Combination Rules.**
7. **Analytic Process Regions** are defined where one process dominates. **Analytic Region Modelling (ARM)** simulation of Physics and EM becomes possible.
8. **Continuous Relativity** considers a velocity profile of an infinity of intermediate 'frames' between observers and objects. Object masses 'warp space' to give the velocity profile. **Special and General Relativities are combined**.

Discovered Properties and Uses of *Physics EM Coupling* – 2

In Antennas and Propagation:

1. **The lens model of reception and transmission.** Received waves focussed and transmit wire antenna image magnified.
2. **Explains why the (high) currents in the Goubau single-wire transmission line do not radiate**. And why practical **long-wire patterns** are not as given in the books because of Goubau travelling-wave modes on the antenna wire,
3. **Ground and Surface Wave Layers :** The coupling between layers accounts for **'The Millington Effect'** and **Ground Wave Interference Patterns** with ~40km period. (A bit like neutrino flavour variation with distance.)
4. **Considerable Ground Losses under antennas.** Much higher than expected or predicted in the case of real ground. Wet clay is particularly bad.
5. **Self-coupling** accounts for radiation to and from *electric and magnetic small antennas* with high $Q \sim (2\pi)^3 = 248$
6. **Coupling between *n* like co-located antenna modes** reduces small antenna Q to $Q \sim (2\pi)^3 / \sqrt{n} = 248/\sqrt{n}$
7. **Electro-Magnetic Coupling between co-located electric and magnetic fields** accounts for radiation to and from half-wave dipoles and the loop-monopole.
8. **Analytic Region Modelling (ARM)** for fast and efficient antenna simulation. No matrix inversion is needed. Multiple modes and processes easily modelled.

Measurement of Antenna Efficiency

The Law of Energy Conservation (Second Law of Thermodynamics) Requires:

Power In = Power Radiated + Power Lost as Heat

Thus Antenna **Efficiency** should always be defined as:

(Power Radiated)/(Power In) = 1- (Power Lost as Heat)/ (Power In)

Efficiency can be measured by Q of any antenna if conductor losses are known

The Impact of the *Process Capture* and *Power Combination/Splitting* Rules on Antenna Q and Efficiency η

- Radiation and Loss Resistances are *distributed* and *electromagnetically coupled* . They are *not* connected either in series or in parallel, but by EM coupling.

1. **The mathematics discovered for combining resistances in an efficiency or Q formula is the *<u>RSS (Root-Sum-of-the-Squares) Rule</u>*. From (loop) Q measurements and we find the RSS Rule to be** $R_{meas} = \sqrt{(R_{rad}^2 + R_{loss}^2)}$
2. ***<u>The Power Splitting Rule</u>* for coupled distributed resistances is found to be according to the square of the resistances** $P_1/P_2 = R_1^2 / R_2^2$

- **These two discoveries** were made from extensive ‘Wideband-Q’ measurements of small loops and originally reported and used in:
  - 1. Underhill, M. J., and Harper, M., ‘‘Simple Circuit Model of Small Tuned Loop Antenna Including Observable Environmental Effects’, *IEE Electronics Letters*, Vol.38, No.18, pp. 1006-1008, 2002.
  - 2. Underhill, M. J., and Harper, M., “Small antenna input impedances that contradict the Chu-Wheeler Q criterion”, Electronics Letters, Vol. 39, No. 11, 23rd May 2003.

- The efficiency of any antenna large or small is thus

$$\eta = (R_{rad}/R_{meas})^2 = R_{rad}^2/(R_{rad}^2 + R_{loss}^2) = (Q_{meas}/Q_{rad})^2 = Q_{meas}^2 /\{Q_{meas}^{-2} - Q_{loss}^{-2}\}$$
$$= 1 - (R_{loss}/R_{meas})^2 = \{1 - Q_{meas}^2 / Q_{loss}^2\} = 1 - (Q_{meas} \times R_{loss}/X_l)^2$$

- The loss resistance R_{loss} unfortunately cannot be determined directly from a single antenna Q measurement. *You cannot measure two things with one measurement*!

How to Measure Q of Any Antenna

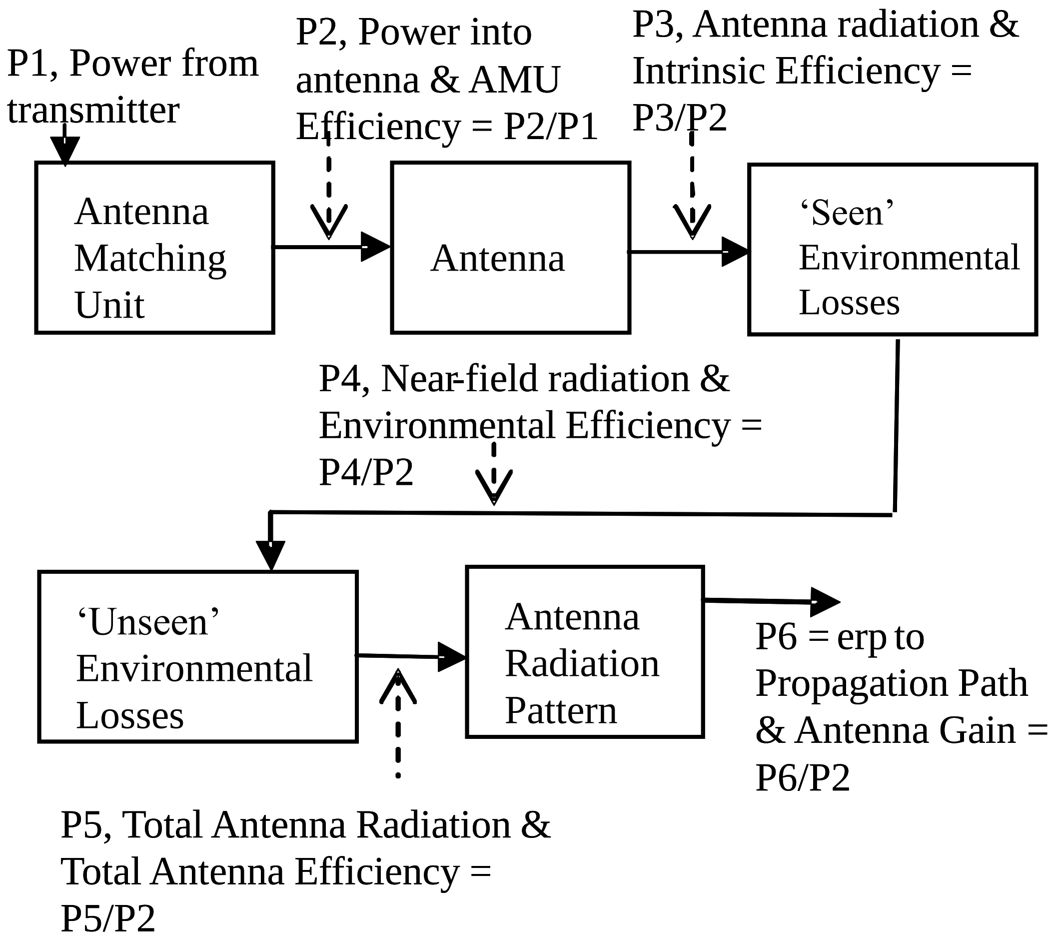
1. At the frequency of interest f_0 match the antenna to 50 ohms to give a 1:1 SWR (on the Antenna Analyser).
    - Use an ATU or match network with a lower Q than the antenna.
    - The L-match is the best practical choice.
2. Detune (the analyser) to lower frequency f_1 where the SWR is 2.62.
3. Detune 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?

- The half-power or -3dB points occur when the reactance of tuned circuit becomes equal to ± j50 ohms, where $j = \sqrt{(-1)}$.
- Then the Reflection Coefficient is $\rho = \{1-(1 \pm j)\}/\{(1+(1 \pm j)\}$.
- The modulus of the reflection coefficient $= |\rho| = 1/\sqrt{(2^2 + 1)} = 1/\sqrt{5}$
- And this gives an $\text{SWR} = (1+|\rho|) / (1+|\rho|) = (1+ 1/\sqrt{5})/(1 - 1/\sqrt{5}) = 2.6180$

DEFINITIONS OF ANTENNA EFFICIENCY AND EFFECTIVENESS

“Where does the power go?”



P1, Power from transmitter

P2, Power into antenna & AMU Efficiency = P2/P1

P3, Antenna radiation & Intrinsic Efficiency = P3/P2

Antenna Matching Unit

Antenna

‘Seen’ Environmental Losses

P4, Near-field radiation & Environmental Efficiency = P4/P2

‘Unseen’ Environmental Losses

Antenna Radiation Pattern

P6 = erp to Propagation Path & Antenna Gain = P6/P2

P5, Total Antenna Radiation & Total Antenna Efficiency = P5/P2

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!

Minimum Conductor Diameter? – Efficiency of *Any* Antenna from Q_{rad} or Q_{meas} and Estimated Conductor Loss Q_{loss}

- The inductance per unit length is known or can be measured. The Specific Resistivity of any conductor material is known and specified
- The R_{loss} in ohms/per metre conductor length for plumbing copper for frequency in MHz is

$$R_{loss}(Cu) = 8.94\times10^{-5}\sqrt{(f_{MHz})}\,/d = 8.94\times10^{-2}\sqrt{(f_{MHz})}\,/d_{mm}$$

- **New empirical formula** for inductance per metre length:

$$L(\mu H) = (160d)^{0.16} = (0.16d_{mm})^{0.16}$$

- The conductor Q_{loss} per metre is thus

$$Q_{loss} = Xl/R_{loss} = 2\pi f_{MHz} L/R_{loss}$$

$$= 2\pi d_{mm} f_{MHz} \times(0.16d_{mm})^{-0.16}/\{8.94\times10^{-2}\sqrt{(f_{MHz})}\}$$

$$\mathbf{Q_{loss} = 94.22\sqrt{(f_{MHz})}\times d^{0.84}}$$

- The following table using this formula gives Q_{loss} values for amateur bands and a range of copper tube sizes. For low loss $Q_{loss} > Q_{rad}$
- Efficiency is:

h = (Qmeas/Qrad)2 = {1- Qloss2/Qmeas2} = 1/{1 + (Qloss/Qrad)2}

What Copper Conductor Diameter? – Efficiency η of Any Antenna from Q_{rad} or Q_{meas} with Estimated Conductor Loss Q_{loss}

Table of Q_{loss} for Efficiency $\eta = (Q_{meas}/Q_{rad})^2 = \{1 - Q_{loss}^2/Q_{meas}^2\} = 1/\{1 + (Q_{loss}/Q_{rad})^2\}$

Band MHz	**Plumbing Copper Conductor Diameter mm. (For Aluminium × 1.7)**										
	0.5	1	2.5	4	6	10	15	22	28	35	54
0.136	19.4	34.7	75.0	111.3	156.5	240.4	337.9	466.2	570.9	688.5	991.1
0.472	36.2	64.7	139.8	207.4	291.6	447.8	629.6	868.5	1063.5	1282.7	1846.4
1.8	70.6	126.4	272.9	405.1	569.4	874.5	1229.4	1696.0	2076.8	2504.9	3605.7
3.5	98.5	176.3	380.6	564.8	794.0	1219.5	1714.3	2364.9	2895.9	3493.0	5027.9
7	139.3	249.3	538.2	798.8	1122.9	1724.6	2424.4	3344.5	4095.5	4939.8	7110.5
14	196.9	352.5	761.2	1129.6	1588.0	2439.0	3428.7	4729.8	5791.9	6985.9	10055.8
21	241.2	431.8	932.2	1383.5	1944.9	2987.1	4199.2	5792.8	7093.6	8556.0	12315.8
28	278.5	498.6	1076.4	1597.5	2245.8	3449.2	4848.9	6688.9	8191.0	9879.6	14221.1
50	372.2	666.2	1438.5	2134.8	3001.1	4609.2	6479.5	8938.5	10945.6	13202.2	19003.7
70	440.4	788.3	1702.0	2525.9	3550.9	5453.7	7666.7	10576.1	12951.0	15621.0	22485.5
144	631.6	1130.6	2441.1	3622.9	5093.0	7822.1	10996.2	15169.1	18575.4	22404.8	32250.4
430	1091.5	1953.8	4218.4	6260.5	8800.8	13516.9	19001.8	26212.7	32098.9	38716.4	55729.9
1296	1894.9	3391.9	7323.4	10868.7	15278.9	23466.4	32988.5	45507.3	55726.1	67214.5	96751.2

For $Q_{rad} = Q_{loss}$, $\eta = 0.5$ or *50%*. For $Q_{rad} = 2Q_{loss}$, $\eta = 0.2$ or *20%*. For $Q_{rad} = ½Q_{loss}$, $\eta = 0.8$ or *80%*. For $Q_{rad} = Q_{loss}/3$ $\eta = 0.9$ or *90%*. For $Q_{rad} = 3Q_{loss}$, $\eta = 0.1$ or *10%*. For $\eta < \sim 0.1$, then $\eta \approx (Q_{loss}/Q_{rad})^2$

Empirical values of Q_{rad} for various antenna types: Half-wave dipole $Q_{rad} \sim 8$ to 15. Short Dipole $Q_{rad} \sim 120$ to 200. Small single mode tuned loop $Q_{rad} \sim 220$ to 400. Two mode E-H antenna $Q_{rad} \sim 90$ to 150. Two mode double tuned small loop $Q_{rad} \sim 150$ to 280. New Loop-Monopole $Q_{rad} \sim 6$ to 11.

G3LHZ

Discovered Optimum Size Range of Small Antennas – Replacing the Chu Criterion

- Small tuned loop diameter *D*
  - Above 1.1m, the Q starts to rise slowly. Also the capacitor voltage for a given power rises proportional to *D*. This limits power handling.
  - Below about *D* = 65cm the coupling to free-space becomes sub-critical and R_{rad} starts to fall rapidly and Q_{rad} rises rapidly. Efficiency falls
  - For a receive small loop D should not go lower than about 35cm. This gives an effective antenna noise figure of 12dB which is just about acceptable at HF.
  - Two turn double tuned dual mode loops have Q_{rad} reduced by $\sim 1/\sqrt{2}$
  - Electromagnetic coupling in the loop-monopole lowers Q_{rad} by ~40 times
- These practical results show that **small loops do not scale with frequency.**
  - Theoretical justification of this finding is in hand.
  - It is related to the capture area of an antenna increasing inversely as the frequency squared $\sim 1/f^2$.
  - Also to the fact that the (Goubau) stored energy distance is $\propto 1/f^{0.5}$

This talk was given at the Progress In Electromagnetic Research Symposium (PIERS), 27th to 30th March 2012 in Kuala Lumpur.

Novel Analytic EM Modelling of Antennas and Fields

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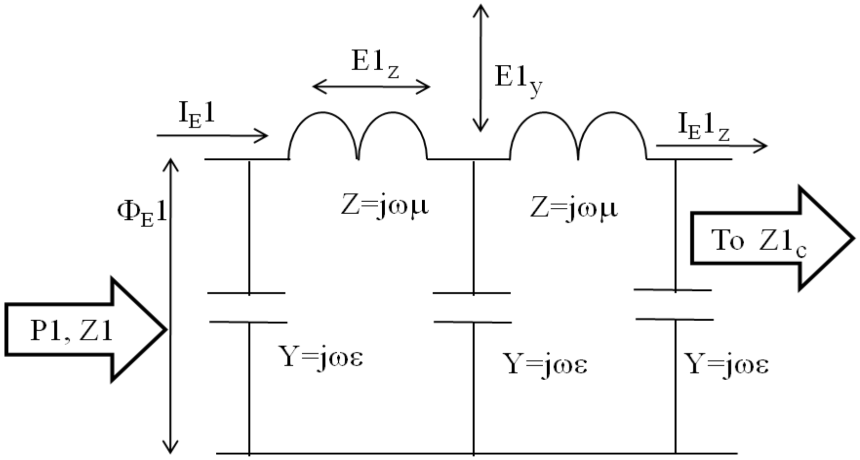
Basis of Method

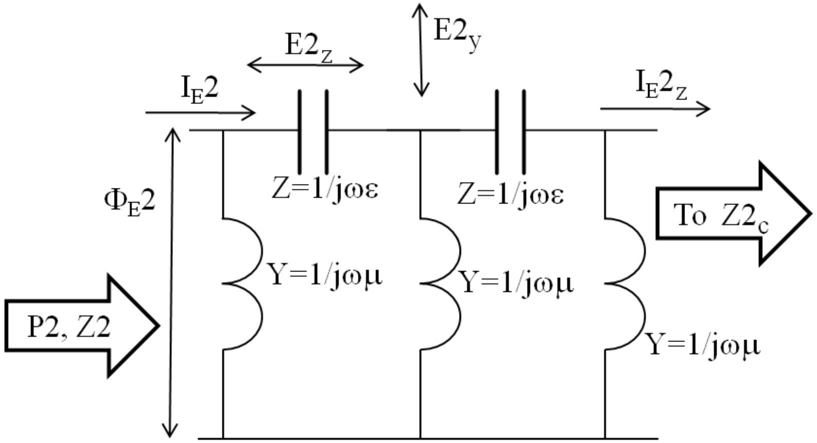
- Analytic Region Modelling is based on two newly observed physical laws, ‘process capture’ and ‘electro-magnetic (EM) (or *Physics*) coupling’ [1].
- These laws define ‘process regions’ in space, in which only one physical or electromagnetic process is dominant.
- The third law that is strictly obeyed (by the new laws) is ‘energy conservation’.
- This is particularly useful for establishing the overlapping boundaries between process regions where the processes are partially coupled progressively through space.

The Local Ether Four Transmission Line Model of EM.

- The Physical EM Model (PEM) [1] is an underlying basis for ARM.
- It is a two low-pass and high-pass pairs of co-located transmission lines in a ‘local ether’.
- One LP/HP pair represents conventional and electric displacement current, with electric vector potential. The other represents magnetic displacement current and magnetic vector potential.
- The local ether is the region of the stored energy of an antenna. The local ether is a new definition of the near field region.



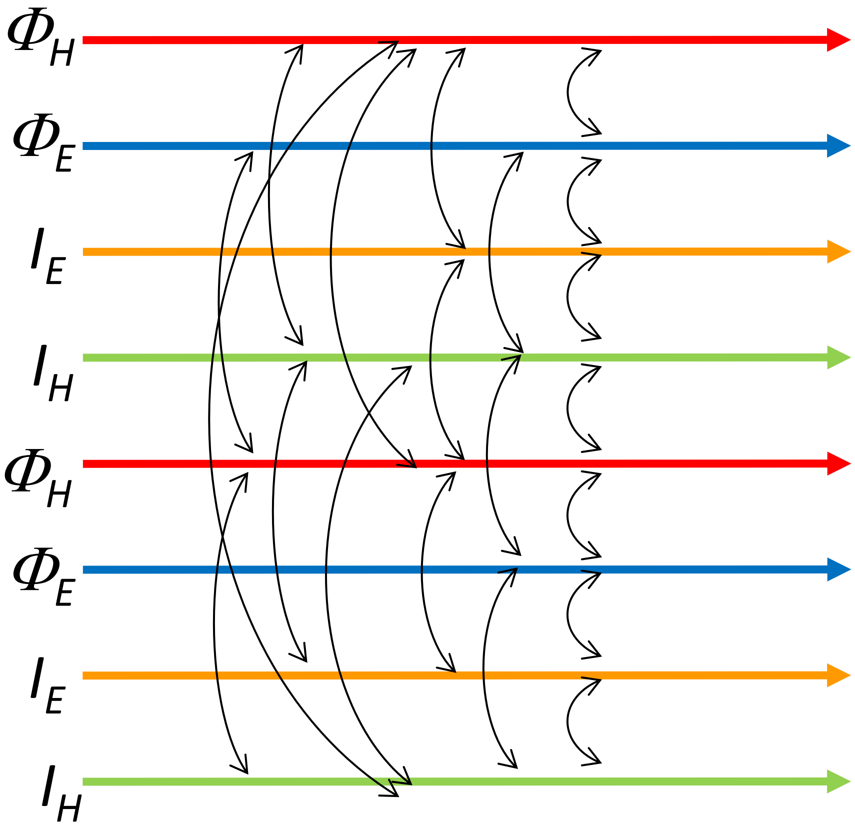
(b) Low-Pass E-field line



(c) High-Pass E-field line,

VARIOUS WAVE IMPEDANCES IN THE COUPLED TRANSMISSION LINE (CTL) MODEL OF ALL ELECTROMAGNETICS

Figure 1. The coupling factors between the various types of power flow filaments in the (four) Coupled Transmission Line model of Electro-Magnetic (EM) waves. The types are defined by which type of potential or current is dominant. There are two out of the four possible groups of power flow filaments shown. The filaments may be adjacent and non-overlapping, if of the same type, or fully overlapping, if of different types.



Process Capture

- ‘Process capture’ is a fundamental law originally seen in small tuned loop antennas for the various radiation and loss resistances [2].
- We can then deduce that overlapping distributed processes combine at any co-local point according to the RSS (Root-Sum-of-the-Squares) law.
- The strongest process ‘captures’ and suppresses the weaker ones.
- Over a short (coupling) distance the suppression is progressive.

Goubau Single Wire Transmission Line

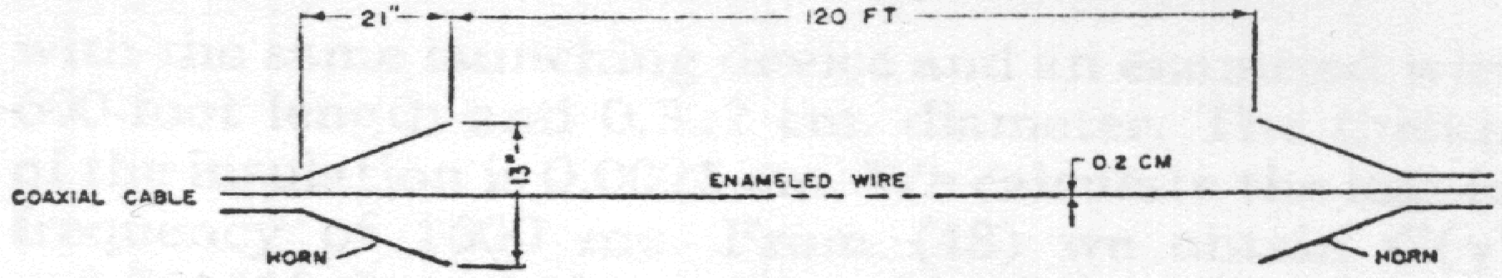


FIG. 11. Sketch of a surface wave transmission line.

"Surface Waves and Their Application to Transmission Lines", by Georg Goubau, J.A.P., Vol. 21, Nov., 1950, pp 1119 – 1128.

- Enamel coat on wire 0.005cm (= 50micron), $\varepsilon_r = 3$, $\tan\delta = 8\times10^{-3}$. 10 watts into this dielectric layer would burn it off! Dielectric layer is not needed?

- At 3.3GHz, theoretical Sommerfeld surface wave line loss = 1.62dB, horns = 0.2dB each, so total theory = 2.0dB. Measured loss = 2.3dB, constant to ±0.1dB from 1.5 to 3.3GHz!

- Loss from skin resistance of wire is = 1.7dB at 3.3GHz (assuming line impedance is 120π = 377ohms – probably nearer 300ohms). ***Thus line radiation loss of 2.3-1.7=0.6dBis negligible.***

- "Current" theory, "Method of Moments", NEC etc. all say that the *current*, or *current squared* on the line should radiate, but it does not! Why?

- No valid theory exists as yet for the Goubau Line. Is it is ignored as an embarrassment?!

- The Goubau Line is an example why "Theory should come from practice" as Archimedes would require! Arguably it will prove the most significant discovery of the twentieth century?

The Goubau Coupling Distance

Stored Energy on Goubau Single Wire Transmission Line

- There is a critical (Goubau) radial distance r_G from a (wire) source at which the stored energy density starts to decay rapidly. The measured minimum usable horn size is found to be inversely proportional to frequency.
- With distance from source r in metres we find that at the critical frequency f_c of approximately 14MHz r_{GW} is one metre.
- For an extended surface source, as associated with a surface wave, the critical distance r_{GS} is larger by a value about π, but to be confirmed by further experiments (e.g. on antenna to ground absorption height). We therefore have:

$$r_{Gw} = \left(\frac{f_c}{f}\right)^{1/2} = \left(\frac{14}{f_{MHz}}\right)^{1/2} \quad (1)$$

$$r_{GS} = \pi r_{GW} = \pi\left(\frac{f_c}{f}\right)^{1/2} = \left(\frac{140}{f_{MHz}}\right)^{1/2} \quad (2)$$

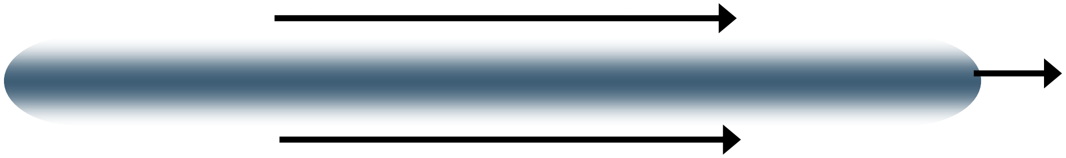
Analytic Region Modelling

- With the above definitions, three dimensional analytic expressions for all physical quantities surrounding an antenna, over a surface, in a waveguide, etc. may be obtained.
- The physical quantities can include, all fields, potentials, displacement currents, power flow (Poynting) vectors, spatial impedances and Qs, etc.
- Process capture allows finite regions to be represented in compact form with very few terms.
- No matrix inversion is required.
- The accuracy of the model in given cases may be considerably improved by a few practical measurements to calibrate the model.

2. Implementation of Analytic Region Modelling

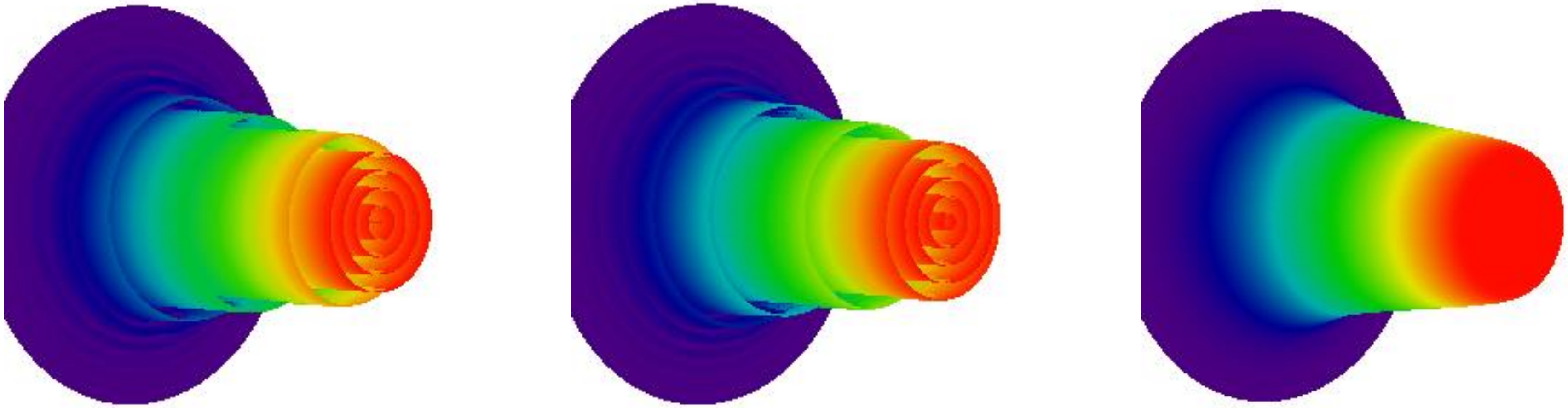
- ARM models the physics of antennas and propagation. The space containing the antennas and the propagation paths is divided into overlapping regions. Because of process capture the physical process in each region can be represented by a simple analytic formula.
- Mathcad is chosen for implementing the formulas of ARM. It is not the only possible choice. But it is preferred for its visual layout of formulas and good 3D and 2D plotting capabilities. Rotation of 3D antenna plots is a particularly useful facility. Three Mathcad examples of ARM are now given.

3.The EM String-Arrow Model of a Photon



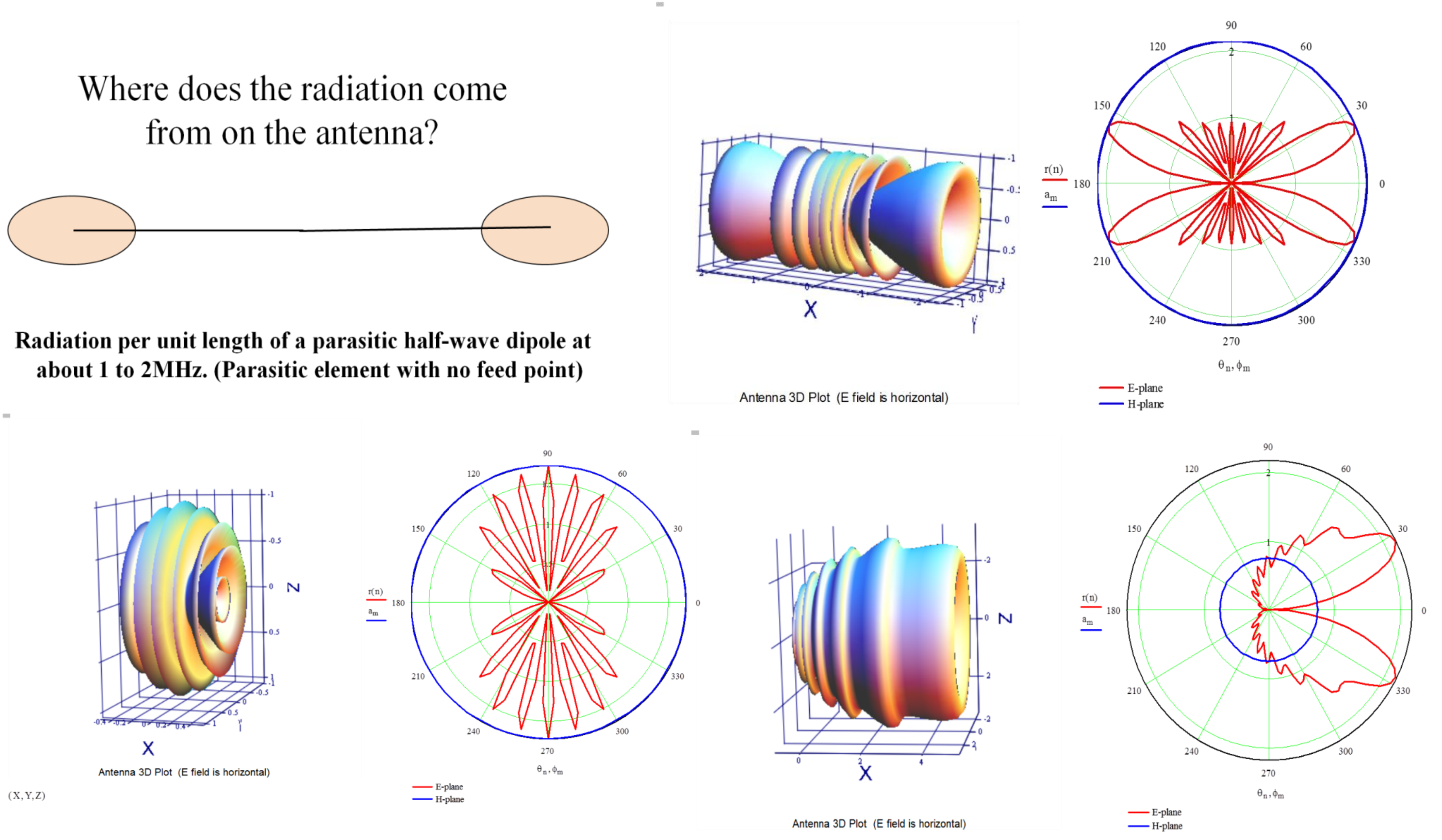
- In reference [5] a photon in free space is shown to be a cylindrical 'arrow', travelling at the speed of light, of radius = $(f_c/f)^{1/2}$ where f_c is obtained from Goubau single wire non-radiating transmission line and surface wave measurements as ~ 14MHz.
- The photon length is $c/2\delta f$ where $2\delta f$ is the photon line bandwidth.
- The cross–section of the photon is similar to the distribution of energy that surrounds the Goubau line.
- It is a number of interlaced layers of two complementary types e.g. *Cos(kr)* and *Sin(kr)* of radial distance *r*.
- The edge of the energy distribution of the photon is sharp and possibly it is this that makes the photon stable and non-dissipative.

3. ARM of the String-Arrow Model of a Photon



- Figure 1 is an ARM representation of the cross section of the energy of a photon or on a Goubau single wire transmission line. In-phase, quadrature and magnitude parts of equation 3 are shown.
- For a visible photon the radius of the string arrow profile is about 300 wavelengths corresponding to 4×300=1200 layers interlaced at quarter wavelength intervals. Obtained by changing one parameter.
- These are Mathcad 3D plots in cylindrical coordinates rotated so that the structure may be seen.
- Once the analytic formulas are known the pictorial representation may be chosen as desired.

4. AR Modelling of Antenna Patterns



Where does the radiation come from on the antenna?

Radiation per unit length of a parasitic half-wave dipole at about 1 to 2MHz. (Parasitic element with no feed point)

Figure 2. Top left: radiation from the antenna ends. Top right: 4.5λ wire antenna pattern using the Kraus/Balanis formula. Bottom left: an ARM pattern of 4.5λ top left. Bottom right: end-fed 4.5λ travelling wave wire at low frequency.

Any Dipole Antenna Plot - MJU Mathcad programme

- The radiation pattern is defined by $R_{n,m}$. "North" is the reference direction and is to the right (with m = 0, n = 0).
- The latitude angle θ_n extends for 360 degrees starting from the north pole in 360/n degree steps down to the south pole and back up to the north pole on the opposite side of the sphere. This ensures that both sides of the E and H field patterns are plotted.
- As a consequence the longitude angle ϕ_n only extends for 180 degrees in m steps of 180/m degrees, so that the 3D pattern is only plotted once and the spherical integration surface is only covered once.
- The Directivity D is the power density $(R_{n,m})^2$ in the broadside direction divided by the power density $(R_{n,m})^2$ averaged over the 4π (steradians) solid angle of the far-field sphere.
- F is the front-to-back ratio.

To set the range and steps of the angle variables: -

$n := 0..120$ $\qquad \theta_n := \frac{\pi}{1}\cdot\left(0 + \frac{n}{60}\right)$ $\qquad m := 0..30$ $\qquad \phi_m := \frac{\pi}{1}\cdot\left(-.5 + \frac{m}{30}\right)$ $\qquad i := \sqrt{(-1)}$

The formula for the radiation pattern in conventional spherical coordinates: -

$$R_{n,m} := \left|\frac{\cos(0.5\ L\ \cos(\theta_n)) - \cos(0.5\ L)}{\sin(\theta_n)}\right| + 10^{-10}$$

Note: the 10^{-10} is to prevent the log of zero error.

To convert the matrix from spherical to cartesian coordinates for the 3D plot: -

$Z_{n,m} := R_{n,m}\cdot\sin(\theta_n)\cdot\cos(\phi_m)$ $\qquad Y_{n,m} := R_{n,m}\ \sin(\theta_n)\ \sin(\phi_m)$ $\qquad X_{n,m} := (R_{n,m})\cdot\cos(\theta_n)$

To set the longitude for E and H field polar plots: -

$m := 0$ $\qquad r_n := R_{n,m}$

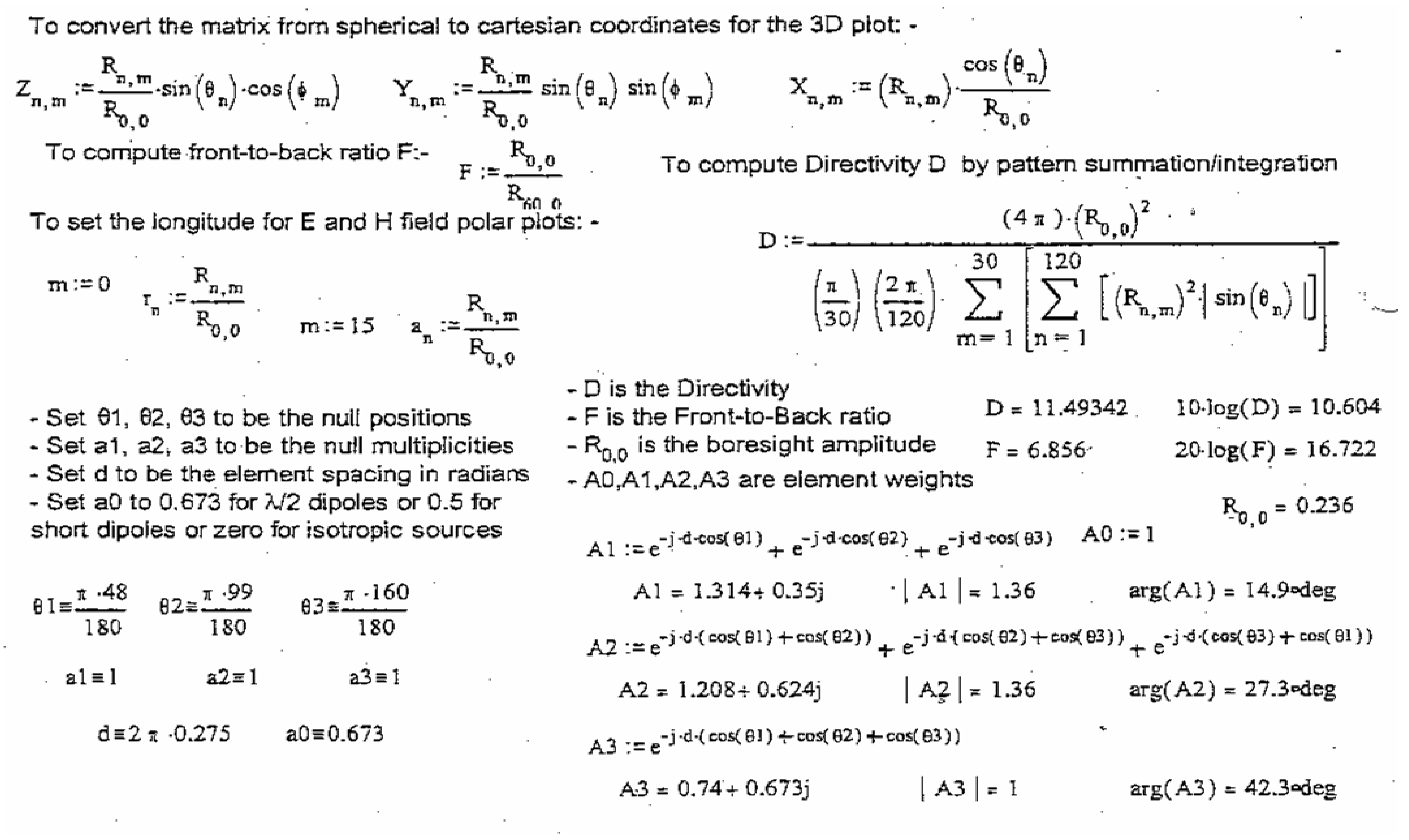
$m := 15$ $\qquad m := 0..30$ $\qquad a_m := R_{n,m}$

To compute front-to-back ratio F:-

$$F := \frac{R_{0,0}}{R_{60,0}}$$

To compute Directivity D by pattern summation/integration:-

$$D := \frac{(4\ \pi)\cdot(R_{30,0})^2}{\left(\frac{\pi}{30}\right)\cdot\left(\frac{2\ \pi}{120}\right)\cdot\sum_{m=1}^{30}\left[\sum_{n=1}^{120}\left[(R_{n,m})^2\cdot\sin(\theta_n)\right]\right]}$$



To convert the matrix from spherical to cartesian coordinates for the 3D plot: -

$$Z_{n,m} := \frac{R_{n,m}}{R_{0,0}} \cdot \sin\left(\theta_n\right) \cdot \cos\left(\phi_m\right) \qquad Y_{n,m} := \frac{R_{n,m}}{R_{0,0}} \sin\left(\theta_n\right) \sin\left(\phi_m\right) \qquad X_{n,m} := \left(R_{n,m}\right) \cdot \frac{\cos\left(\theta_n\right)}{R_{0,0}}$$

To compute front-to-back ratio F:- $F := \frac{R_{0,0}}{R_{60,0}}$

To compute Directivity D by pattern summation/integration

To set the longitude for E and H field polar plots: -

$m := 0 \quad r_n := \frac{R_{n,m}}{R_{0,0}} \qquad m := 15 \quad a_n := \frac{R_{n,m}}{R_{0,0}}$

$$D := \frac{(4\pi) \cdot \left(R_{0,0}\right)^2}{\left(\frac{\pi}{30}\right)\left(\frac{2\pi}{120}\right) \cdot \sum_{m=1}^{30} \left[\sum_{n=1}^{120} \left[\left(R_{n,m}\right)^2 \cdot \left|\sin\left(\theta_n\right)\right|\right]\right]}$$

- D is the Directivity
- F is the Front-to-Back ratio
- $R_{0,0}$ is the boresight amplitude
- A0,A1,A2,A3 are element weights

$D = 11.49342 \qquad 10 \cdot \log(D) = 10.604$

$F = 6.856 \qquad 20 \cdot \log(F) = 16.722$

$R_{0,0} = 0.236$

- Set θ1, θ2, θ3 to be the null positions
- Set a1, a2, a3 to be the null multiplicities
- Set d to be the element spacing in radians
- Set a0 to 0.673 for λ/2 dipoles or 0.5 for short dipoles or zero for isotropic sources

$\theta 1 \equiv \frac{\pi \cdot 48}{180} \qquad \theta 2 \equiv \frac{\pi \cdot 99}{180} \qquad \theta 3 \equiv \frac{\pi \cdot 160}{180}$

$a1 \equiv 1 \qquad a2 \equiv 1 \qquad a3 \equiv 1$

$d \equiv 2\pi \cdot 0.275 \qquad a0 \equiv 0.673$

$A1 := e^{-j \cdot d \cdot \cos(\theta 1)} + e^{-j \cdot d \cdot \cos(\theta 2)} + e^{-j \cdot d \cdot \cos(\theta 3)} \qquad A0 := 1$

$A1 = 1.314 + 0.35j \qquad |A1| = 1.36 \qquad \arg(A1) = 14.9 \cdot \deg$

$A2 := e^{-j \cdot d \cdot (\cos(\theta 1) + \cos(\theta 2))} + e^{-j \cdot d \cdot (\cos(\theta 2) + \cos(\theta 3))} + e^{-j \cdot d \cdot (\cos(\theta 3) + \cos(\theta 1))}$

$A2 = 1.208 + 0.624j \qquad |A2| = 1.36 \qquad \arg(A2) = 27.3 \cdot \deg$

$A3 := e^{-j \cdot d \cdot (\cos(\theta 1) + \cos(\theta 2) + \cos(\theta 3))}$

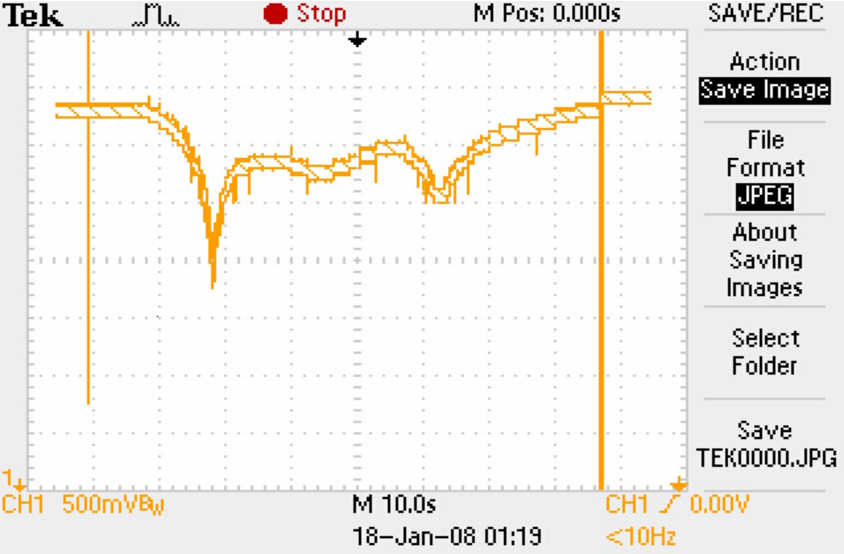
$A3 = 0.74 + 0.673j \qquad |A3| = 1 \qquad \arg(A3) = 42.3 \cdot \deg$

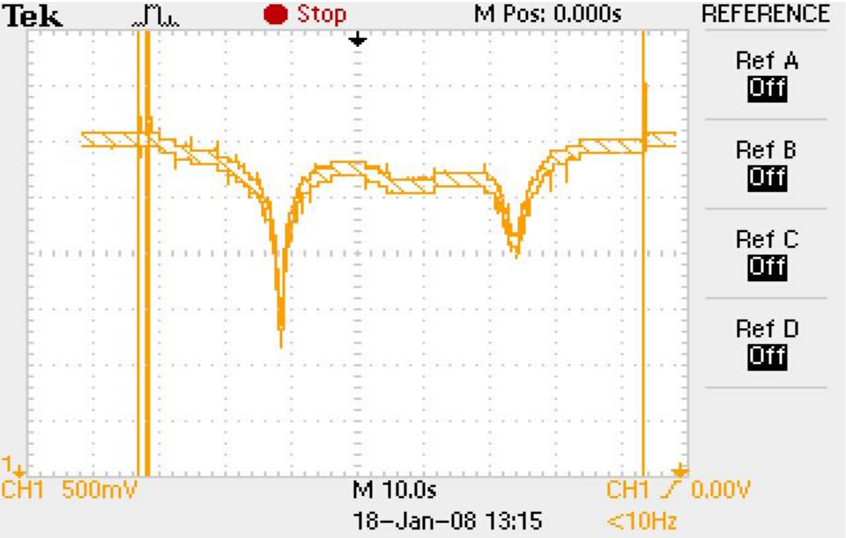
Demo of Antenna Pattern Modelling

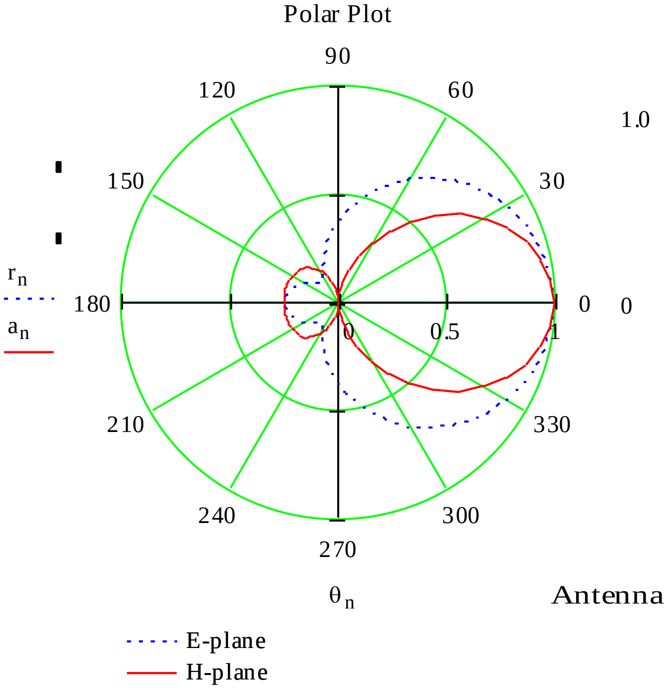
A choice from:

1. Loop-dipole/monopole
2. Any length dipole with sinusoidal current
3. End-fed long-wire/Beverage
4. Tuned coiled-hairpin
5. CFA, EH and Franklin MW BC antennas – two mode verticals.
   - *The CFA and EH antenna patterns can be derived as if they were Franklin antennas that are much reduced in size.*

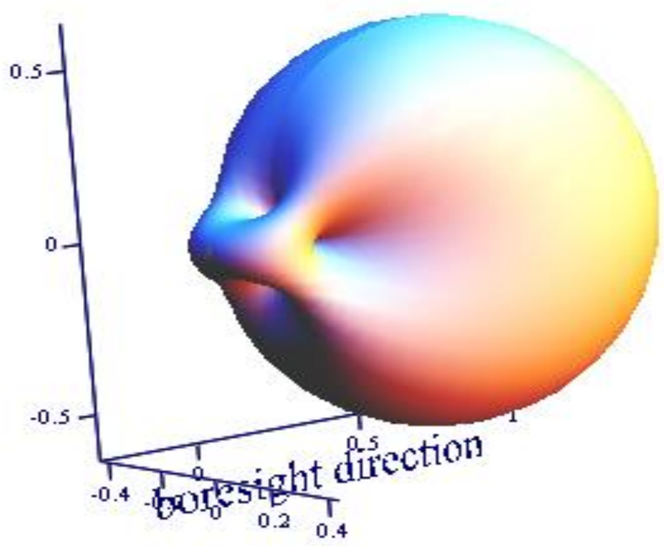
Heuristically Derived Antenna Pattern of Coiled Hairpin







Antenna 3D Plot



5. ARM of Effect of Ground Loss on Low Height Antenna Patterns

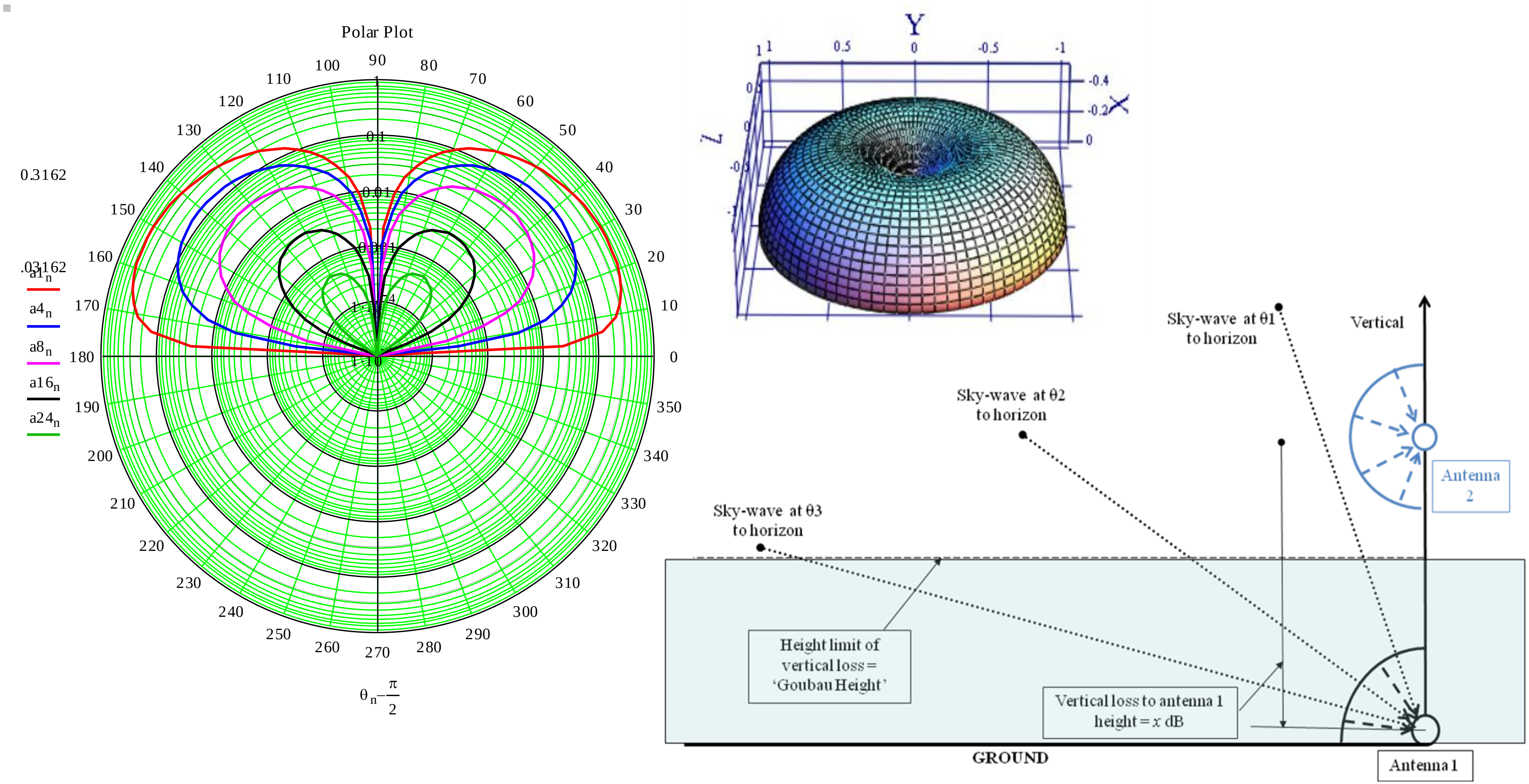


Figure 3. Bottom right: Ground Loss Scenario for small antenna. Top right: Pattern of short vertical whip or small horizontal (tuned) loop over perfect ground. Left: Far-field Radiation Pattern for total vertical path coupled ground loss values between 1dB (outer red plot) and 24dB (inner green plot).

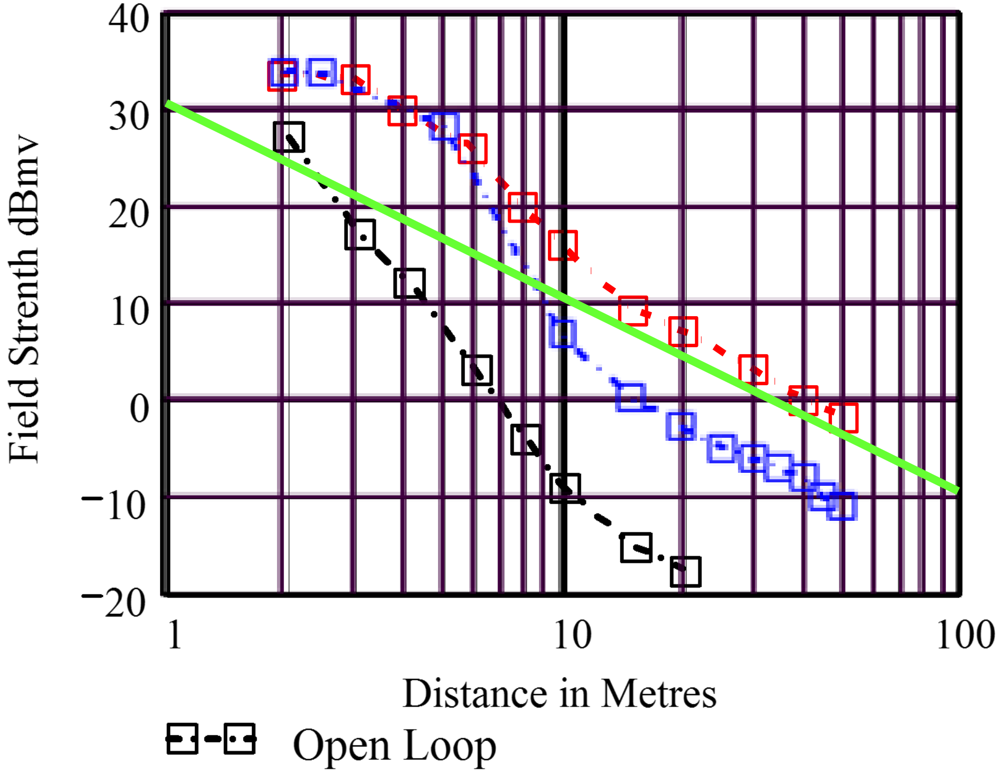
4. Conclusions

- ‘Analytic Region Modelling’ (ARM) is based on partitioning any EM scenario into separate sometimes overlapping ‘regions’ or ‘frames’.
- Within each region one process dominates and captures other processes according to the ‘process capture’ RSS Law.
- ‘Process capture’ means that the number of significant modes and processes for any antenna or array even including environment and propagation is quite small.
- Thus ‘Analytic Region Modelling’ (ARM) is very fast and efficient and scalable to problems of high complexity.
- It follows that ARM could well be the future of most, if not all, Antennas, Propagation and EM modelling.

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.



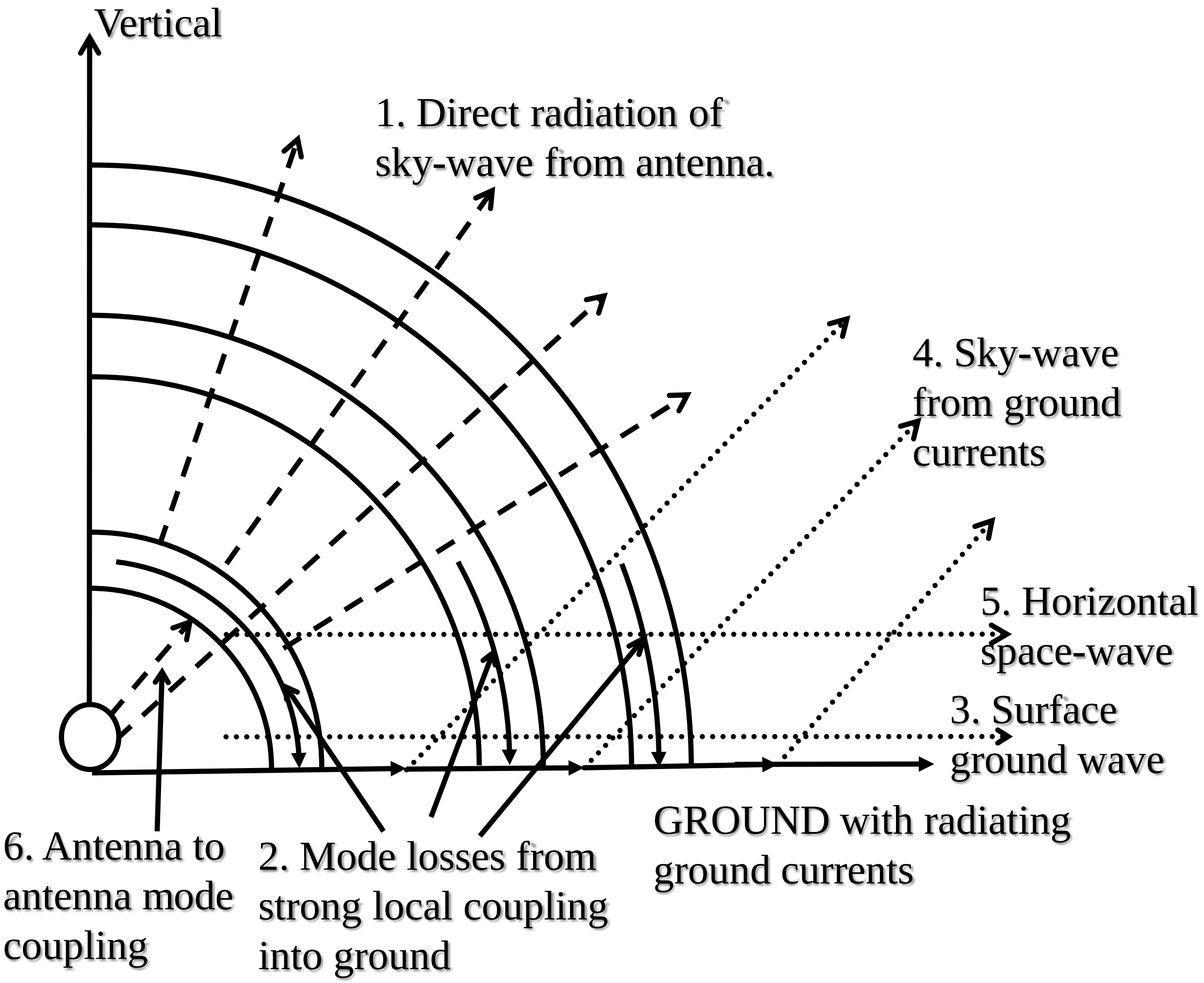
Conclusions from these results:

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**

Radiation mechanisms of a small antenna over medium loss ground

Processes

- Direct radiation of sky-wave from antenna.
- Antenna mode losses from strong local coupling to ground
- Sky-wave from ground surface wave and currents
- Sky-wave to horizontal space-wave layer
- Heat losses in antenna.
- Antenna to antenna mode coupling



Vertical

1. Direct radiation of sky-wave from antenna.

4. Sky-wave from ground currents

5. Horizontal space-wave

3. Surface ground wave

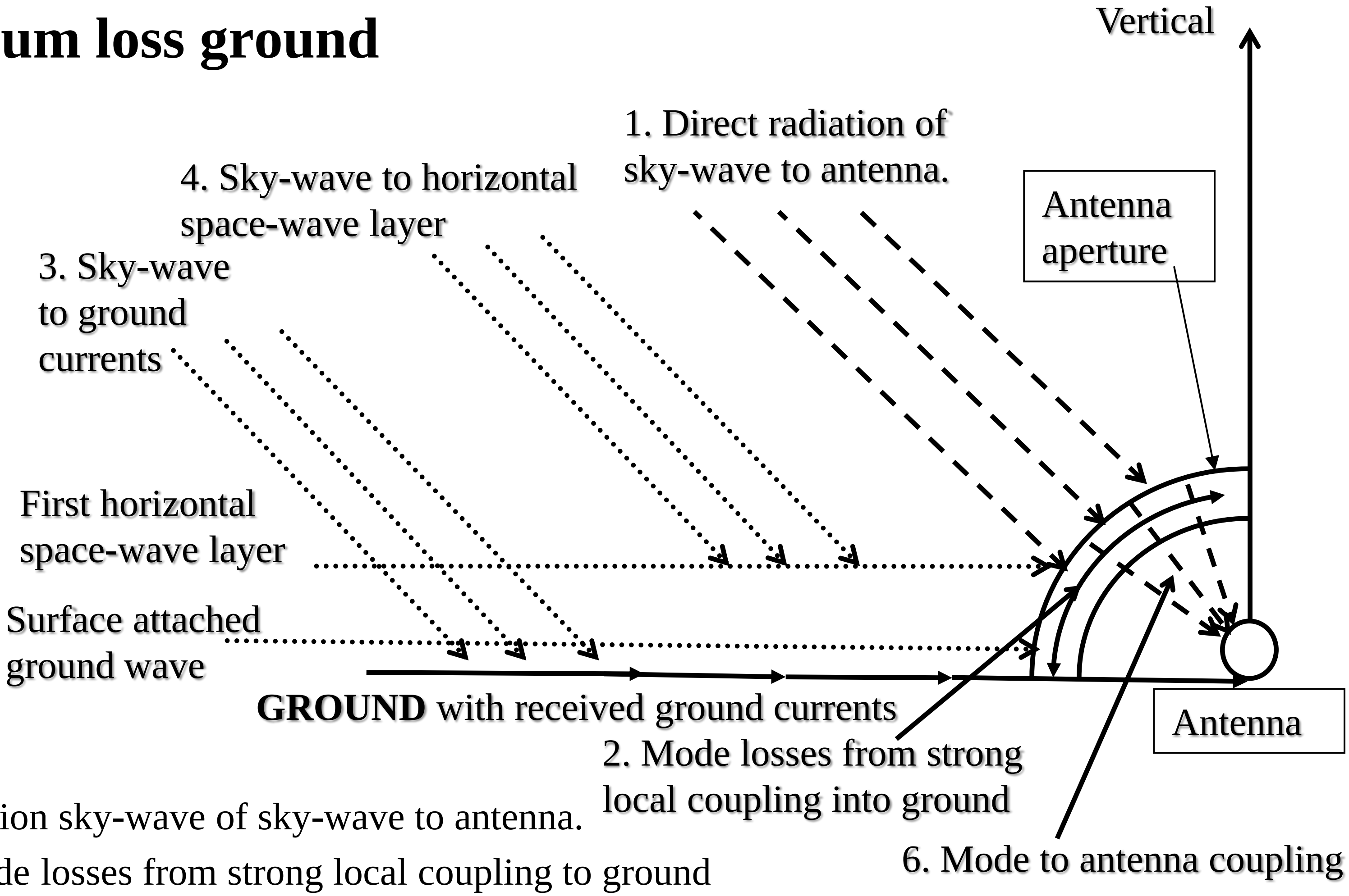
GROUND with radiating ground currents

6. Antenna to antenna mode coupling

2. Mode losses from strong local coupling into ground

G3LHZ

Reception mechanisms of a small antenna over medium loss ground



Vertical

1. Direct radiation of sky-wave to antenna.

4. Sky-wave to horizontal space-wave layer

3. Sky-wave to ground currents

Antenna aperture

First horizontal space-wave layer

Surface attached ground wave

GROUND with received ground currents

Antenna

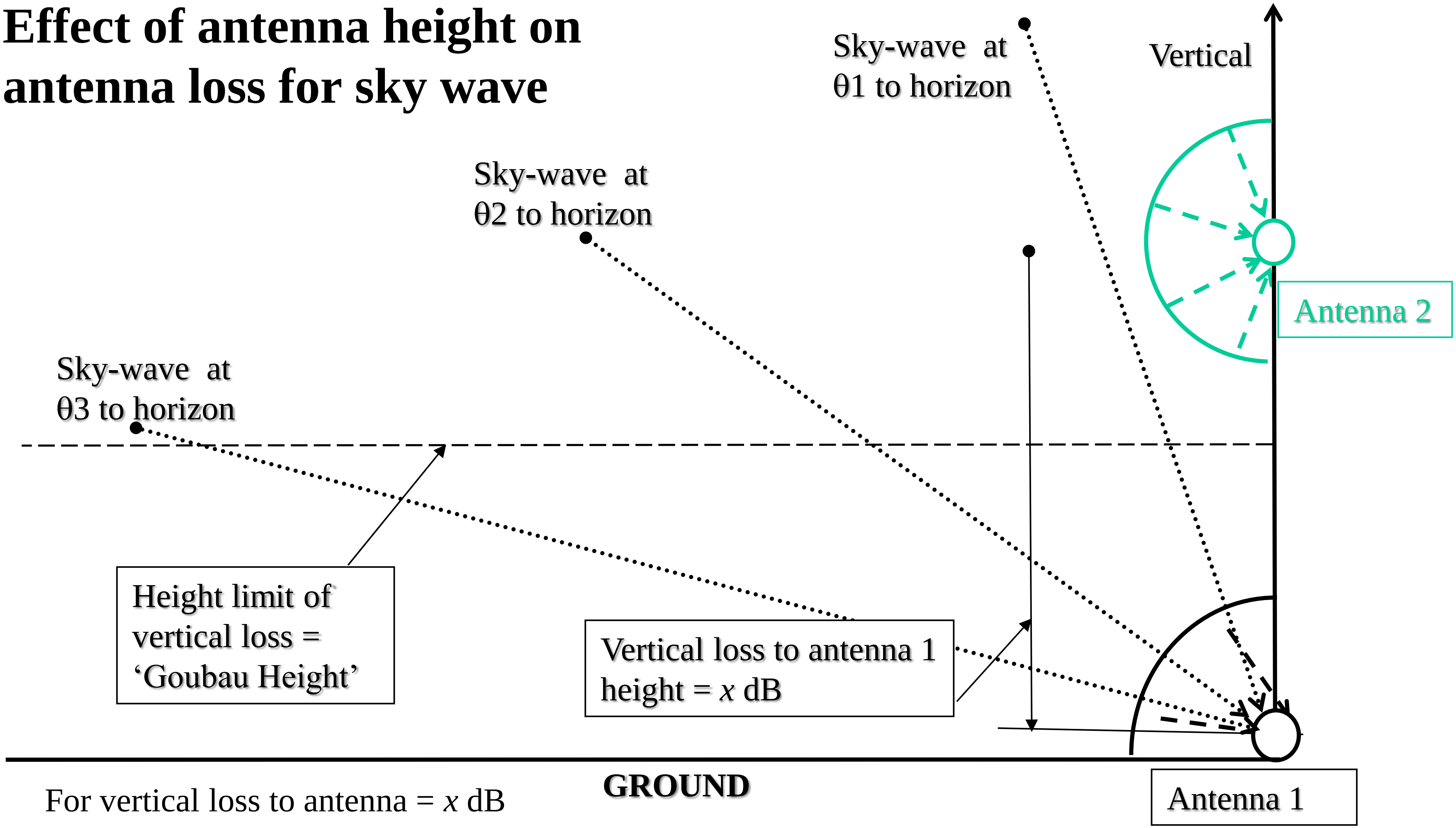
2. Mode losses from strong local coupling into ground

6. Mode to antenna coupling

Processes

- Direct radiation sky-wave of sky-wave to antenna.
- Antenna mode losses from strong local coupling to ground
- Sky-wave to ground surface wave and currents
- Sky-wave to horizontal space-wave layer
- Heat losses in antenna.
- Antenna mode to antenna coupling

Effect of antenna height on antenna loss for sky wave



Sky-wave at θ1 to horizon

Vertical

Sky-wave at θ2 to horizon

Antenna 2

Sky-wave at θ3 to horizon

Height limit of vertical loss = ‘Goubau Height’

Vertical loss to antenna 1 height = *x* dB

GROUND

Antenna 1

- For vertical loss to antenna = *x* dB
- At angle θ the sky-wave to antenna loss is increased to *x/sin θ*
- 1/sin 30º = 2. Then loss is *2x* dB.
- 1/sin 10º = 5.8. Then loss is *5.8x* dB.
- Should place antenna higher than the ‘Goubau’ height for low angle sky-wave reception = antenna 2.
- Ground sloping away at 1-in-6 (10º), say, is very beneficial

Conclusions from March 2010

- Old Theory and NEC say that Small Tuned Antennas cannot possibly work! Heuristics (measurements) show they do! EM theory and NEC need upgrades!
- 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 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
- Electromagnetics is still in its infancy. There is much to be discovered.

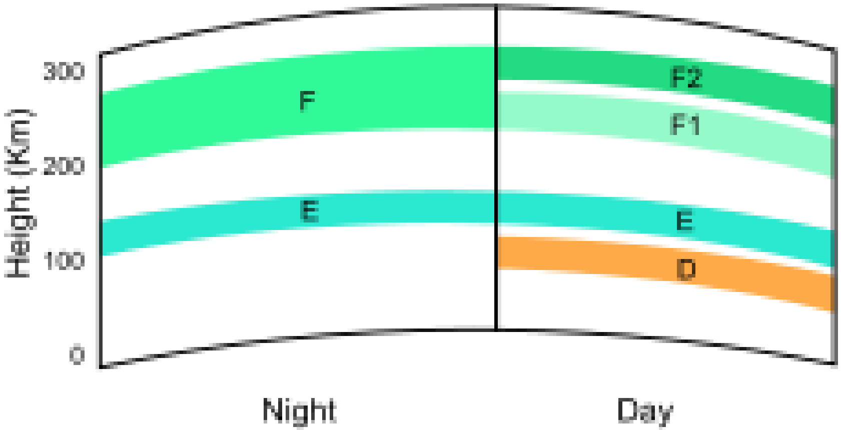
Additional Conclusions at April 2013

- The Novel Loop-Monopole:
  - Destroys the credibility of the Chu Small Antenna Q Criterion
  - Confirms the asymptotic value of EM Coupling as $\kappa = 1/2\pi$.
  - Shows that "It is the coupling that radiates and receives" is the way that all antennas work.
- (Wet) Ground Absorption Losses between 2.5 and 4.5MHz are found to be higher than predicted by existing theory or simulations – 5 to 15dB?
  - Antenna height is crucial. Get above 6× the Goubau height $r_{Gw} = \left(\frac{f_c}{f}\right)^{1/2} = \left(\frac{14}{f_{MHz}}\right)^{1/2}$
  - There is more research to follow on Wave Tilt, Absorption Peaks in the Ground and in the Ionosphere
- Analytic Region Modelling (ARM) is the future of simulation in Physics, and Antennas and Propagation.
  - It is fast because it does not use matrix inversion
  - It can deal with multiple antenna modes and multiple propagation regions.
  - It can deal with surface waves and surface/sky wave power splitting?
  - And antenna pattern formation in the near field.
- Electromagnetics is still in its infancy. There is (much?) more to be discovered.

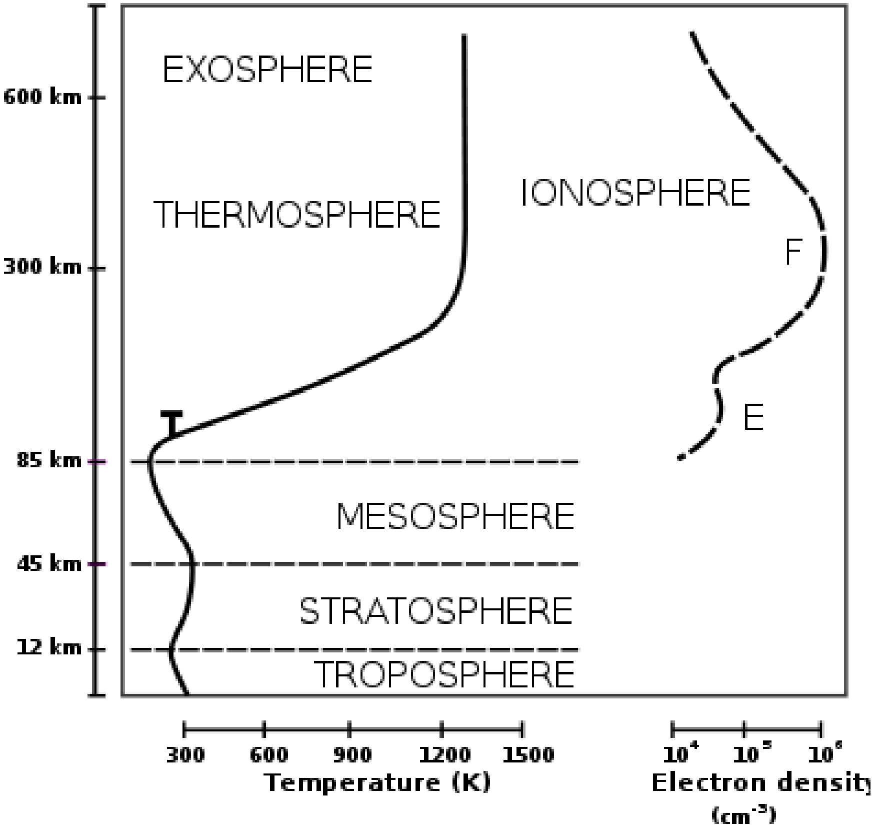
Some New Propagation Research

As at April 2013

The Aurora, The Ionosphere and Short Wave Radio



Ionospheric layers.

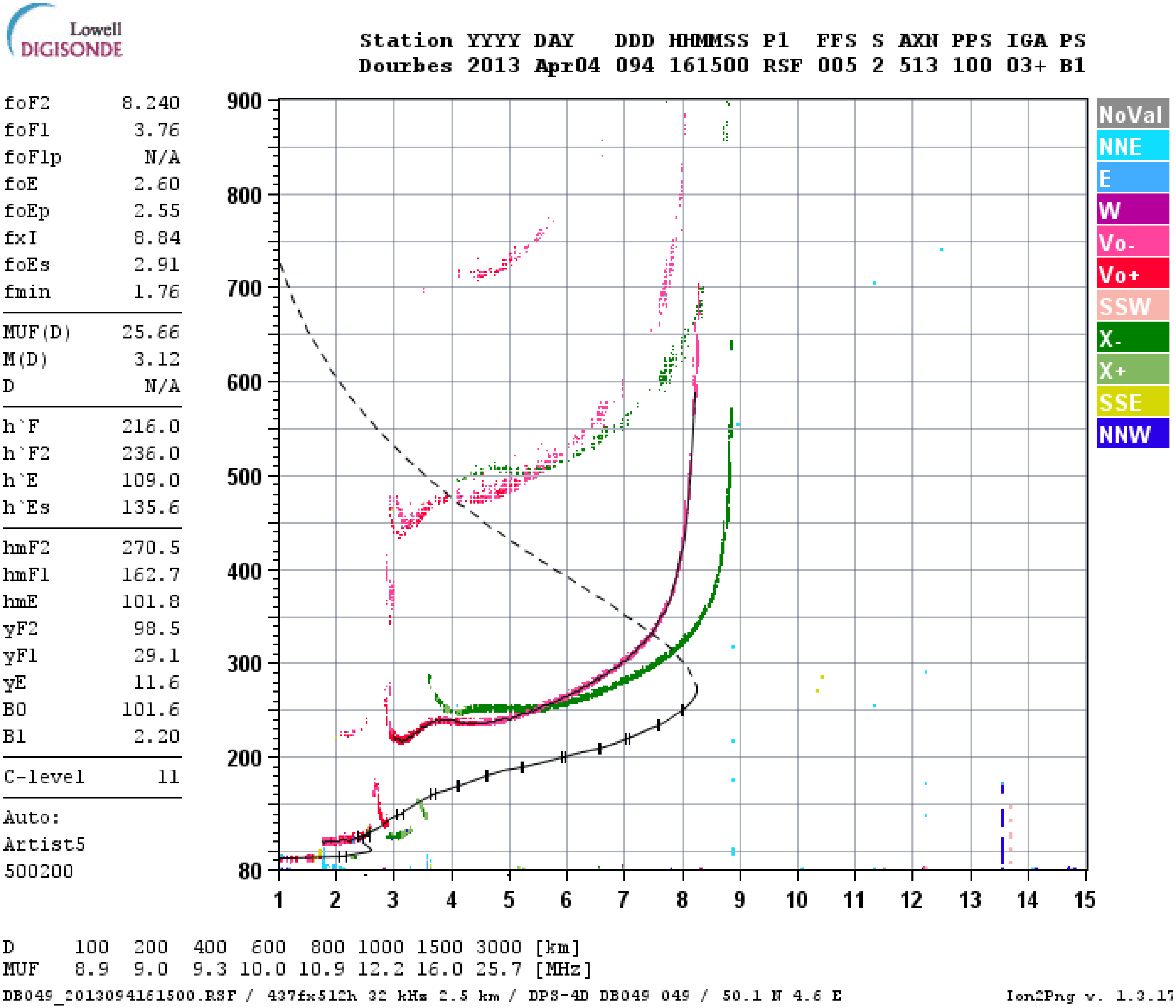


Relationship of the atmosphere and ionosphere

- The ionosphere is a shell of electrons and electrically charged atoms and molecules that surrounds the Earth, stretching from a height of about 50 km to more than 1000 km. It is formed primarily by *ultraviolet radiation* from the Sun.
- By contrast the Aurora is dependent on the *ionised particle flow* from the sun
- The ionosphere is the ‘Mirror in the Sky’ for long distance short-wave radio.
- It is highly dependent on the sunspot number; the more sunspots, the better.

Dourbes Ionosonde 1615 on 04/04/2013

http://digisonde.oma.be/latestFrames.htm



Station	YYYY	DAY	DDD	HHMMSS	P1	FFS	S	AXN	PPS	IGA	PS
Dourbes	2013	Apr04	094	161500	RSF	005	2	513	100	03+	B1

foF2	8.240
foF1	3.76
foF1p	N/A
foE	2.60
foEp	2.55
fxI	8.84
foEs	2.91
fmin	1.76
MUF(D)	25.66
M(D)	3.12
D	N/A
h\`F	216.0
h\`F2	236.0
h\`E	109.0
h\`Es	135.6
hmF2	270.5
hmF1	162.7
hmE	101.8
yF2	98.5
yF1	29.1
yE	11.6
B0	101.6
B1	2.20
C-level	11

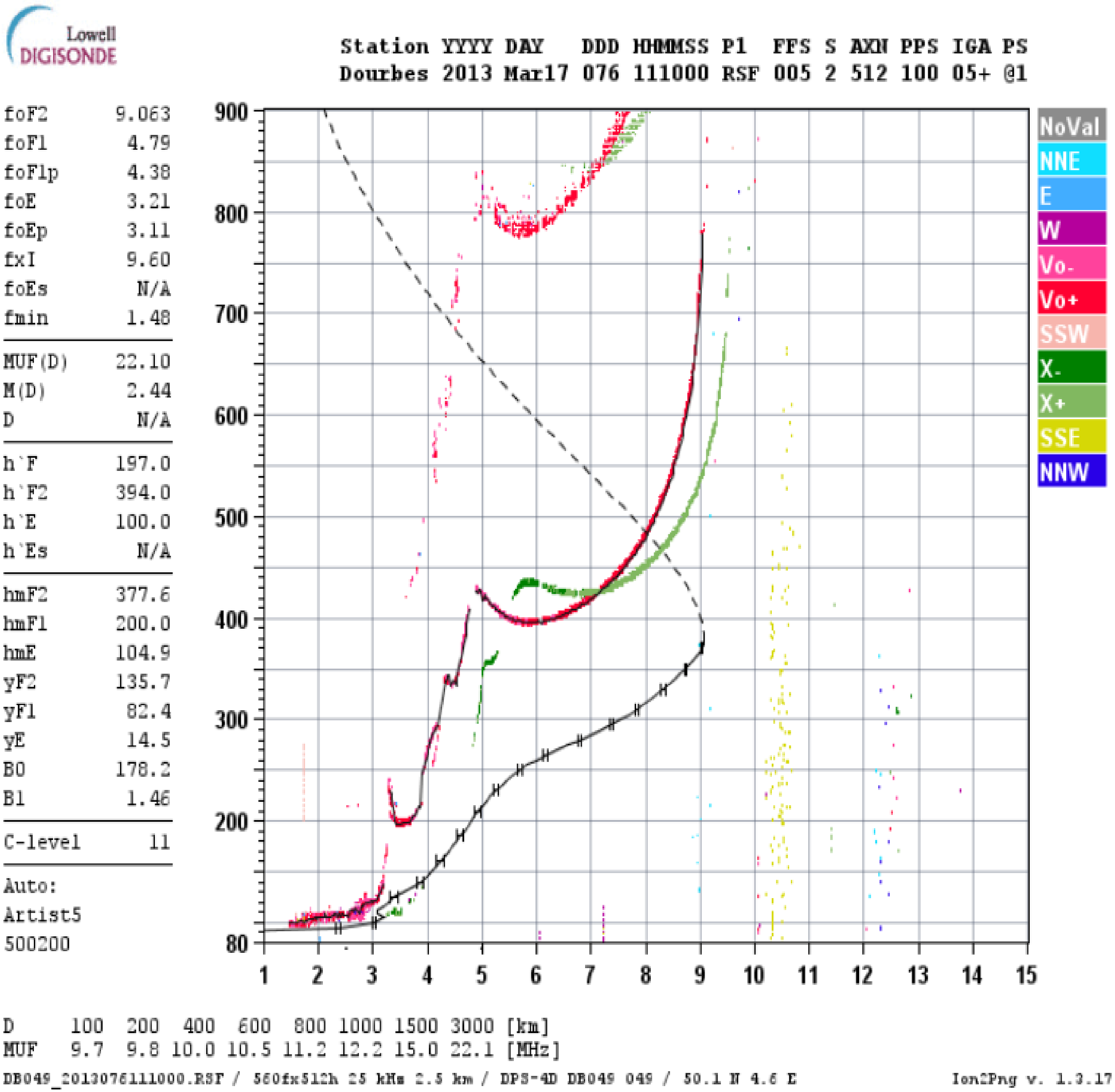
Auto:
Artist5
500200

D	100	200	400	600	800	1000	1500	3000	[km]
MUF	8.9	9.0	9.3	10.0	10.9	12.2	16.0	25.7	[MHz]

DB049_2013094161500.RSF / 437fx512h 32 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E

Ion2Png v. 1.3.17

Very poor BADnet conditions on 17/03/23!



```
Station  YYYY DAY    DDD HHMMSS P1  FFS S AXN PPS IGA PS
Dourbes  2013 Mar17  076 111000 RSF 005 2 512 100 05+ @1
```

foF2	9.063
foF1	4.79
foF1p	4.38
foE	3.21
foEp	3.11
fxI	9.60
foEs	N/A
fmin	1.48
MUF(D)	22.10
M(D)	2.44
D	N/A
h\`F	197.0
h\`F2	394.0
h\`E	100.0
h\`Es	N/A
hmF2	377.6
hmF1	200.0
hmE	104.9
yF2	135.7
yF1	82.4
yE	14.5
B0	178.2
B1	1.46
C-level	11

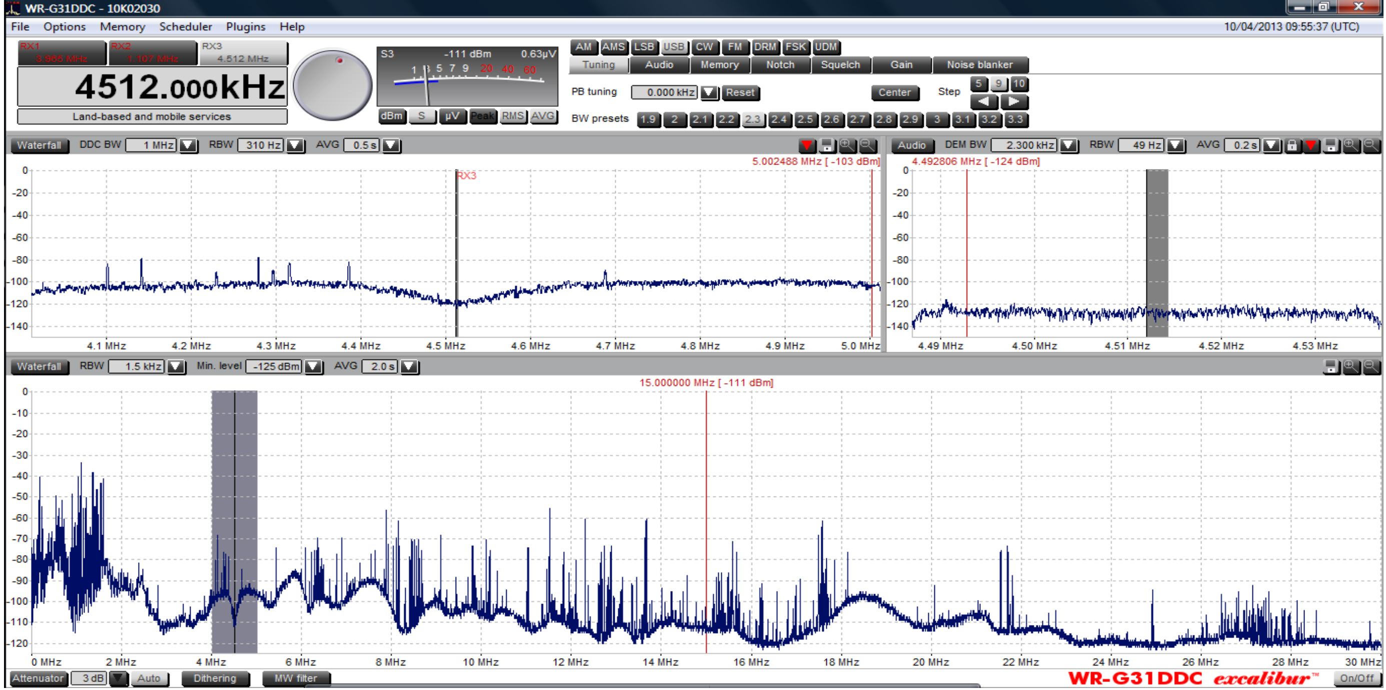
Auto:
Artist5
500200

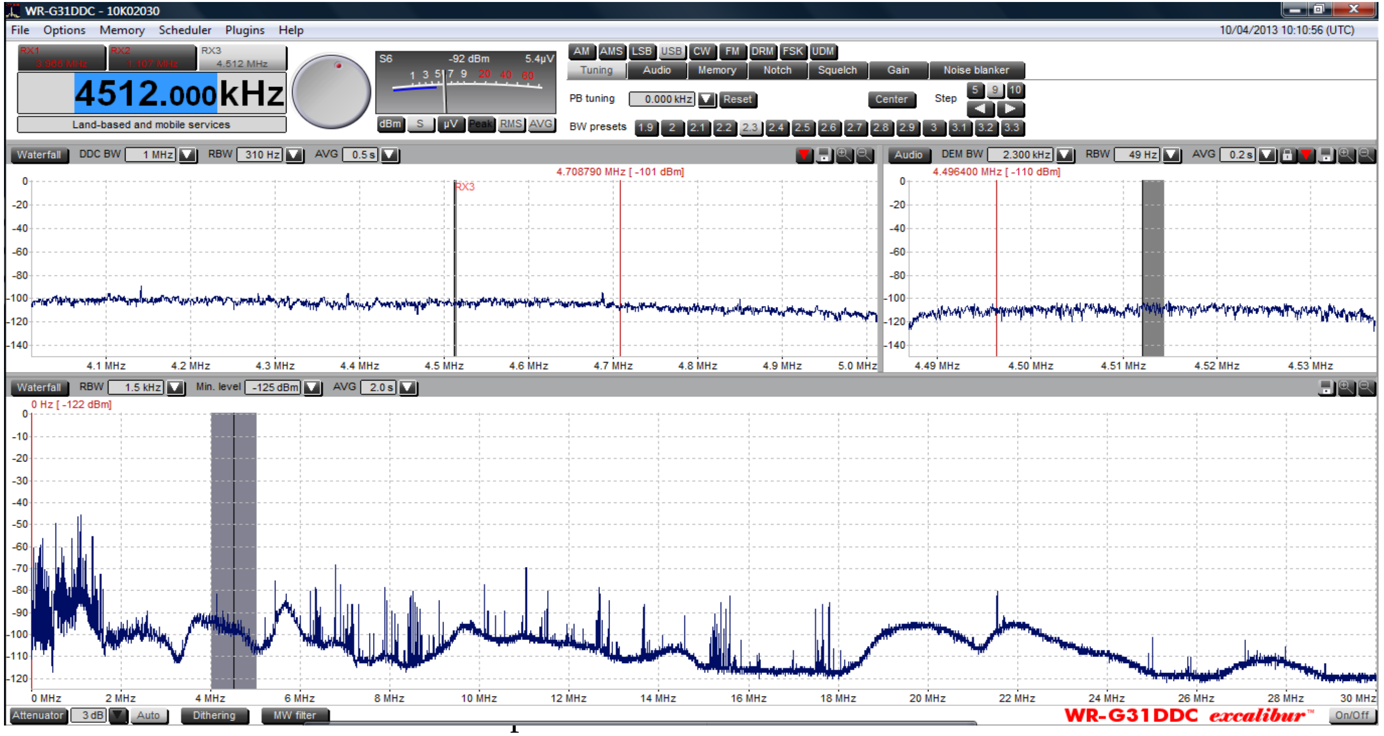
```
D      100  200  400  600  800 1000 1500 3000 [km]
MUF    9.7  9.8 10.0 10.5 11.2 12.2 15.0 22.1 [MHz]
```

DB049_2013076111000.RSF / 560fx512h 25 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E   Ion2Png v. 1.3.17

G3LHZ

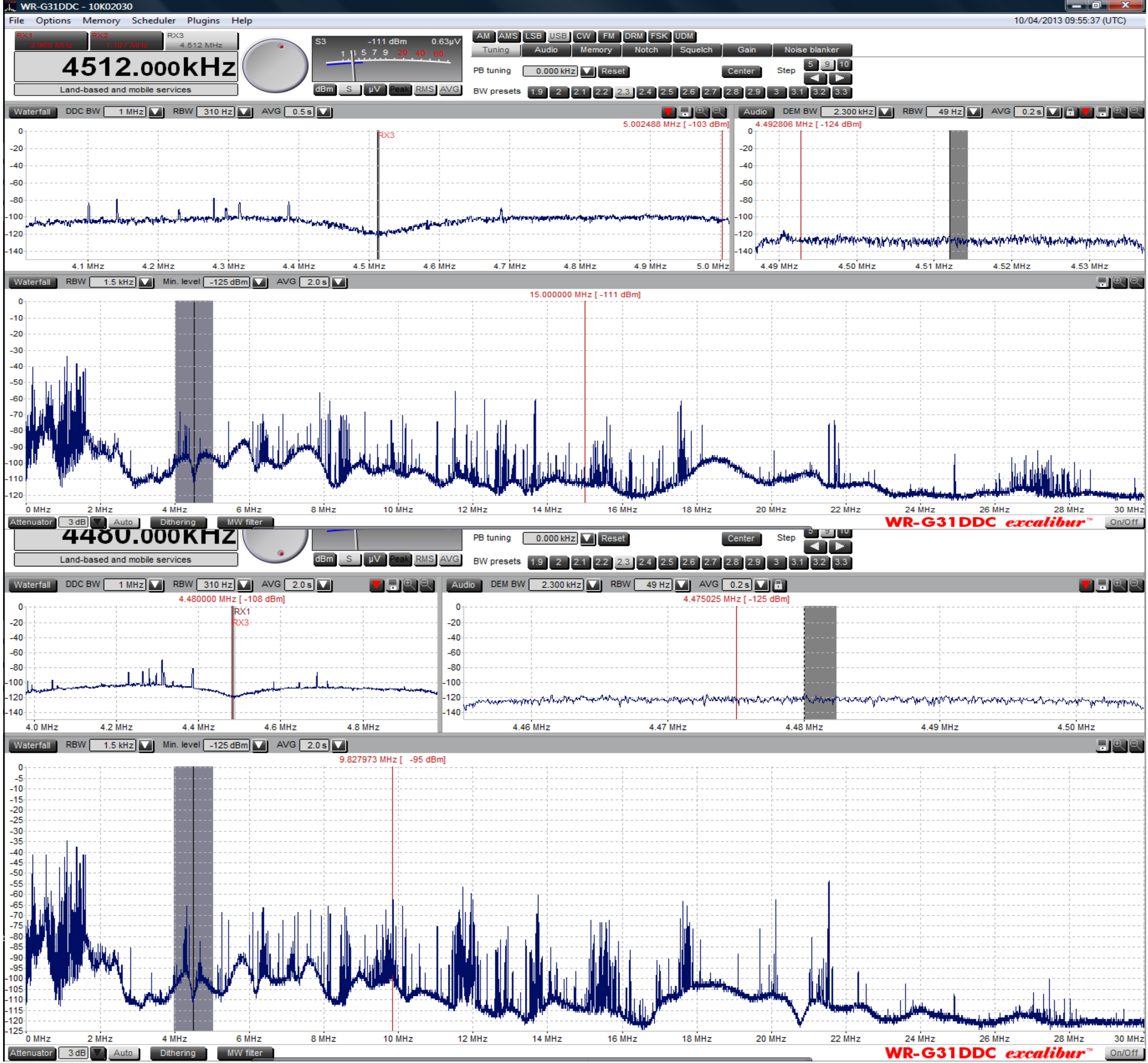
Absorption Peaks/Nulls above ground, High Loop at Top.
Low loop at bottom.
Now thought to be mainly ionospheric, but may also be rain and wet ground absorption





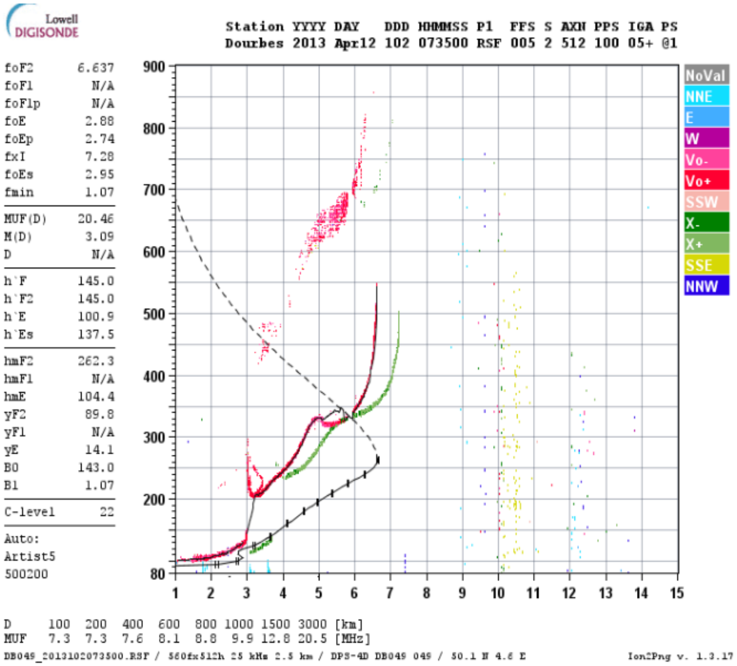
G3LHZ

Wet Ground and Raining High Absorption between 2.6MHz and 4MHz. Also Ionospheric nulls at 4.4 and 6.1MHz



Ionospheric Absorption Peaks/Nulls

Note null at 5657kHz coincides with gap in X-wave ionogram. Why?



Lowell DIGISONDE

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
Dourbes 2013 Apr12 102 073500 RSF 005 2 512 100 05+ @1

foF2 6.637
foF1 N/A
foF1p N/A
foE 2.88
foEp 2.74
fxI 7.28
foEs 2.95
fmin 1.07

MUF(D) 20.46
M(D) 3.09
D N/A

h`F 145.0
h`F2 145.0
h`E 100.9
h`Es 137.5

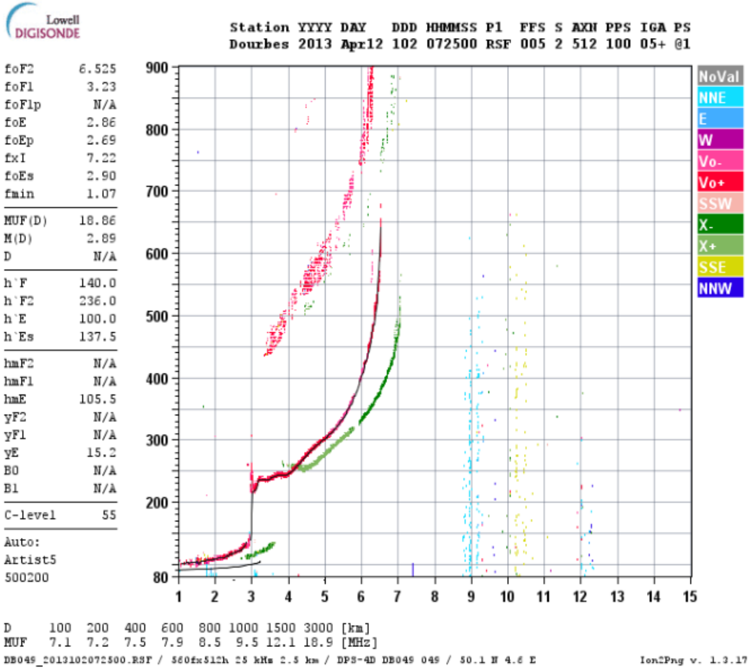
hmF2 262.3
hmF1 N/A
hmE 104.4
yF2 89.8
yF1 N/A
yE 14.1
B0 143.0
B1 1.07

C-level 22

Auto:
Artist5
500200

D 100 200 400 600 800 1000 1500 3000 [km]
MUF 7.3 7.3 7.6 8.1 8.8 9.9 12.8 20.5 [MHz]

DB049_2013102073500.RSF / 560fx512h 25 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E Ion2Png v. 1.3.17



Lowell DIGISONDE

Station YYYY DAY DDD HHMMSS P1 FFS S AXN PPS IGA PS
Dourbes 2013 Apr12 102 072500 RSF 005 2 512 100 05+ @1

foF2 6.525
foF1 3.23
foF1p N/A
foE 2.86
foEp 2.69
fxI 7.22
foEs 2.90
fmin 1.07

MUF(D) 18.86
M(D) 2.89
D N/A

h`F 140.0
h`F2 236.0
h`E 100.0
h`Es 137.5

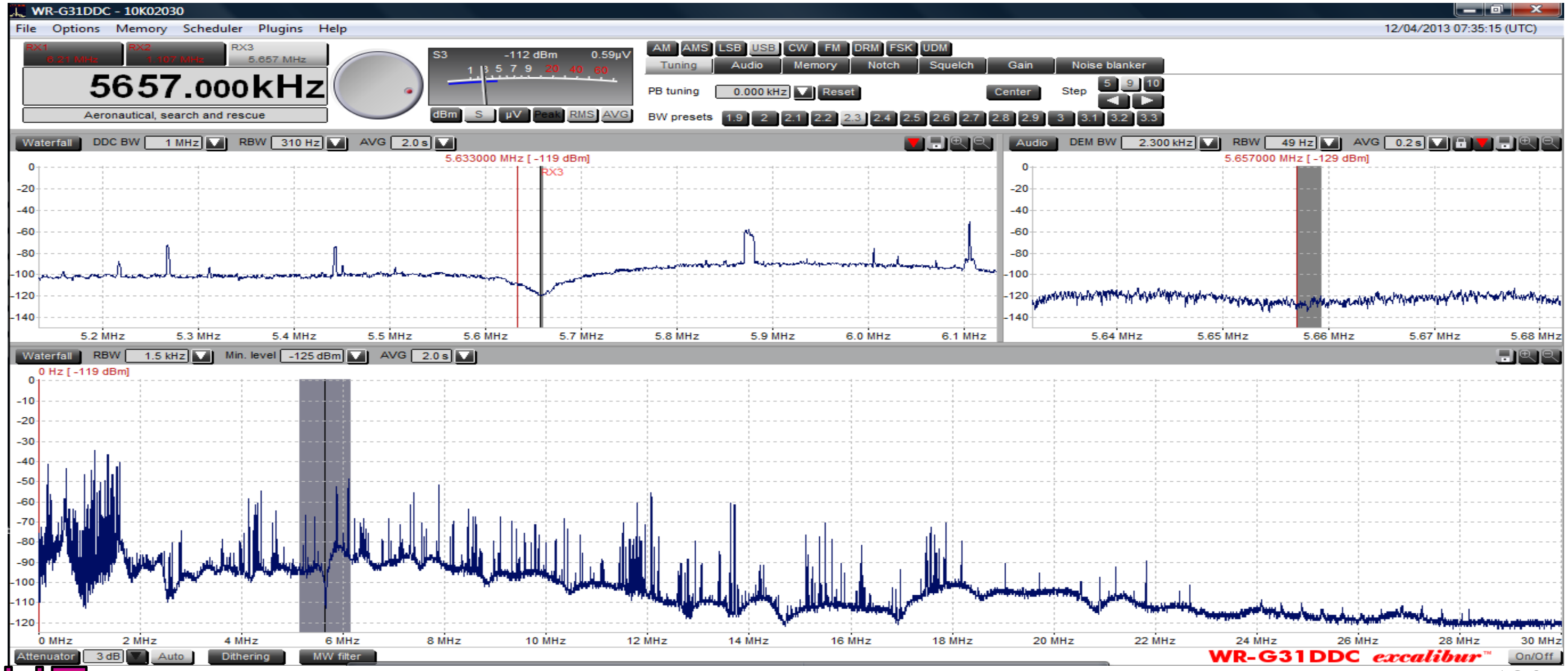
hmF2 N/A
hmF1 N/A
hmE 105.5
yF2 N/A
yF1 N/A
yE 15.2
B0 N/A
B1 N/A

C-level 55

Auto:
Artist5
500200

D 100 200 400 600 800 1000 1500 3000 [km]
MUF 7.1 7.2 7.5 7.9 8.5 9.5 12.1 18.9 [MHz]

DB049_2013102072500.RSF / 560fx512h 25 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E Ion2Png v. 1.3.17



WR-G31DDC - 10K02030

12/04/2013 07:35:15 (UTC)

RX1 6.21 MHz
RX2 1.107 MHz
RX3 5.657 MHz

5657.000kHz

Aeronautical, search and rescue

S3 -112 dBm 0.59μV

PB tuning 0.000 kHz

Waterfall DDC BW 1 MHz RBW 310 Hz AVG 2.0 s

5.633000 MHz [-119 dBm]

Audio DEM BW 2.300 kHz RBW 49 Hz AVG 0.2 s

5.657000 MHz [-129 dBm]

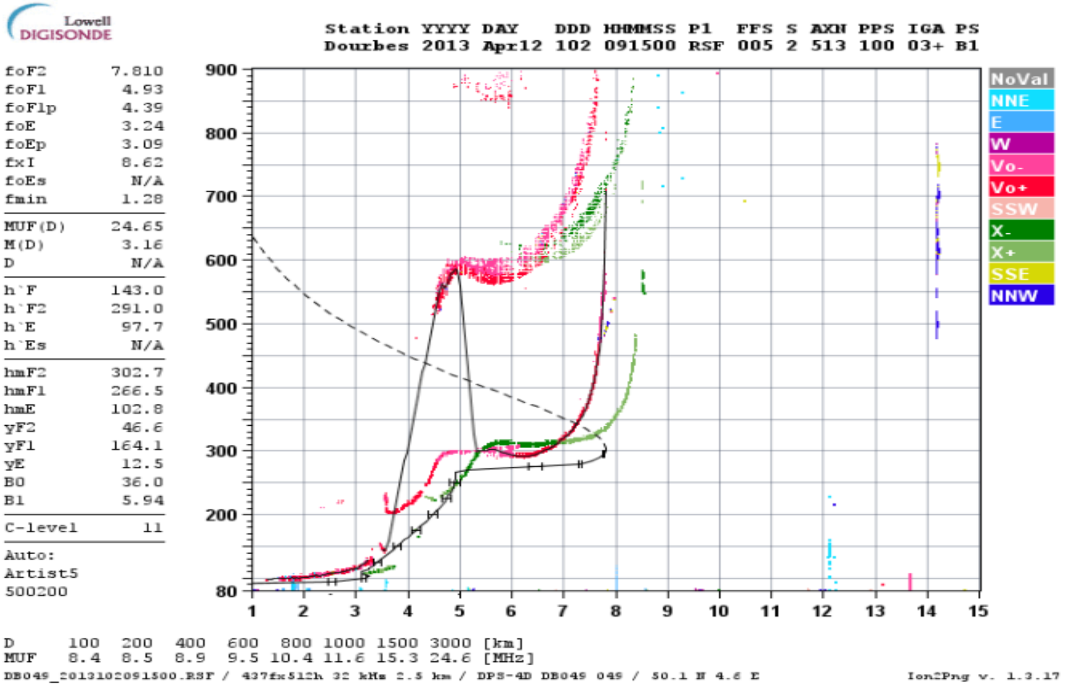
Waterfall RBW 1.5 kHz Min. level -125 dBm AVG 2.0 s

0 Hz [-119 dBm]

Attenuator 3 dB

Ionospheric Absorption Peaks/Nulls

Note null at 4490kHz coincides with gap in X-wave ionogram. Why?



Lowell DIGISONDE

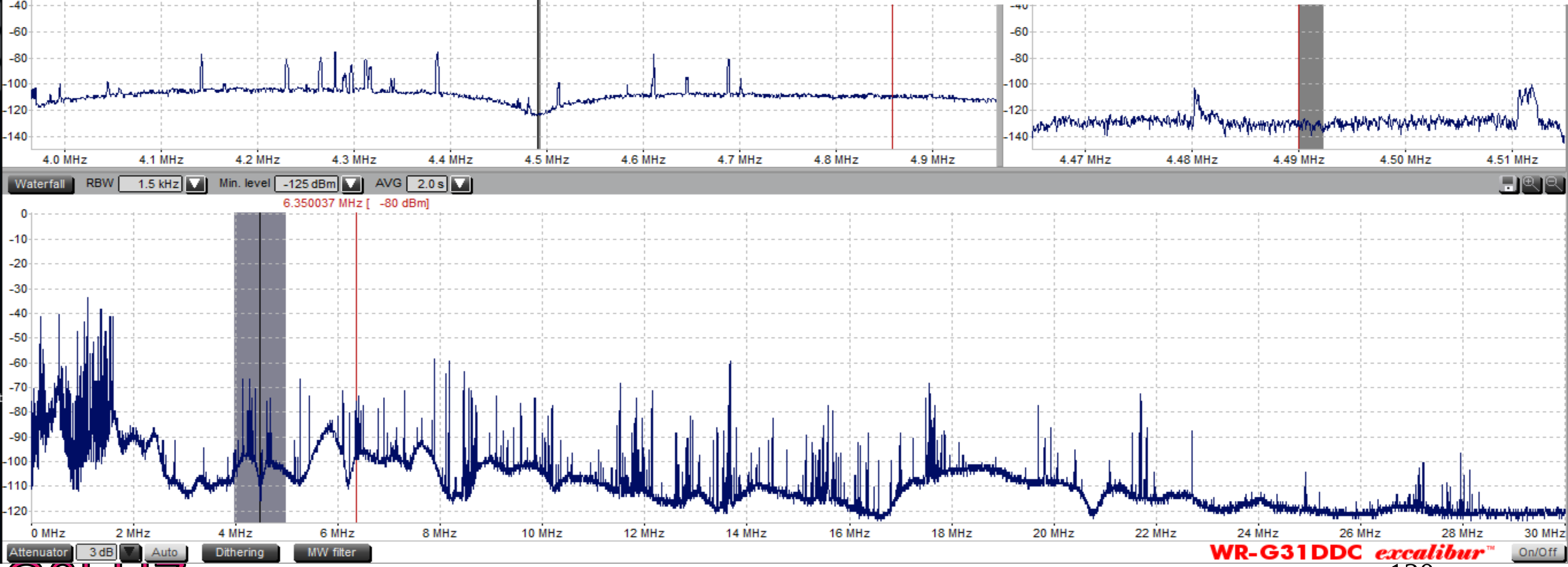
Station	YYYY	DAY	DDD	HHMMSS	P1	FFS	S	AXN	PPS	IGA	PS
Dourbes	2013	Apr12	102	091500	RSF	005	2	513	100	03+	B1

foF2	7.810
foF1	4.93
foF1p	4.39
foE	3.24
foEp	3.09
fxI	8.62
foEs	N/A
fmin	1.28
MUF(D)	24.65
M(D)	3.16
D	N/A
h\`F	143.0
h\`F2	291.0
h\`E	97.7
h\`Es	N/A
hmF2	302.7
hmF1	266.5
hmE	102.8
yF2	46.6
yF1	164.1
yE	12.5
B0	36.0
B1	5.94
C-level	11

Auto:
Artist5
500200

D	100	200	400	600	800	1000	1500	3000	[km]
MUF	8.4	8.5	8.9	9.5	10.4	11.6	15.3	24.6	[MHz]

DB049_2013102091500.RSF / 437fx512h 32 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E   Ion2Png v. 1.3.17



WR-G31DDC - 10K02030

RX1 6.21 MHz
RX2 1.107 MHz
RX3 4.49 MHz

4490.000kHz

Land-based and mobile services

S2 -115 dBm 0.41µV

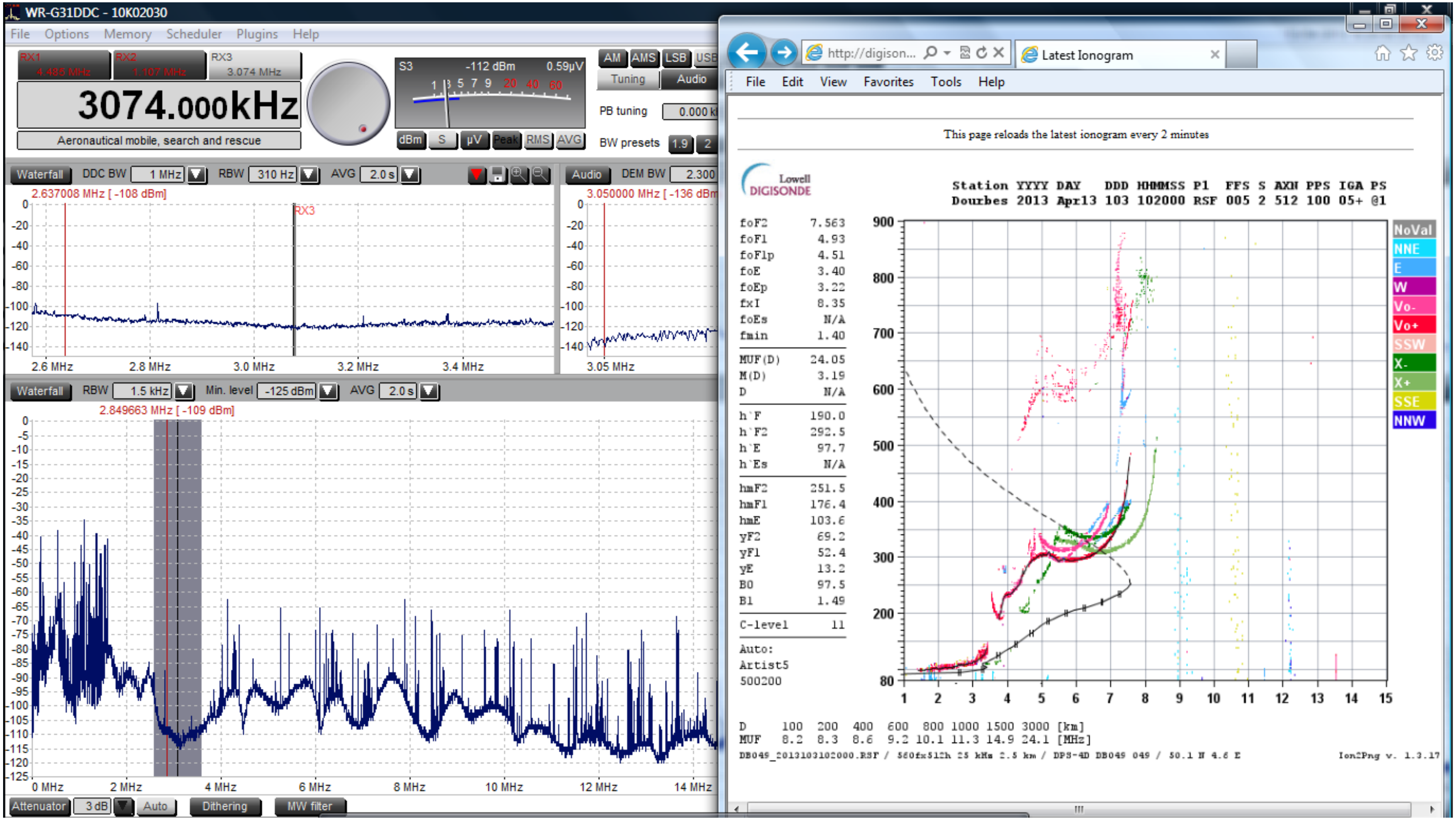
DDC BW 1 MHz
RBW 310 Hz
AVG 2.0 s

RBW 1.5 kHz
Min. level -125 dBm
AVG 2.0 s

6.350037 MHz [-80 dBm]

Attenuator 3 dB

Disturbed Ionosphere giving Noise Absorption Trough 2.5 to 4MHz



RX1 4.485 MHz

RX2 1.107 MHz

RX3 3.074 MHz

3074.000kHz

Aeronautical mobile, search and rescue

S3 -112 dBm 0.59µV

PB tuning 0.000 k

BW presets 1.9 2

DDC BW 1 MHz

RBW 310 Hz

AVG 2.0 s

DEM BW 2.300

2.637008 MHz [-108 dBm]

3.050000 MHz [-136 dBm

RBW 1.5 kHz

Min. level -125 dBm

AVG 2.0 s

2.849663 MHz [-109 dBm]

Attenuator 3 dB

This page reloads the latest ionogram every 2 minutes

Station	YYYY	DAY	DDD	HHMMSS	P1	FFS	S	AXN	PPS	IGA	PS
Dourbes	2013	Apr13	103	102000	RSF	005	2	512	100	05+	@1

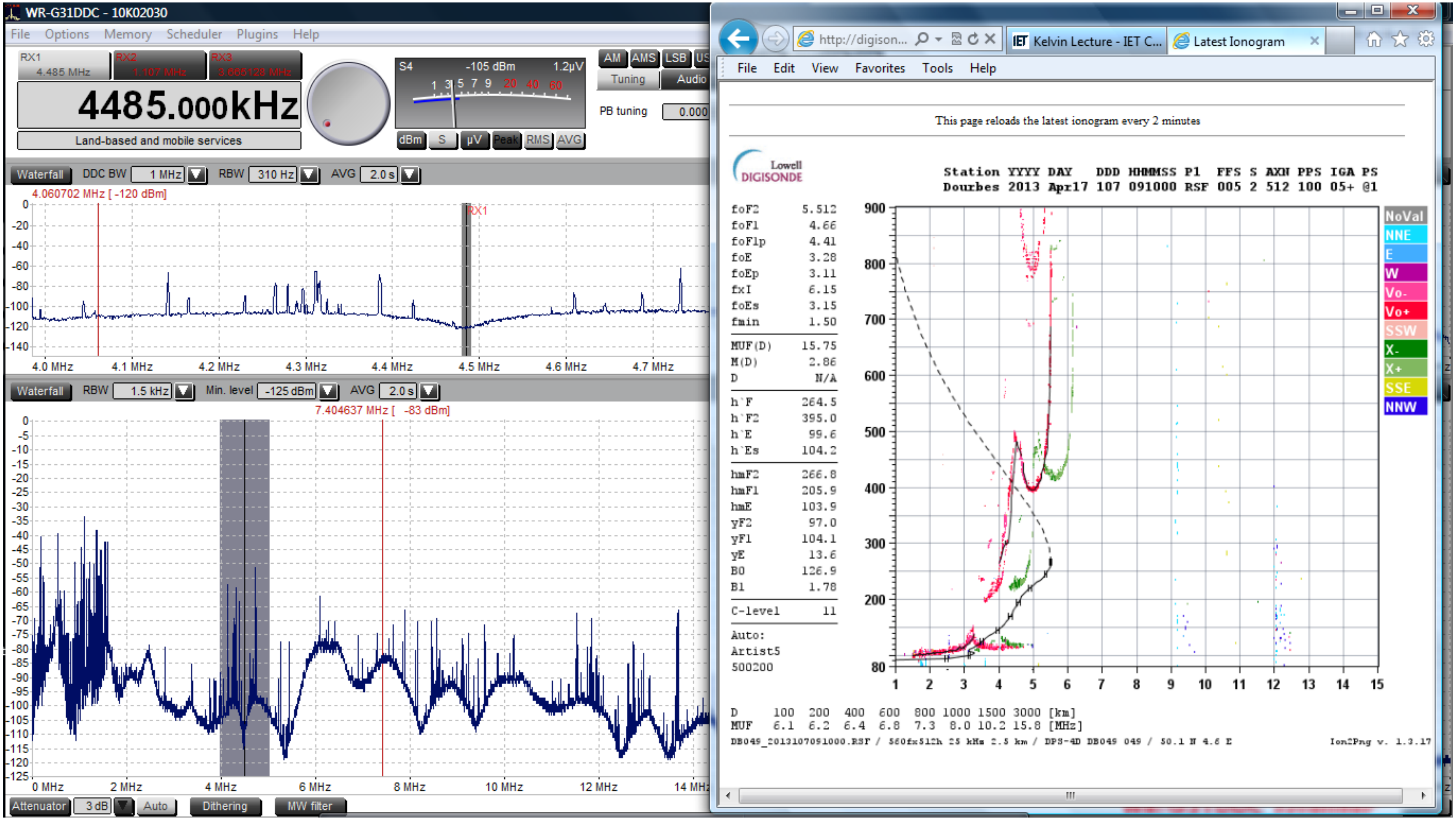
foF2	7.563
foF1	4.93
foF1p	4.51
foE	3.40
foEp	3.22
fxI	8.35
foEs	N/A
fmin	1.40
MUF(D)	24.05
M(D)	3.19
D	N/A
h\`F	190.0
h\`F2	292.5
h\`E	97.7
h\`Es	N/A
hmF2	251.5
hmF1	176.4
hmE	103.6
yF2	69.2
yF1	52.4
yE	13.2
B0	97.5
B1	1.49
C-level	11

Auto:
Artist5
500200

D	100	200	400	600	800	1000	1500	3000	[km]
MUF	8.2	8.3	8.6	9.2	10.1	11.3	14.9	24.1	[MHz]

DB049_2013103102000.RSF / 560fx512h 25 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E

Nulls at 4485kHz and 5365kHz. Why?



WR-G31DDC - 10K02030

RX1 4.485 MHz
RX2 1.107 MHz
RX3 3.665128 MHz

4485.000kHz

Land-based and mobile services

S4 -105 dBm 1.2µV

PB tuning 0.000

Waterfall DDC BW 1 MHz RBW 310 Hz AVG 2.0 s

4.060702 MHz [-120 dBm]

Waterfall RBW 1.5 kHz Min. level -125 dBm AVG 2.0 s

7.404637 MHz [-83 dBm]

Attenuator 3 dB

This page reloads the latest ionogram every 2 minutes

```
Station  YYYY DAY   DDD HHMMSS P1  FFS S AXN PPS IGA PS
Dourbes  2013 Apr17 107 091000 RSF 005 2 512 100 05+ @1

foF2       5.512
foF1       4.66
foF1p      4.41
foE        3.28
foEp       3.11
fxI        6.15
foEs       3.15
fmin       1.50

MUF(D)     15.75
M(D)       2.86
D          N/A

h`F        264.5
h`F2       395.0
h`E        99.6
h`Es       104.2

hmF2       266.8
hmF1       205.9
hmE        103.9
yF2        97.0
yF1        104.1
yE         13.6
B0         126.9
B1         1.78

C-level    11

Auto:
Artist5
500200

D      100  200  400  600  800 1000 1500 3000 [km]
MUF    6.1  6.2  6.4  6.8  7.3  8.0 10.2 15.8 [MHz]
DB049_2013107091000.RSF / 560fx512h 25 kHz 2.5 km / DPS-4D DB049 049 / 50.1 N 4.6 E     Ion2Png v. 1.3.17
```

G3LHZ

Thank you

Questions?

Additional Slides

These are supporting slides for the talk

Simple Rho-Q Method for Antenna Efficiency -1

- **It is a simplified form of the 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 a 'distributed impedance power splitting' function**

$$\eta = (R_{rad}/R_{meas})^2 = (Q_{meas}/Q_{rad})^2 = 1 - (R_{loss}/R_{meas})^2$$

$$= 1 - Q_{meas}^2 / Q_{loss}^2 = 1 - (Q_{meas} \times R_{loss}/X_l)^2$$

- In the above we have used reactance $X_l = 2\pi fL$ and $R_{meas} = X_l / Q_{meas} = 2\pi fL/Q$
- 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 C_{ir}, and the conductor tube or wire effective diameter d.
- The skin effect loss resistance R_{loss} 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 then found to be

$$R_{loss} = \sqrt{(0.4 \times f_{MHz} \times \rho)} \times C_{ir}/d \qquad (2)$$

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

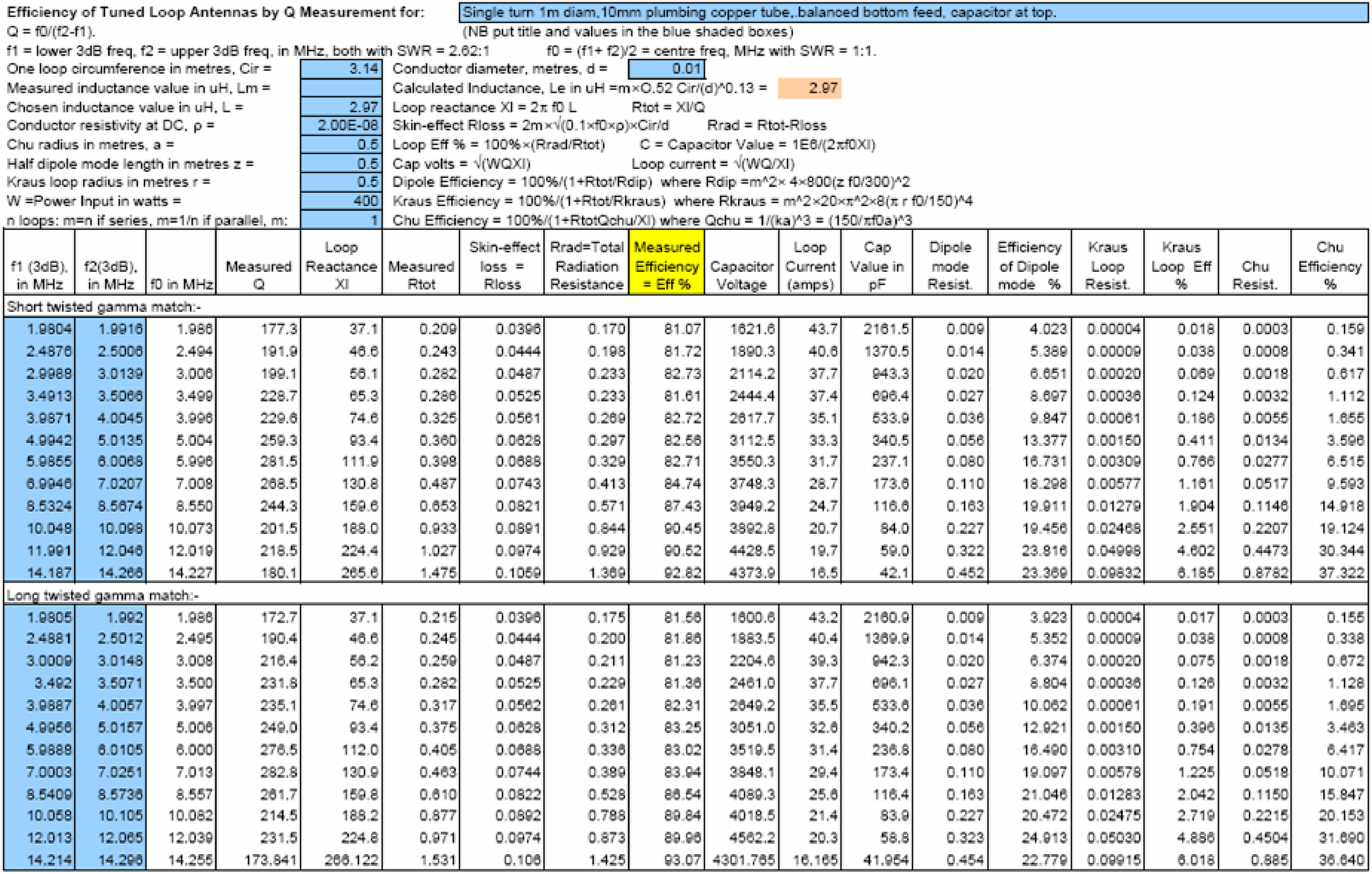
$$R_{loss}(Cu) = 8.94\times10^{-5}\sqrt{(f_{MHz})}\times C_{ir}/d \qquad (4)$$

- For typical aluminium tube the DC loss resistivity is 2.9 times higher than plumbing copper and its skin effect resistance is $\sqrt{2.9} = 1.7$ times higher. Then the loss for aluminium tube can be given as

$$R_{loss}(Al) = 1.52\times10^{-4}\sqrt{(f_{MHz})}\times C_{ir}/d \qquad (5)$$

- These values are then used in the efficiency formula. The following spreadsheets have 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×O.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

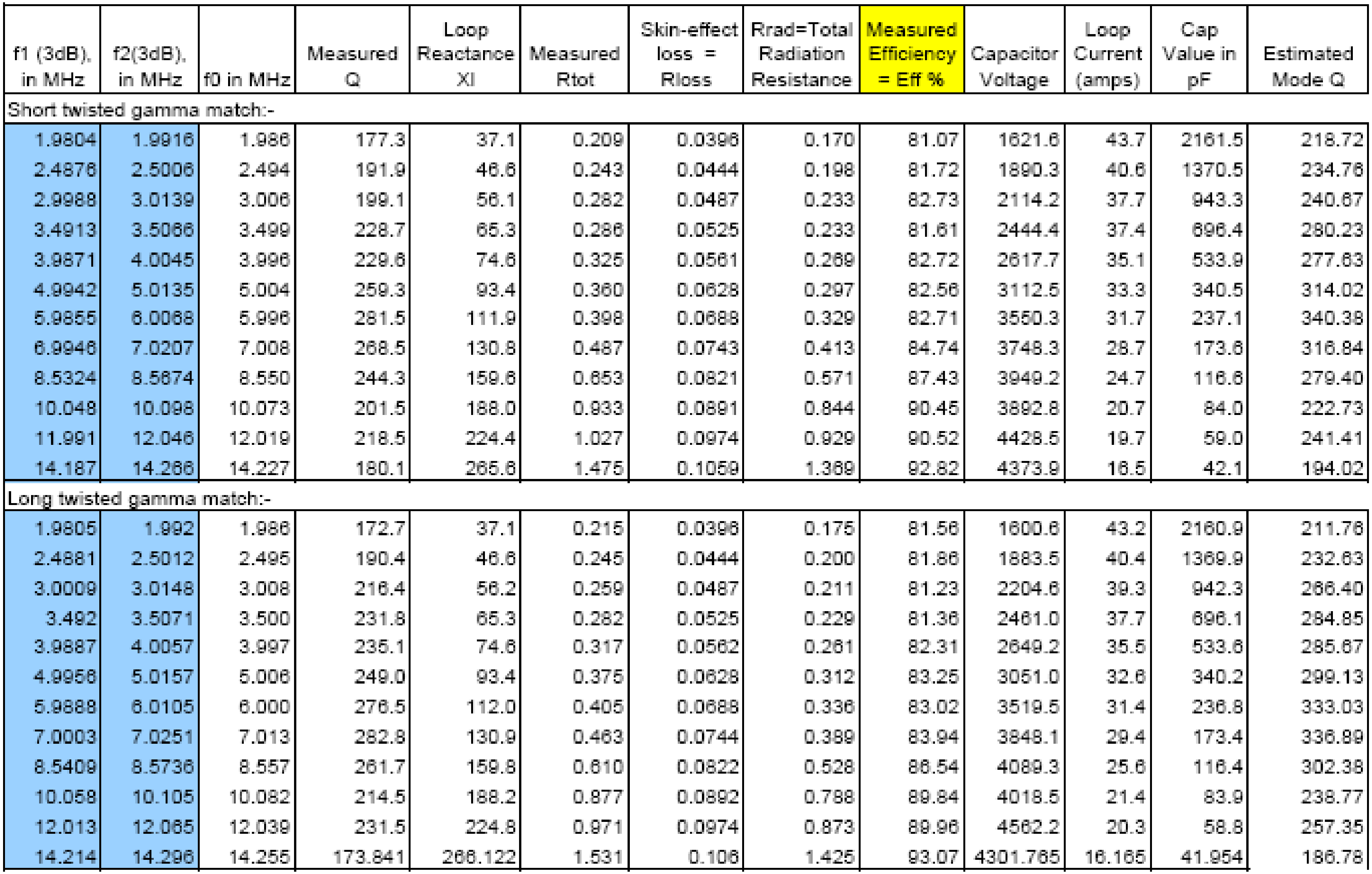
n loops: m=n if series, m=1/n if parallel, m: 1 Chu Efficiency = 100%/(1+RtotQchu/Xl) where Qchu = 1/(ka)^3 = (150/πf0a)^3

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	14.266	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	6.195	0.8782	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	8.5736	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
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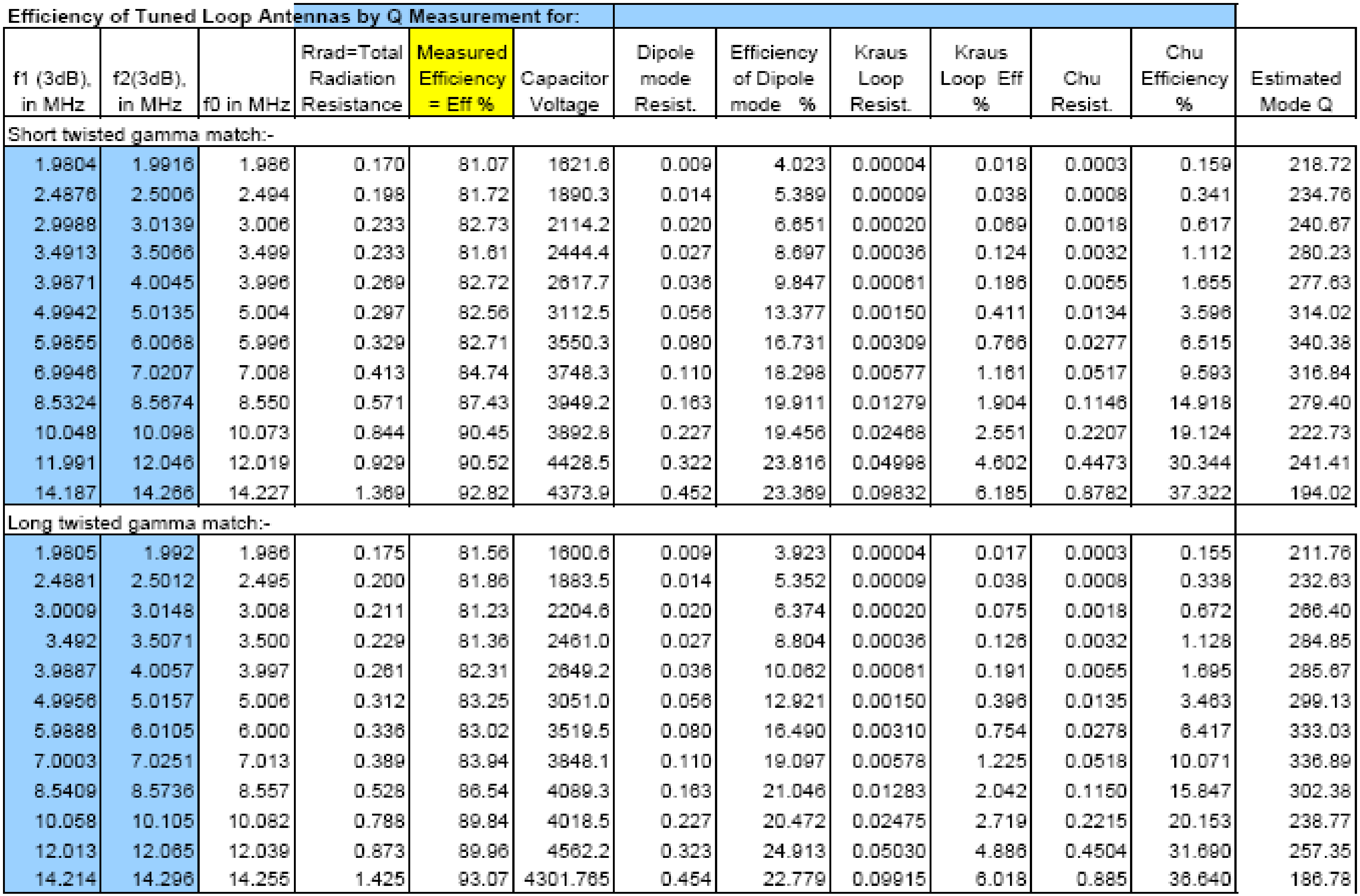
7.0003	7.0251	7.013	282.8	130.9	0.463	0.0744	0.389	83.94	3848.1	29.4	173.4	336.89
8.5409	8.5736	8.557	261.7	159.8	0.610	0.0822	0.528	86.54	4089.3	25.6	116.4	302.38
10.058	10.105	10.082	214.5	188.2	0.877	0.0892	0.788	89.84	4018.5	21.4	83.9	238.77
12.013	12.065	12.039	231.5	224.8	0.971	0.0974	0.873	89.96	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
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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
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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
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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).**
- Efficiency can be determined more precisely over the various frequency bands using the concept of conductor Q_{loss} as follows

Loop Design Formulas - Inductance

- Practical measurements show that single turn loop inductor of conductor diameter *d* is proportional to wire length, and $d^{0.16}$, even if it is ‘squashed’.
- Measurements show that the inductance per unite length is 1μH for d = 6mm diameter tube it varies as $d^{1/2\pi} = d^{0.16}$ Thus we have:
- **<u>New empirical formula</u>** for inductance per metre length:
  - $L(\mu H) = (160d)^{-0.16}$
- Loop Area *A* has a negligible effect until the loop has more than one or two turns.
- The traditional formulas such as *Patterson’s* (of *Patterson* loop fame?) $L(\mu H) = 0.00508A \times [2.303 \log (4A/d) - 2.451]$ is not accurate for single turn loops. A more complicated formula from *Grover* is more accurate. Neither apply to ‘squashed’ loops’
- Also measurements show that loop inductance appears to increase with frequency. But this can be ascribed to ‘end’ stray capacity. So we shall ignore this

This talk was given at the Progress In Electromagnetic Research Symposium (PIERS), 27th to 30th March 2012 in Kuala Lumpur.

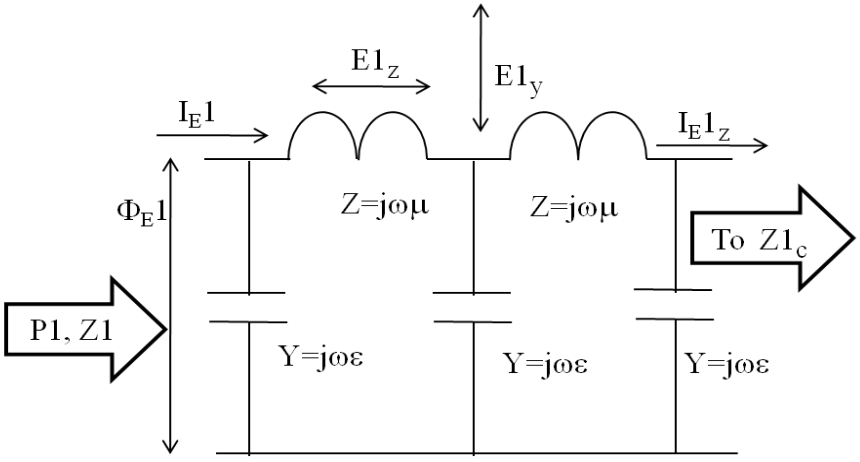
Maxwell’s Transfer Functions

Michael J (Mike) Underhill

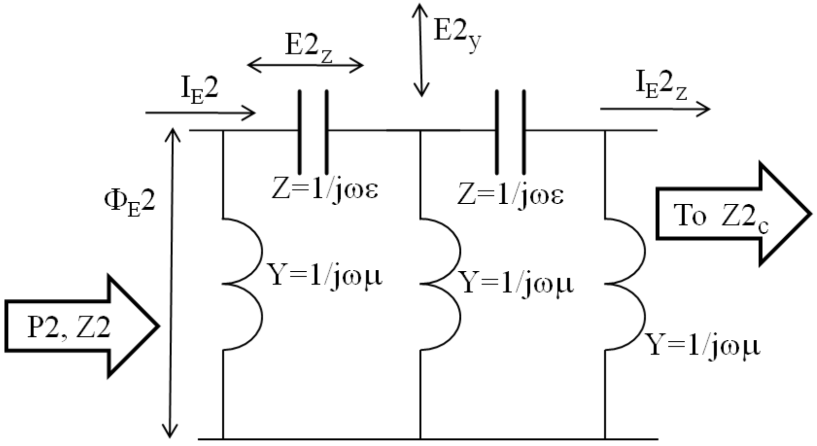
Underhill Research Ltd, UK

The Local Ether Four Transmission Line Model of EM.

- The Physical EM Model (PEM) [2] is an underlying basis for MTFs.
- It is a two low-pass and high-pass pairs of co-located transmission lines in a 'local ether'.
- One LP/HP pair represents conventional and electric displacement current, with electric vector potential (as below). The other covers magnetic displacement current and magnetic vector potential.
- The local ether is the region of the stored energy of an antenna. The local ether is a new definition of the near field region.



(b) Low-Pass E-field line



(c) High-Pass E-field line,

2. The Modified Classical Maxwell's Equations

$$divD = \nabla \cdot D = \rho_E \qquad (1) \qquad\qquad divB = \nabla \cdot B = \rho_M \qquad (2)$$

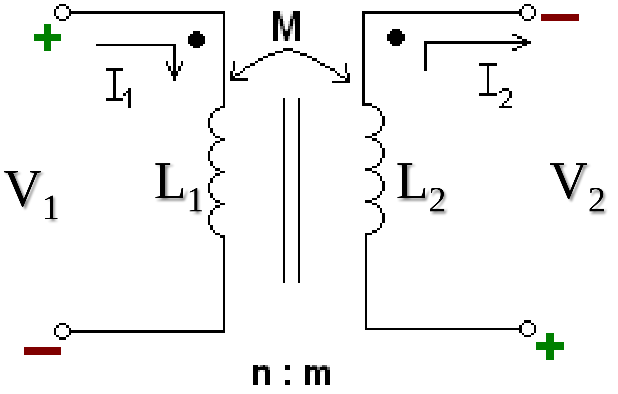
$$curlH = \nabla \times H = +\frac{\partial D}{\partial t} + J_R + J_E \qquad (3) \qquad\qquad -curlE = -\nabla \times E = \frac{\partial B}{\partial t} + J_M \qquad (4)$$

$D = \varepsilon E$ where generally in the near-field $\varepsilon > \varepsilon_0$ (5)

$B = \mu H$ where generally in the near-field $\mu > \mu_0$ (6)

- The fundamentally important *modification* is that ε and μ are allowed to increase over $\varepsilon_0$and μ_0 and become functions of position in near field space in the 'constitutive relations' (5) and (6).
- This removes a 100 years old dogma that there is no ether and now allows progress.
- Separately it can be shown that this is not contradicted by the Michelson-Morley Experiment.
- So ε and μ now can define the 'local ether' that surrounds any antenna or physical object [1].
- $\partial B/\partial t$ is defined as the magnetic displacement current as in (3) .
- $\partial D/\partial t$ is defined as the electric displacement current as in (4).

Partial EM Coupling Model



Coupling factor, $\kappa = M/\sqrt{(L_1 L_2)} \leq 1$

Also we have $nL_2 = mL_1$

$V_2 := \kappa\,(m/n)\,V_1$ $\qquad$ $V_1 := \kappa\,(n/m)\,V_2$

$I_1 := \kappa\,(n/m)\,I_2$ $\qquad$ $I_1 := \kappa\,(m/n)\,I_2$

- The transformer is a model of magnetic/inductive EM coupling.
- The ‘capacitance transformer’ is used for electric/capacitative EM coupling .
- In the coupling equations the sources are on the right and the sinks are on the left. *The coupling equations are not reversible.*
- The symbol ‘ := ’ means ‘depends on’.
- In general sink strengths are less than source strengths.

Local Coupling of Fields

- *For reasonably uniform local space anywhere away from the surface of the antenna we find that the asymptotic (causal) coupling between the fields in Maxwell's equation is not the 100% that* has *implicitly been assumed since the equations were originally constructed.*
- In fact a value of around $\kappa_0 = 1/2\pi$ is what has been found experimentally. Thus experimental measurement validates any theory that predicts $\kappa_0 = 1/2\pi$.
- This value can be used both for local points away from any sources or for plane waves in space.
- It means that the sensitivity of simple field detectors in practice is less than expected by $\kappa_0 = 1/2\pi$ or -16dB.

Supporting Evidence for $\kappa_0 = 1/2\pi$.

- Some of the supporting evidence in addition to evidence in reference [2] are the findings:
- (a) that small tuned loop size scales inversely as the square root of frequency,
- (b) that the small tuned loop asymptotic antenna Q is about 248 = $(2\pi)^3$ and
- (c) small tuned loops can easily have measured efficiencies of >90%, as predicted by (b) and
- (d) by observation that high power small tuned loops do not overheat and self-destruct as they would if they were inefficient.

Maxwell’s Transfer Functions (MTFs)

- Thus Maxwell’s equations should be converted to be causal (cause and effect) transfer functions.
- We find that only the constitutive relations in equations 5 and 6 need to be made into two pairs of unidirectional causal equations as given in equations 9a to10b.
- This enforces causality into all the Maxwell equations.
- The ‘becomes equal to’ sign ‘:=’ is unidirectional and is used in equations 9 and 10.

$$D := \kappa \varepsilon E \qquad \text{(9a),} \qquad E := \kappa \frac{D}{\varepsilon} \qquad \text{(9b)}$$

$$B := \kappa \mu H \qquad \text{(10a),} \qquad H := \kappa \frac{B}{\mu} \qquad \text{(10b)}$$

5. Imposition of Conservation of Energy on Maxwell's Equations –2

- We therefore conclude that E and H are essentially potentials and are fundamentally different from D and B.
- As an example we redefine the div operator as the square root of the Laplacian:

$$(\nabla\cdot) = (\nabla^2)^{1/2} = \left[\left(\frac{\partial}{\partial x}\right)^2 + \left(\frac{\partial}{\partial y}\right)^2 + \left(\frac{\partial}{\partial z}\right)^2\right]^{1/2} \qquad (11)$$

6. The Causal Maxwell’s Equations

With $\kappa = \kappa_0 = 1/2\pi$ we can now set out the causal Maxwell equations as:

$$div D = \nabla \cdot D = \rho_E \qquad (12) \qquad\qquad div B = \nabla \cdot B = \rho_M \qquad (13)$$

$$-curl E = -\nabla \times E = \frac{\partial B}{\partial t} \oplus J_M \qquad (14) \qquad\qquad curl H = \nabla \times H = \frac{\partial D}{\partial t} \oplus J_R \oplus J_E \qquad (15)$$

$$D := \kappa_0 \varepsilon E \qquad (16a), \qquad\qquad E := \kappa_0 \frac{D}{\varepsilon} \qquad (16b)$$

$$B := \kappa_0 \mu H \qquad (17a), \qquad\qquad H := \kappa_0 \frac{B}{\mu} \qquad (17b)$$

- In (12) to (17b) sources are on the right and sinks are on the left.
- As before these equations describe the physics of what is happening with sources and sinks at the same point in space.
- The field pairs are not 100% coupled. The coupling is $\kappa_0 = 1/2\pi$.
- This is an important discovery with far-reaching consequences.

7. Maxwell’s Transfer Functions (MTFs) – 3

$divD = \nabla \cdot D = j\left(k_z^2 + k_r^2\right)^{1/2} D = 0$ (18), $divB = \nabla \cdot B = j\left(k_z^2 + k_r^2\right)^{1/2} B = 0$ (19)

$curlE_x = \frac{\partial E_x}{\partial y} = jkE_x$ and $\frac{\partial B_y}{\partial t} = j\omega B_y = j\kappa\mu H_y$ to give: $-jk\delta E_x = j\kappa\mu H_y$ (20)

$curlH_y = \frac{\partial E_x}{\partial y} = jkE_x$ and $\frac{\partial B_y}{\partial t} = j\omega B_y = j\kappa\mu H_y$ to give: $-jk\delta E_x = j\kappa\mu H_y$ (21)

$\delta D_x := \kappa\varepsilon E_x \oplus$ (22a), $\delta E_x := \kappa \frac{D_x}{\varepsilon}$ (22b)

$\delta B_y := \kappa\mu H_y \oplus$ (23a), $\delta H_y := \kappa_0 \frac{B_y}{\mu}$ (23b)

- (19) to (23) are Maxwell’s Transfer Functions in terms of impedances and admittances. The sinks are on the left and sources on the right.
- The δ sign shows that these equations can be integrated to sum all the contributions to the parameter on the left.
- The coupling κ is now a dyadic and therefore a function of the distance between two relevant points in space.
- The ⊕ sign warns where *RSS integration* should be used.

Four Loosely Coupled Wave Equations

- For the above MTFs we find *four loosely coupled* ($\kappa_0 = 1/2\pi$) *travelling wave equations* for E, D, H, and B of the form:

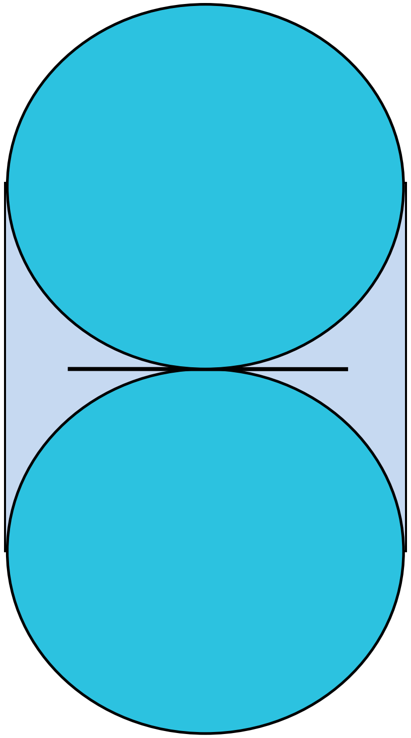
$\frac{\partial^2 X}{\partial z^2} = -\varepsilon\mu \frac{\partial^2 X}{\partial t^2}$ all four equations having velocity, $c_{EM} = 1\big/\sqrt{\varepsilon\mu}$ (24)

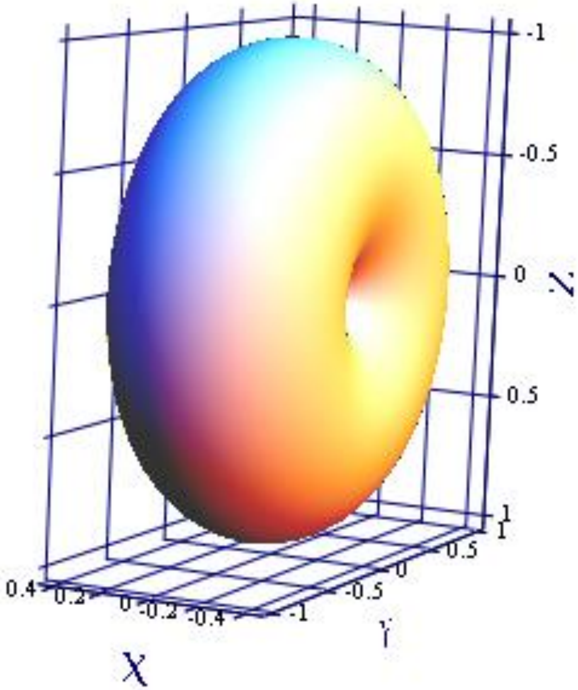
- The partial coupling of 1/2π means that the initial impedance E/H close to an electric or magnetic field source can be one of the two values respectively $2\pi Z_0 = 2400$ or $Z_0/2\pi = 60$.
- Beyond the Goubau Distance $r_G = \left(14/f_{MHz}\right)^{1/2}$ the impedance rapidly approaches $Z_0 = 120\pi = 377$ ohms in both cases.
- The *evanescent wave profile* solution of the Maxwell (Transfer Function) Equations are then derived by applying equation 8. We then obtain the profile for vector potentials such as E and H [1]:

Conclusions

- Maxwell’s Equations have been converted into Maxwell’s Transfer Functions (MTFs), mainly by redefinition of the mathematical operators and the EM fields in the original equations.
- **And by Newly Defining and Quantifying the Fundamental Concept of *ElectroMagnetic (EM) Coupling* or *Physics Coupling*.**
- MTFs are ‘causal’ equations with frequency and time responses provided by Laplace Transform structures.
- MTFs are thus engineering tools for solving practical problems in electromagnetics, antennas and propagation.
- MTFs naturally fit with the ‘Physical Model of Electro-magnetism’ (PEM) [1].
- MTFs can provided the underlying analytic equations for the method of ‘Analytic Region Modelling (ARM) [4]

Radiation patterns of Dipoles



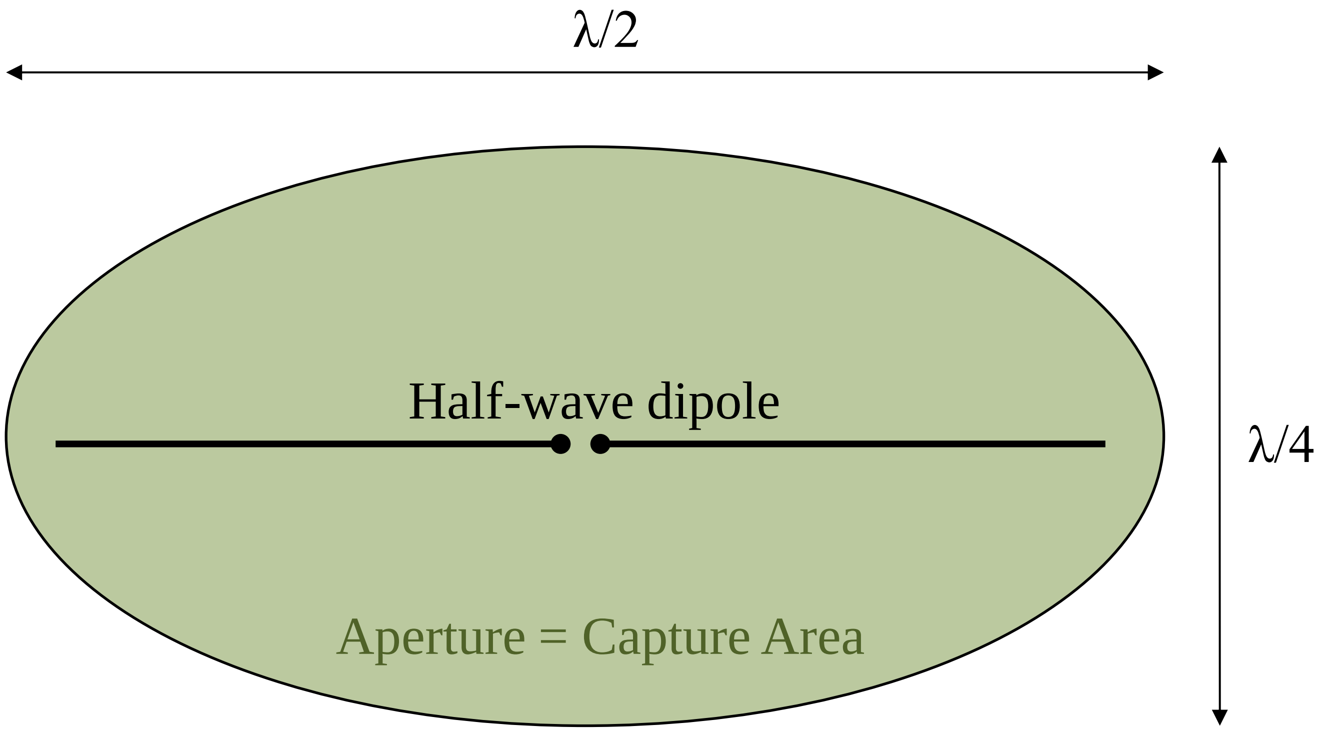


Antenna 3D Plot (E field is horizontal)

(X, Y, Z)

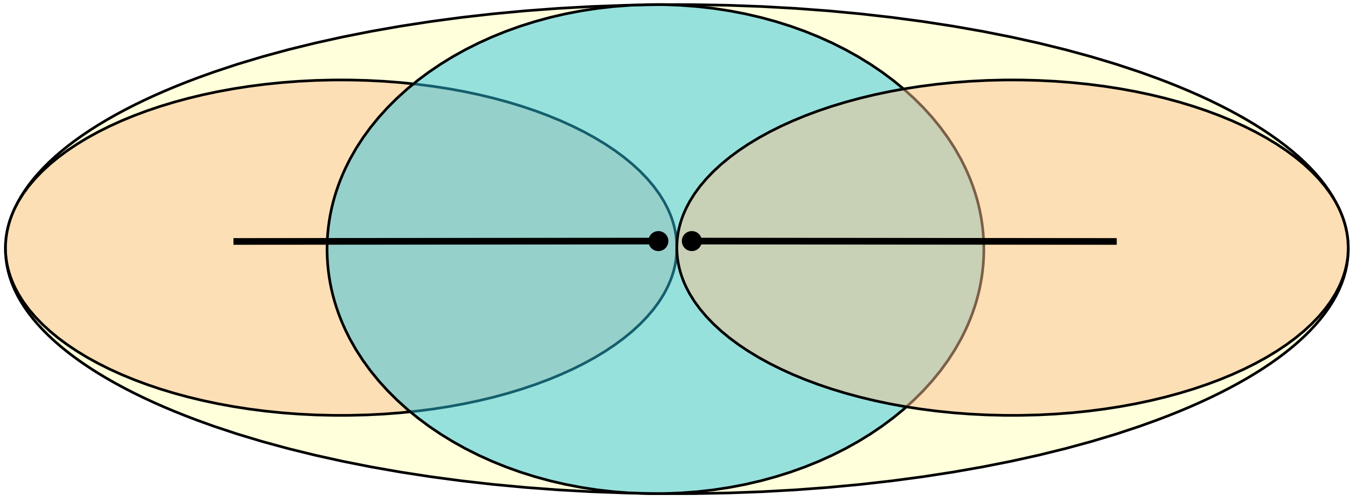
- **Short Dipole ‘Doughnut’ Radiation Pattern**
- **3D picture on right from Mathcad - ‘Any Dipole’ program**

Antenna Aperture and Capture Area



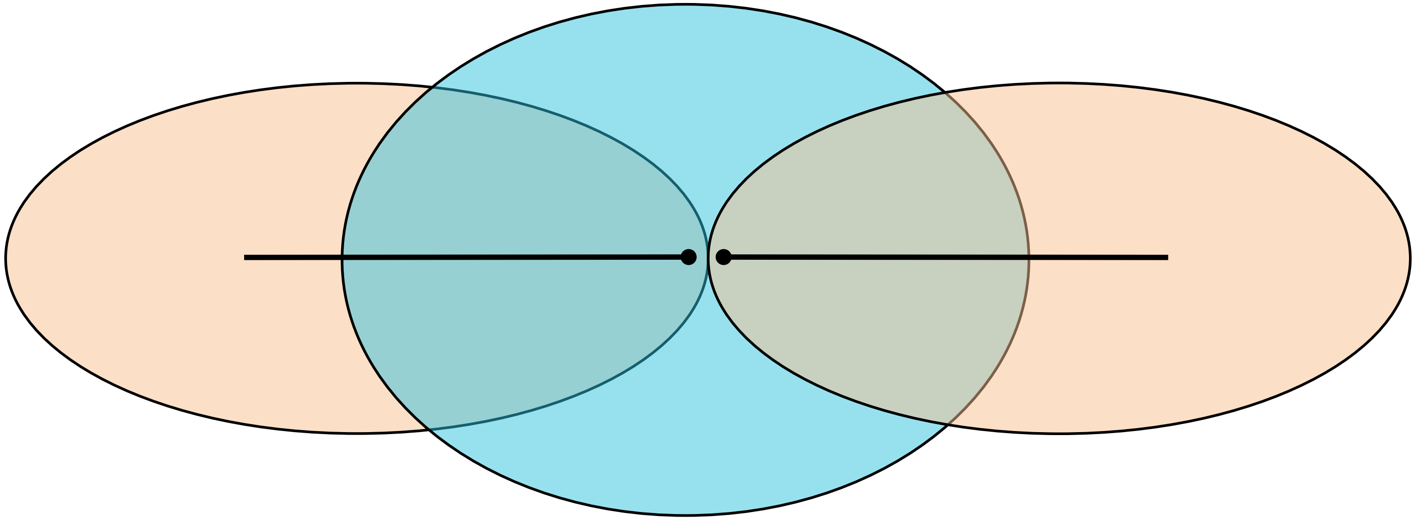
- **Half-wave dipole receiving aperture and capture area**
- **Why is it so large?**
- **Is it a focussing effect like a lens?**

Antenna with two types of stored energy



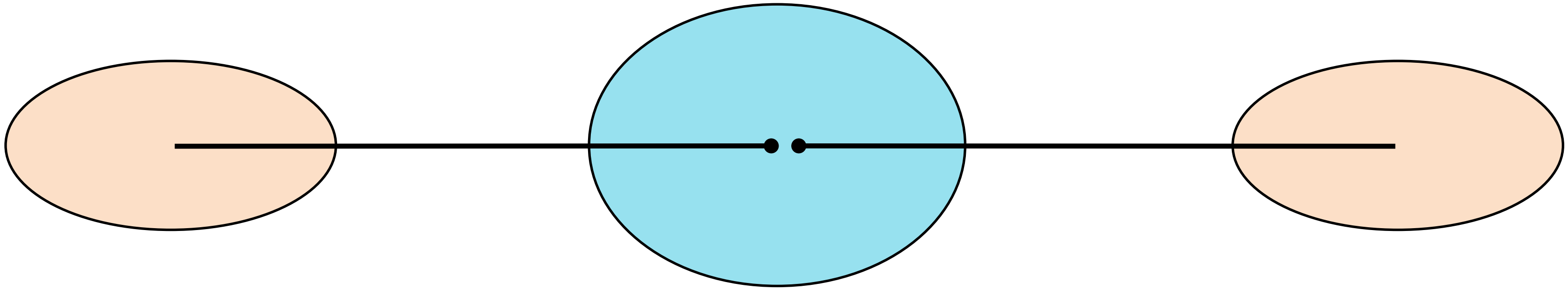
- **Electric, Magnetic and Total Energy of a (Short) Dipole at UHF**

Where does the radiation come from on the antenna?



- **Radiation per unit length of a half-wave dipole at about 5 to 10MHz.**

Where does the radiation come from on the antenna?



- Radiation per unit length of a half-wave dipole at about 1 to 2MHz.

Goubau Single Wire Transmission Line

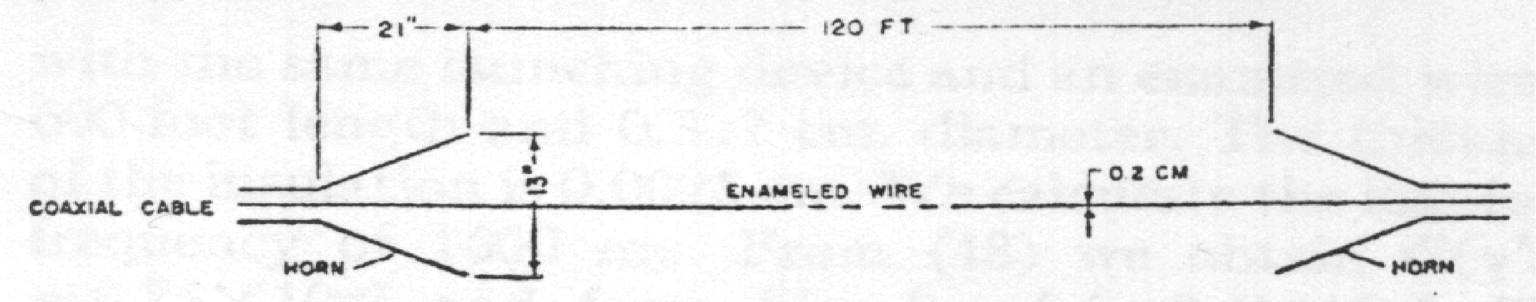


FIG. 11. Sketch of a surface wave transmission line.

"Surface Waves and Their Application to Transmission Lines", by Georg Goubau, J.A.P., Vol. 21, Nov., 1950, pp 1119 – 1128.

•Enamel coat on wire 0.005cm (= 50micron), $\varepsilon_r = 3$, $\tan\delta = 8\times10^{-3}$. 10 watts into this dielectric layer would burn it off! Dielectric layer is not needed?

•At 3.3GHz, theoretical Sommerfeld surface wave line loss = 1.62dB, horns = 0.2dB each, so total theory = 2.0dB. Measured loss = 2.3dB, constant to ±0.1dB from 1.5 to 3.3GHz!

•But loss from skin resistance of wire is = 1.7dB at 3.3GHz (assuming line impedance is 120π = 377ohms – probably nearer 300ohms). ***Thus line radiation loss is negligible.***

•But "Current" theory, "Method of Moments", NEC etc. all say that the *current*, or more exactly the *current squared* on the line should radiate! If anything it should be the current, not current squared, that radiates.

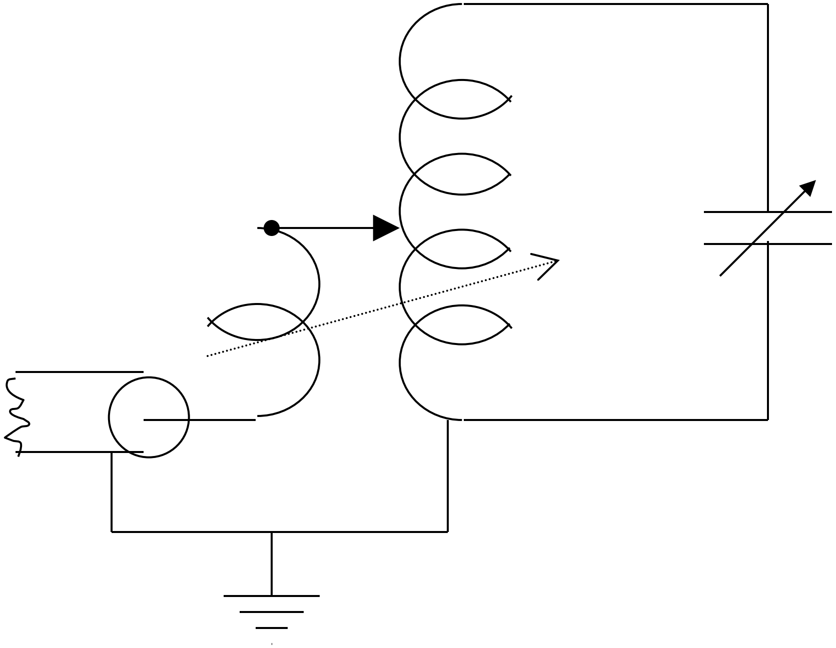
•No valid theory exists as yet for the Goubau Line. Perhaps it is ignored as an embarrassment by the experts?!

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.



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

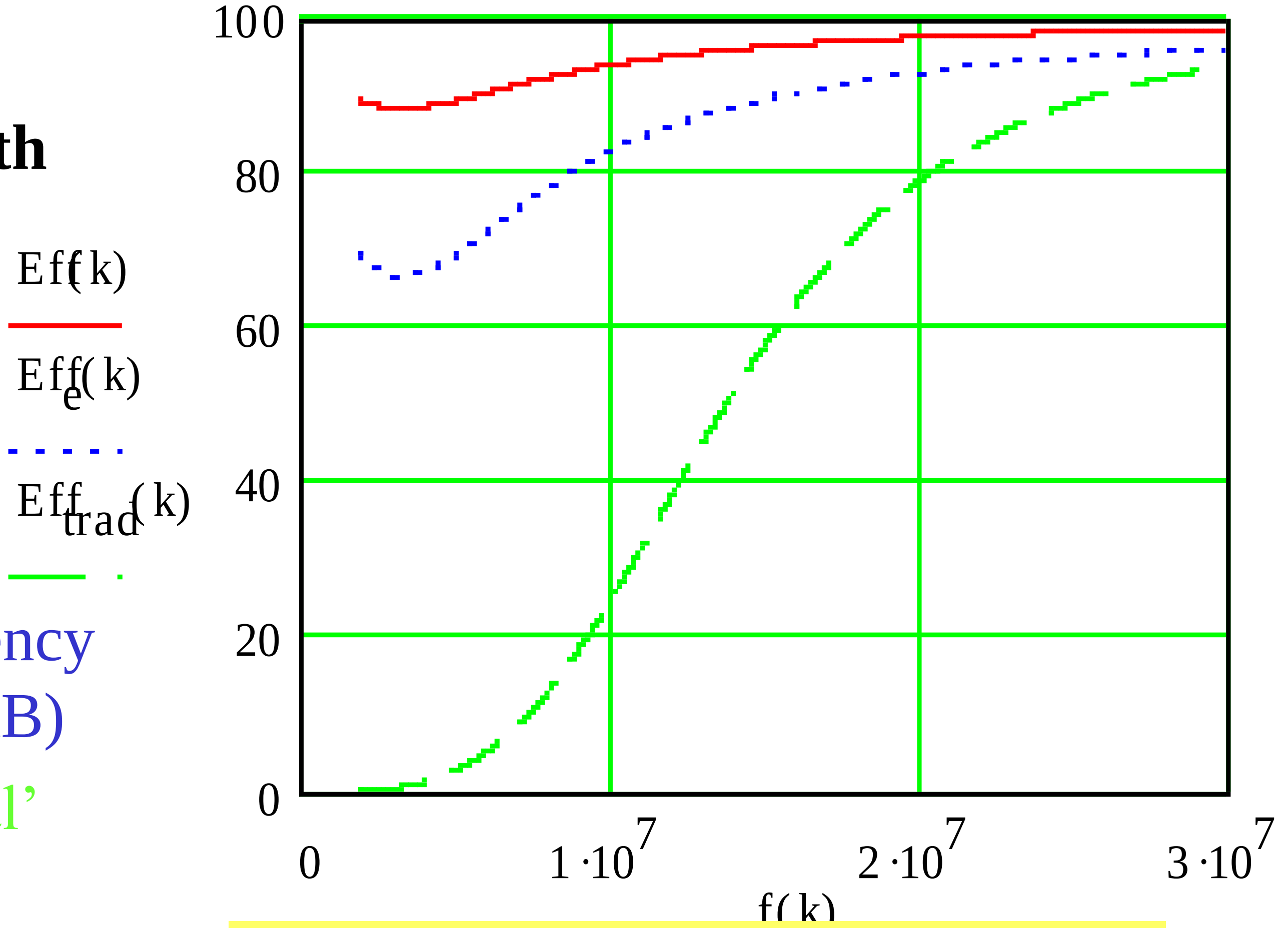
- **Antenna efficiency is**

  = (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 experimentally 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' (like-to-like) propagation/coupling method*
  - *(e) the 'A/B antenna comparison' method*

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

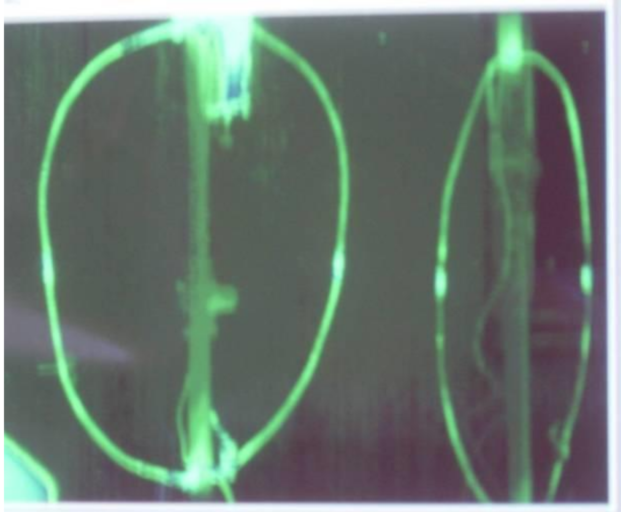
- **Two turn 1m loop with 10mm copper tube:**

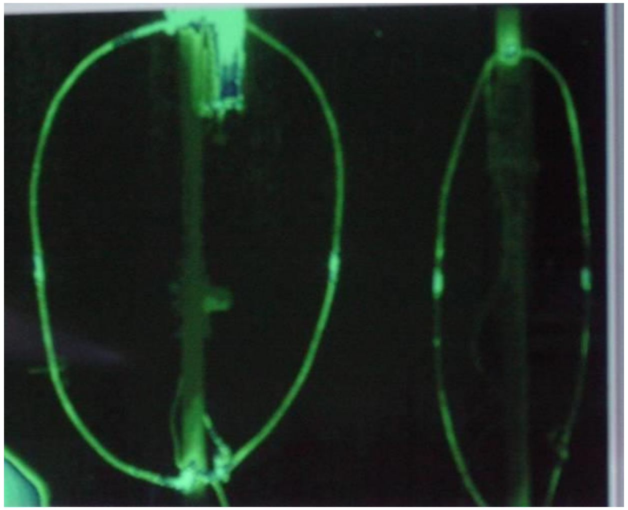
1. Measured Intrinsic Efficiency = Eff(k) >88% (-0.6dB)
2. Measured Environmental Efficiency = $\mathrm{Eff}_e(k)$ >66% (-1.8dB)
3. Traditional ‘classical’ prediction of Loop Efficiency = $\mathrm{Eff}_{trad}(k)$. At 1.8MHz = 0.08% or -31dB !!!!



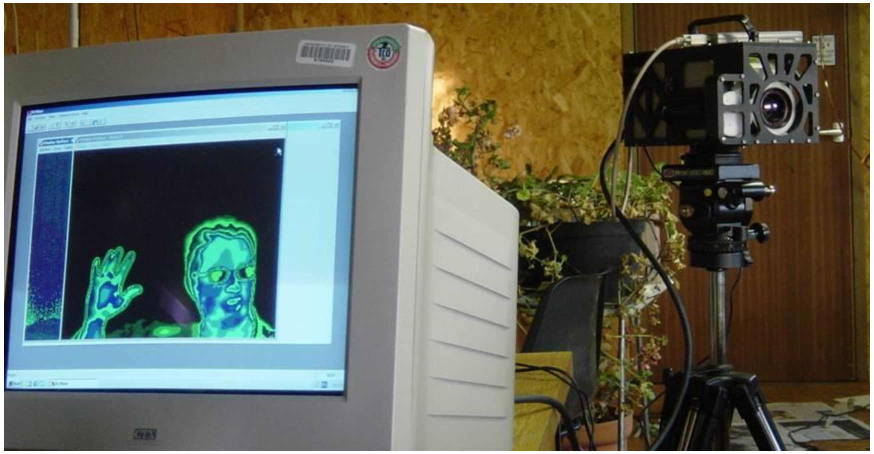
Classical 1.8MHz = -31dB
Theory:- 3.6MHz = -19dB
14MHz = -3dB 5MHz = -13dB
28MHz = -<1dB 7MHz = -6dB

‘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!

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.

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. *Newly discovered loop radiation resistance – the Retarded Biot-Savart Mode*

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

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

- 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*.

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

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 $\sigma = 2\pi f\varepsilon$. $f_c \sim 1\text{-}30$MHz

   – 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 ($f^{½}$)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

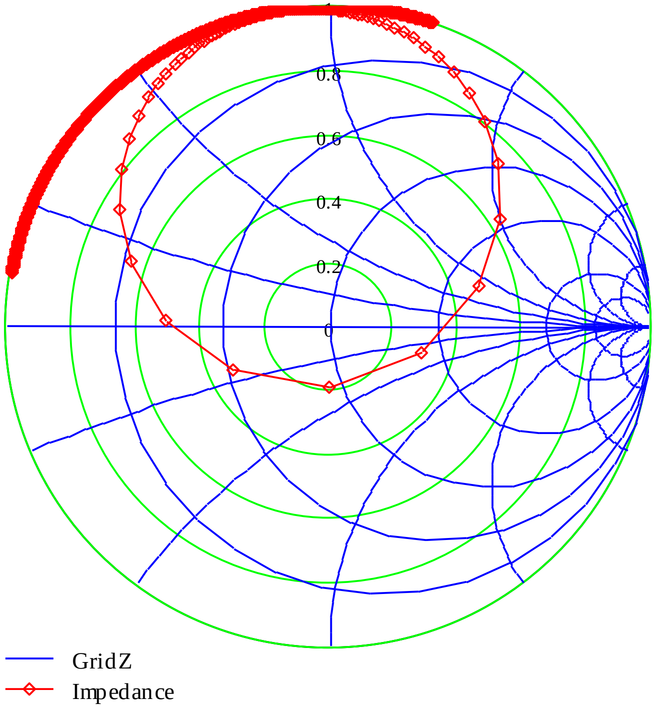
$k_e \equiv 0.08$

$k_t \equiv 0.4$

$k_c \equiv 0.1$

$f_g \equiv 10 \cdot 10^6$

$k_{dip} \equiv 0.39$



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

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

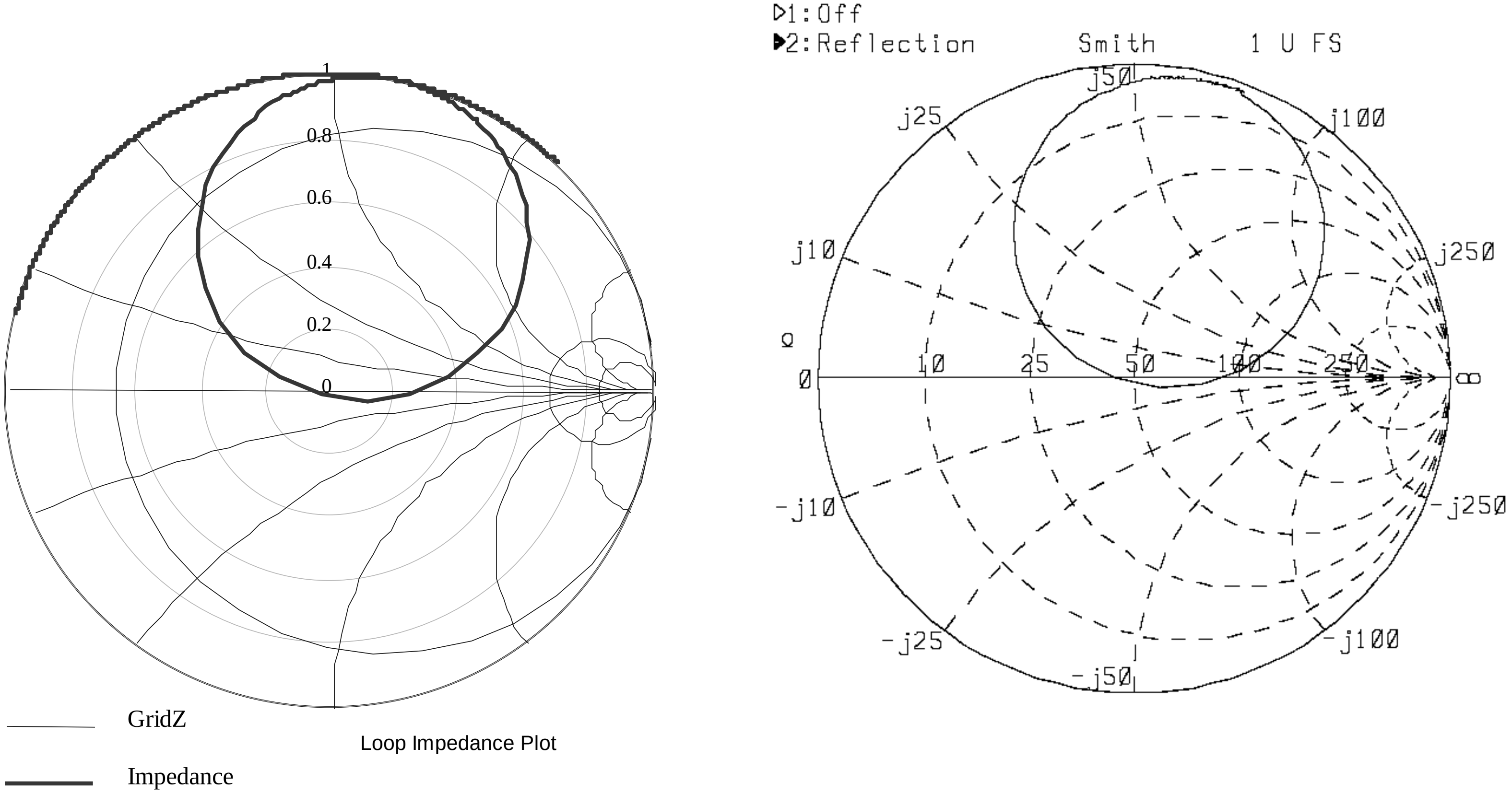
$Q_{il} \equiv 520$

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

f_{res} is the loop resonant frequency

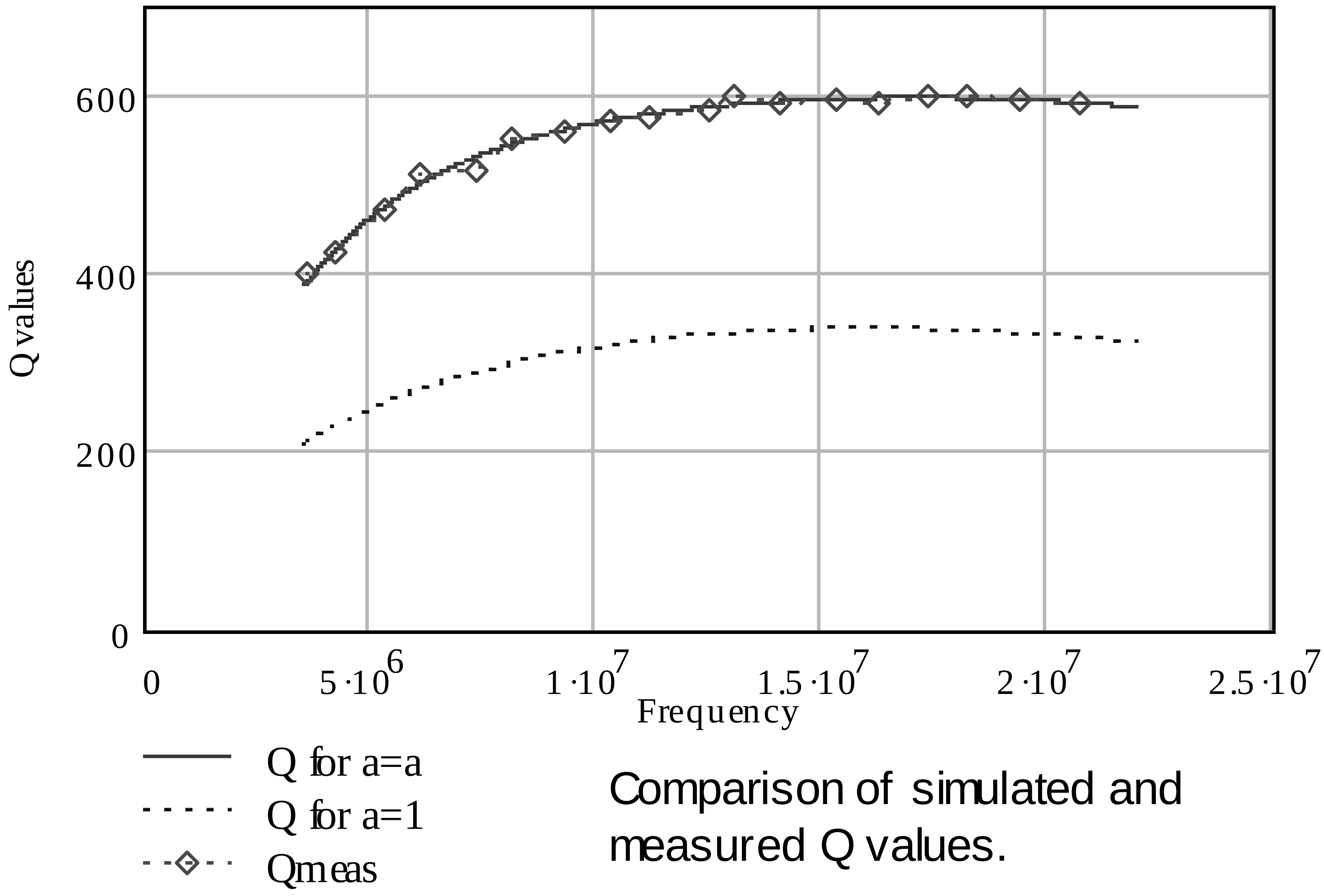
$f_{res} = 1.851 \times 10^7$

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)

Comparison of measured Q values with model predictions over the loop tuning range. Upper with RSS power combining of radiation and loss resistances. Lower with resistances added conventionally.



Comparison of simulated and measured Q values.

MJU Mathcad Loop Worksheet - 2

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

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

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

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

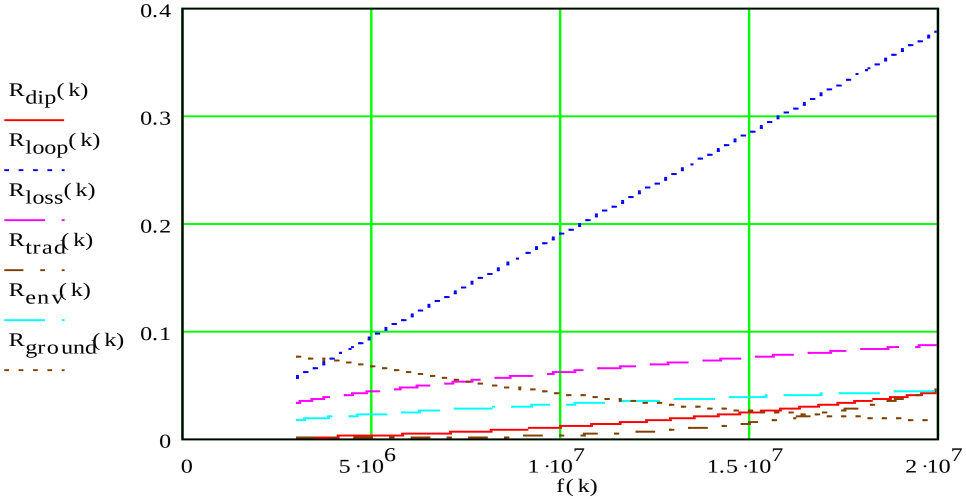
$$R_{env}(k) := k_{e}\cdot\left(f(k)\cdot 10^{-6}\right)^{0.5}$$

Select Q table

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

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

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



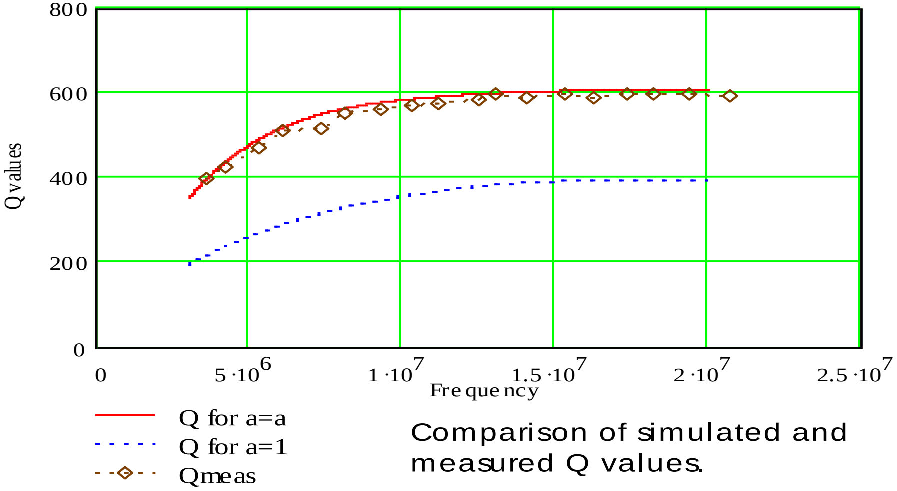
$$R_{tot1}(k) := \begin{pmatrix} R_{loss}(k)\ \ldots \\ + R_{ground}(k)\ \ldots \\ + R_{loop}(k)\ \ldots \\ + R_{env}(k)\ \ldots \\ + R_{dip}(k)\ \ldots \\ + R_{trad}(k) \end{pmatrix}$$

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

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

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

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



Comparison of simulated and measured Q values.

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

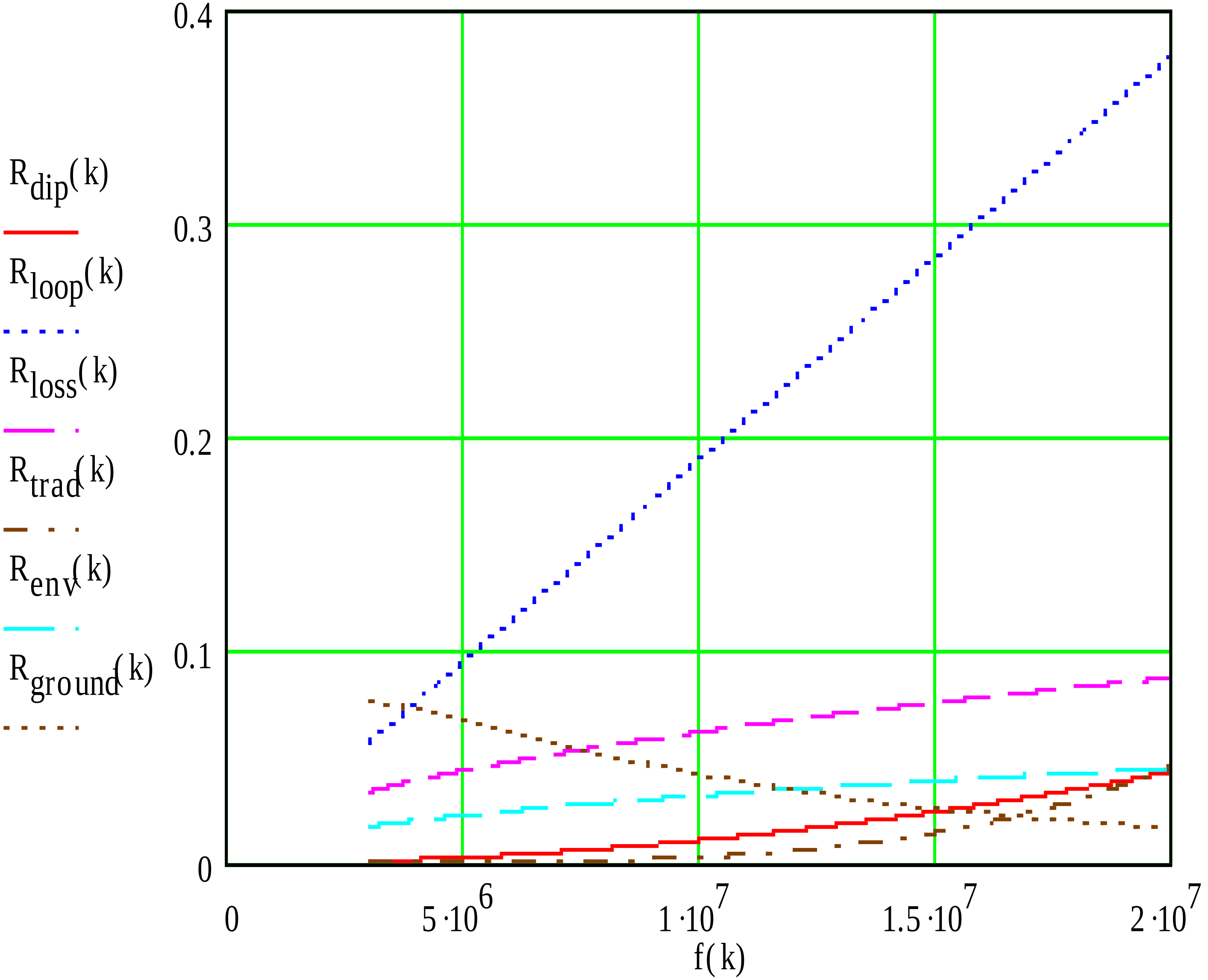
Operating Bandwidth for 1.5:1 SWR, BW(k) = 0.35BW(3dB)

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

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

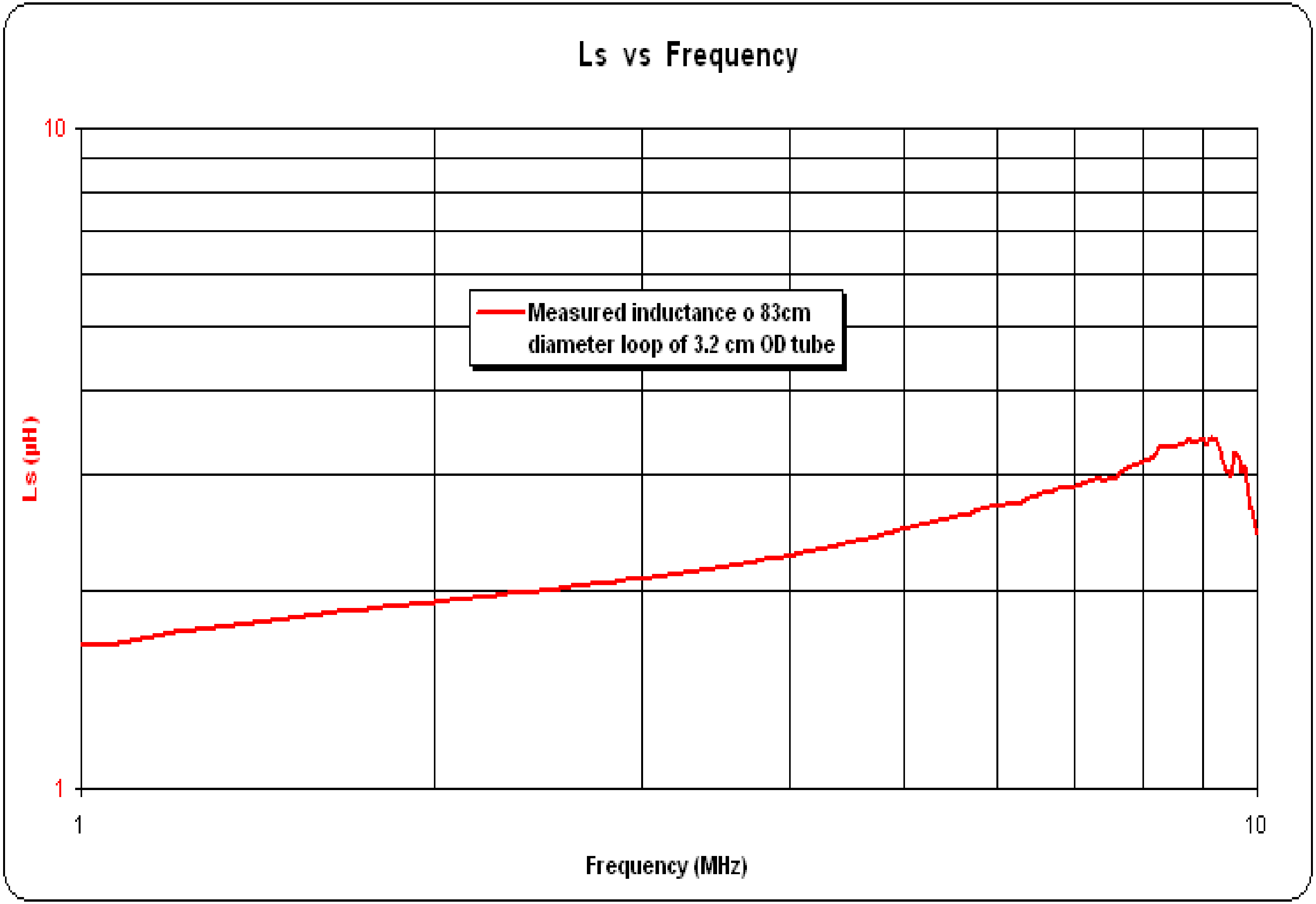
$$Q_{min}(reality) = [\{120\}^2/ka + (ka)^6]^{0.5}$$

  - ***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

$$R_{dip}(k) := \left(k_{dip}\cdot\frac{f(k)\cdot D_{loop.m}}{3\cdot10^{8}}\cdot\frac{\pi}{2}\right)^{2}\cdot200$$

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

$$R_{trad}(k) := \left[k_t\cdot\left(\frac{f(k)\cdot D_{loop.m}}{3\cdot10^{8}}\right)\right]^{4}\cdot10\pi^{6}$$

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

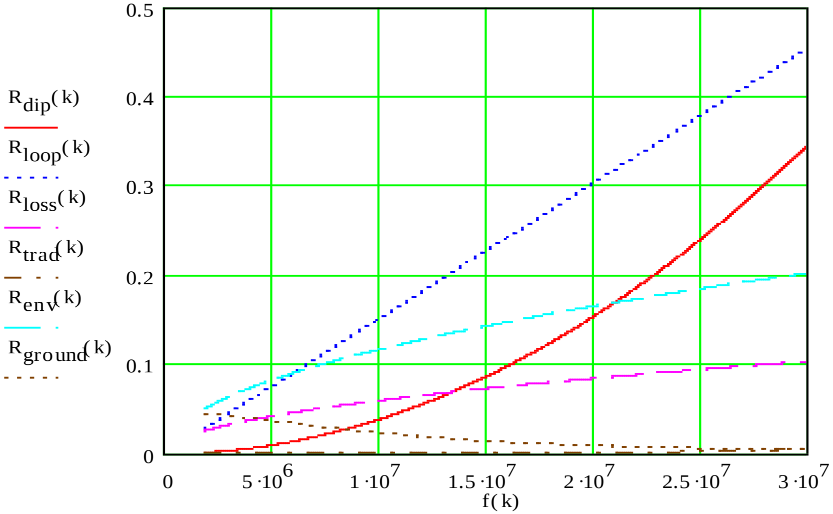
$$R_{env}(k) := k_e\cdot D_{loop.m}^{2}\cdot\left(f(k)\cdot10^{-6}\right)^{0.5}$$

Select Q table

$Q_f := Q_{f2}$

$$R_{loss}(k) := b\cdot\left(f(k)\cdot10^{-6}\right)^{0.5}$$

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



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

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

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

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

$$Z_1(k) := \frac{1\cdot k_m^{2}\cdot R_{tot}(k)^{-1}\cdot\left(\omega_k\cdot L_1\right)^{2}}{1+\left(\omega_k\cdot L_2\right)^{2}\cdot50^{-2}}$$

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}: $k_c = 0.1$

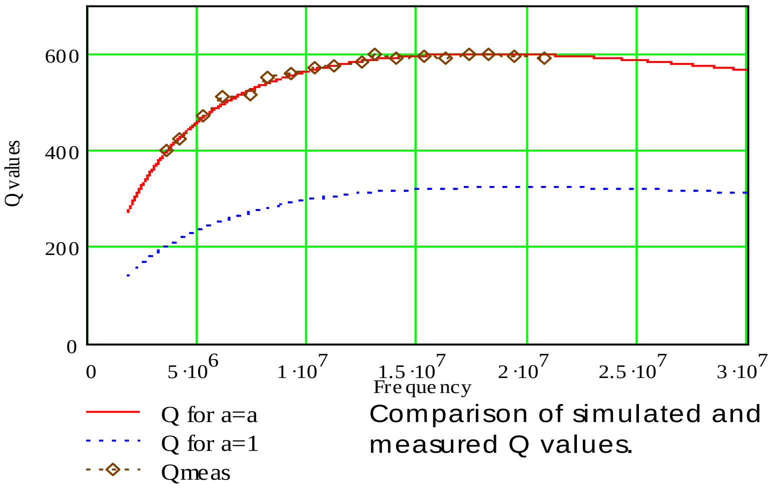
and f_g = 10MHz

$k_{dip} = 0.39$

$k_m = 1/20$ $Q_{ml} = 520$

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

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



Comparison of simulated and measured Q values.

$$Eff_e(k) := \left[1-\left(\frac{R_{loss}(k)^{a}+R_{env}(k)^{a}}{R_{tot}(k)^{a}}\right)^{\frac{1}{a}}\right]\cdot100$$

$$Eff(k) := \left[1-\left(\frac{R_{loss}(k)}{R_{tot}(k)}\right)^{1}\right]\cdot100$$

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

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

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}: $k_c = 0.125$
and $f_g = 20MHz$
$k_{dip} = 1$
$k_m = 1/20$
$Q_{il} = 520$

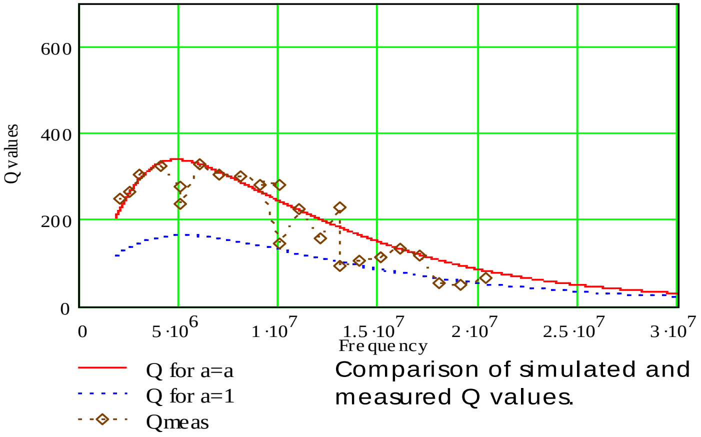
$1 + (\omega_k \cdot L_2) \cdot 50$

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

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

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

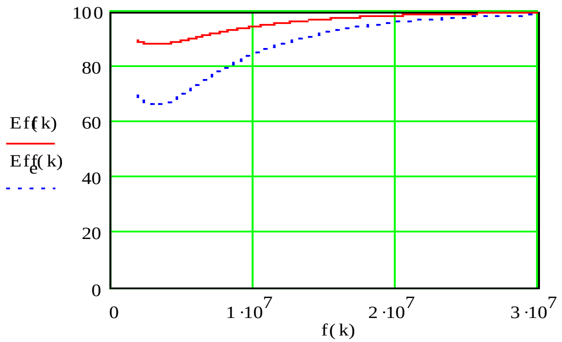
$$Eff(k) := \left[1 - \left(\frac{R_{loss}(k)}{R_{tot}(k)}\right)^1\right] \cdot 100$$

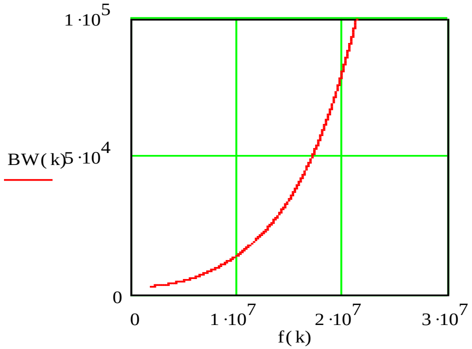


Comparison of simulated and measured Q values.

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

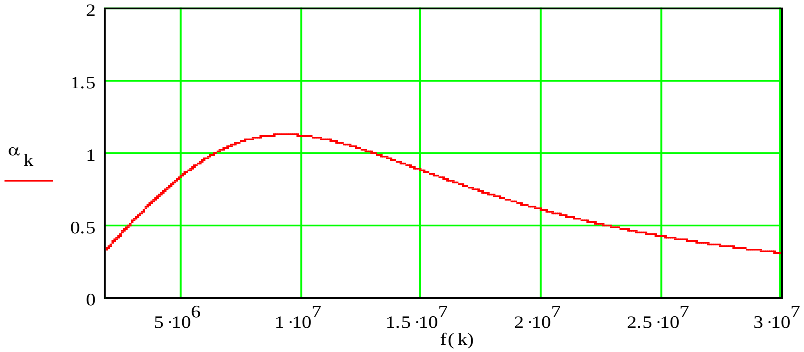
$$BW(k) := \frac{0.35 \cdot f(k)}{Q_{BW}(k)}$$





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

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)



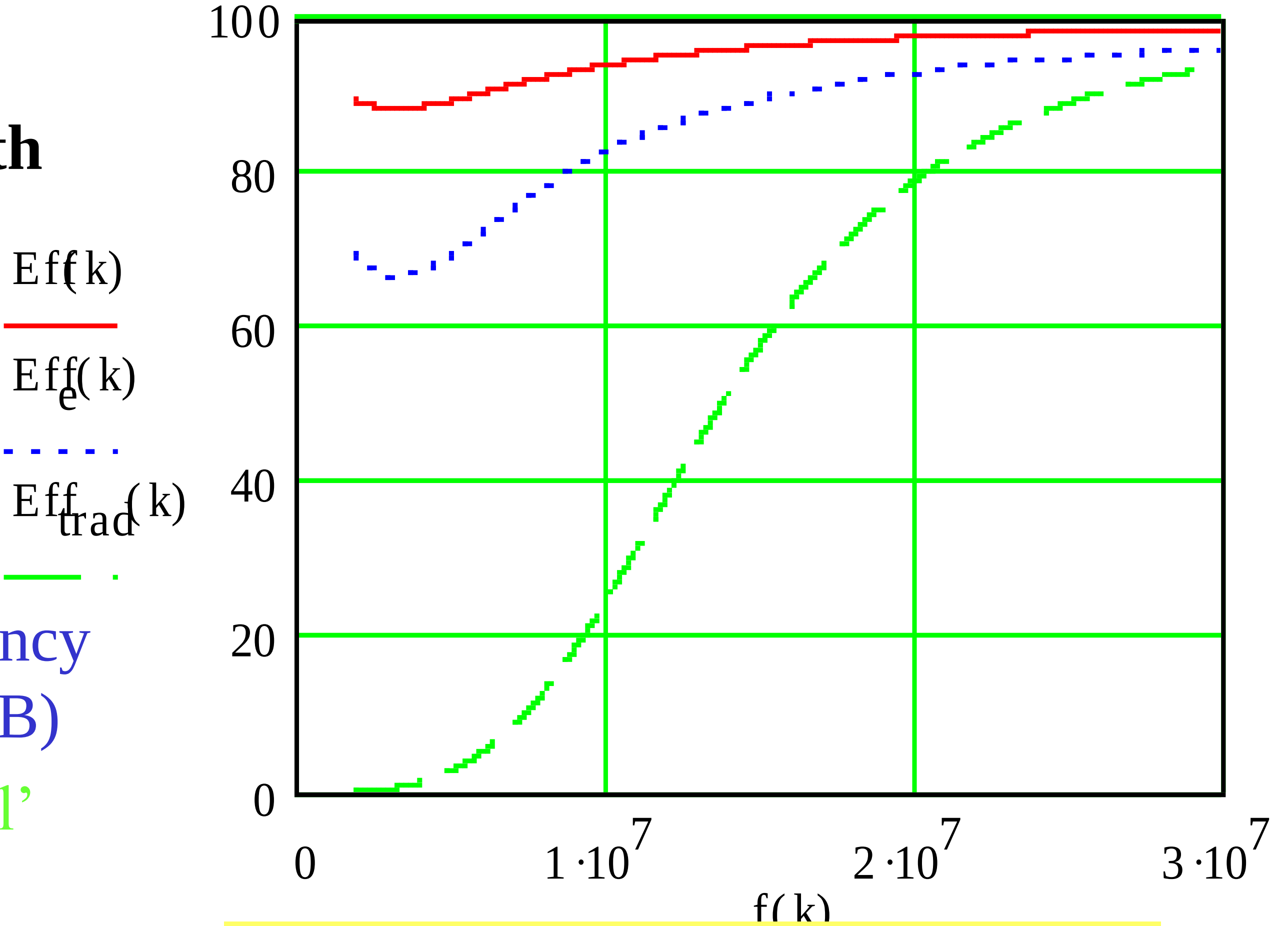
Using Heuristics to resolve the ‘Loop Controversy’ once and for all time!

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 !!!!



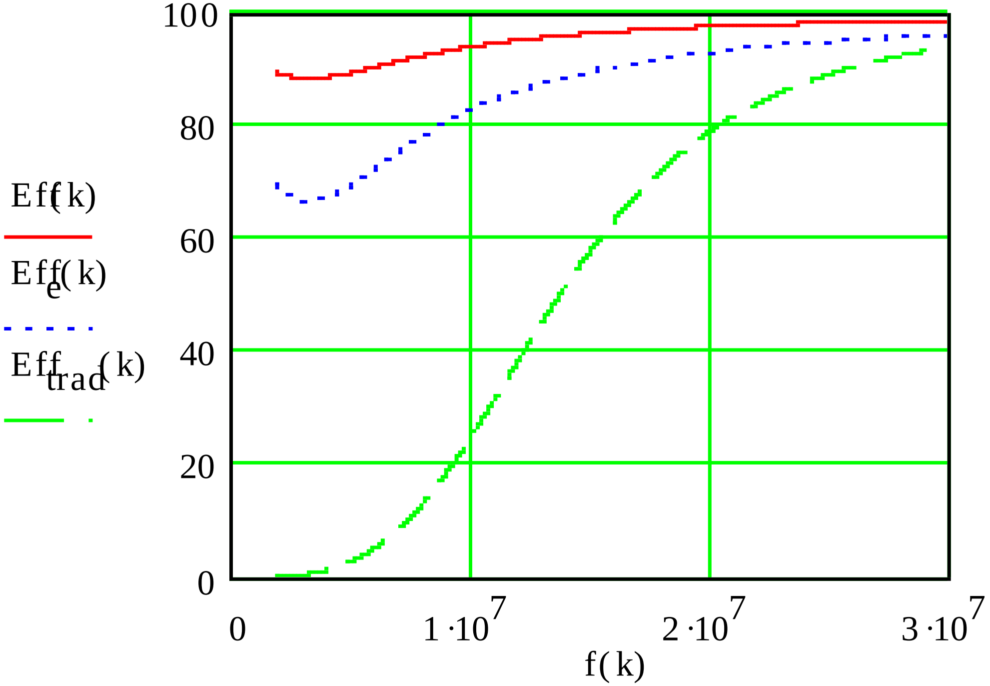
Classical Theory:-
14MHz = -3dB
28MHz = -<1dB

1.8MHz = -31dB
3.6MHz = -19dB
5MHz = -13dB
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 !!!!

G3LHZ

Heuristics for (Loop) Antennas with Propagation

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

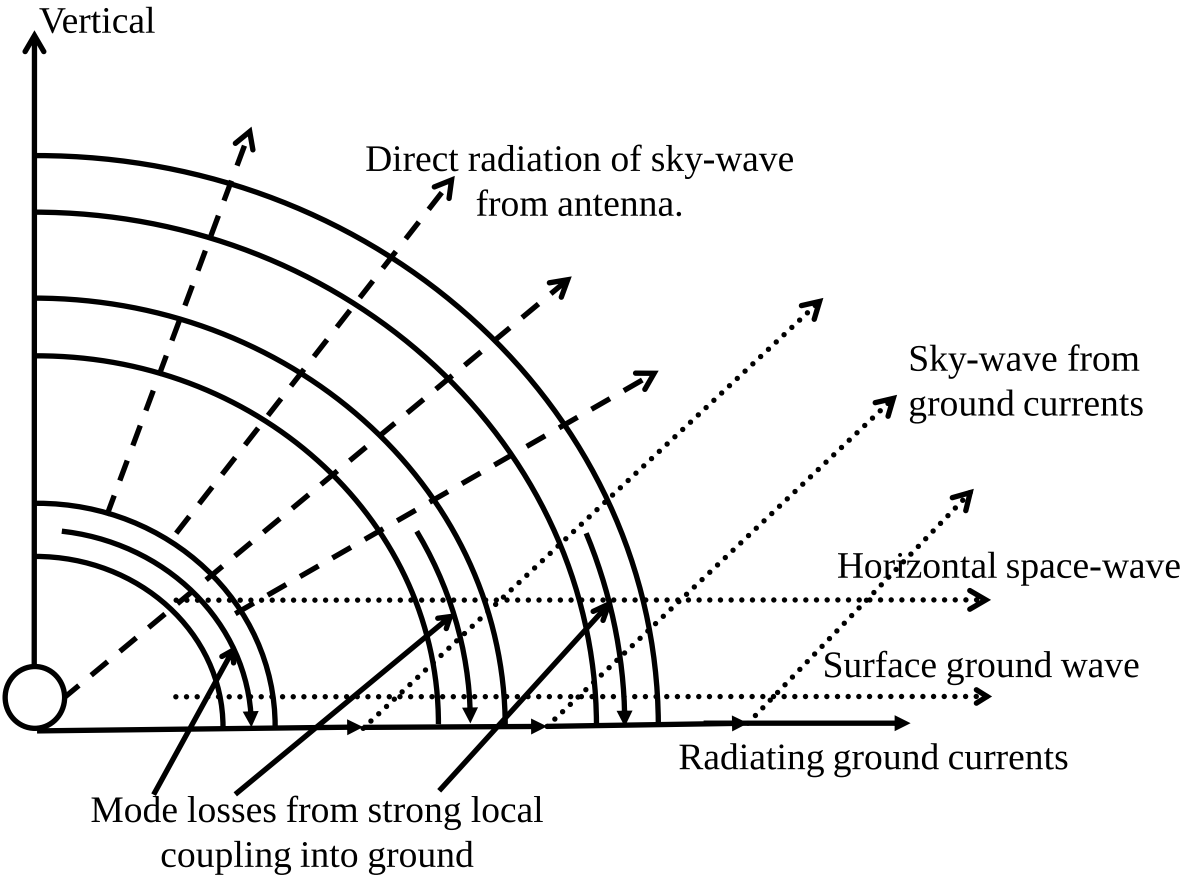
1.Heat losses in antenna.

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



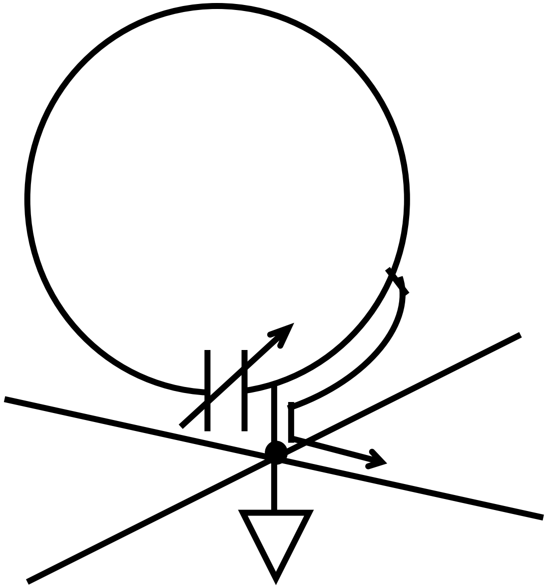
Where does the input power go? How much power couples straight into the ground under a small antenna? Does this propagate under the ground? What is the pattern and polarisation of the antenna when close to ground as compared to free space? How much surface/ground wave is launched, and of what type? Are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

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

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?

The G3LHZ loop-monopole arrangement



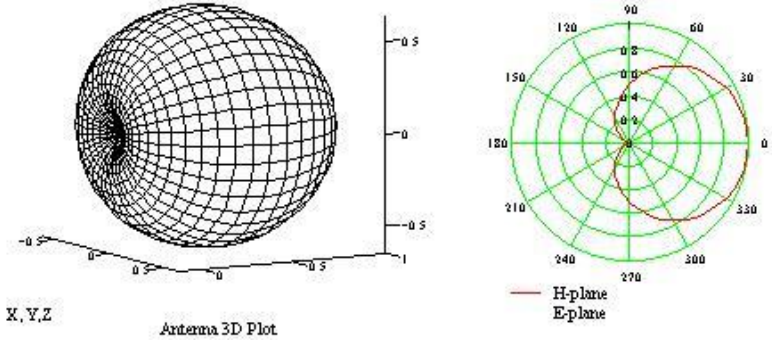
- Gamma-fed Grounded Monopole-Loop with small ground plane.
- The ground-plane can be a ‘bowtie’ about twice or three times the loop size
- An attic ground-plane much reduces EMC interference to and from house wiring
- The pattern is of a vertical monopole combined with a vertical loop.
- It is directional 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.

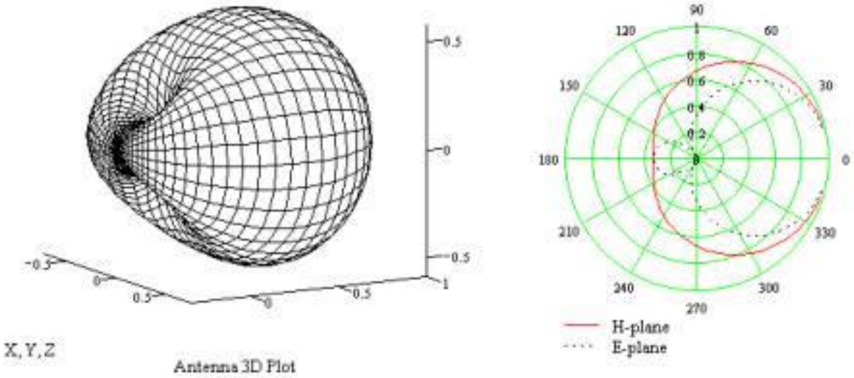
$R_{0,0} = 2$ F = 20 log(F) = α = dipole/loop

d = 0 10log(D) = 4.777 D = 3.004121 α = 1



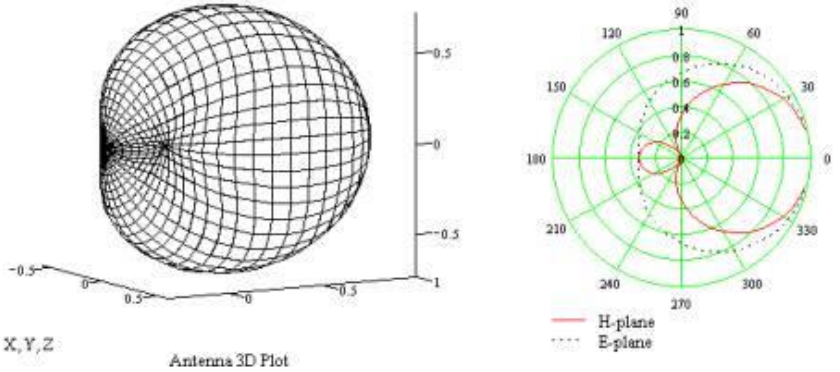
$R_{0,0} = 3$ F = 3 20·log(F) = 9.542 α = dipole/lo

d = 0 10·log(D) = 4.32 D = 2.7037089 α = 2



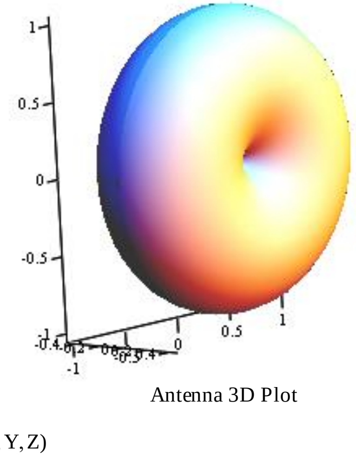
$R_{0,0} = 1.5$ F = 3 20·log(F) = 9.542 α = dipole/loop

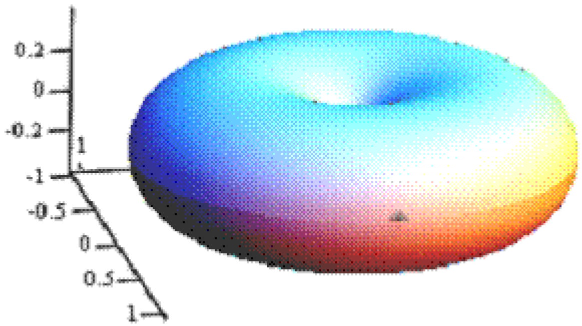
d = 0 10·log(D) = 4.32 D = 2.7037089 α = 0.5



Simulated Heuristic Loop Patterns –

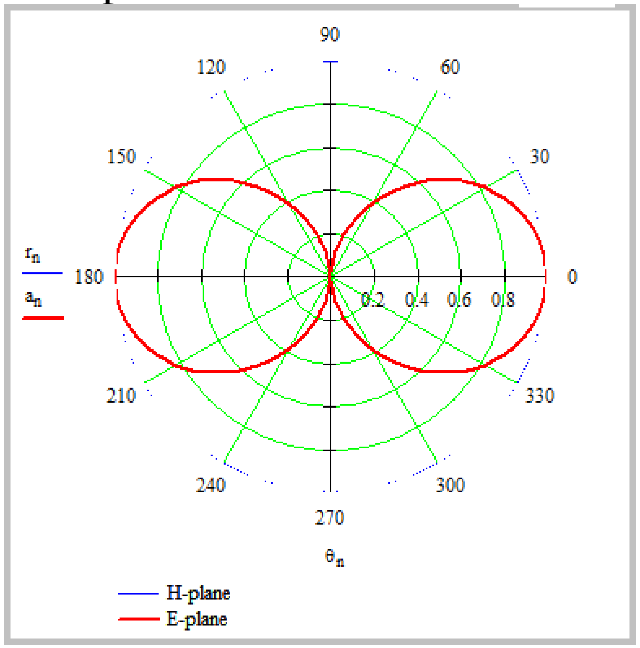
Mini-Loop on left. λ/2 Midi-Loop on right

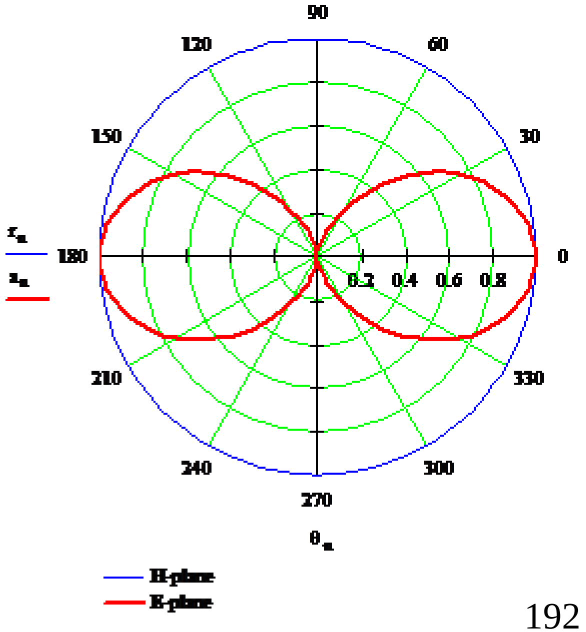




Mini-Loop Directive Gain = 1.5 = 1.76dBi

Midi-Loop Directive Gain = 1.87 = 2.7dBi





Shifnal CFA and Matching Network – 26 March 2002

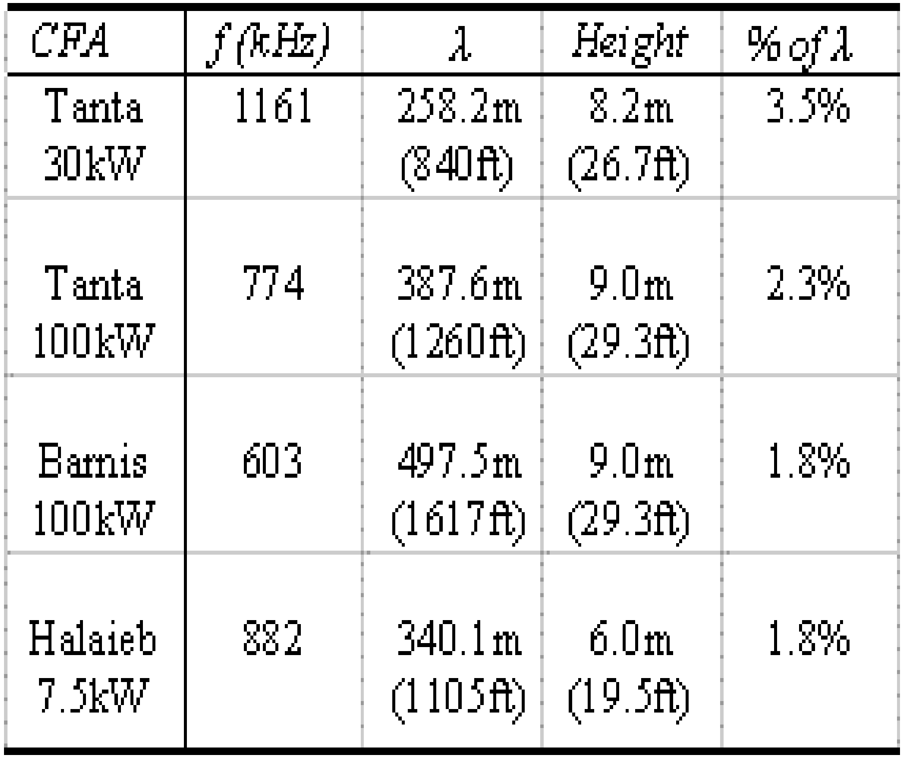
Environment of CFA at Shifnal (Tong) – 972 kHz

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.

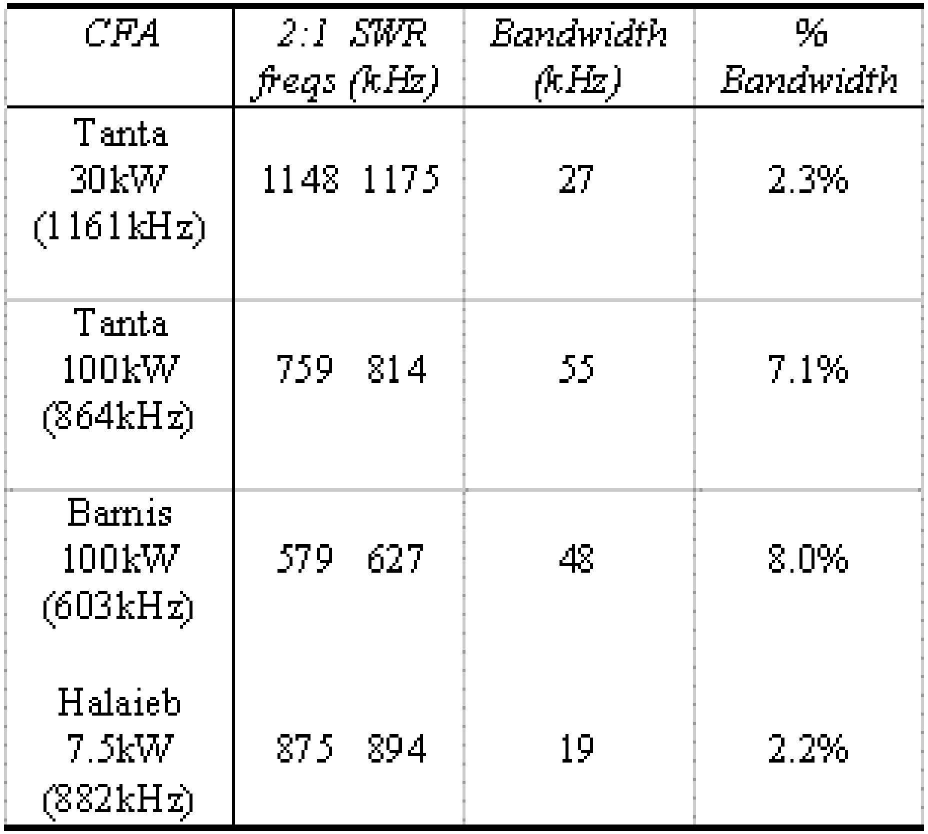
CFAs at Tanta in Egypt

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

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

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.

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:-**

Arnos EH Dipole - 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:

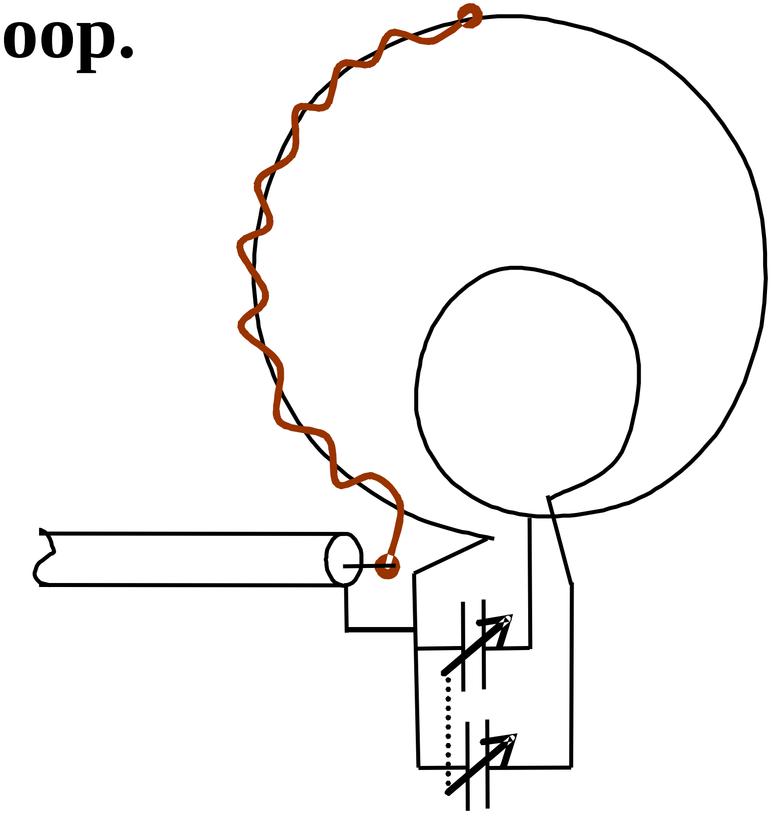
- Can the two sides agree to separate *environmental losses* from *antenna losses* and to measure these separately?
- Can the two sides avoid claming that that there is only one way to measure *antenna efficiency* and theirs is the only way?
- **Can the two sides agree a set of measurements that will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

Multi-mode and multi-resonant loops

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

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

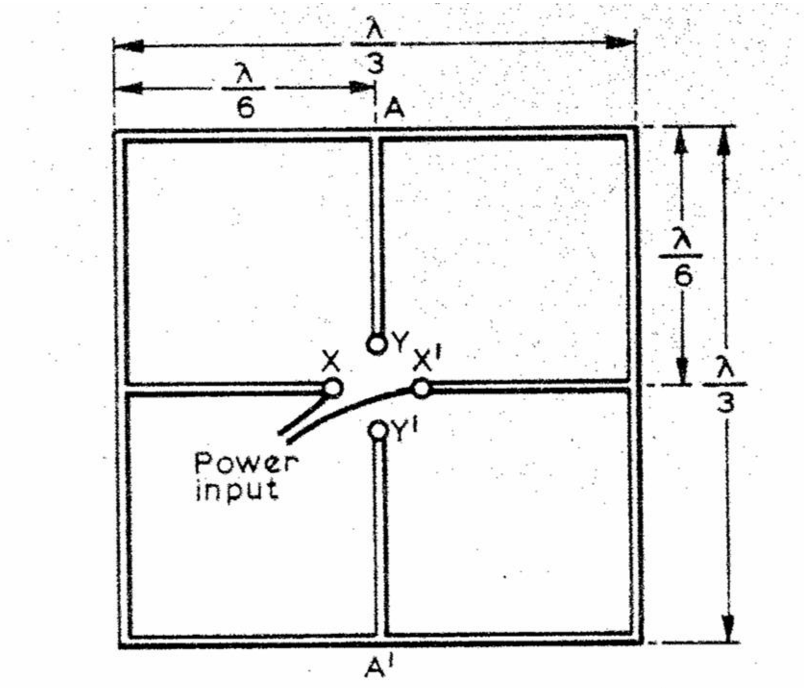
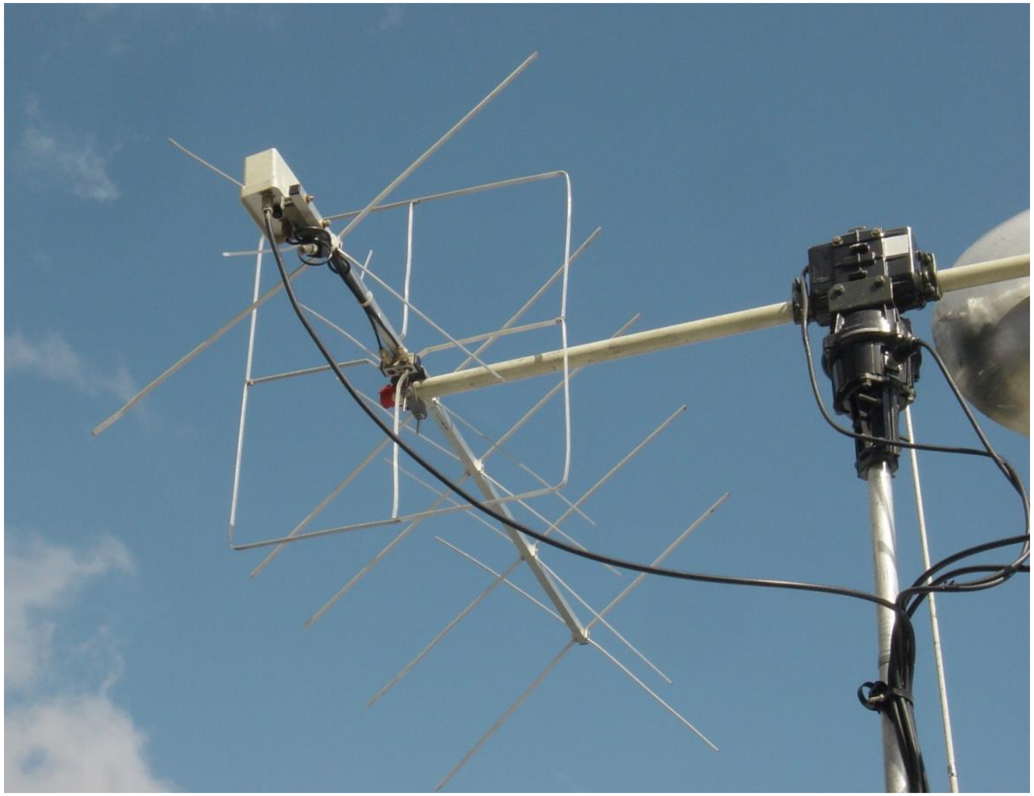


Fig 3. Isolated inputs of the new quad element

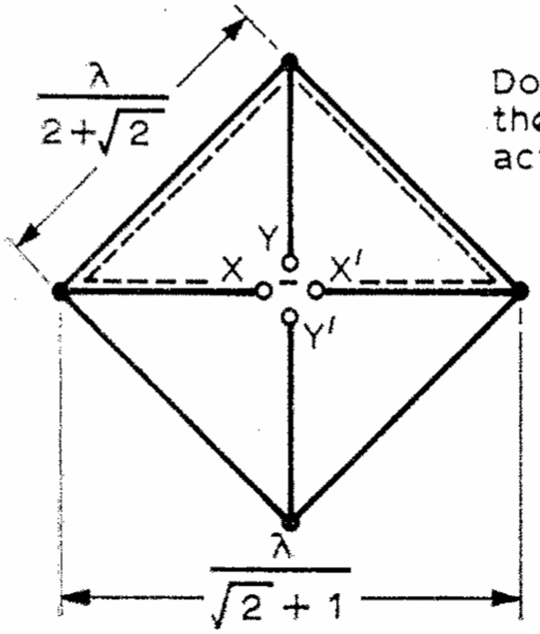
‘The ip quad – a new versatile quad driven element’
by M. J. Underhill, G3LHZ,
Radio Communication,
September 1976



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

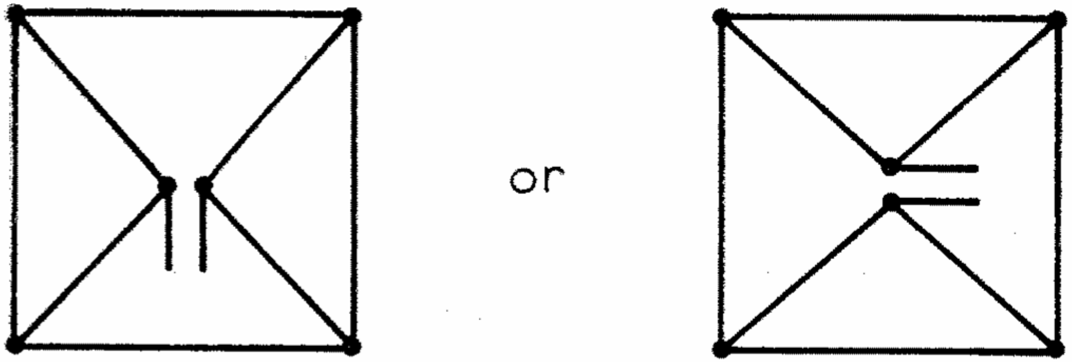
G3LHZ Diagonal IP-Quad

First Reported in
Technical Topics
November 1976



Dotted line shows one of the horizontally polarized active loops = λ long

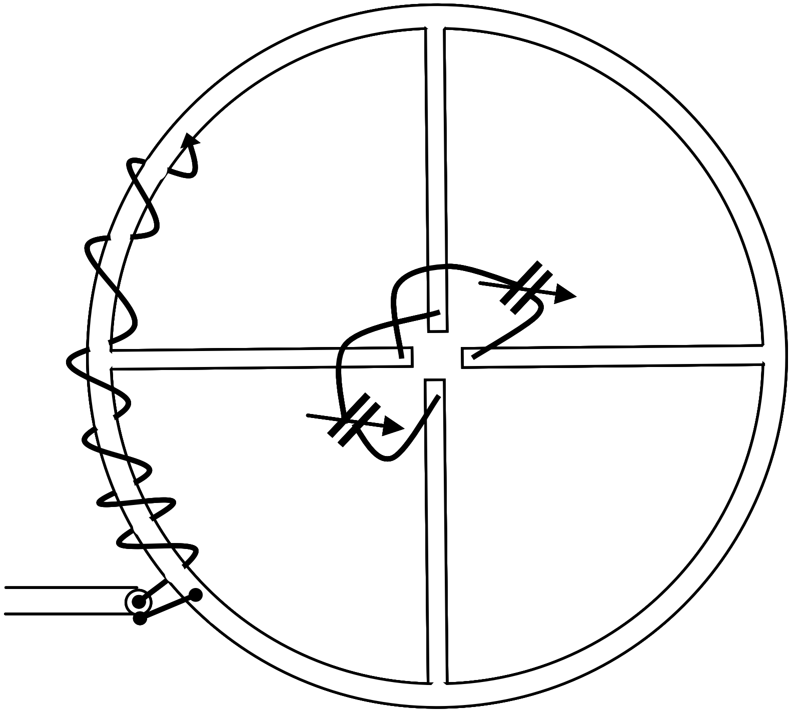
Fig 4. Modified form of ip quad element developed by G3LHZ and termed a dip quad



(a) Horizontal polarization (b) Vertical polarization

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



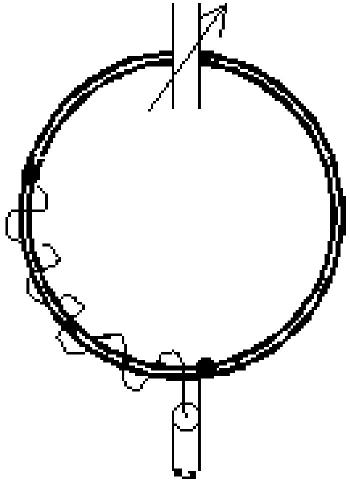
- Based on IP quad structure but much ‘smaller’ with respect to a wavelength.
- Independent two frequency tuning.
- Polarisation can be changed from horizontal to vertical by varying the tuning.
- When both ‘ports’ tuned to the same frequency the bandwidth is nearly doubled.
- 1.7 m diameter loop of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

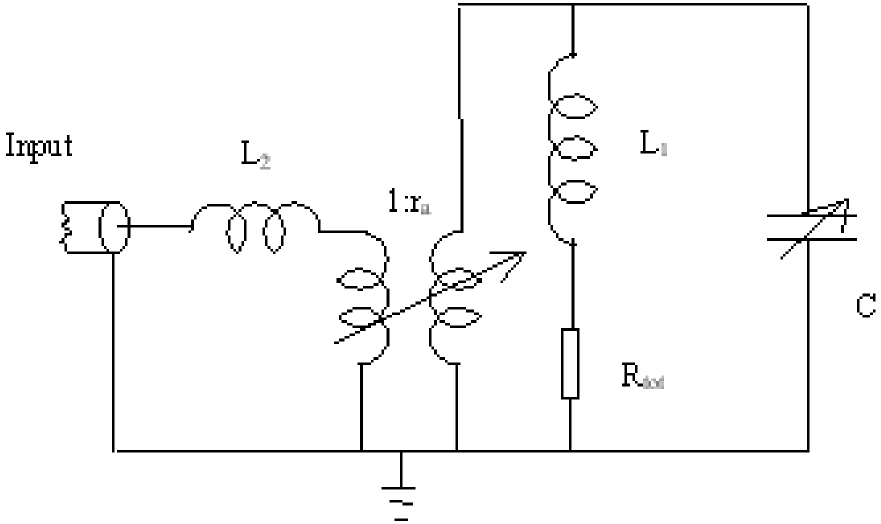
Reasons for Corner Fed Square Loop

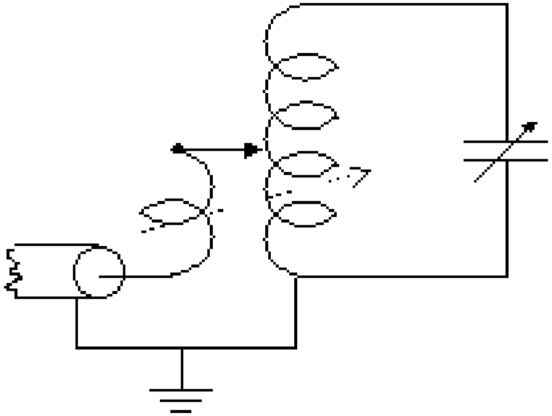
- Above1m ‘Egg-beater’ for LF, with ‘figure-of-eight’ loop inside for HF is too complicated. However both work well
- Parallel loops double the bandwidth and reduce inductance.
- Reduced inductance gives greater power handling at the cost of a larger tuning capacitor. Q is also about 1/√2 lower.
- Corner 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

Loop Matching and Equivalent Circuits





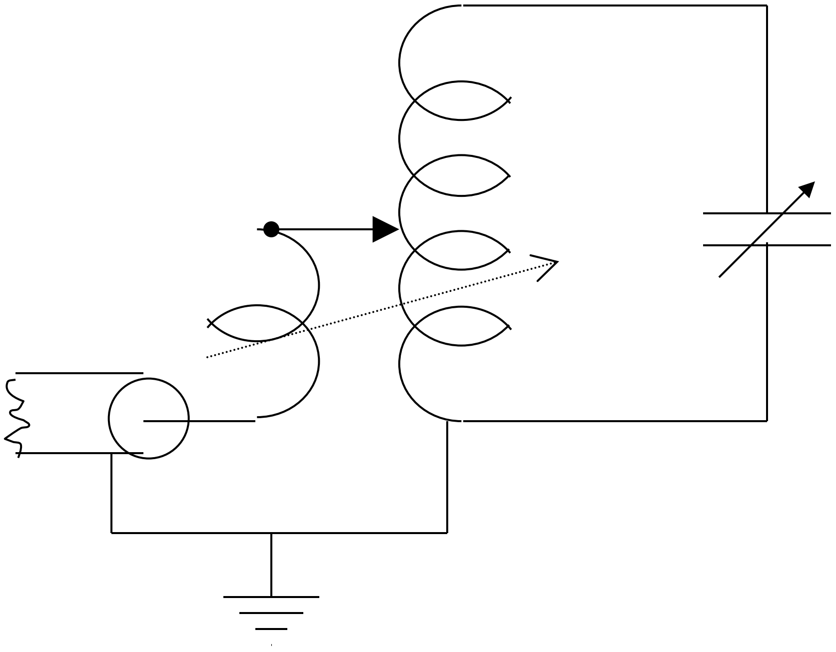


The Twisted Gamma Match - 1

- 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.

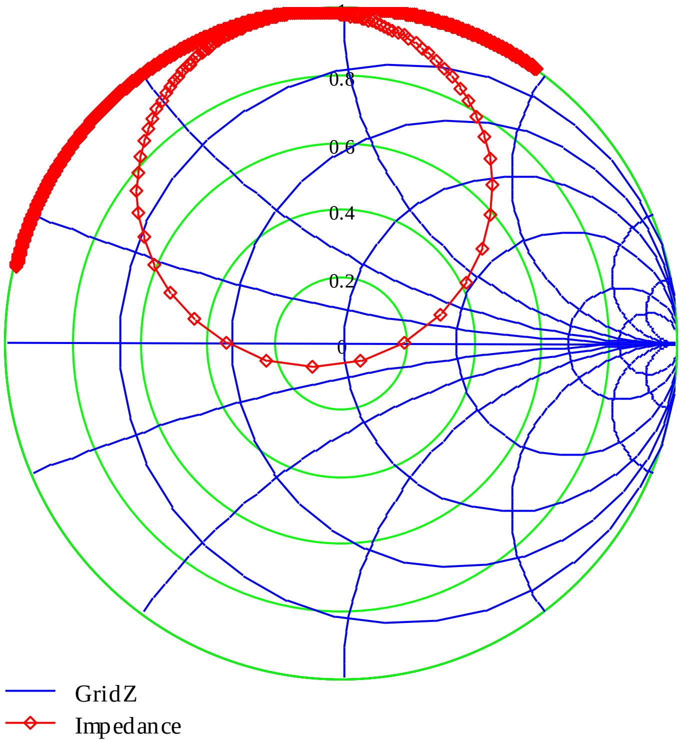
The Twisted Gamma Match - 2

- 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)

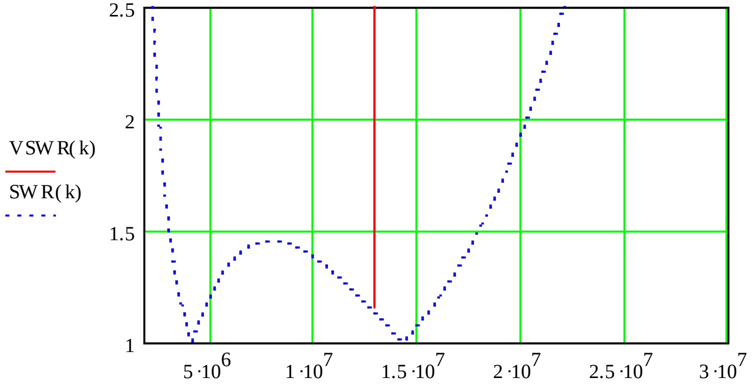


Smith Chart - (r = 0.2 is 1.5:1 SWR)

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

f_{res} is the loop resonant frequency

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



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. =I /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: $L_1 = 2.569 \times 10^{-6}$

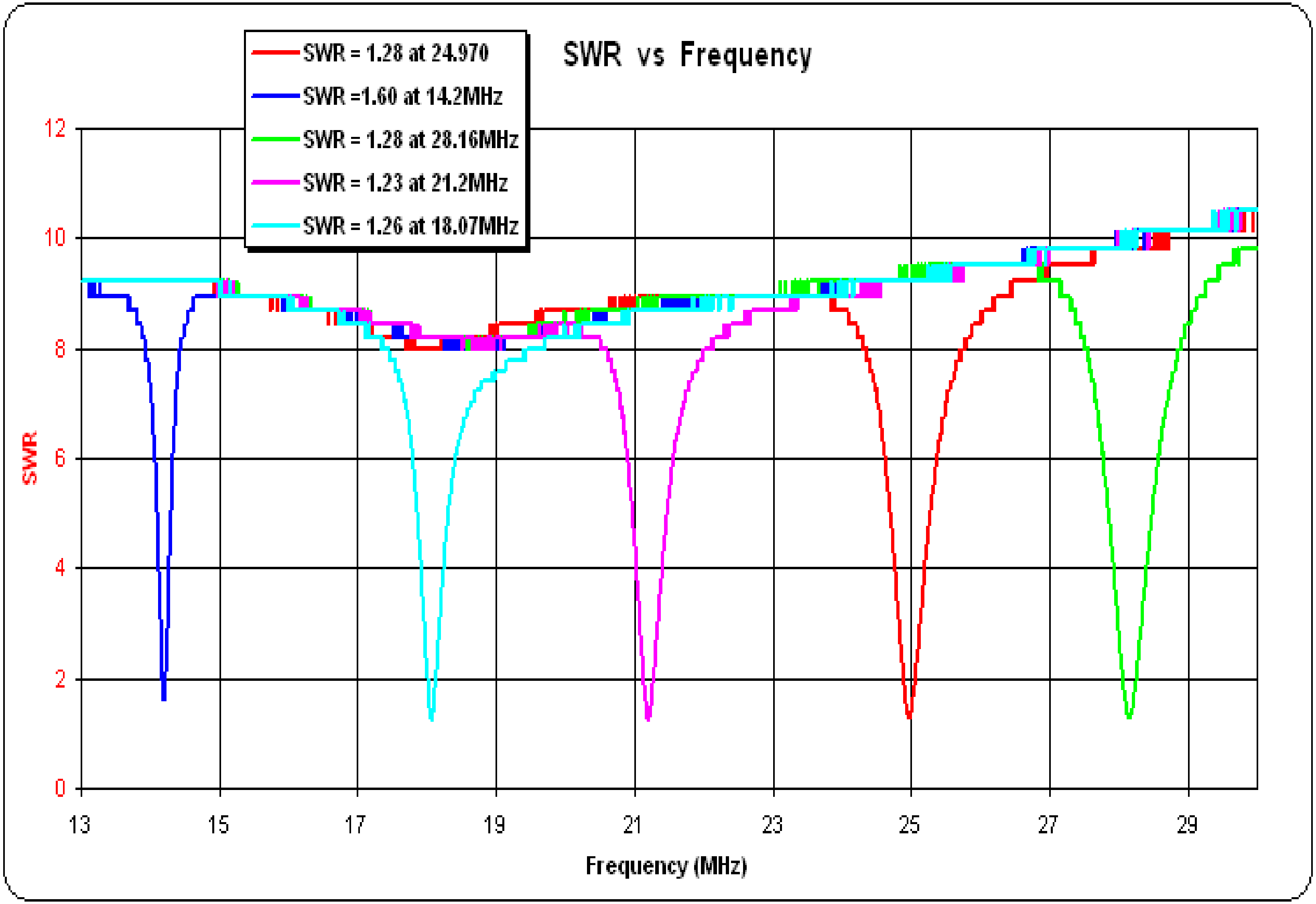
Choose extra input inductance factor:

$\alpha_{Lgam} \equiv .2$

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

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

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

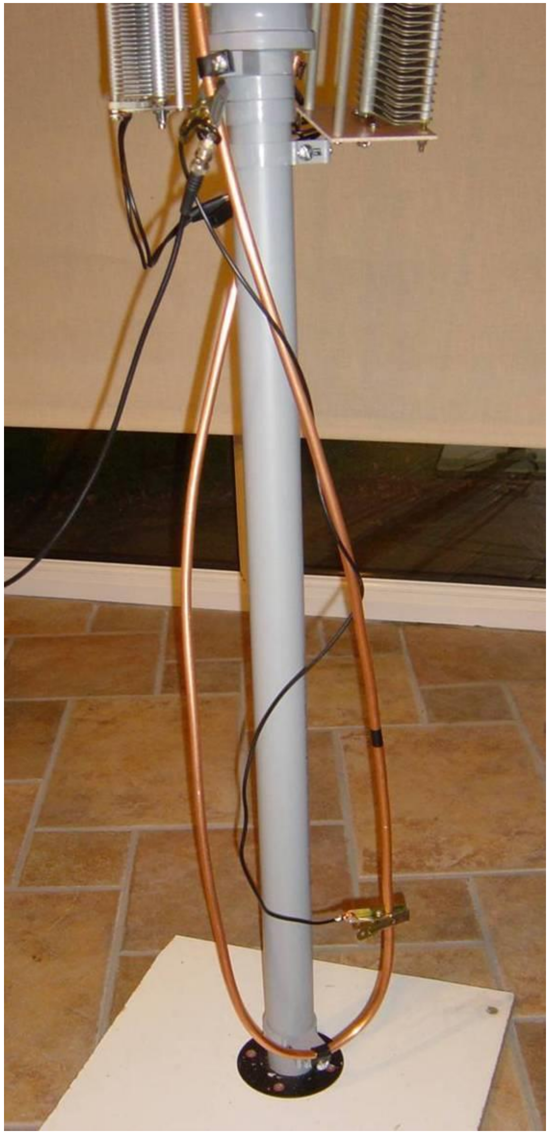
   $$v_g = c_{em}/Q_{loc}$$

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?

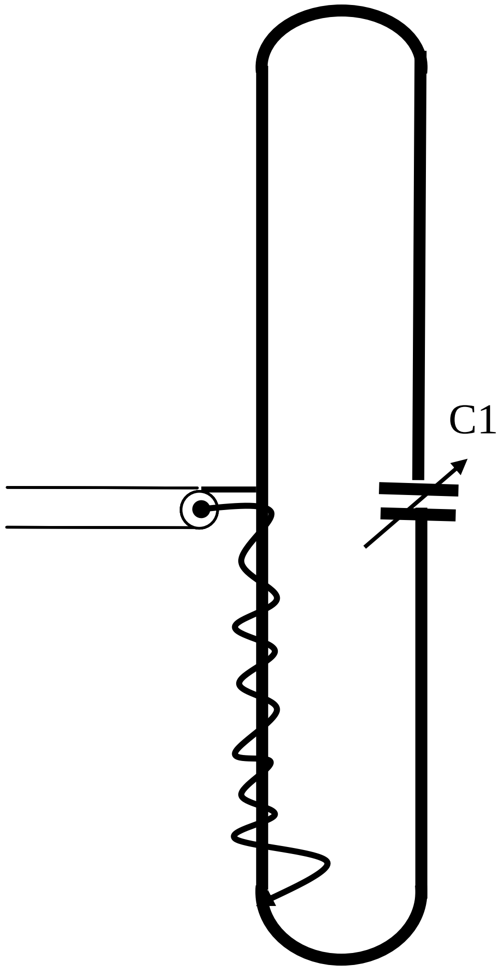
- Traditional theory says that none of these antennas should work. But they do!
- Q and heat measurements once again show efficiencies of 80% to 90% or more.
- Can we use heuristics to find out why?
- What can we observe from these ‘impossible’ antennas?

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

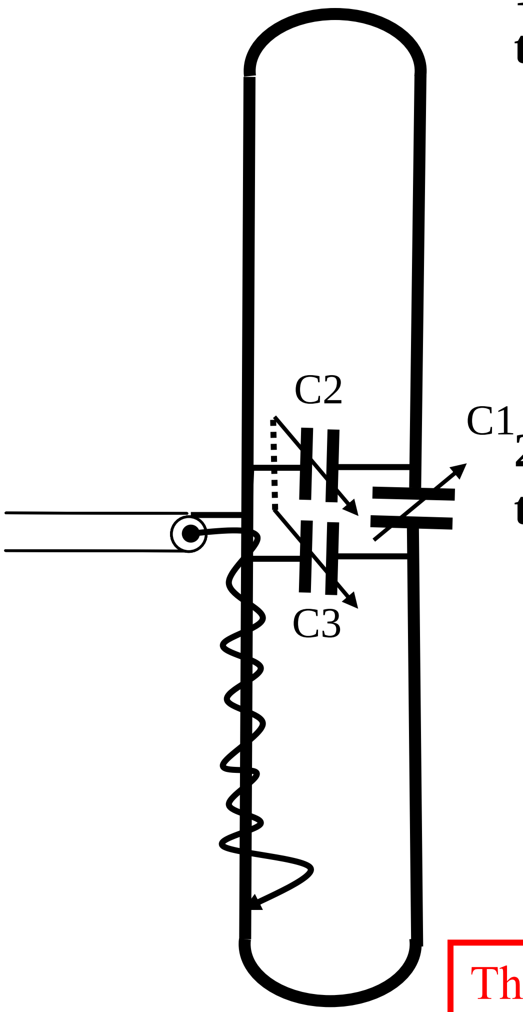


Basic and Double Tuned Folded Dipoles Compared

(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:

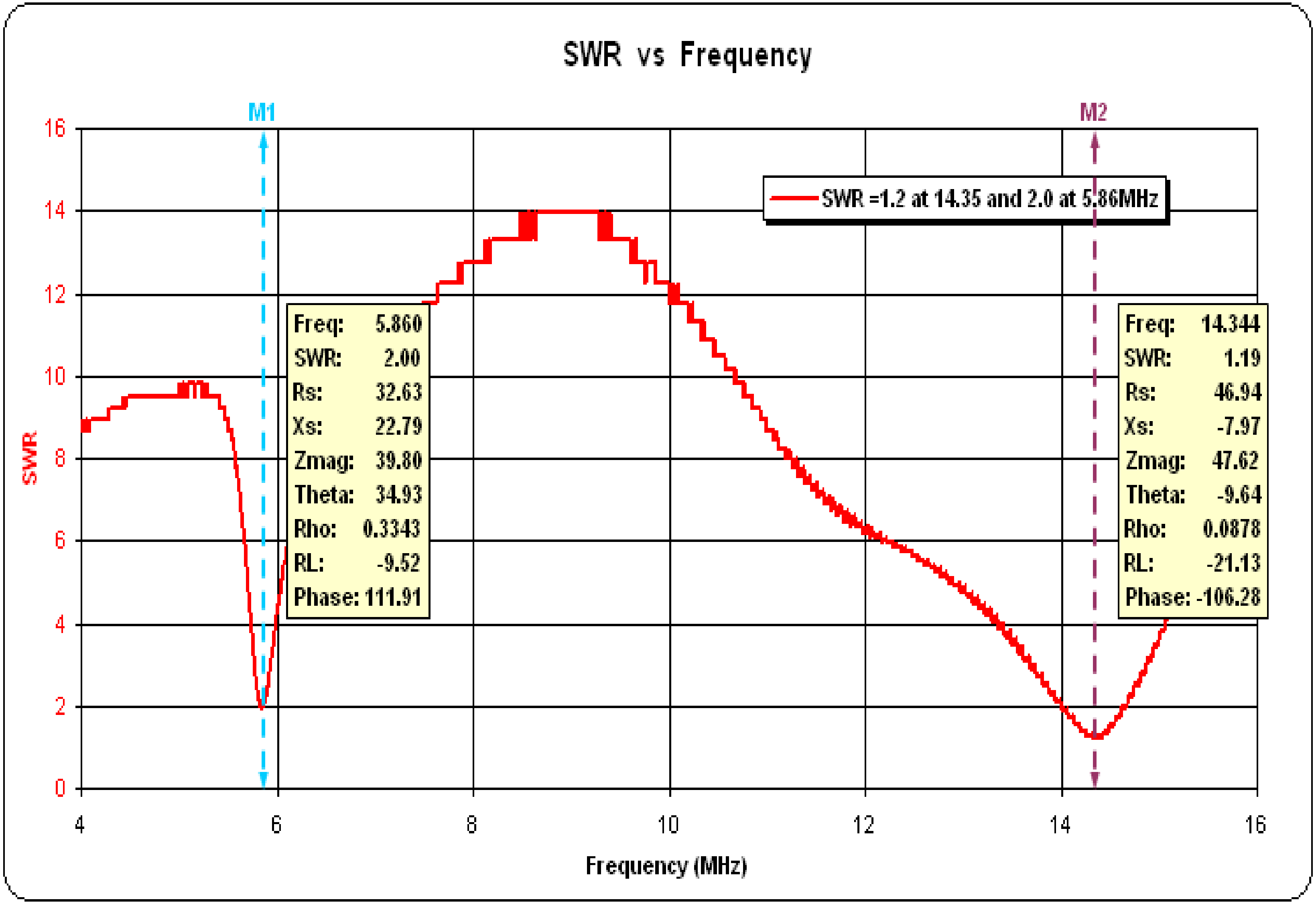
- Tuning ranges 1.8 to 11MHz and 5 to 45MHz
- Without capacitor switching
- Q about 150 over both ranges
- Two switched gamma matches recommended

The ‘radiating currents’ cancel out.

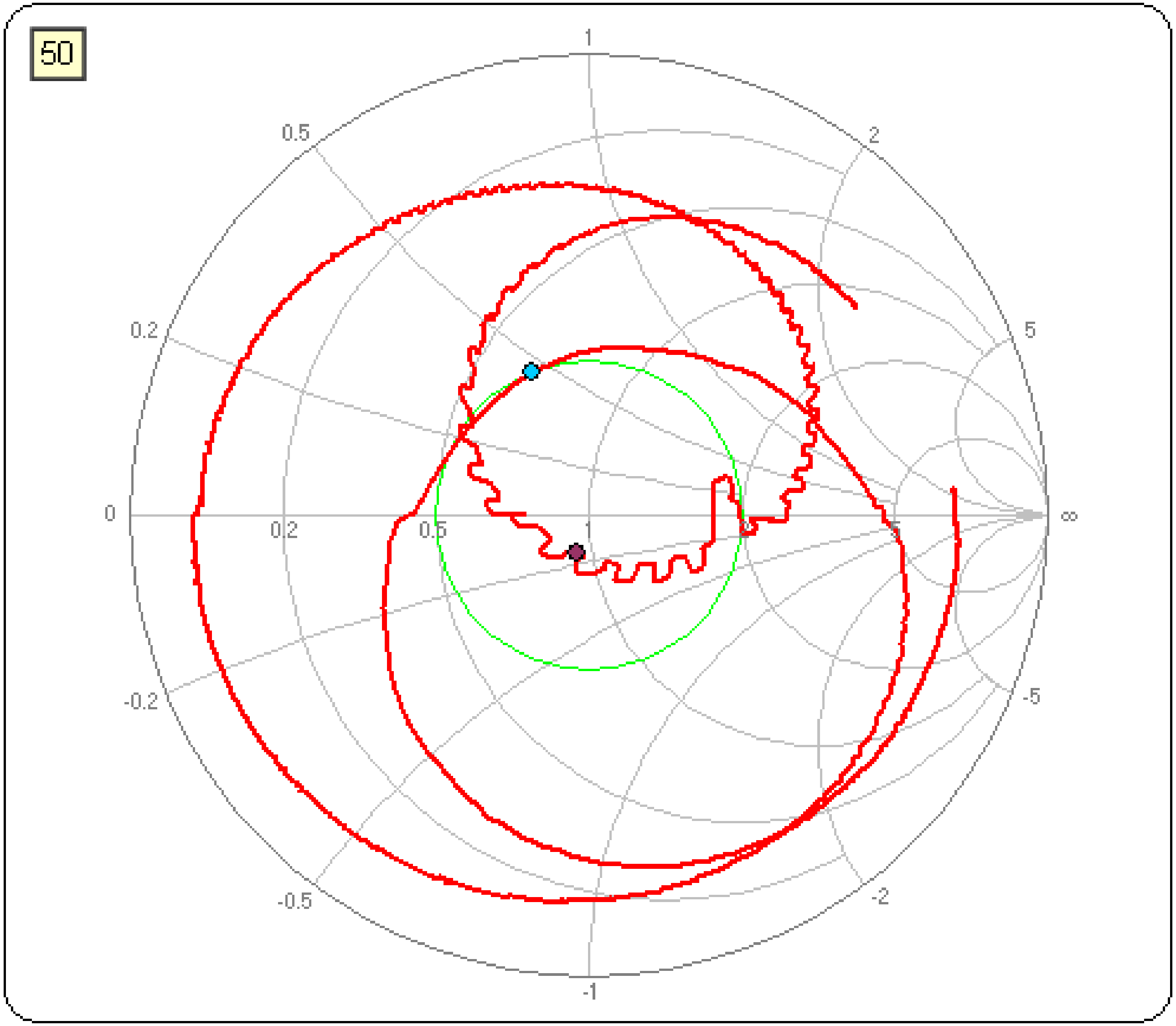
Therefore Old EM theory and NEC say that these antennas cannot possibly work!

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 ×52×4.06/(86×3.14) = 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

The New Radiation/Reception Theory – derived heuristically from observations of the above 'impossible' antennas

- The receiving capture area of a wire (dipole) antenna is many times greater than the physical area of the antenna. Why?
- There must be a 'focussing lens' surrounding the antenna. This must exist irrespective of the power to or from the antenna
- 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 we find 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!**

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

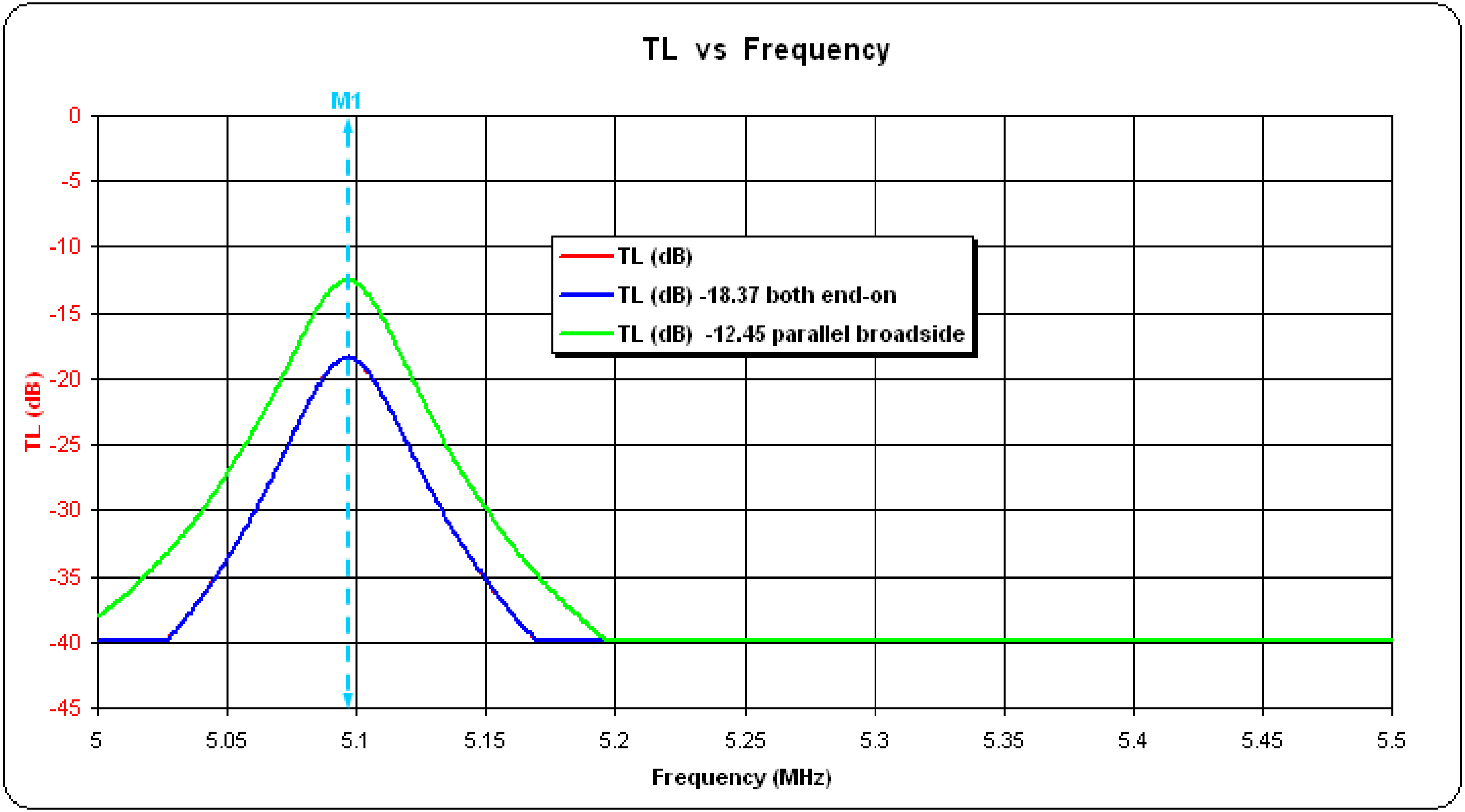
Twisted loop-gamma feed →

- 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

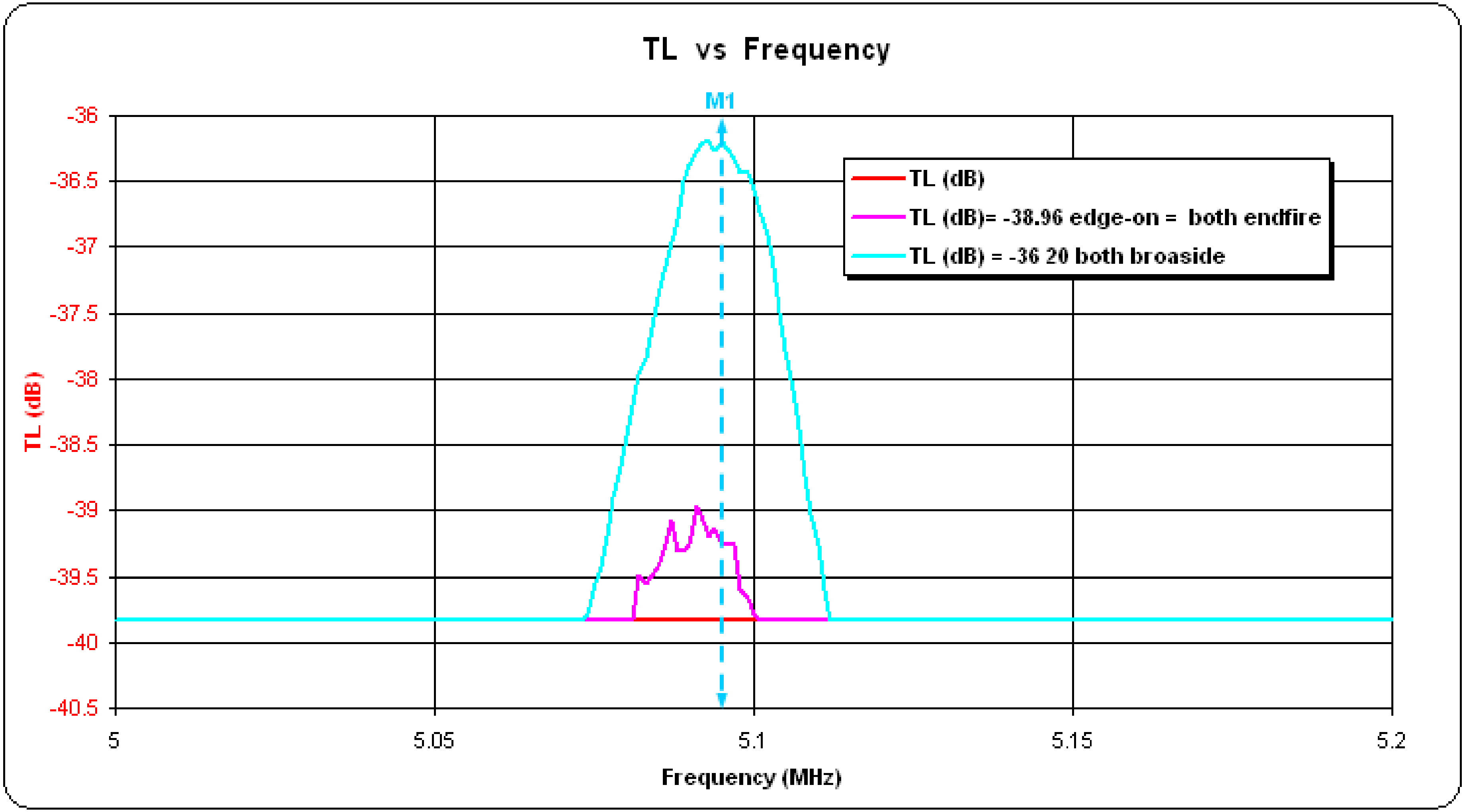
- Antenna patterns under investigation:
  - *Depends on type and orientation of field sensor!*
  - An *identical pair* of antennas is the only safe way to sort this out!
  - This is the heuristic approach:
  - Do the measurements!
- First results:
  - There are two dipole patterns
  - The horizontally 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)



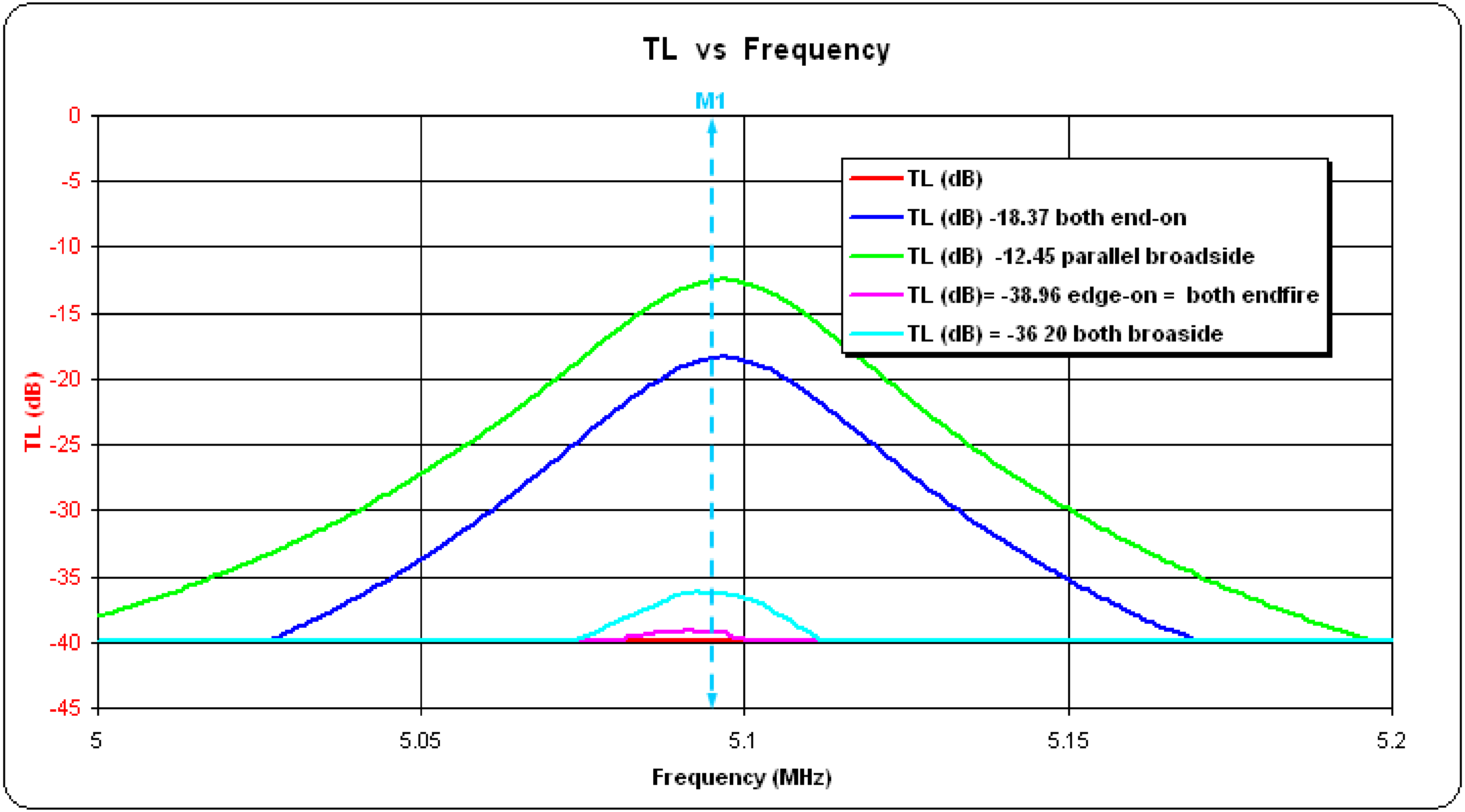
Also note that there are deep nulls if either hairpin is rotated by 90°

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?***

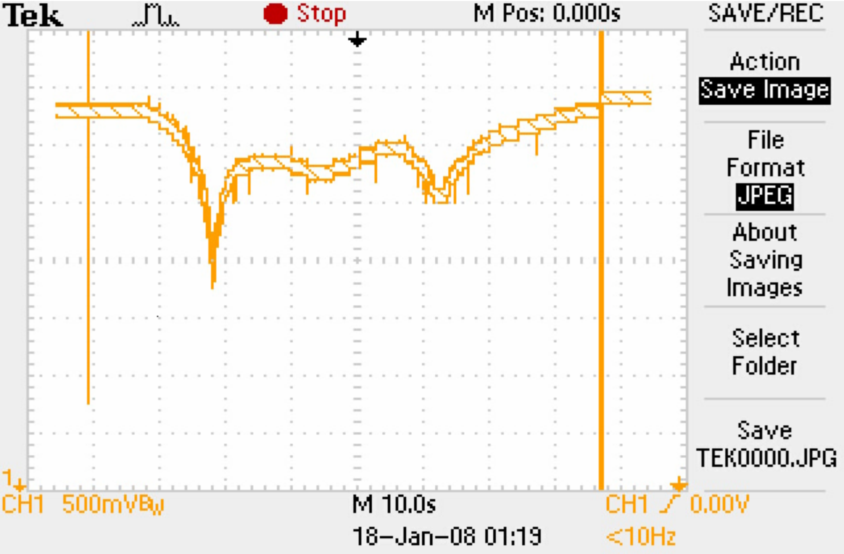
Coiled Tuned Hairpin

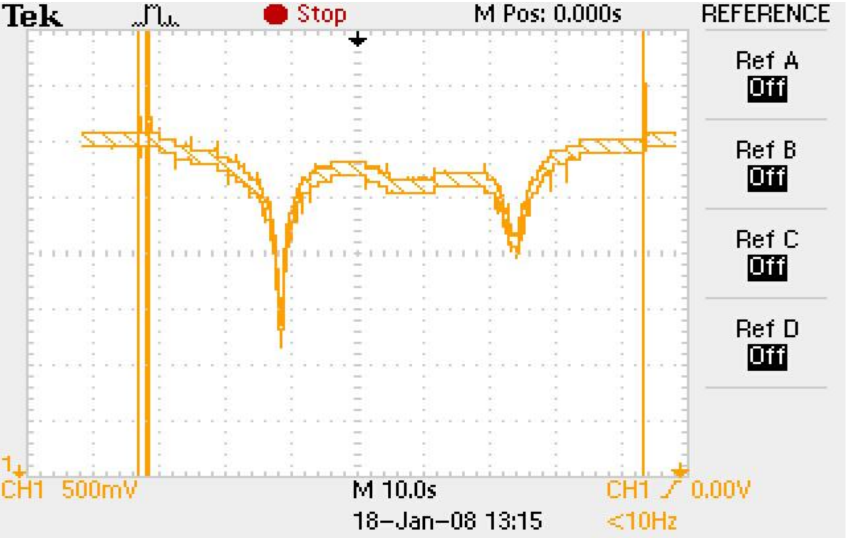
- 80cm diameter coiled
- >200watts 2 to 10MHz
  - Can be double tuned to go to 30MHz
- What is the pattern? – under investigation – heuristically!

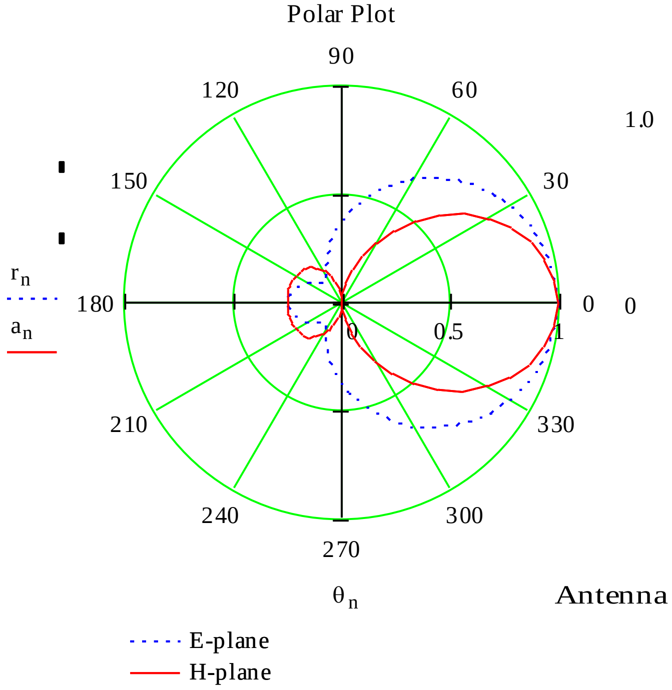
Coiled Double-Tuned Hairpin

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

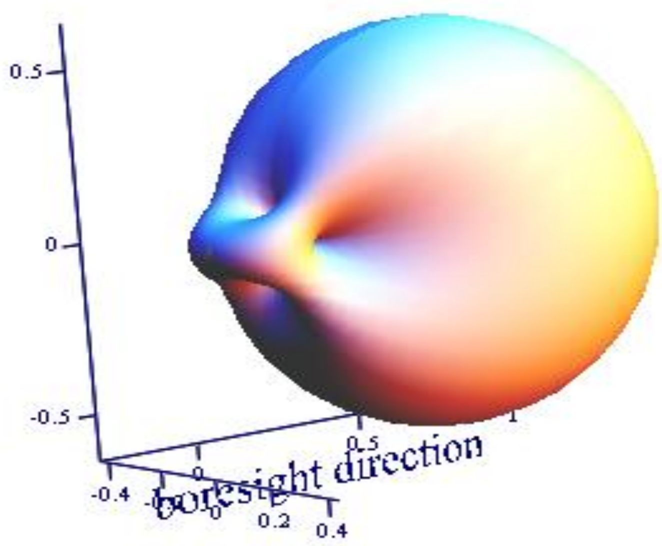
Heuristically Derived Antenna Pattern of Coiled Hairpin







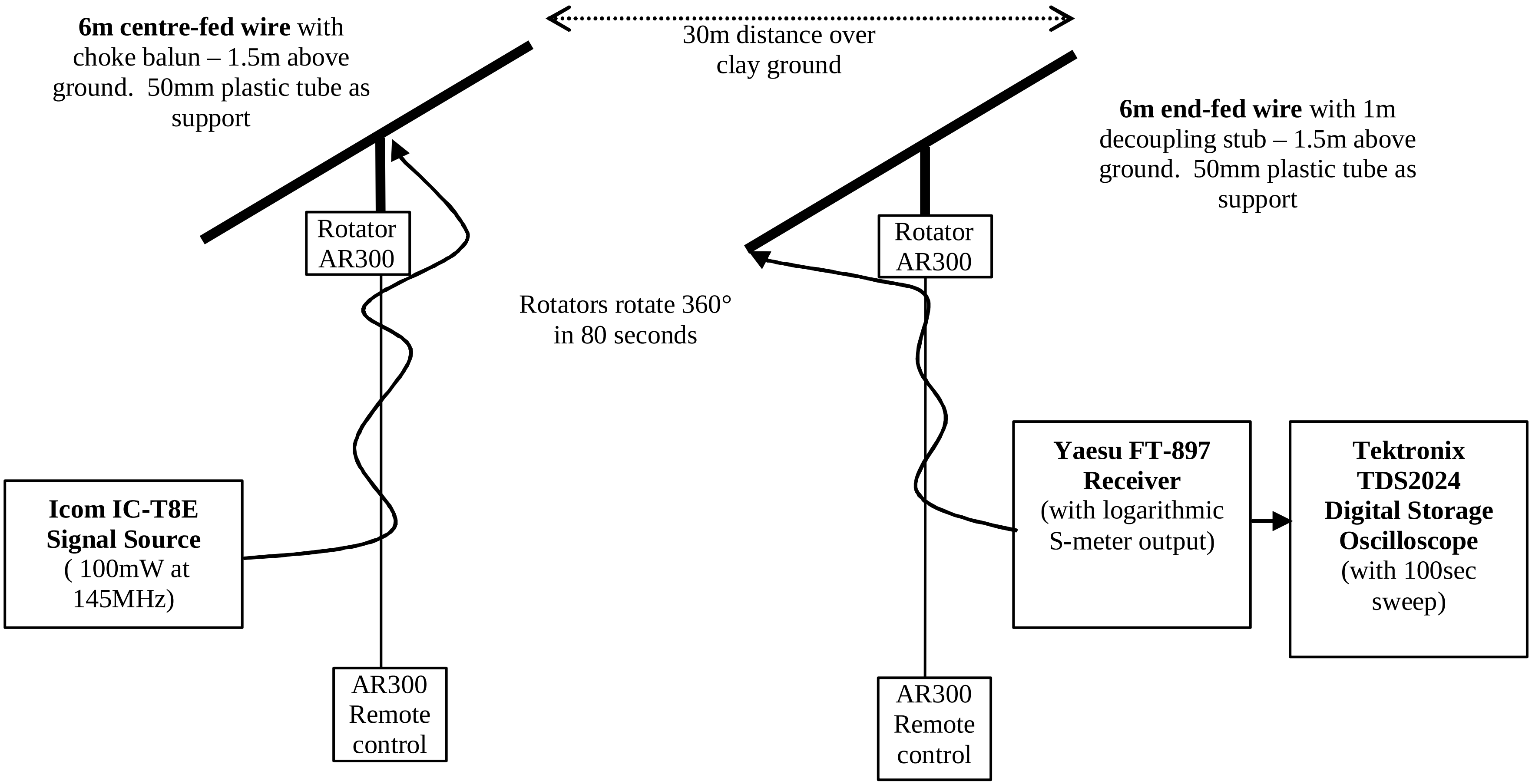
Antenna 3D Plot



(X, Y, Z)

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.



6m centre-fed wire with choke balun – 1.5m above ground. 50mm plastic tube as support

30m distance over clay ground

6m end-fed wire with 1m decoupling stub – 1.5m above ground. 50mm plastic tube as support

Rotator AR300

Rotator AR300

Rotators rotate 360° in 80 seconds

Icom IC-T8E Signal Source
(100mW at 145MHz)

AR300 Remote control

AR300 Remote control

Yaesu FT-897 Receiver
(with logarithmic S-meter output)

Tektronix TDS2024 Digital Storage Oscilloscope
(with 100sec sweep)

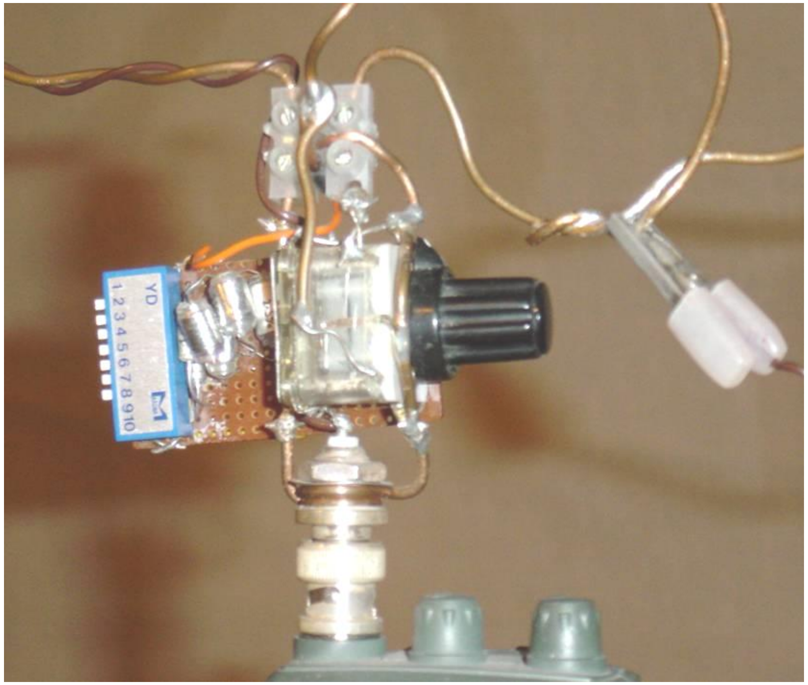
Figure 2: Underhill Research Open Range for Small Antenna Measurement. (Illustrating Rotatable 6.1m End-fed Horizontal Wire (inside plastic pipe) at 16m Distance with UR 35cm Receiving Loop in Foreground.)

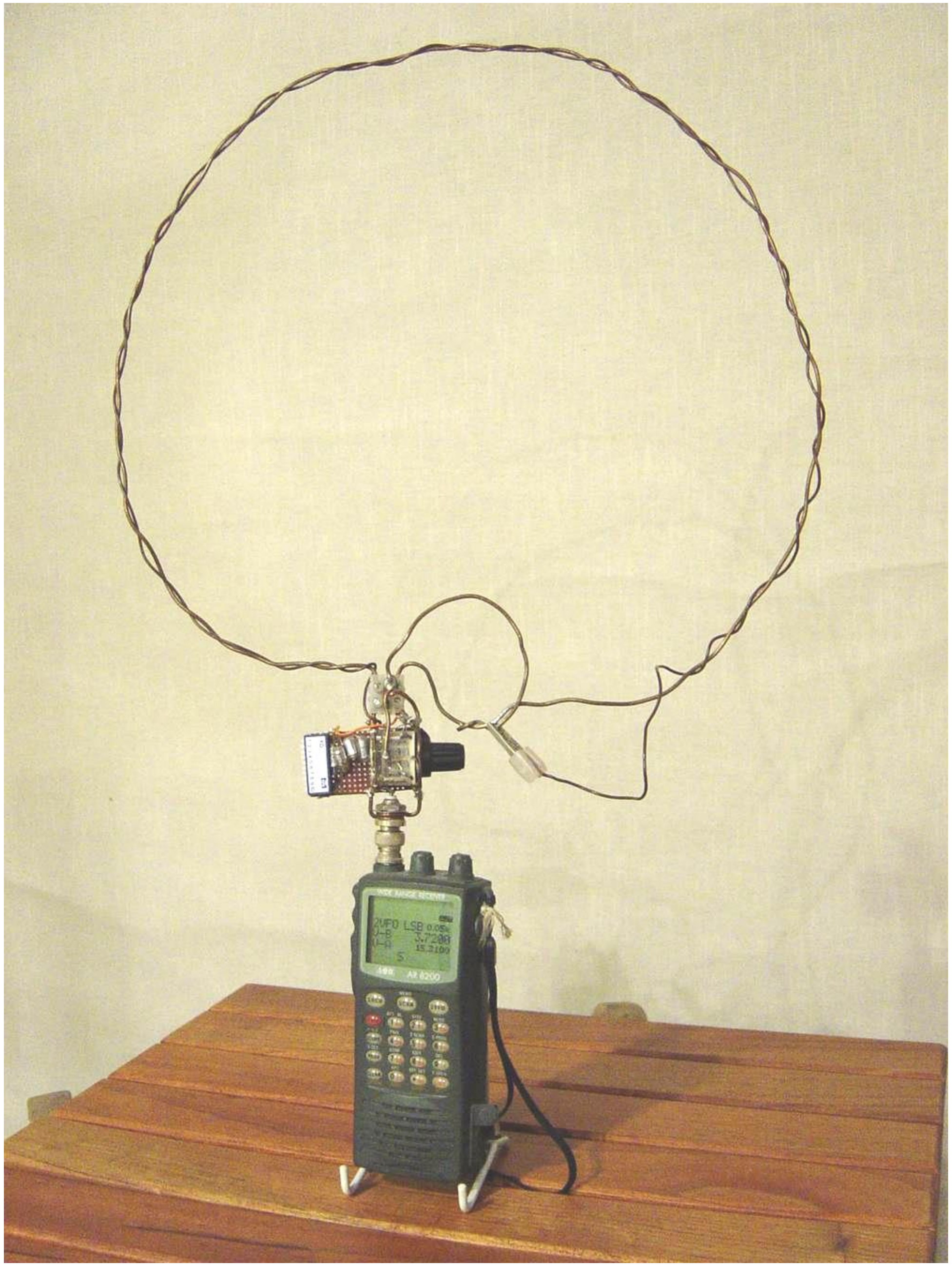
Small Tuned Antenna and Loop Construction

- 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

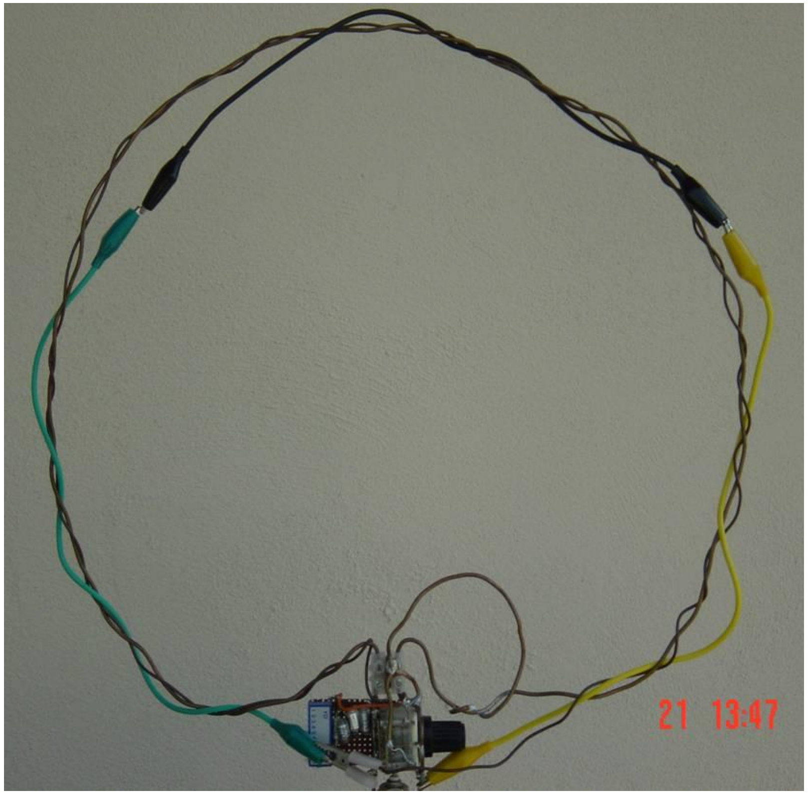




Experimental Antennas (Explained by Goubau ?)

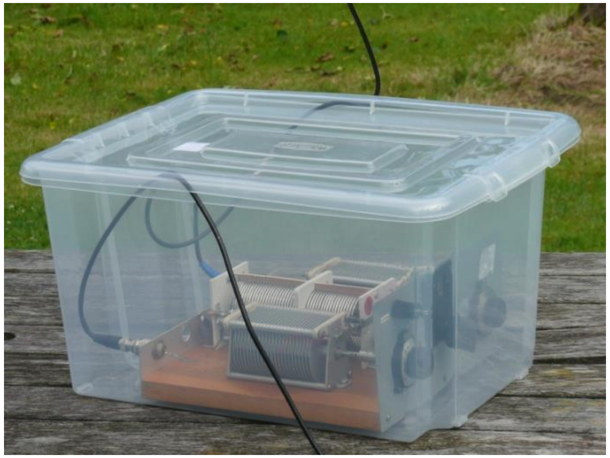
Wide-band Un-tuned Receiving Loops (Field Sensors)

- 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)?

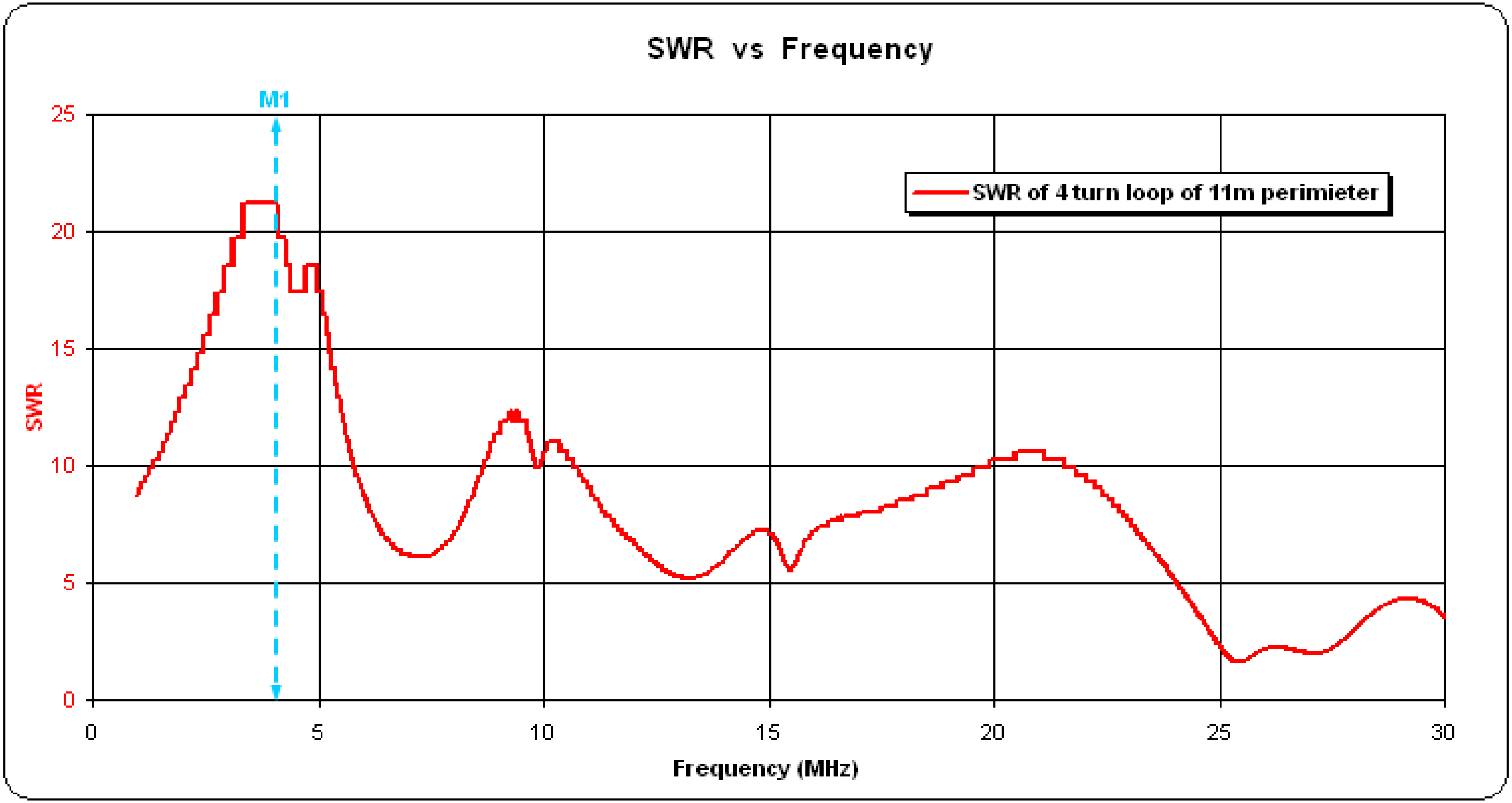


Broadband and Wide-band Tuning Multi-turn Transmitting Loop

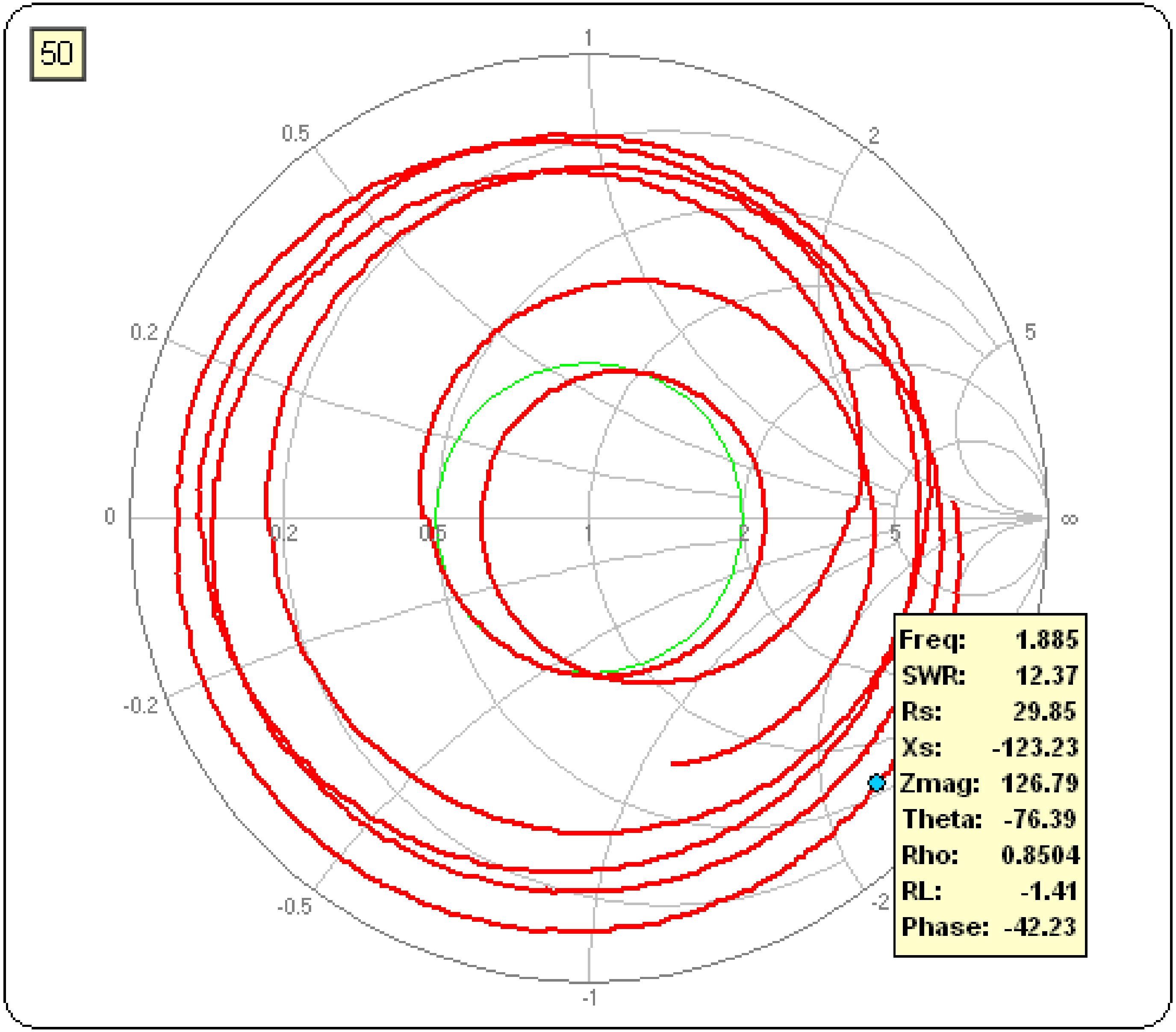
- Rounded square loop 11 metre perimeter in plastic water pipe
- Four turns of single core 2.5mm PVC covered domestic wire
- 4:1 impedance balun
- Best when vertical – 12db better?
- SWR<6:1 from 5 to 30MHz with no tuning
- Q = 30 to 40 from 1.8 to 30MHz when tuned
- Takes 800w but original T-match (C1, L, C2) ATU got hot for 80m and top band. So balun removed.



SWR of Broadband and Wide-band Tuning Multi-turn Transmitting Loop – using miniVNA



Smith Plot of Broadband and Wide-band Tuning Multi-turn Transmitting Loop – using miniVNA



Freq: 1.885
SWR: 12.37
Rs: 29.85
Xs: -123.23
Zmag: 126.79
Theta: -76.39
Rho: 0.8504
RL: -1.41
Phase: -42.23

Broadband and Wide-band Tuning Multi-turn Transmitting Loop with additional horizontal midi loop of 50m perimeter on or just above ground

- SWR<6:1 from 5 to 30MHz with no tuning but needs to be re-measured
- Q = 20 to 30 from 1.8 to 30MHz when tuned
- Takes 800w easily but original T-match (C1, L, C2) modified to be L-match on 80m
- Cannot use L-match on top band. Need more capacitance. So power limit is reduced – to 500 watts. But antenna Q is lower at 20 on top band.

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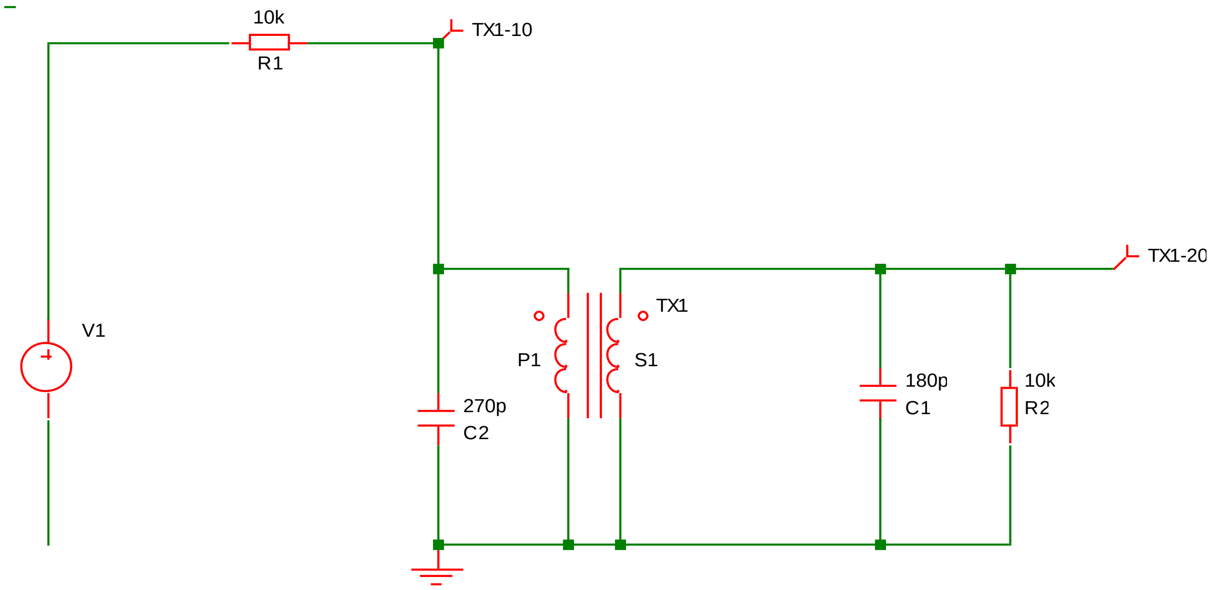
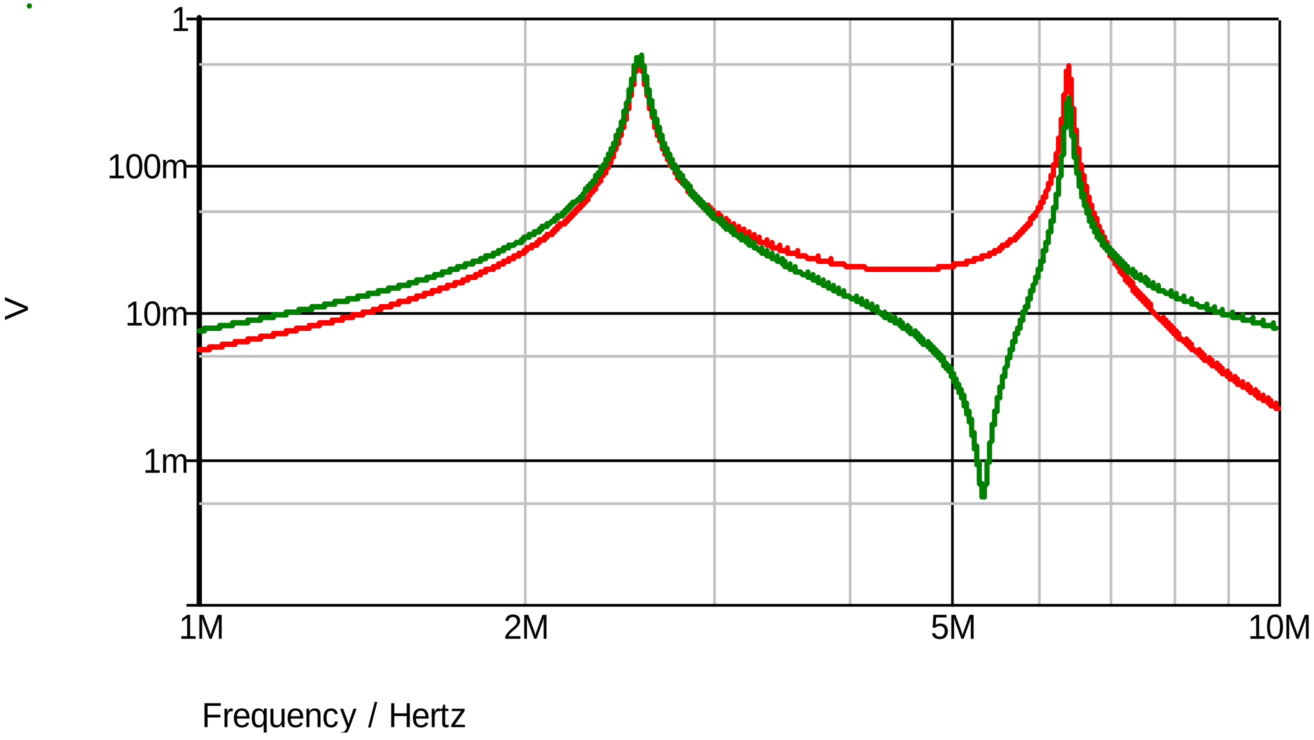
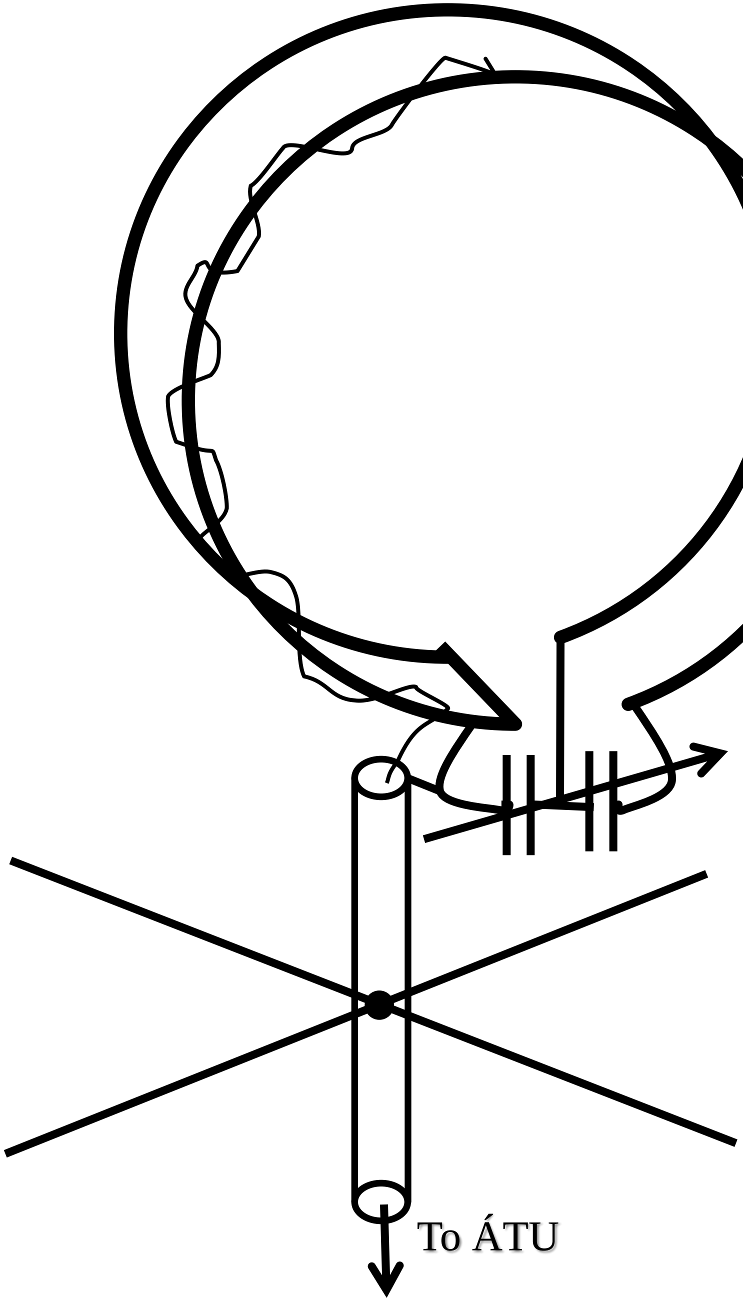
Coupled tuned circuit model of Coupled Mode (loop) Antenna





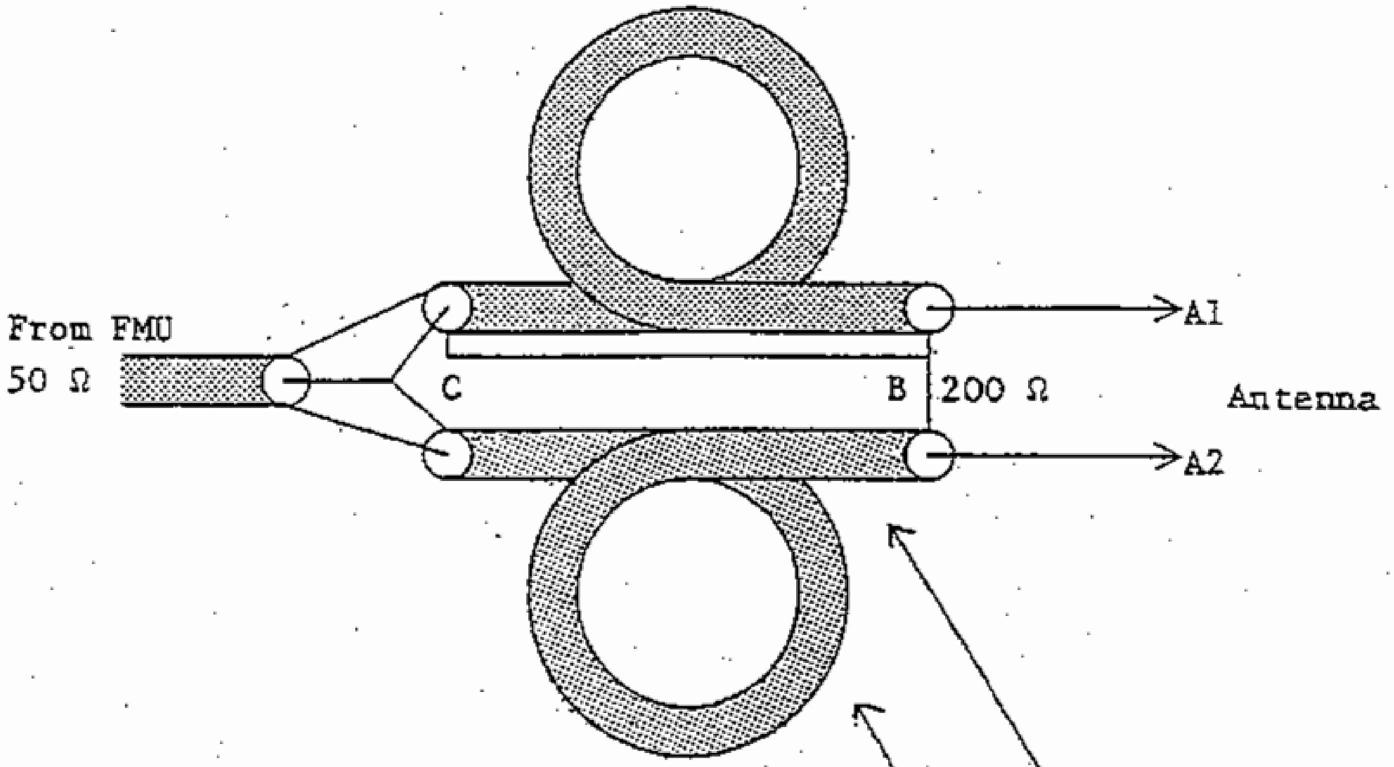
Tuneable Coupled Field Loop with Ground-Plane or Vertical Counterpoise

- Under development
- 2 magnetic modes below10MHz
- Additional electric mode above 10MHz
- 5:1 SWR above 10MHz – relies on ATU
- ~1.5m diameter
- Target Q <140
- 3 to 60MHz
- 1.8MHz with side-loading two turns?
- Counterpoise is essential.
- Counterpoise can be tower, or elevated ground plane if in attic
- Rotatable as it is directional below ~10MHz



AMA5 loop with 2 turns end connected side loading gives Q about 50 to 140

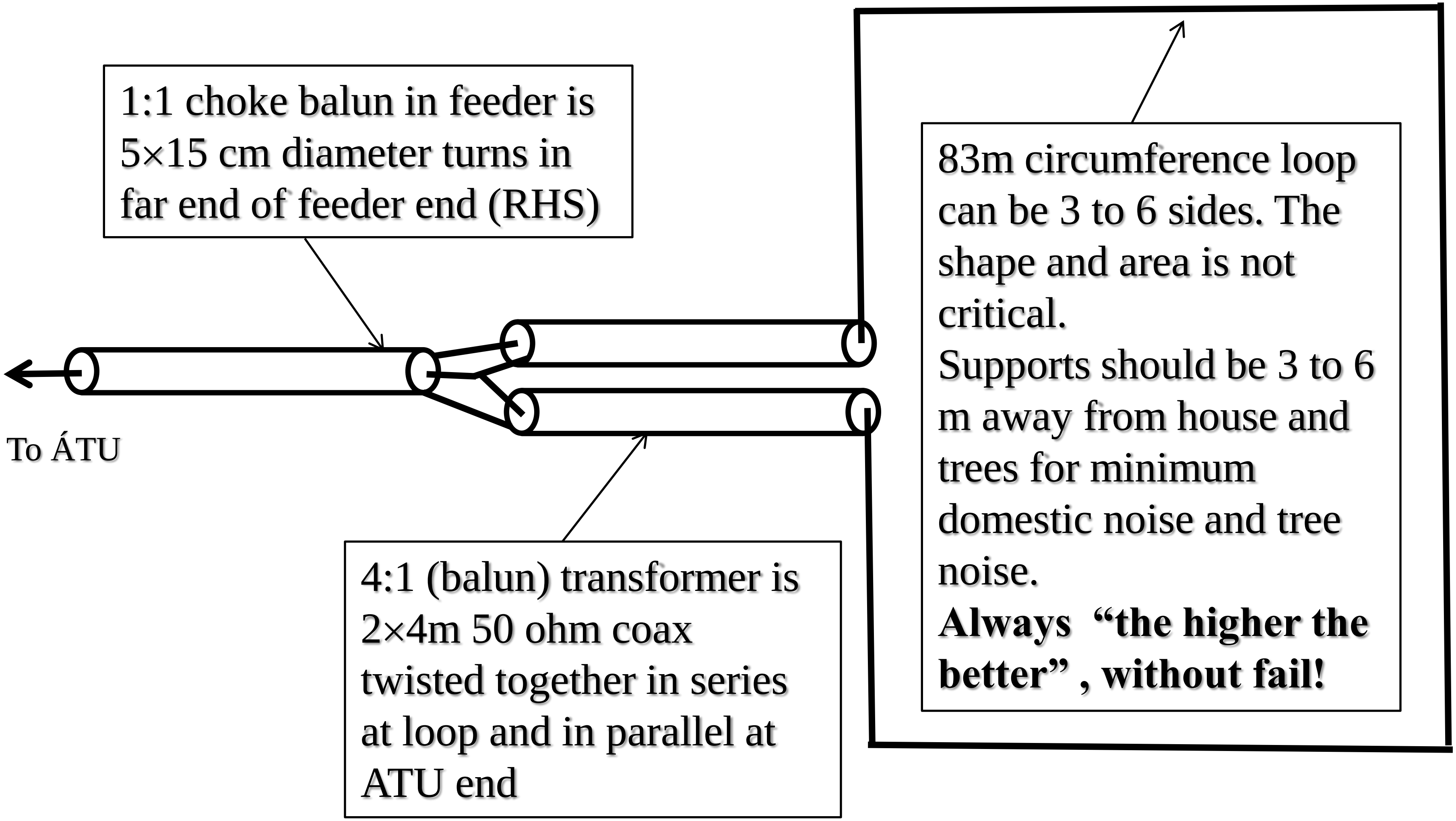
4:1 Wideband Balun Transformer



100 Ω coax or 2 x 50 Ω with outers connected
~ 250 cm lengths in 5 or 6 turns

Fig. 19 Pre-match unit (PMU) 50 to 200 ohm wideband balun transformer

Original Reference Antenna at G3LHZ = 83m circumference horizontal loop for 1.8 to 60 MHz



1:1 choke balun in feeder is 5×15 cm diameter turns in far end of feeder end (RHS)

To ÁTU

4:1 (balun) transformer is 2×4m 50 ohm coax twisted together in series at loop and in parallel at ATU end

83m circumference loop can be 3 to 6 sides. The shape and area is not critical.

Supports should be 3 to 6 m away from house and trees for minimum domestic noise and tree noise.

Always "the higher the better" , without fail!