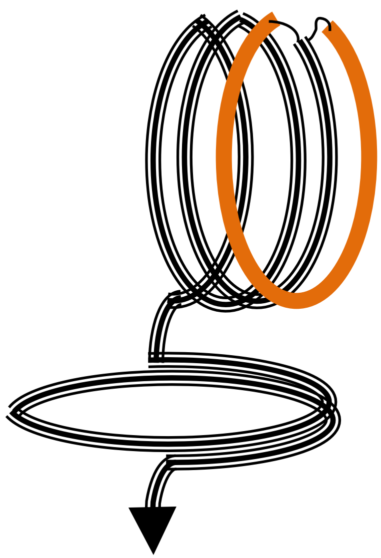
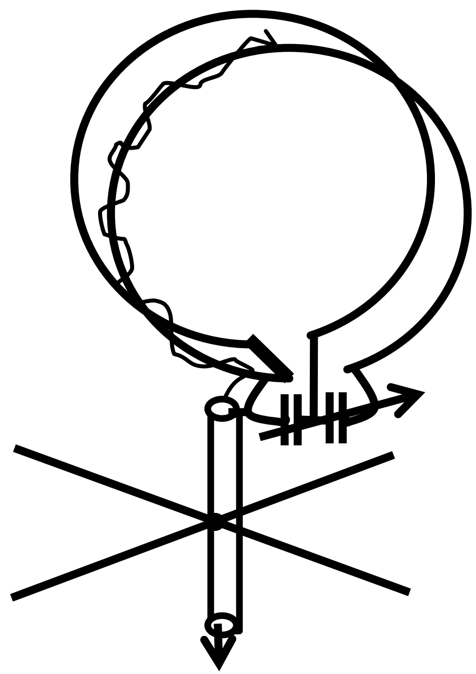
Transportable 1.2m Square Loop-Monopole

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.

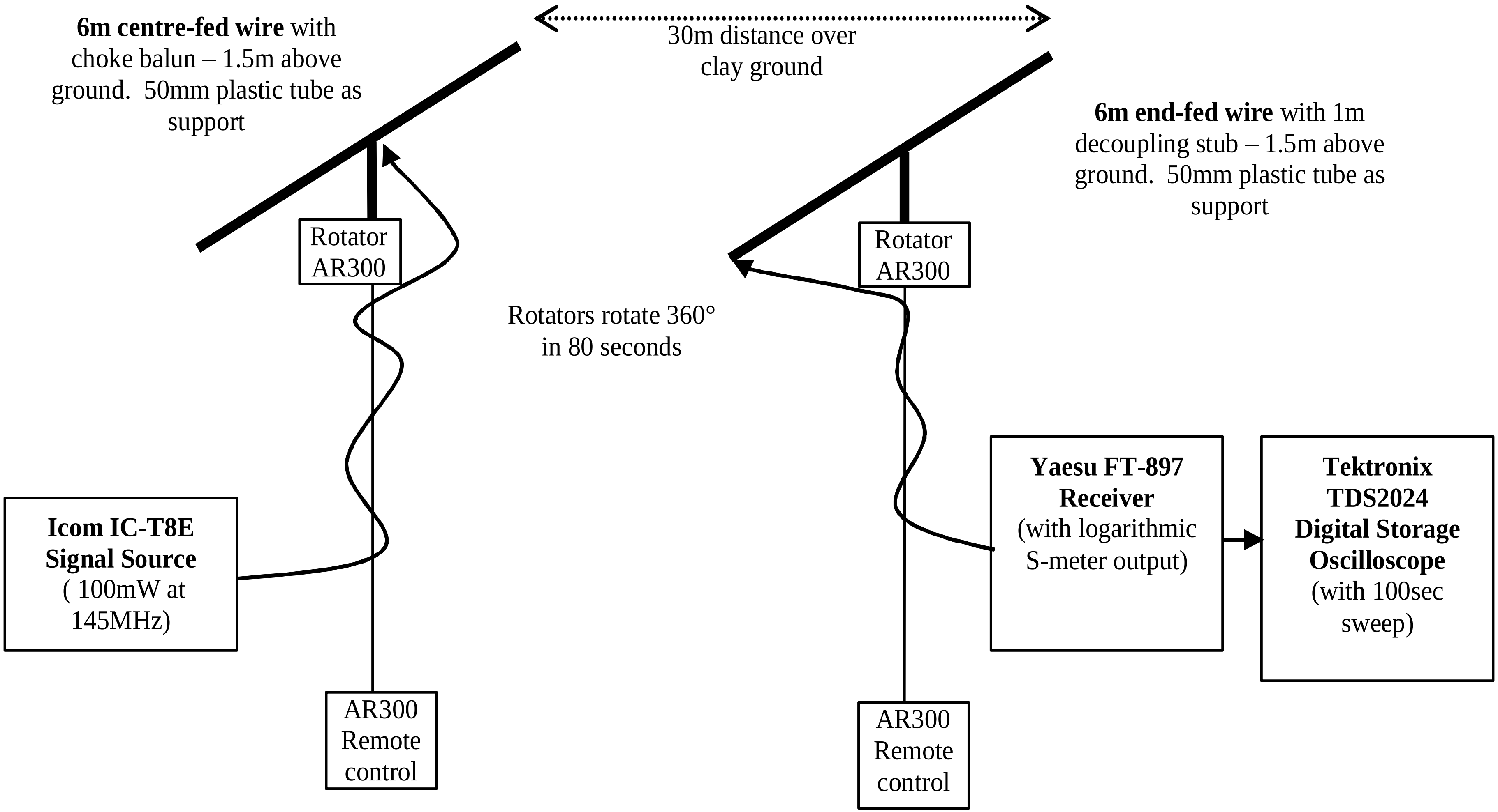




The ‘Two Identical Antenna Method’ for Accurate Path Loss and Field Strength Measurements over Ground

- 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 $P1/\sqrt{L}$. (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.

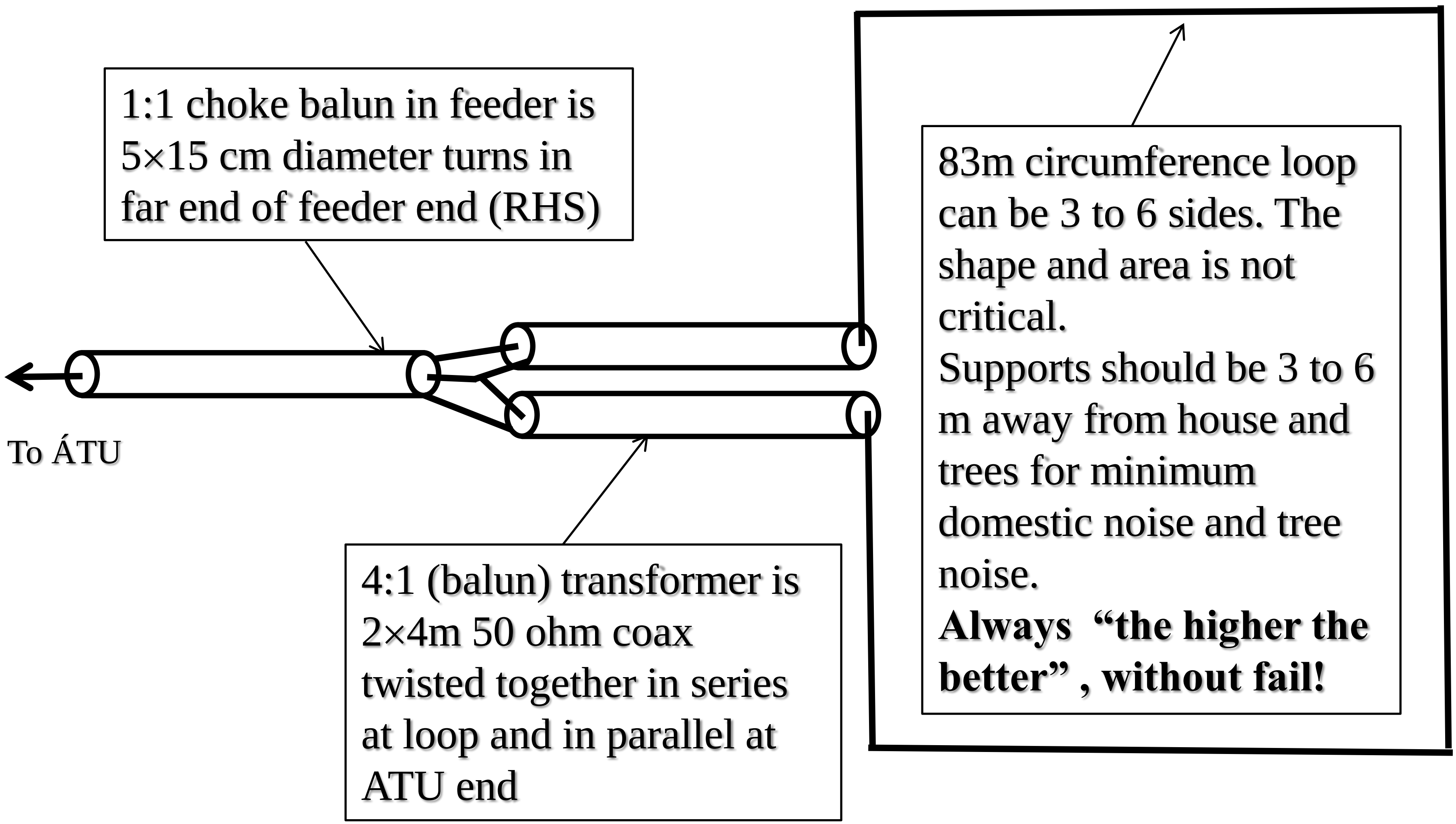
The ‘Two Identical Antenna Method’ Antenna for Accurate Path Loss and Field Strength Measurements over Ground



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

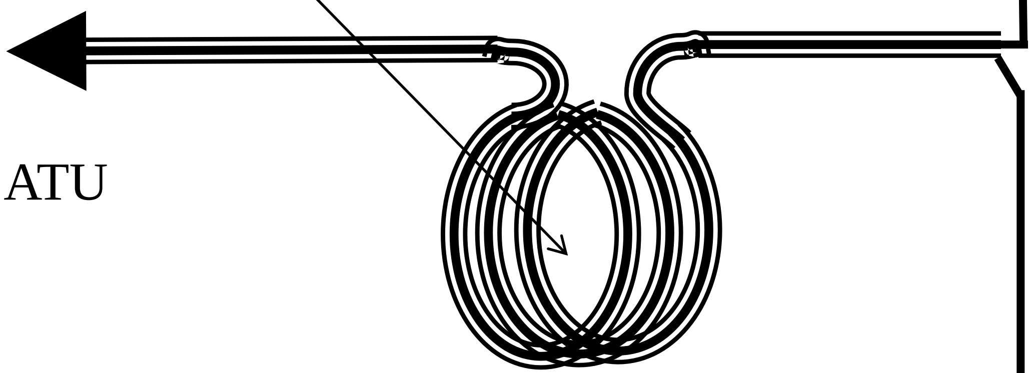
- Usable on all bands from 0.1 to >200MHz with an ATU for lower frequencies.
- No deep nulls >~6dB are observed
- Travelling wave antenna at higher frequencies?
- SWR Plot also indicates this.

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



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.

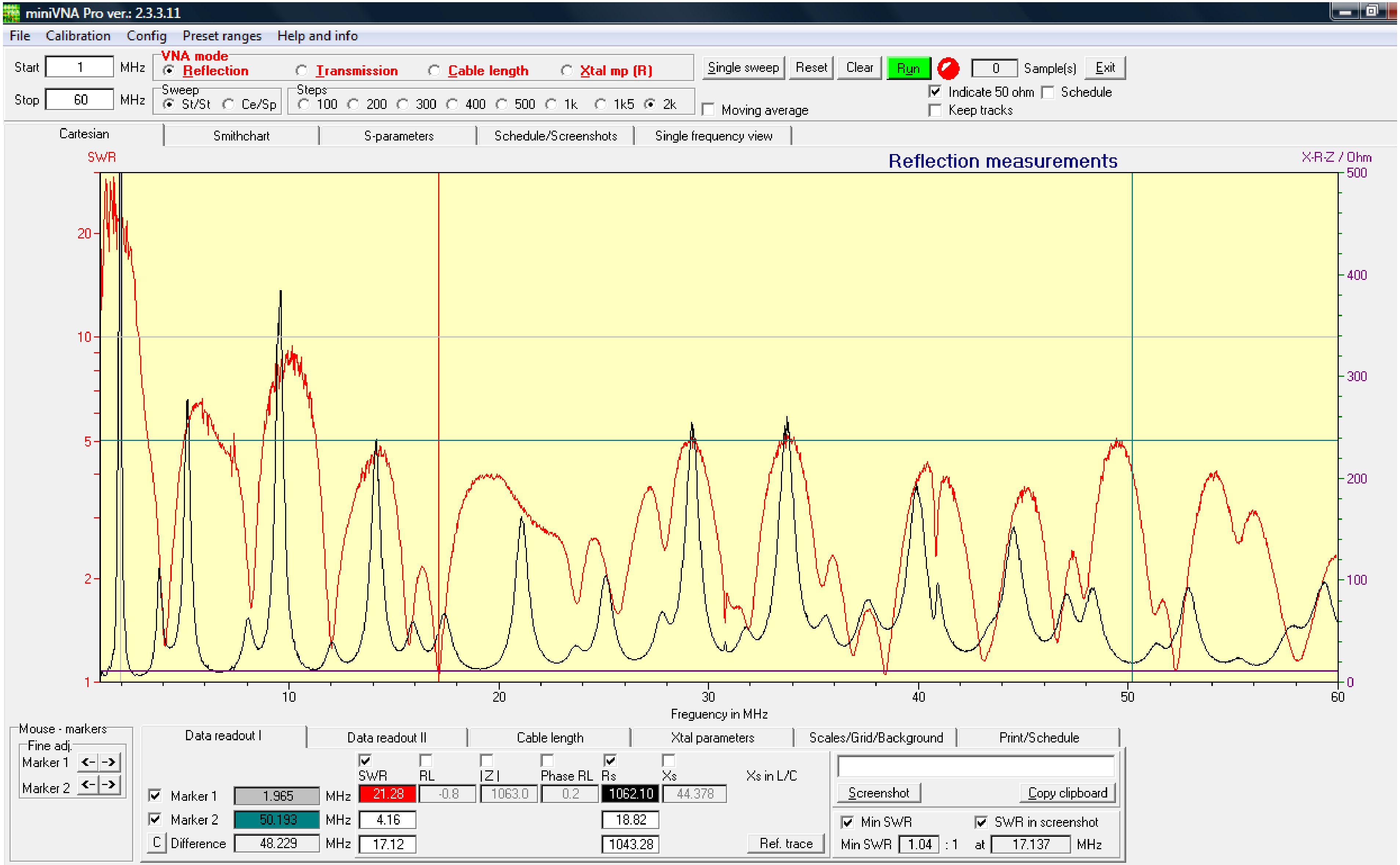


To ATU

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.

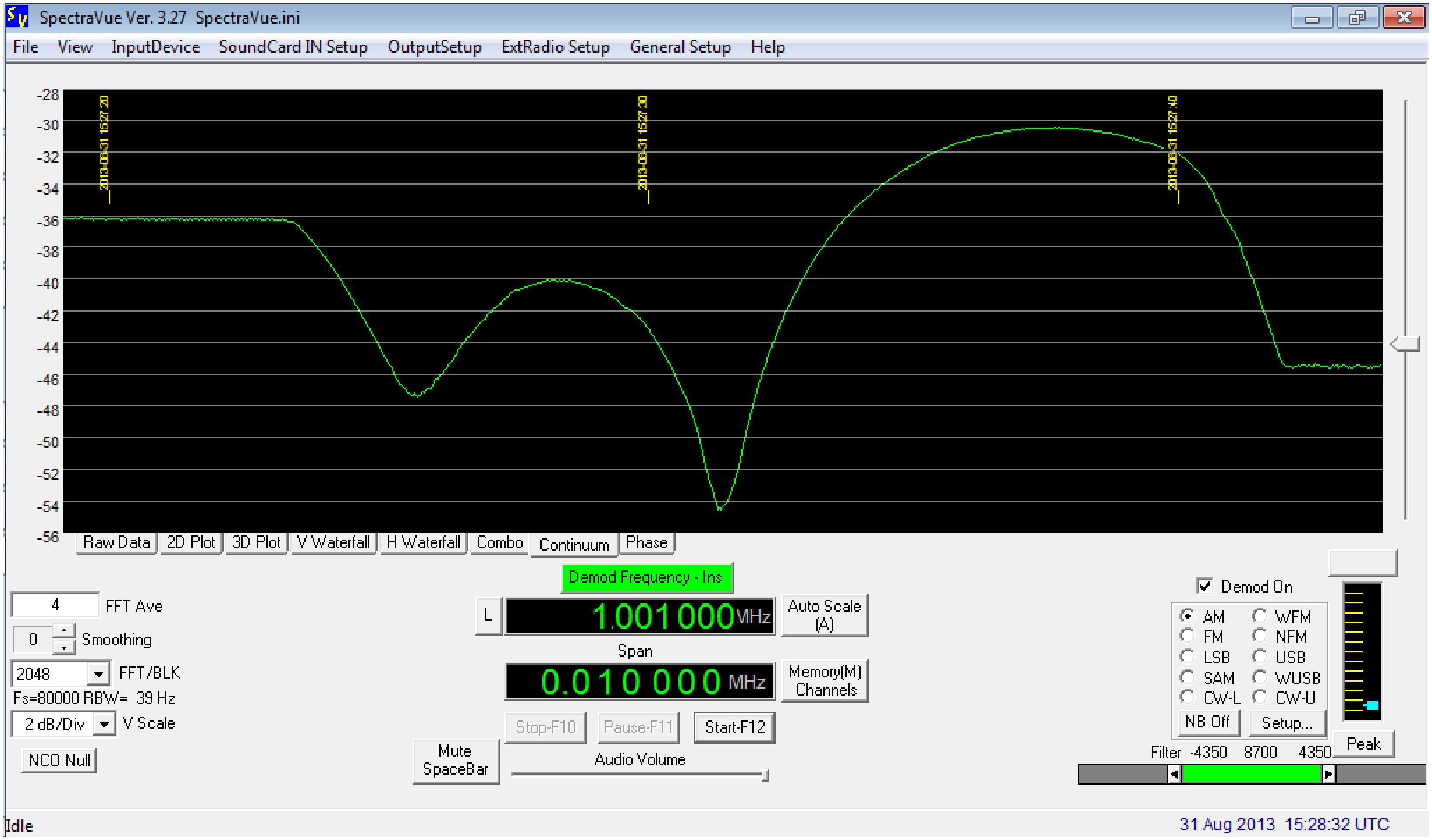
SWR of Original 83m Loop



Demo of Antenna Pattern Measurement

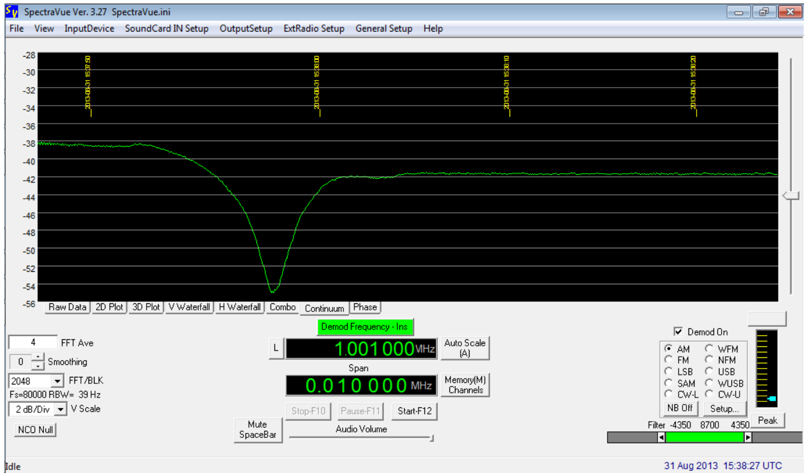
- Signal Source is battery-powered Elecraft KX3 with up to ~0dBm output.
- Calibrated receiver with ~0.2db pattern resolution is the FunCube Pro+ with SpectraView software. In ‘Continuum’ mode.
- A constant velocity rotator then gives storable scope time trace of the antenna pattern over 360^0. (‘Print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

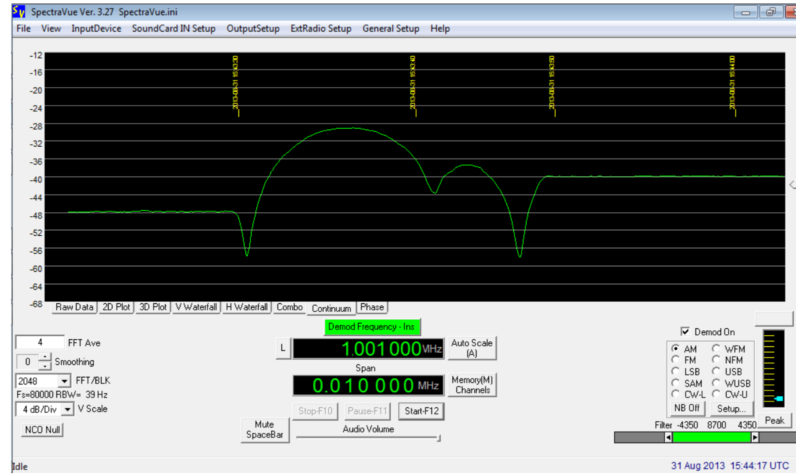
Antenna Patterns of a Pair of Loop-monopoles, one at 180^0 to the other.

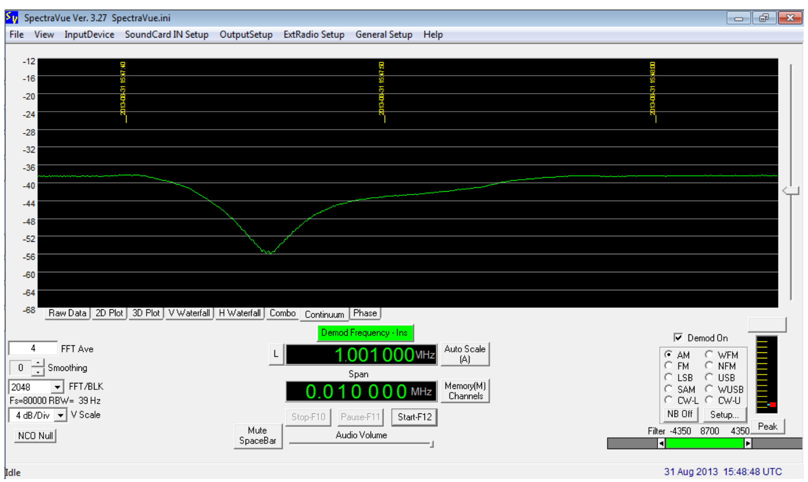


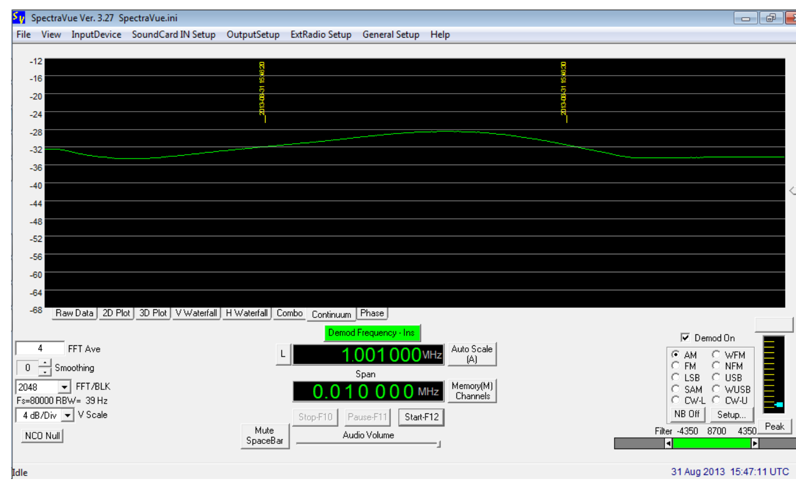
- Measured on FunCubePro + with SpectraVue processing and display software
- Note Front-to-Back ratio of 24dB

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





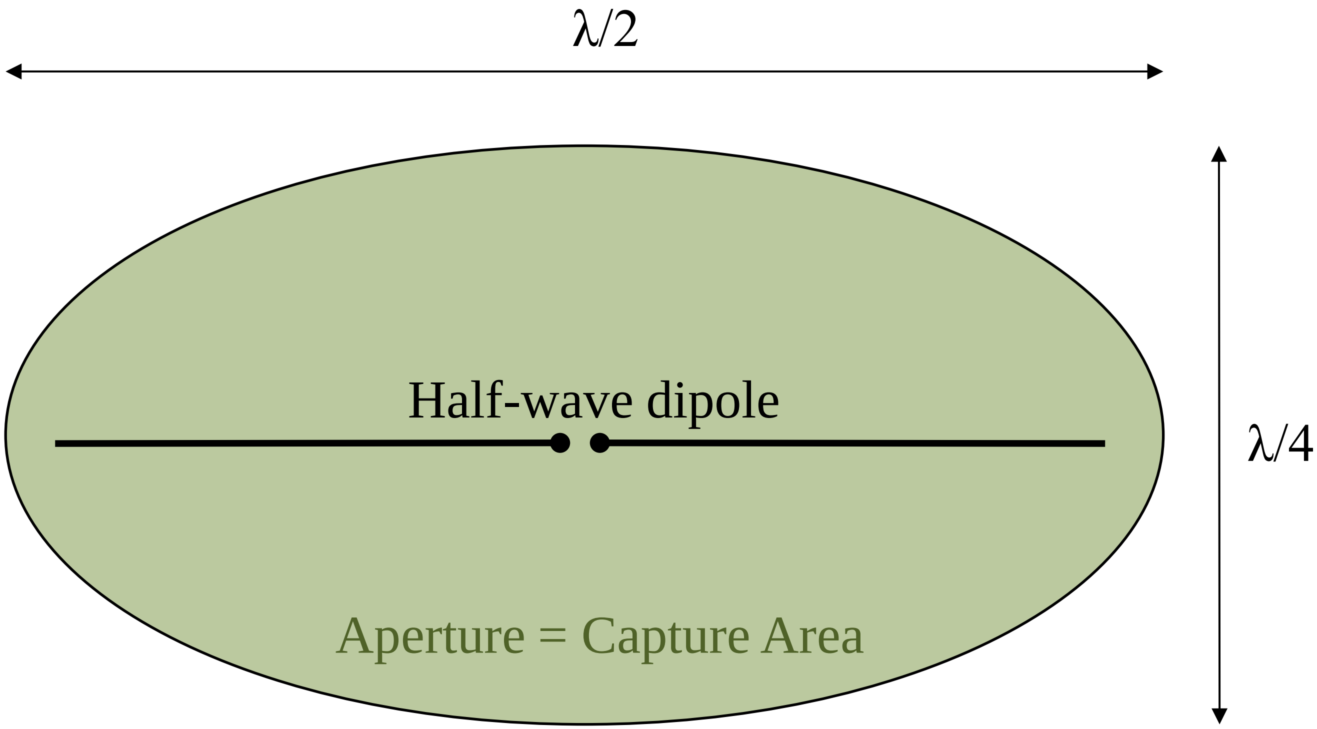




How Does a Wire Antenna Receive?

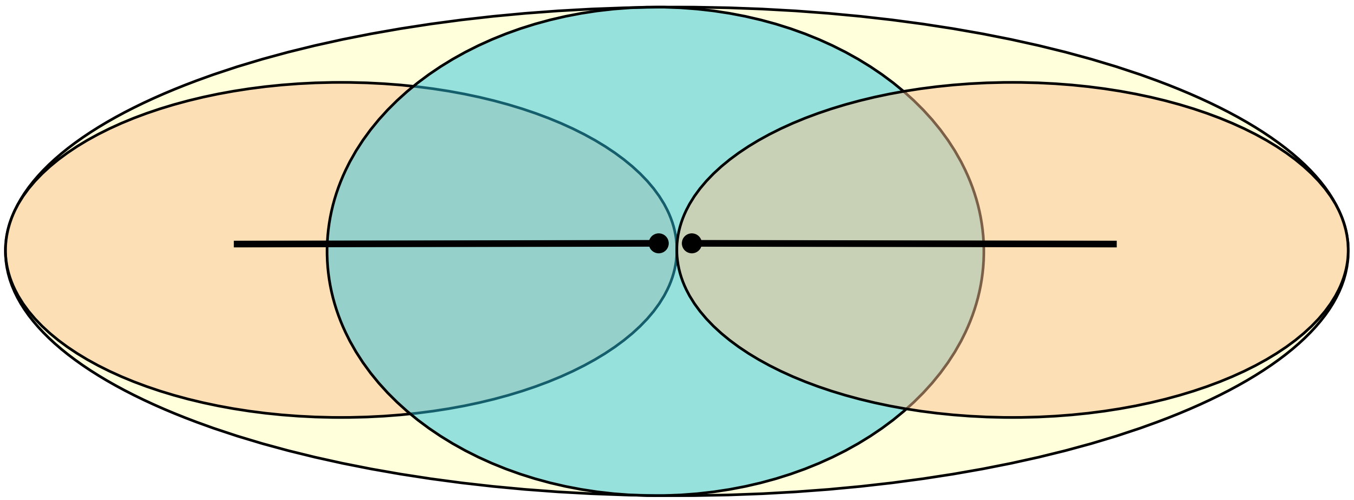
- The Physics of *reception* is an unsolved problem in Antenna Theory.
- There is a mathematical theory but it has to use the ‘principle of reciprocity’.
- Is it a focussing effect by a local ether lens?

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



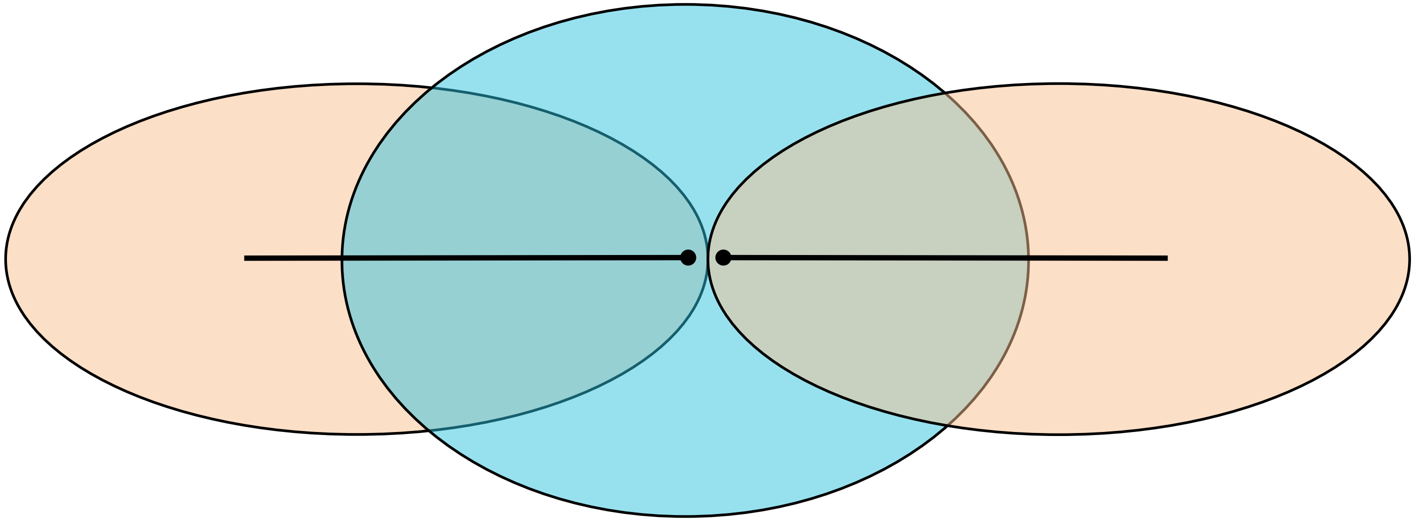
- Why is the receiving aperture and capture area so large? Is it a focussing effect like a lens? (Yes!)
- Also viewed from a few wavelengths do we see the wire magnified to the size of the aperture? (Arguably—Yes!)

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



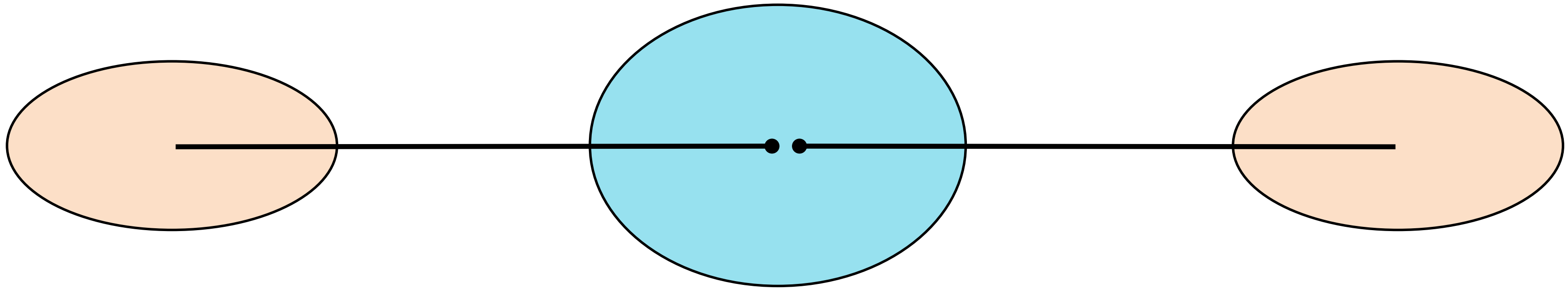
- **Electric, Magnetic and Total Energy of a (Short) Dipole at UHF**

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

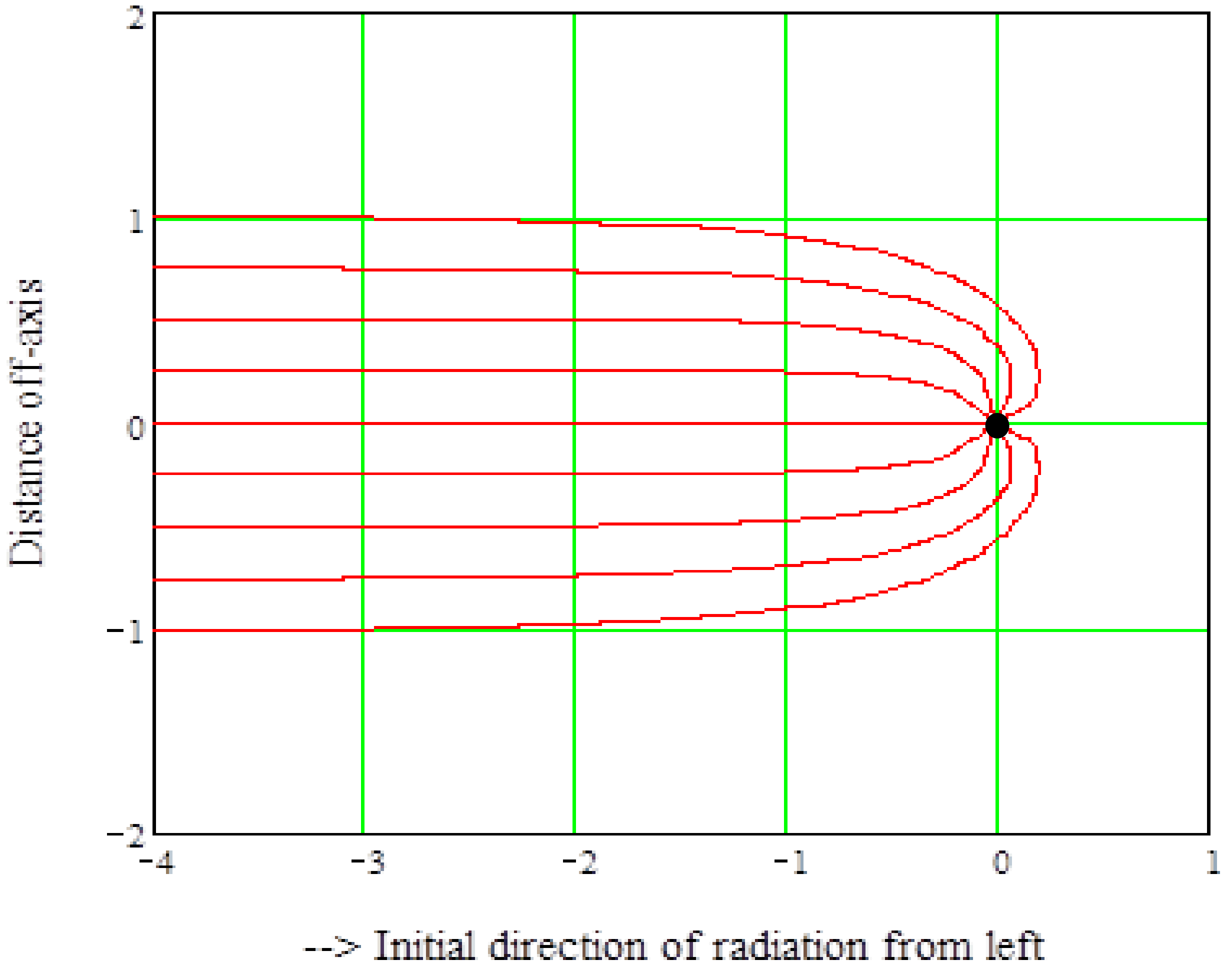
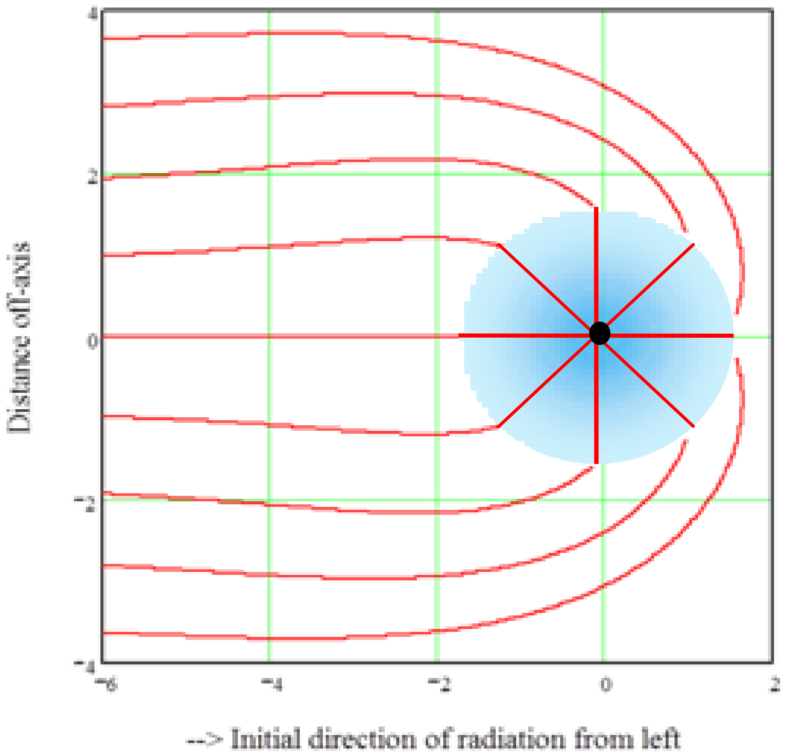


Figure1: Power flow trajectories from aperture left to all angles on a wire dipole at 0,0 on right.

POWER FLOW TRAJECTORY DEPENDENCE ON FREQUENCY



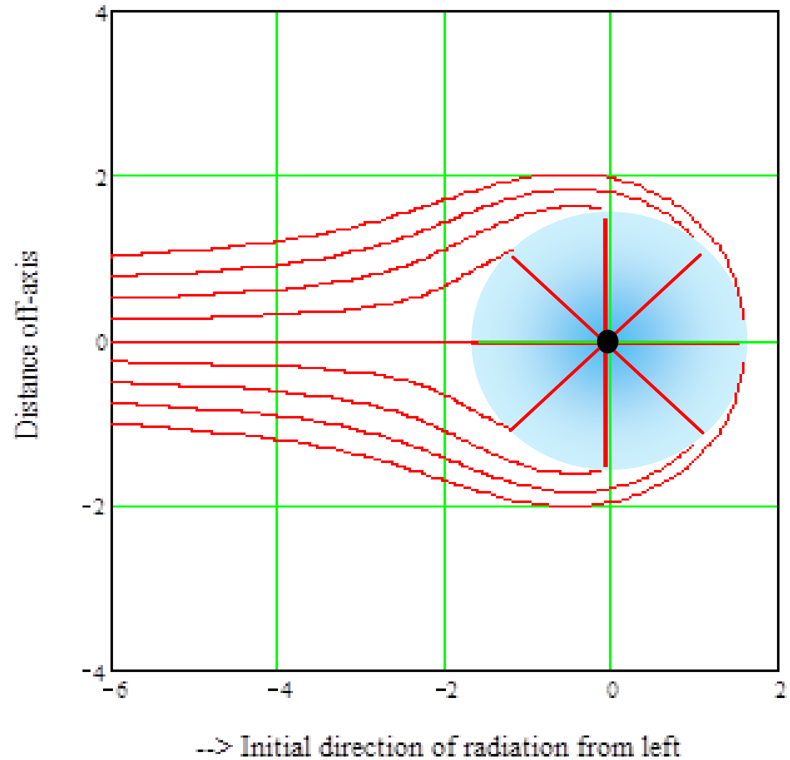


Figure 4: Power flow trajectories from aperture left to all angles on a wire dipole at 0.0 on right. Shaded blue lens region is finite but less than the capture aperture size for a frequency below about 90MHz.

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

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

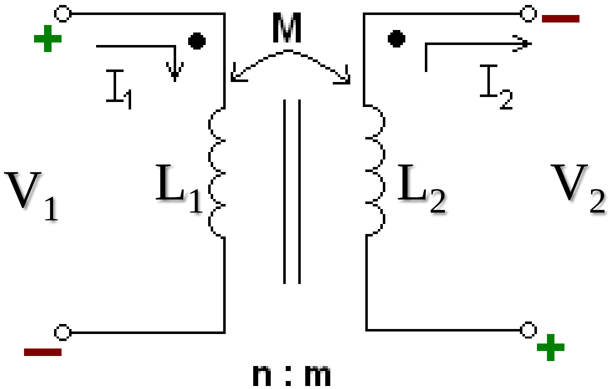
$$curlH = \nabla \times H = +\frac{\partial D}{\partial t} + J_R + J_E \qquad (3) \qquad -curlE = -\nabla \times E = \frac{\partial B}{\partial t} + J_M \qquad (4)$$

$D = \varepsilon E$ 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, $\kappa = M/\sqrt{(L_1\,L_2)} \leq 1$

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.

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

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

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:

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

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

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

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

- 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

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

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

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

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

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

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

$$\delta B_y := \kappa\mu H_y \oplus \qquad (23a),$$

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

- **(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

<u>In Physics and Electromagnetics:</u>

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 *RSS (Root-Sum-of-the-Squares) Rule*. From (loop) Q measurements and we find the RSS Rule to be** $R_{meas} = \sqrt{(R_{rad}^2 + R_{loss}^2)}$
2. ***The Power Splitting Rule* 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 $\pm$ 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 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?"

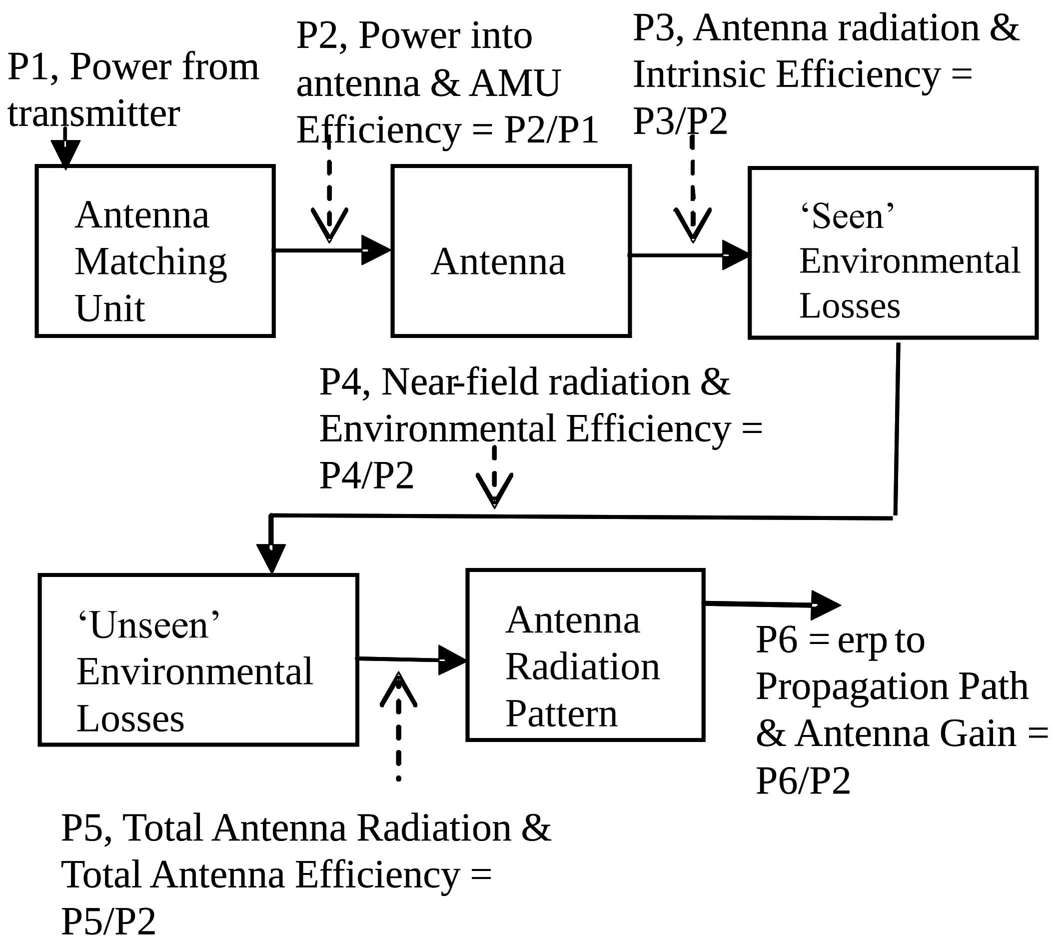


Figure: Various losses and antenna efficiencies

- 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

$$Q_{loss} = Xl/R_{loss} = 2\pi f_{MHz} L/R_{loss}$$
$$= 2\pi d_{mm} f_{MHz} \times(0.16d_{mm})^{-0.16} /\{8.94\times10^{-2}\sqrt{(f_{MHz})}\}$$
$$\boldsymbol{Q_{loss} = 94.22\ \sqrt{(f_{MHz})} \times d^{0.84}}$$

- 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} ~ 8 to 15. Short Dipole Q_{rad} ~ 120 to 200. Small single mode tuned loop Q_{rad} ~ 220 to 400. Two mode E-H antenna Q_{rad} ~ 90 to 150. Two mode double tuned small loop Q_{rad} ~150 to 280. New Loop-Monopole Q_{rad} ~ 6 to 11.

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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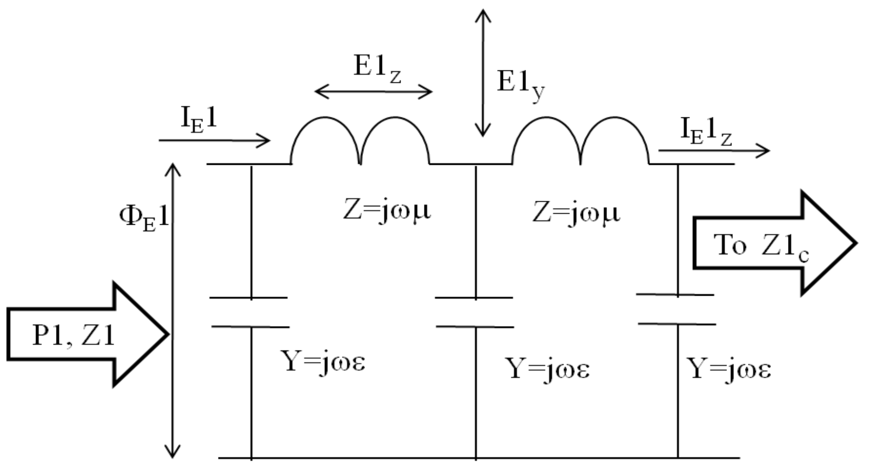
Basis of Method

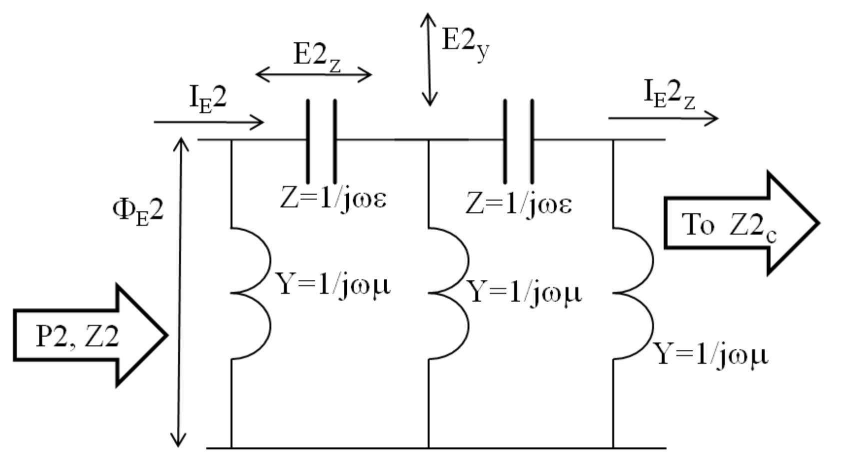
- Analytic Region Modelling is based on two newly observed physical laws, ‘process capture’ and ‘electro-magnetic (EM) (or *Physics*) coupling’ [1].
- These laws define ‘process regions’ in space, in which only one physical or electromagnetic process is dominant.
- The third law that is strictly obeyed (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.



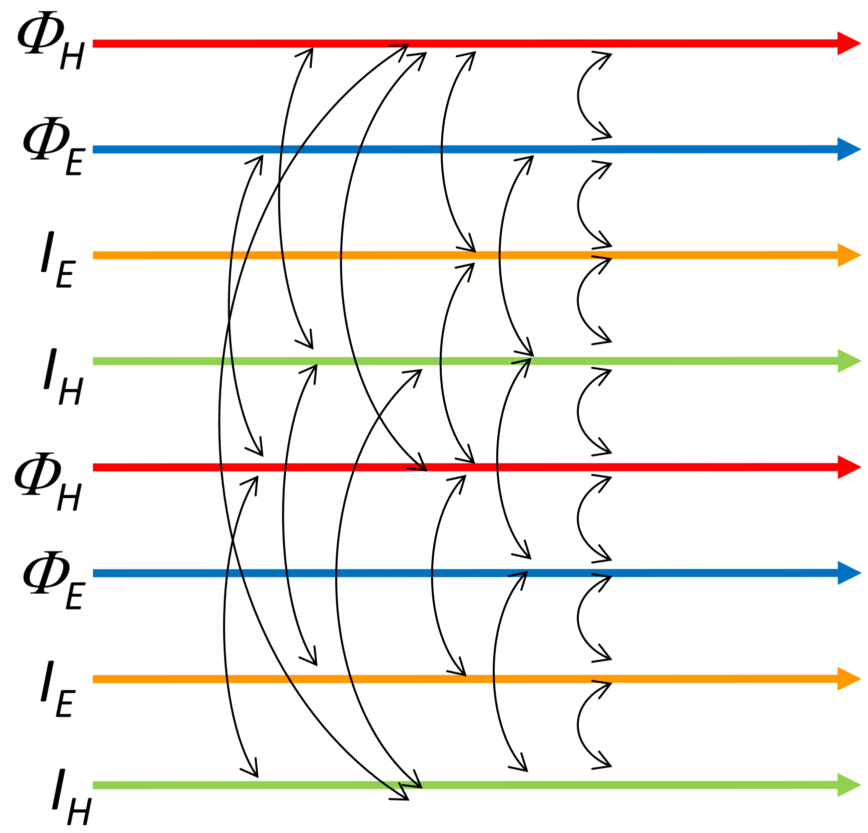
(b) Low-Pass E-field line



(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

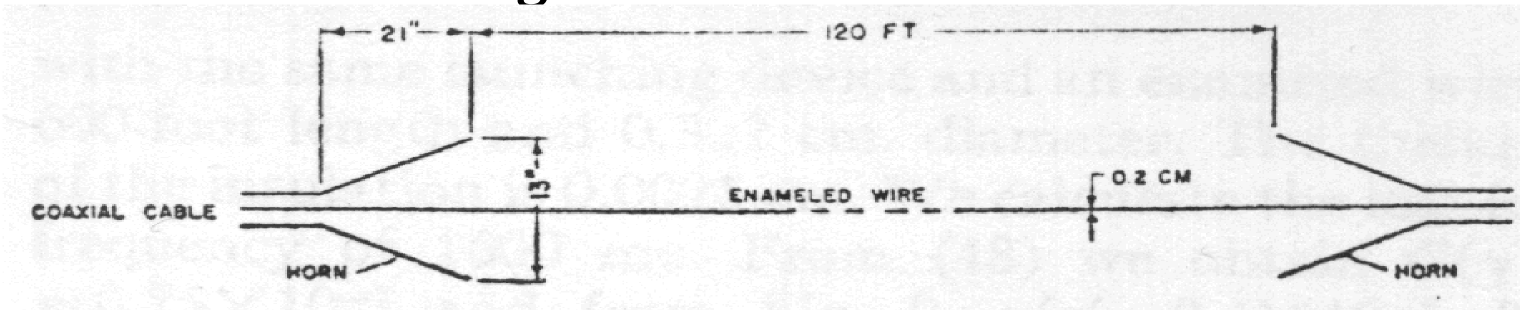


FIG. 11. Sketch of a surface wave transmission line.

"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:

$$r_{Gw} = \left(\frac{f_c}{f}\right)^{1/2} = \left(\frac{14}{f_{MHz}}\right)^{1/2} \quad (1) \qquad r_{GS} = \pi r_{GW} = \pi\left(\frac{f_c}{f}\right)^{1/2} = \left(\frac{140}{f_{MHz}}\right)^{1/2} \quad (2)$$

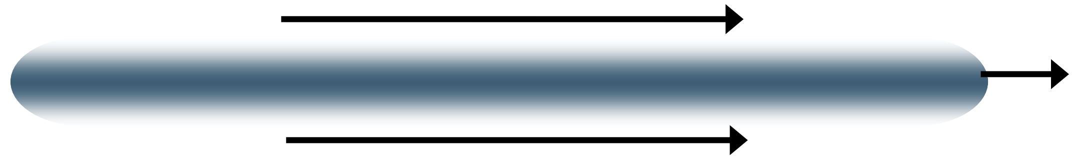
Analytic Region Modelling

- 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

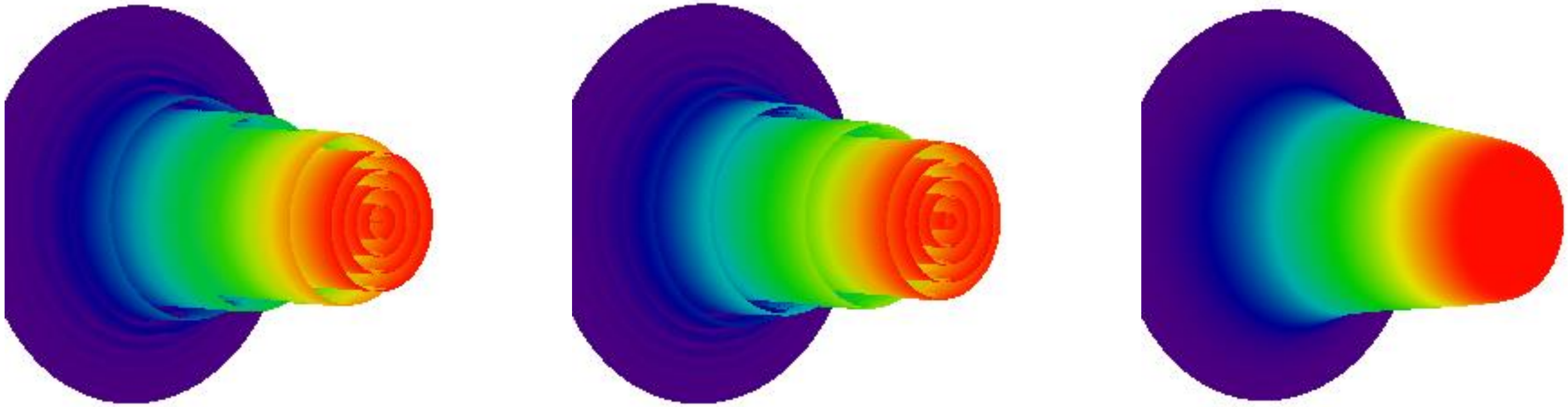
- ARM models the physics of antennas and propagation. The space containing the antennas and the propagation paths is divided into overlapping regions. Because of process capture the physical process in each region can be represented by a simple analytic formula.
- Mathcad is chosen for implementing the 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.

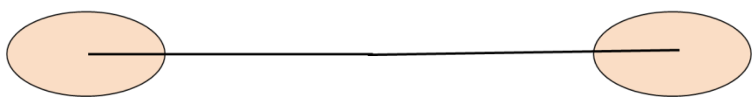
3. ARM of the String-Arrow Model of a Photon



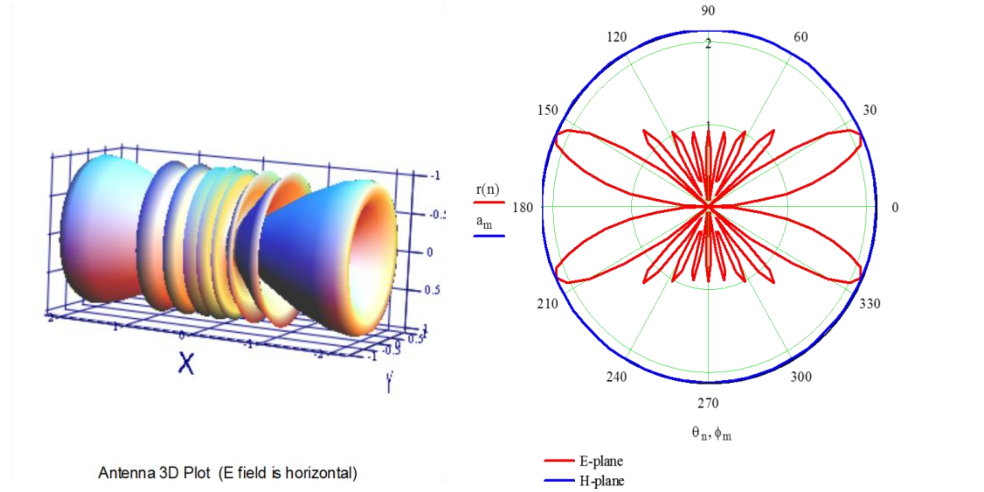
- Figure 1 is an ARM representation of the cross section of the energy of a photon or on a Goubau single wire transmission line. In-phase, quadrature and magnitude parts of equation 3 are shown.
- For a visible photon the radius of the string arrow profile is about 300 wavelengths corresponding to 4×300=1200 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)



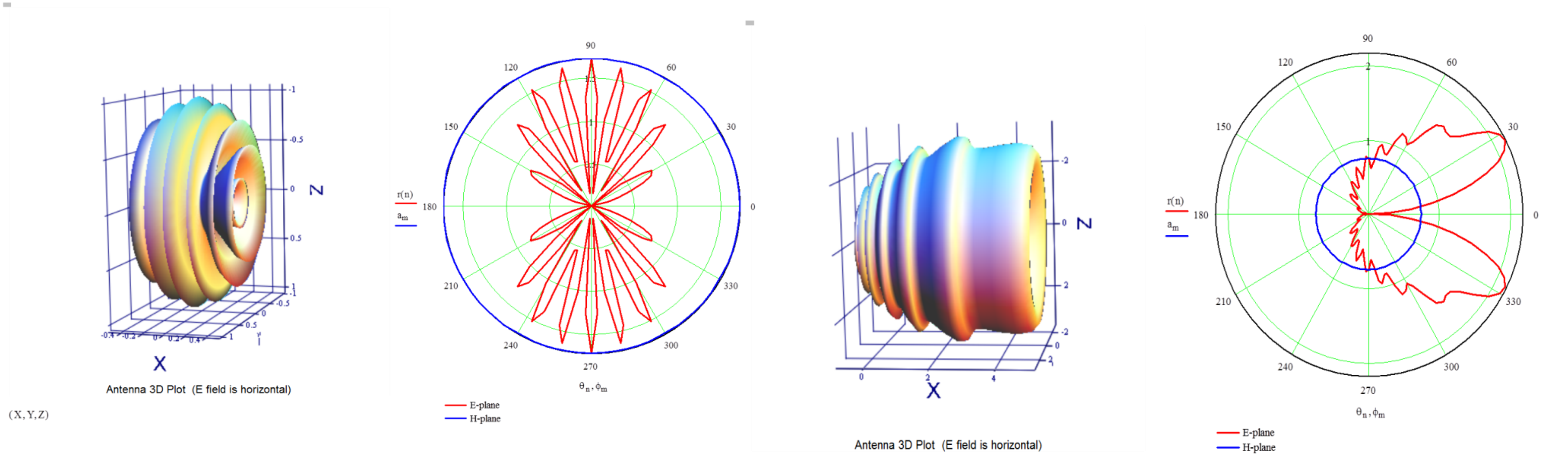


Figure 2. Top left: radiation from the antenna ends. Top right: 4.5λ wire antenna pattern using the Kraus/Balanis formula. Bottom left: an ARM pattern of 4.5λ top left. Bottom right: end-fed 4.5λ travelling wave wire at low frequency.

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: -

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

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: -

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

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

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

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

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

To compute Directivity D by pattern summation/integration:-

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

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

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

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

To compute Directivity D by pattern summation/integration

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

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

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

- 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

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

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

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

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

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

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

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

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

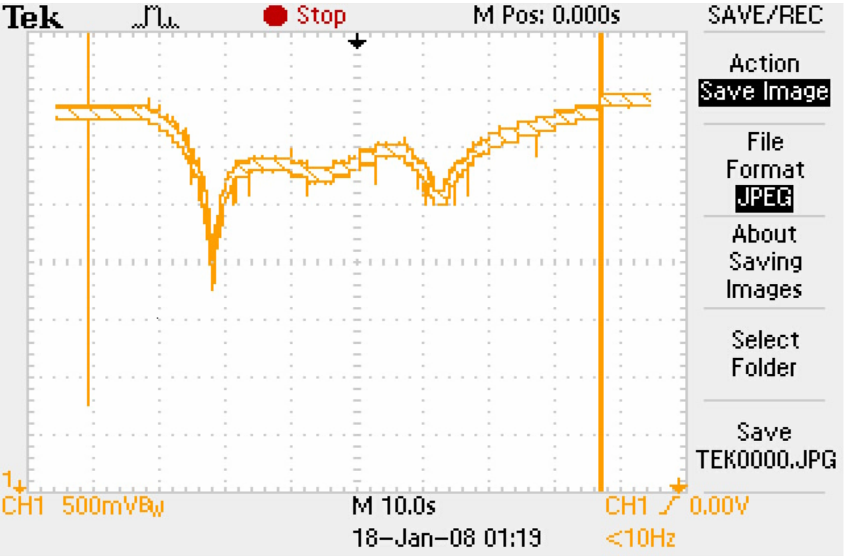
$A3 = 0.74 + 0.673j \qquad |A3| = 1 \qquad \arg(A3) = 42.3\cdot\text{deg}$

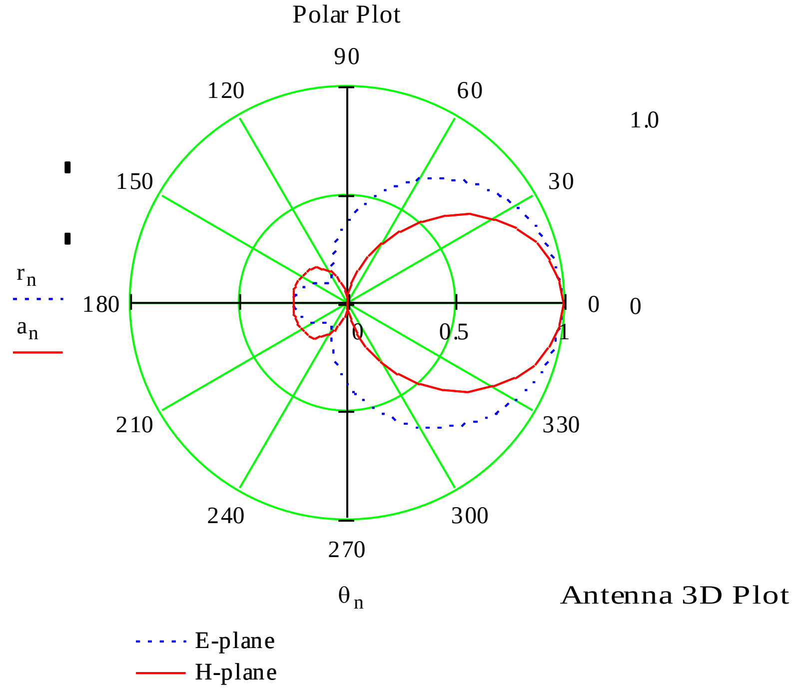
Demo of Antenna Pattern Modelling

A choice from:

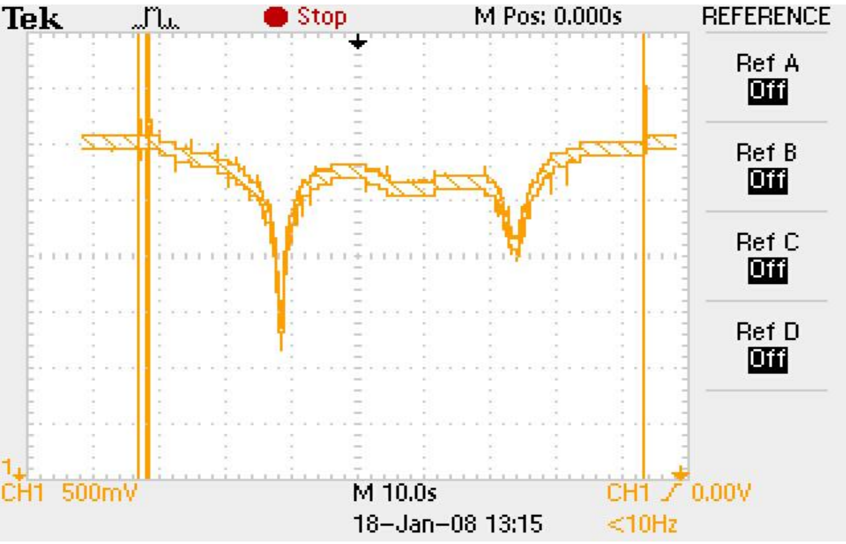
1. Loop-dipole/monopole
2. Any length dipole with sinusoidal current
3. End-fed long-wire/Beverage
4. Tuned coiled-hairpin
5. CFA, EH and Franklin MW BC antennas – two mode verticals.
   – *The CFA and EH antenna patterns can be derived as if they were Franklin antennas that are much reduced in size.*

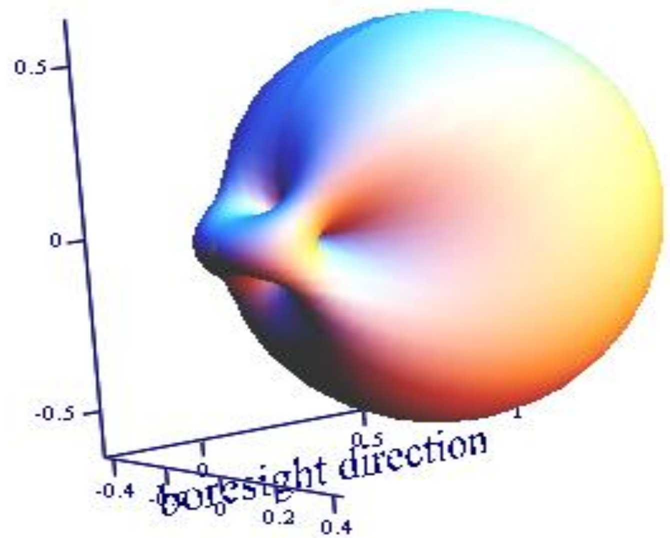
Heuristically Derived Antenna Pattern of Coiled Hairpin





Antenna 3D Plot





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

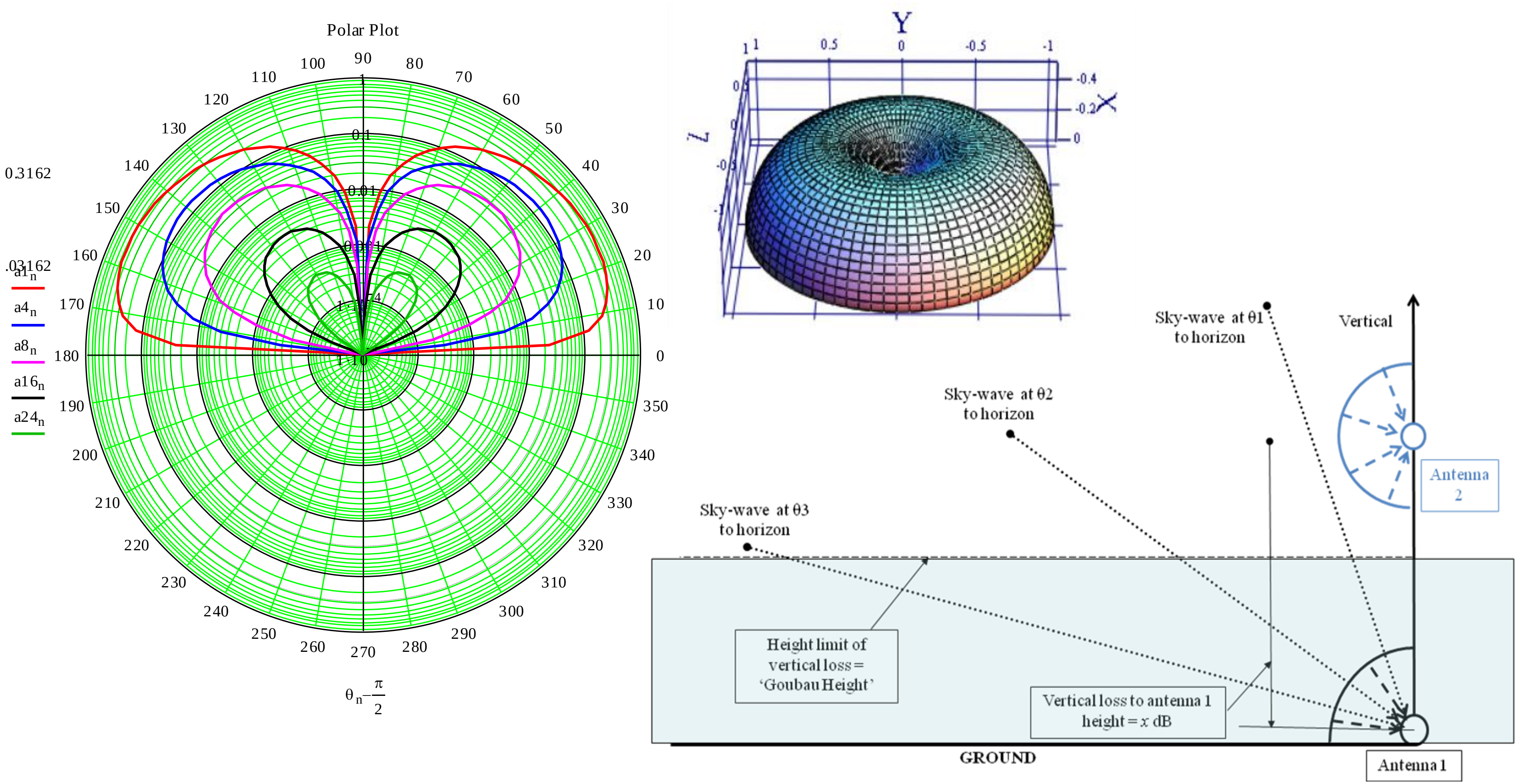


Figure 3. Bottom right: Ground Loss Scenario for small antenna. Top right: Pattern of short vertical whip or small horizontal (tuned) loop over perfect ground. Left: Far-field Radiation Pattern for total vertical path coupled ground loss values between 1dB (outer red plot) and 24dB (inner green plot).

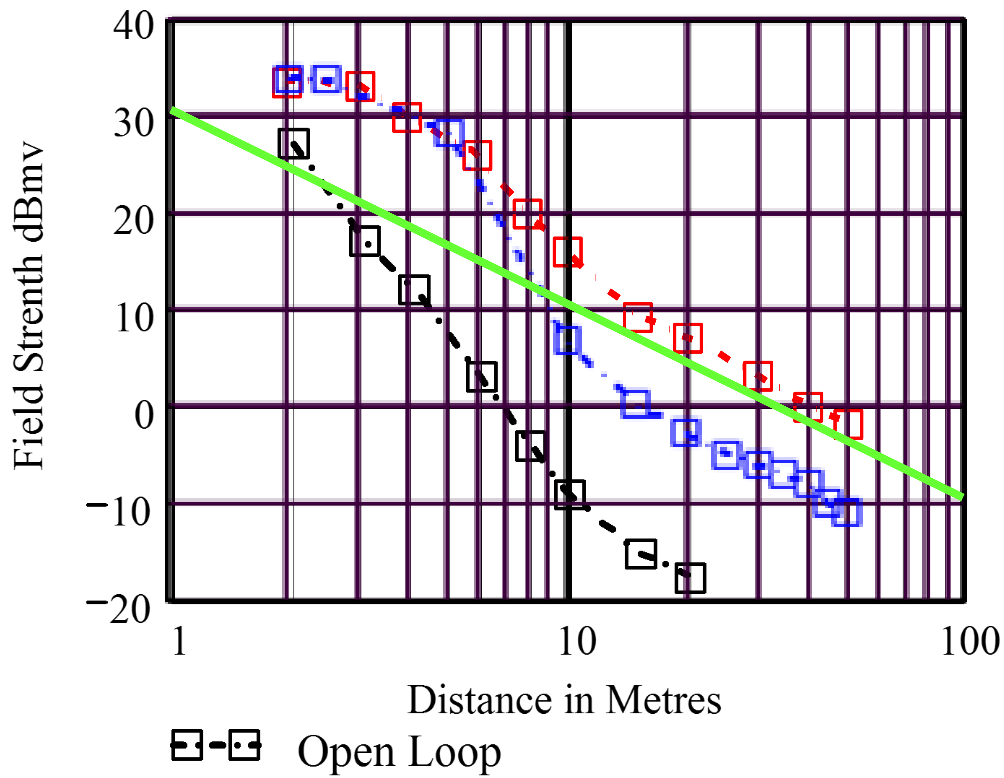
4. Conclusions

- ‘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.



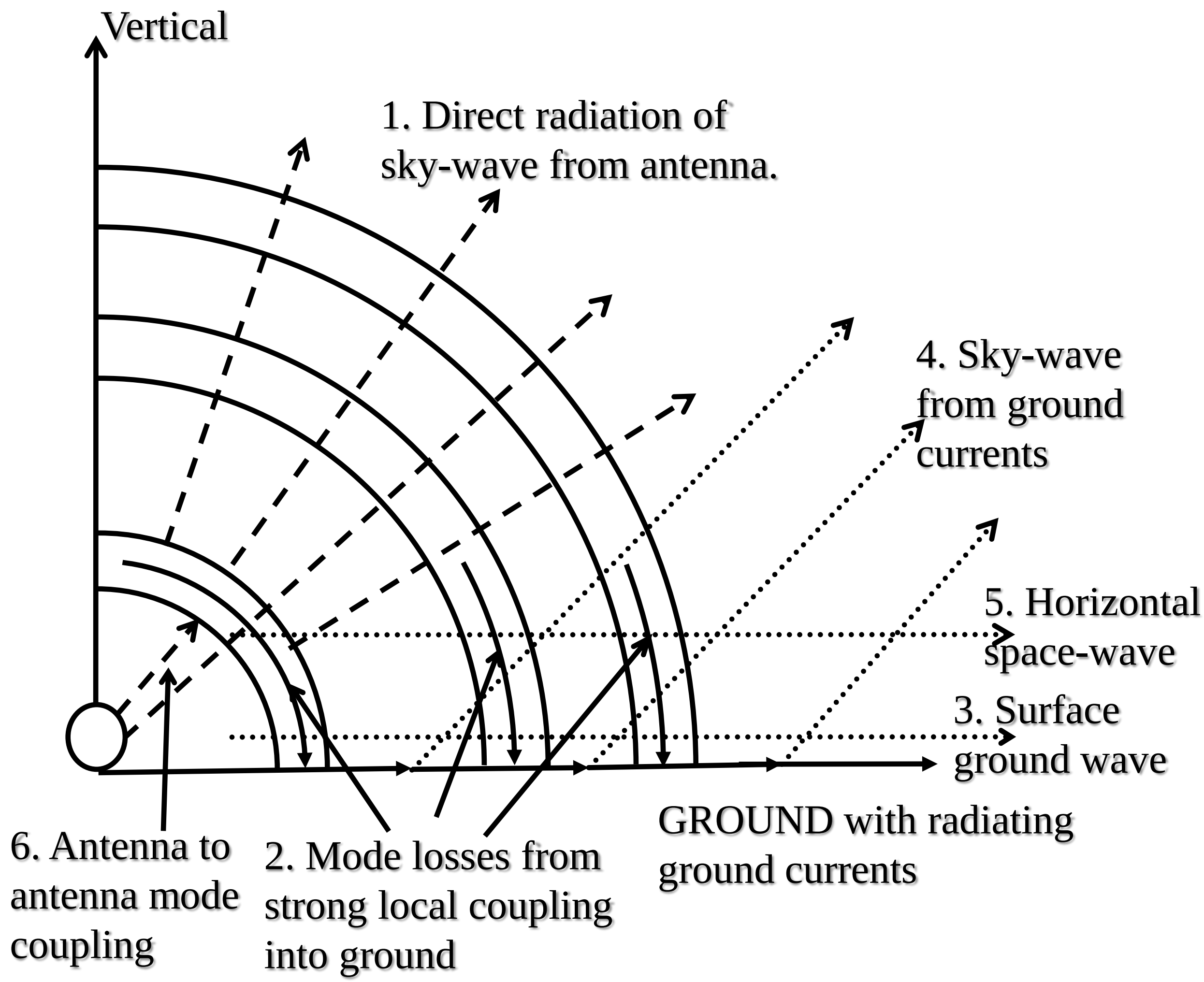
Conclusions from these results:

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**

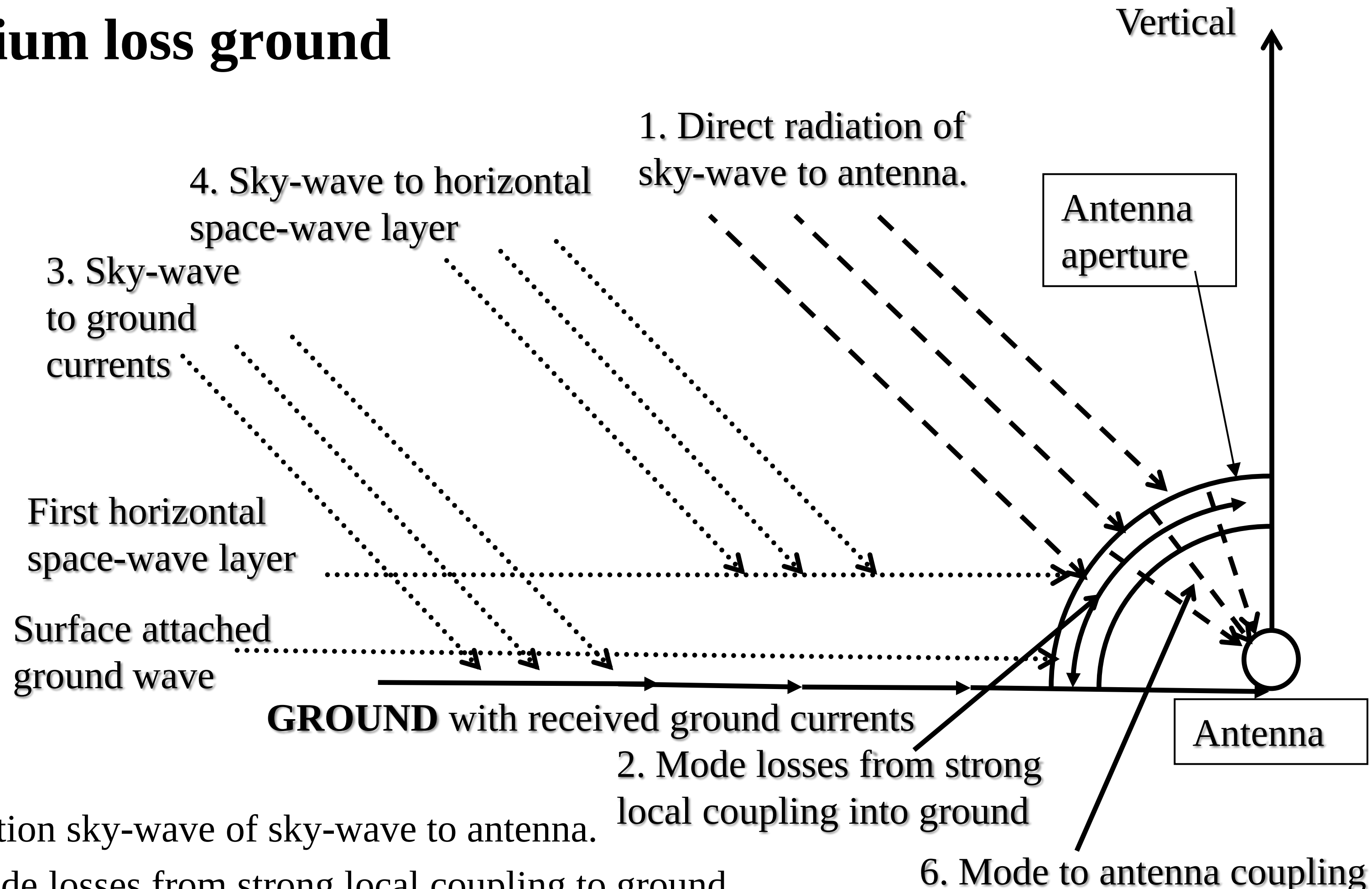
Radiation mechanisms of a small antenna over medium loss ground

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



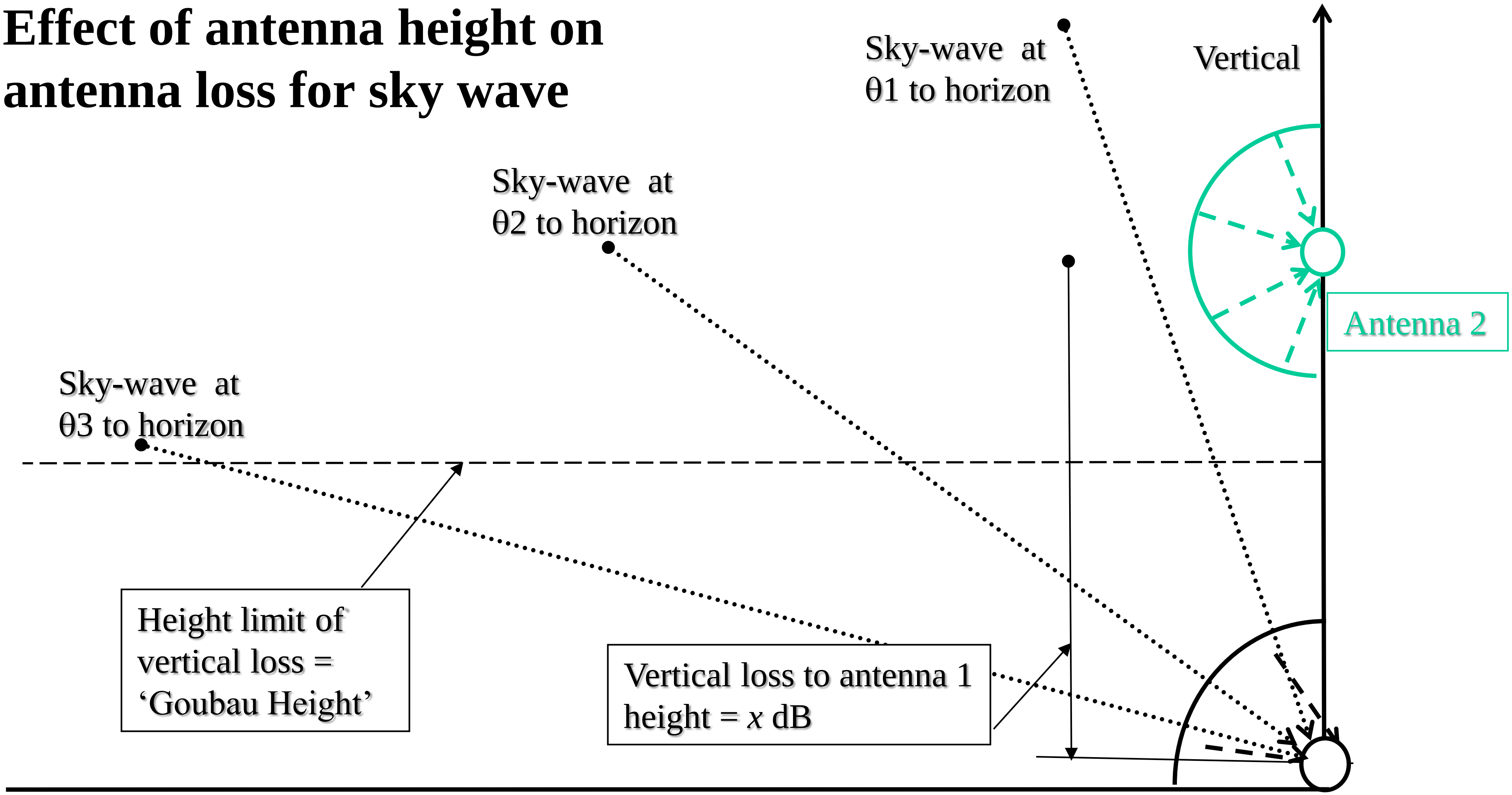
Reception mechanisms of a small antenna over medium loss ground



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



- For vertical loss to antenna = x dB
- At angle θ the sky-wave to antenna loss is increased to $x/\sin\theta$
- 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