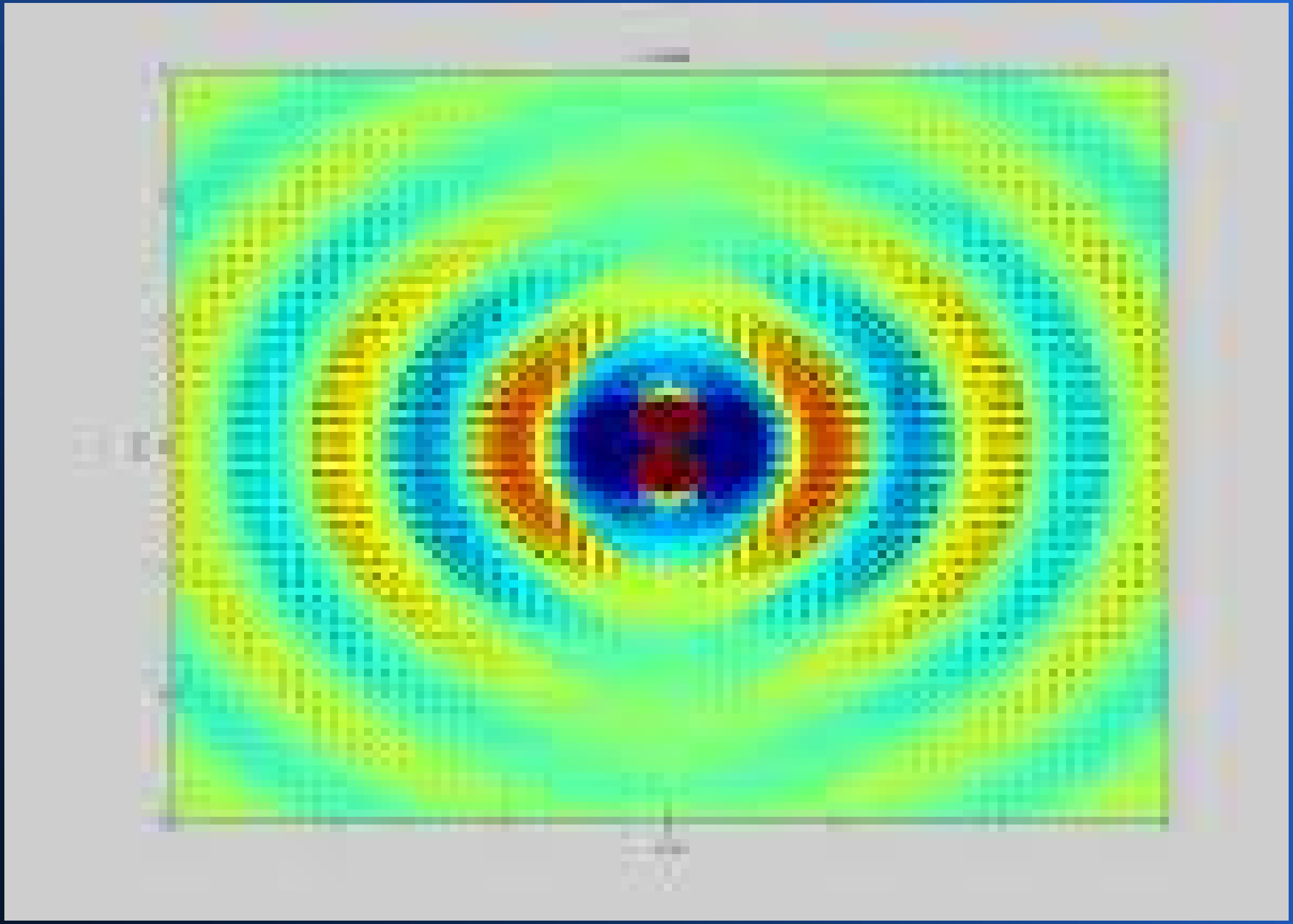
How Aerials really, really, work



Aims

- To talk about fields and how they are generated
- To explain the mechanism of EM radiation
- To use the dipole as an example for:
  - The dynamics
  - Efficiency and Radiation Resistance
  - The need for matching
  - Mounting height
- To discuss unbalanced feeder choices
- Explain how to do the best we can

EM fields

- EM fields exist around any current carrying conductor
- DC does not involve any charge acceleration
- DC does not result in EM waves except switch on/off transients
- AC does produce charge acceleration
- AC produces induced voltages in nearby conductors

The induction field

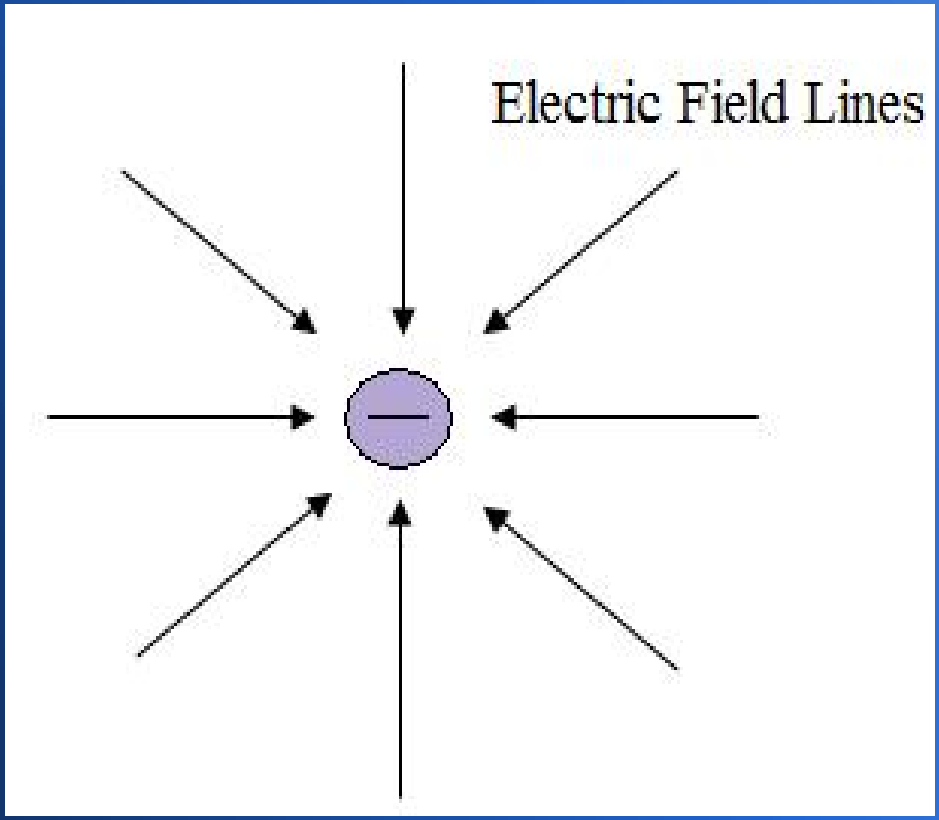
- At low drive frequencies, the induction field is virtually the only field.
- The field causes EM waves to expand and contract, for a dipole, as below:

$\lambda = 300.10^6/f$

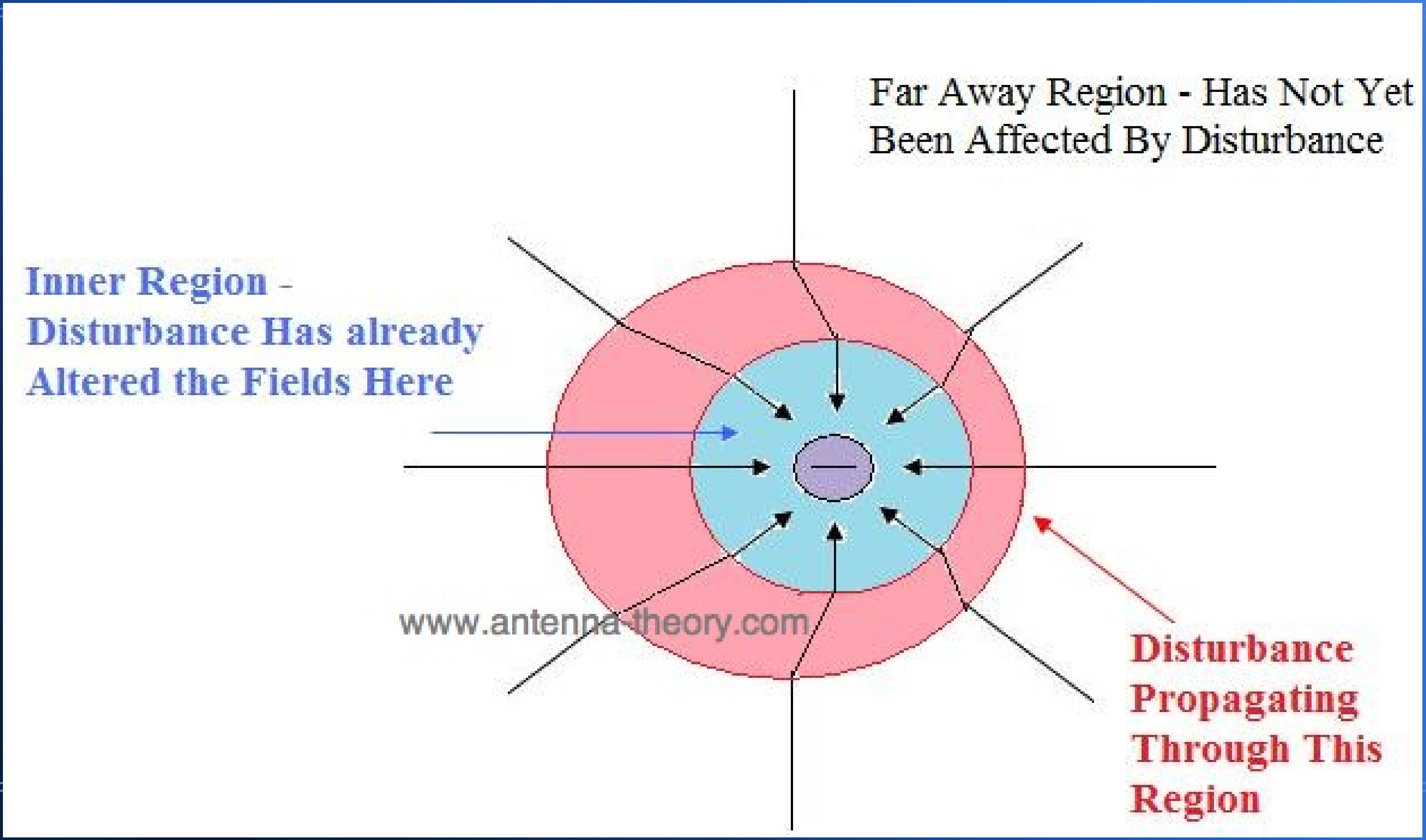
- The wavelength at 50 Hz is 6000km so the induction field is all you get!
- By the time you reach 10kHz, a wavelength of 30,000m the acceleration of charges due to a sinusoidal drive is great enough to start something else happening!
- The rate at which fields can respond is determined by the laws of physics-hence waves

'Waves'

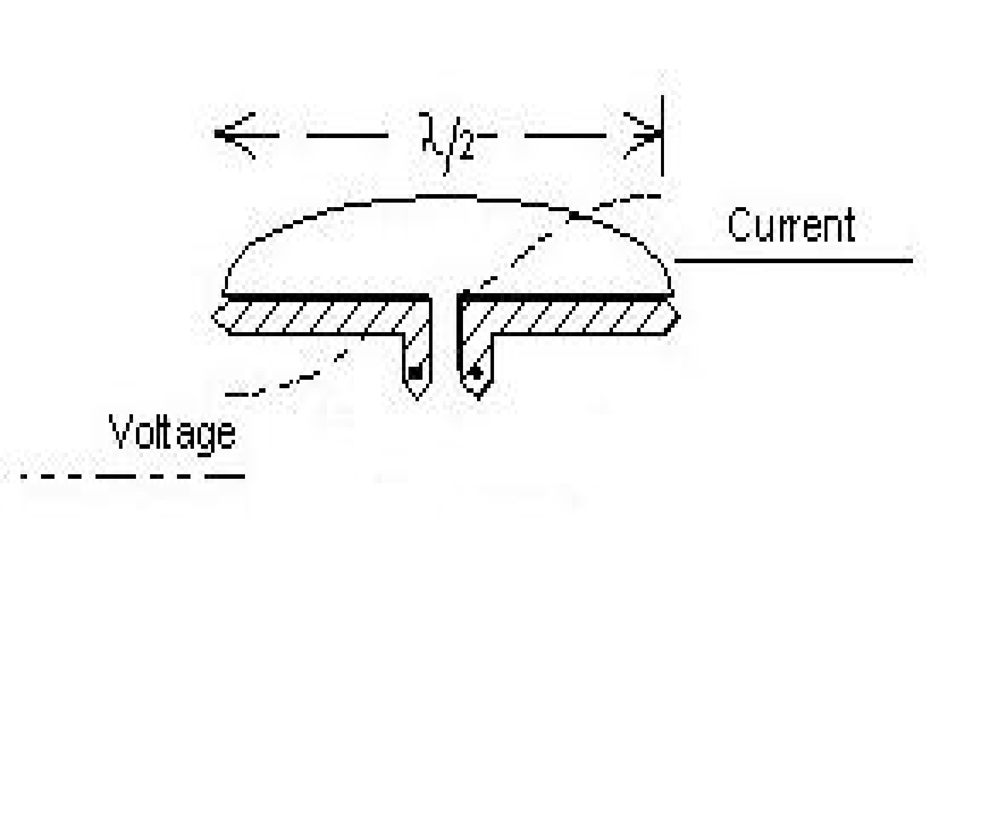
- Point charges have radial fields
- Instantaneous 'action at a distance' is impossible (Physics)
- What happens if you suddenly displace a charge?



'Waves' II


Far Away Region - Has Not Yet Been Affected By Disturbance
Inner Region - Disturbance Has already Altered the Fields Here
www.antenna-theory.com
Disturbance Propagating Through This Region

Consider a λ/2 dipole



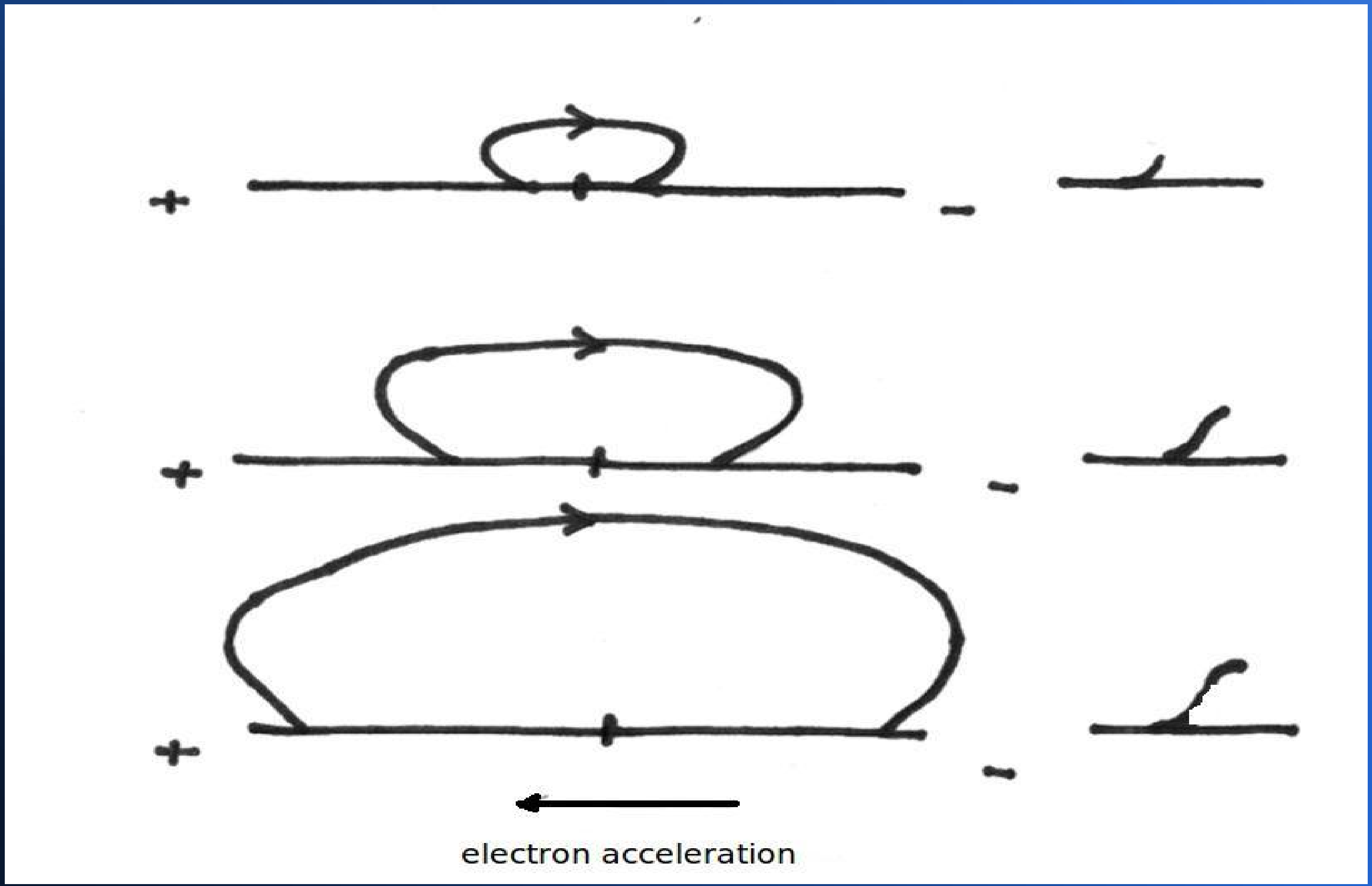
- What is this?
- The sum of incident and reflected waves at a particular instant- or if shown with two positive voltage nodes, RMS
- But really, things are dynamic

The dynamic process

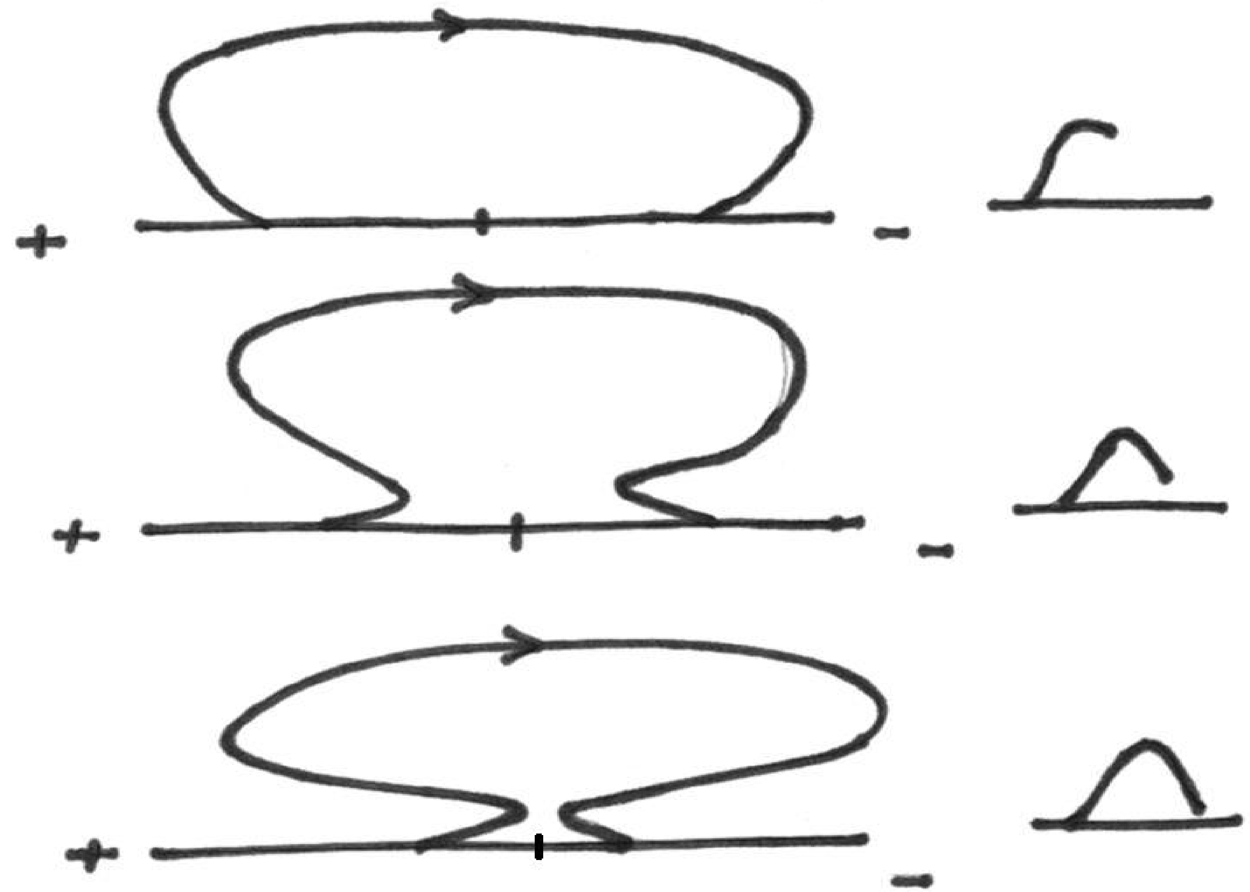
What's happening?

- Consider the current standing wave:
  - During the first quarter cycle, charges are net accelerated, during the second quarter cycle net charges are decelerated
  - Accelerating charges cause an increasing field whilst decelerating charges cause a field contraction
  - The action repeats in the second half cycle but with reversed polarities

Dipole E field dynamics I



Dipole E field dynamics II

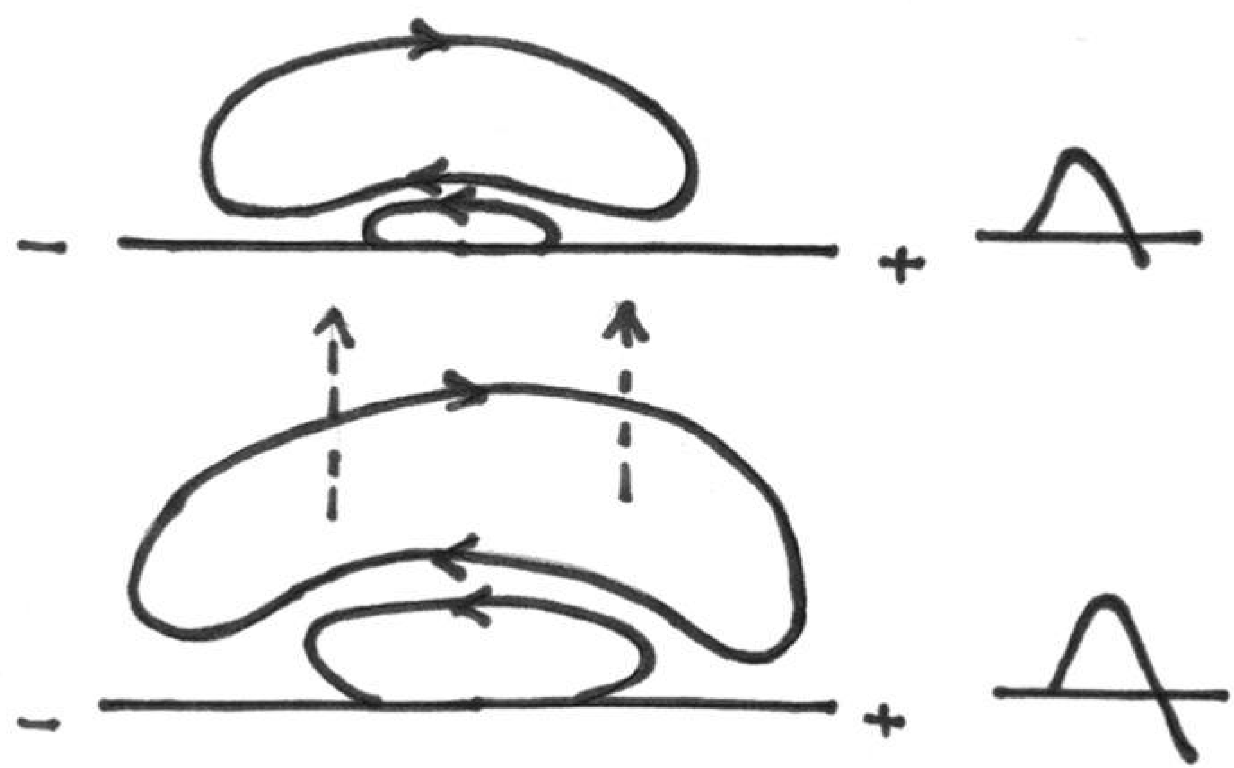


electrons decelerating

IIa

- Q. Why the kink that causes the formation of closed loop fields?
- A. It's a wave caused by decelerating charges
- The field lines cannot cross, so that, when they touch they form a loop, and the remaining fraction outside the loop disappears as the drive goes through zero.

Dipole E field dynamics III



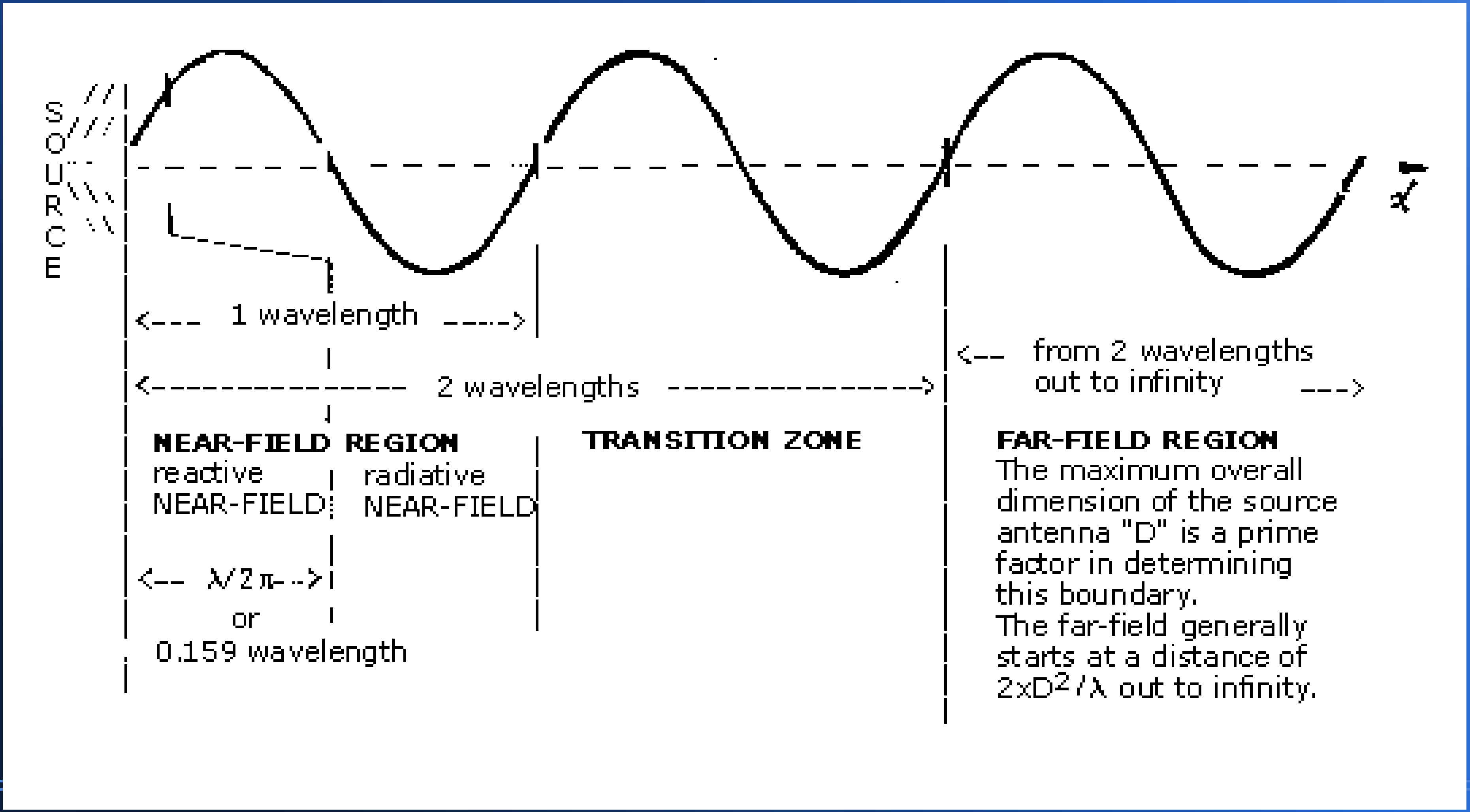
closed loop field forced away at the speed of light - like fields repel

Animation

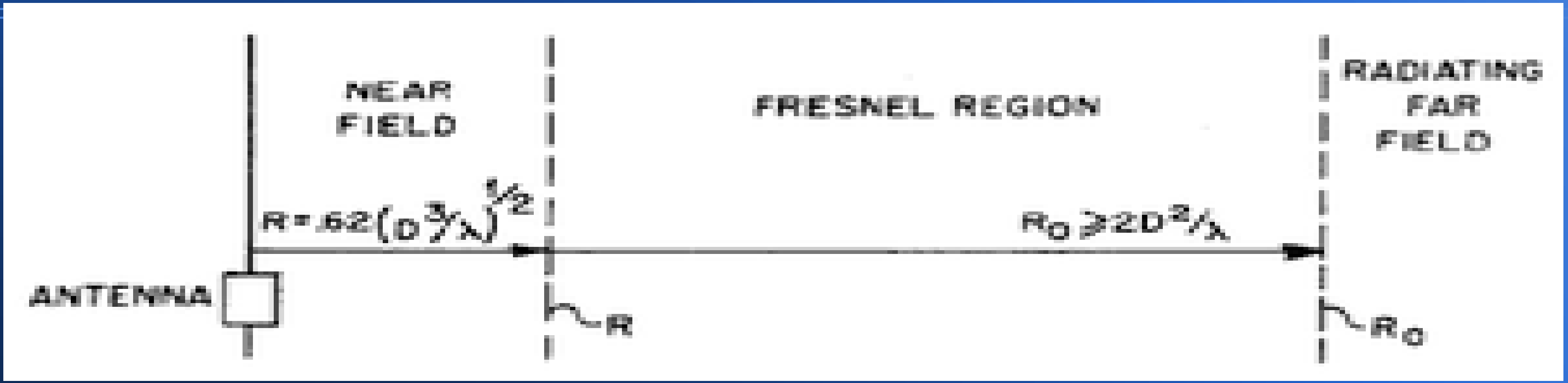
What do you notice?

- The animation shows that not all of the field is radiated away – close to the aerial there is an oscillatory field – this is the NEAR field also known as: the INDUCTION field
- The field radiated away is the FAR field, this is the bit that matters for radio reception at a distance!
- The NEAR field contributes LOSSES

How far do the fields extend?



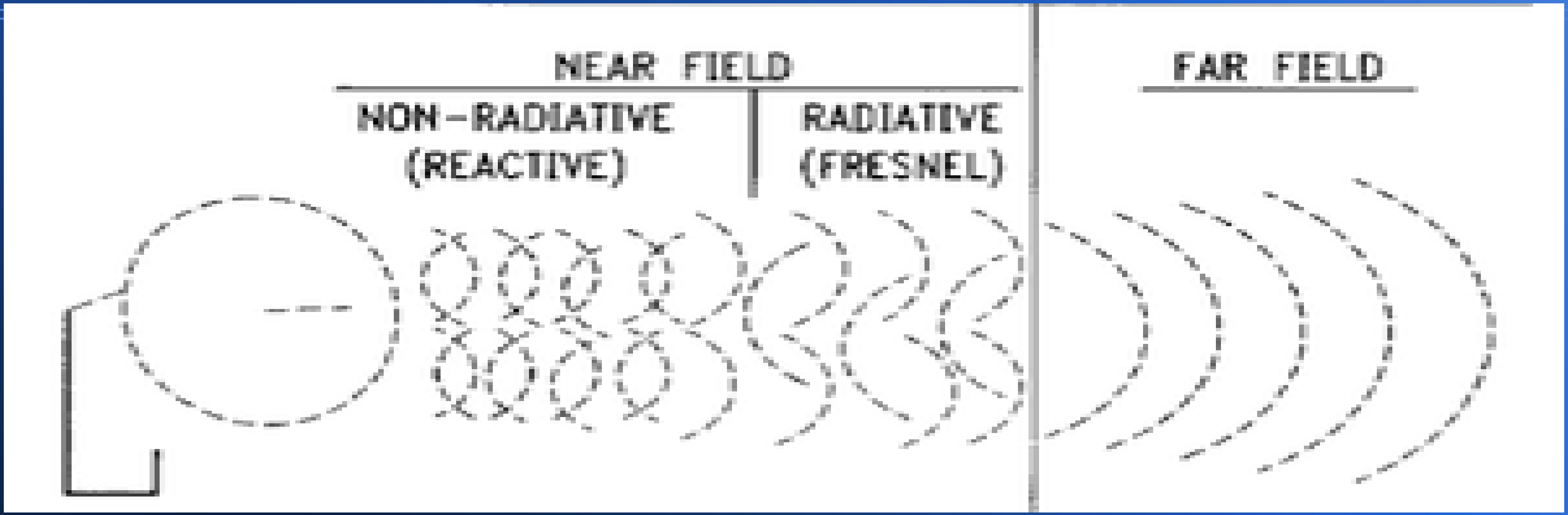
The transition zones



- The form of the EM wave changes as D increases
  - Near field is reactive (stores and returns aerial energy)
  - Fresnel region in non reactive (but complex EM wave relationships – measurement tricky)
  - Far field EH fields settle down as Transverse in phase

diagram source:Wikipedia

Where to measure?



- Reactive - to 0.16 λ - measurement unhelpful
- Fresnel – to 1 λ complex interactions – measurements can be confusing
- Far field – from 2λ – measurements useful and reliable

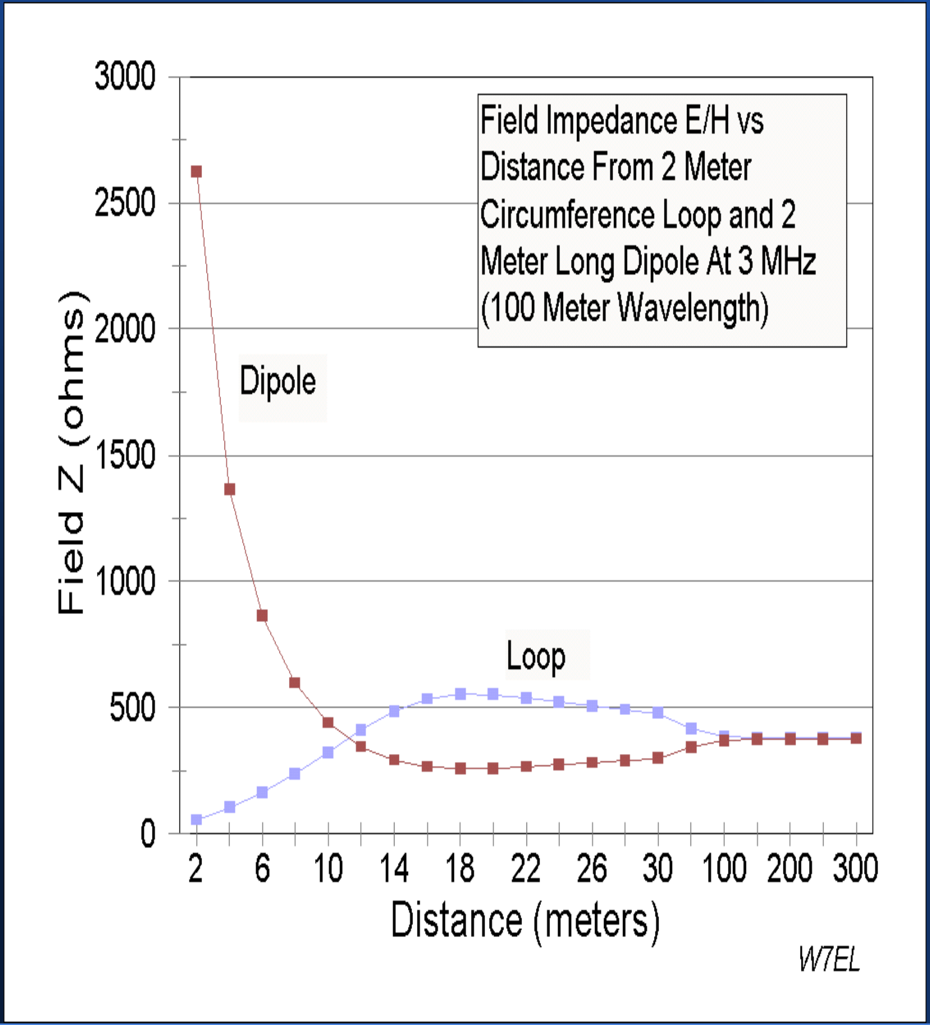
diagram source: Wikipedia

The energy situation

- Total field energy=near field+far field energies
- Of course you can strike a neon at this distance!
- The real test is at

2λ +!

Mag loop or dipole - does it matter?



- Not after 1λ. E and H fields will have the same relative values (Z_{fs}=377Ω)
- Closer – reactive near field is:

E field dominant (dipole)and field impedence= high

and H field dominant (loop)and field impedence=low

- Speculate what this might mean!!!!

Diagram source W8JI

Pros and Cons – alright, Cons!

- Mag loops are smaller – but remember, physics will not be cheated and the price is high Q, narrow bandwidth (0.2%) and a lot of antenna tuning!
- You have to be extraordinarily careful about losses, particularly induction losses – RSJs in the roof? Watch out!
- Capacitor losses? The Volt Amps Reactive will be massive at 100W (20-50 Amps!) - better not have any high resistance joints!
- Whatever else, isn't the antenna aperture rather small? 'You cannot make a small antenna act like a full size one – it all comes down to current distribution over linear spatial distance' Quote - W8JI

Is it safe to have a mag loop in the shack?

- Tend to be used by the space strapped, so it is a temptation
- Near field strength does decline quickly but here are the accepted safety closeness limits

40M - 5 watts - 4 feet	40M - 100 watts - 7 feet	40M - 1500 watts - 11 feet
20M - 5 watts - 5 feet	20M - 100 watts - 9 feet	20M - 1500 watts - 15 feet
10M - 5 watts - 5 feet	10M - 100 watts - 10 feet	10M - 1500 watts - 22 feet

Source: ARRL

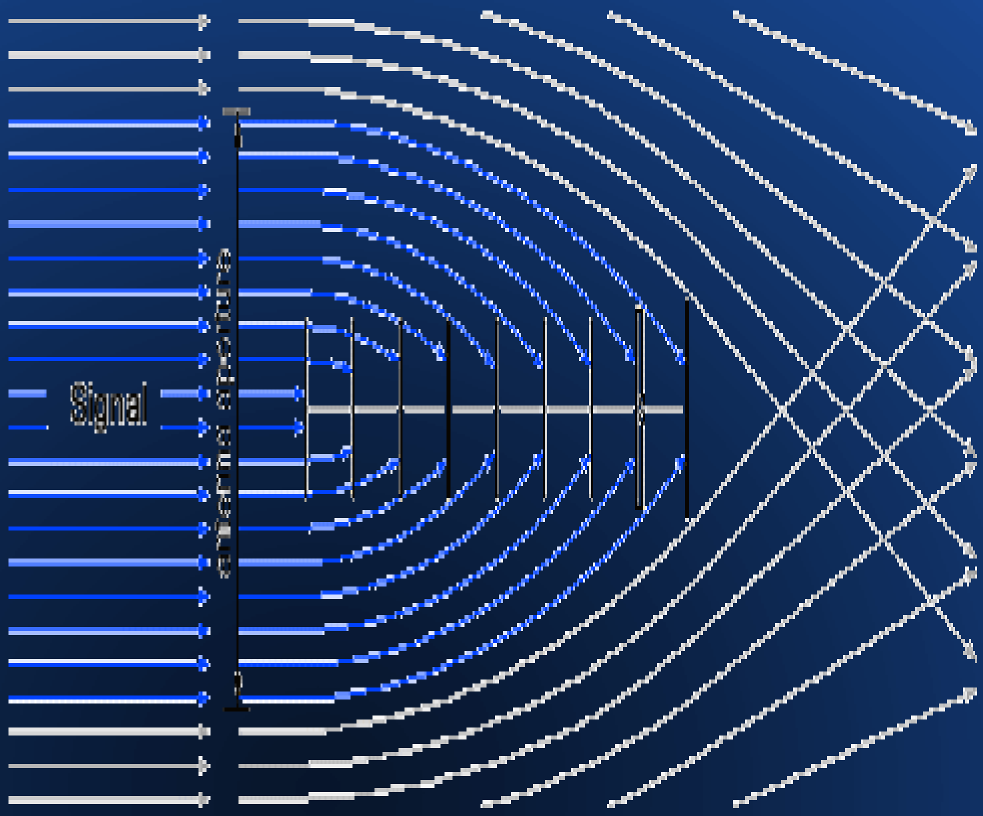
Efficiency

- Eff = (100 x Rradiation) / (Rradiation + Rinductors + Rground + Rother losses)
- Where: Eff is efficiency
- Rradiation is the loss due to the radiated fields.
- Rinductors are the losses due to inductors in the system.
- Rground are the various ground losses.
- Rother losses are any remaining losses in the antenna system.

Antenna Aperture

- The functionally equivalent area (usually modelled as circular) through which an antenna gathers or absorbs energy from an incident em wave.
- Some have been astonished that this is generally bigger than the area of antenna elements – No surprise, passing waves induce currents into the antenna -these cause fields that interact with the original wavefront to bend or focus it.

Aperture 2

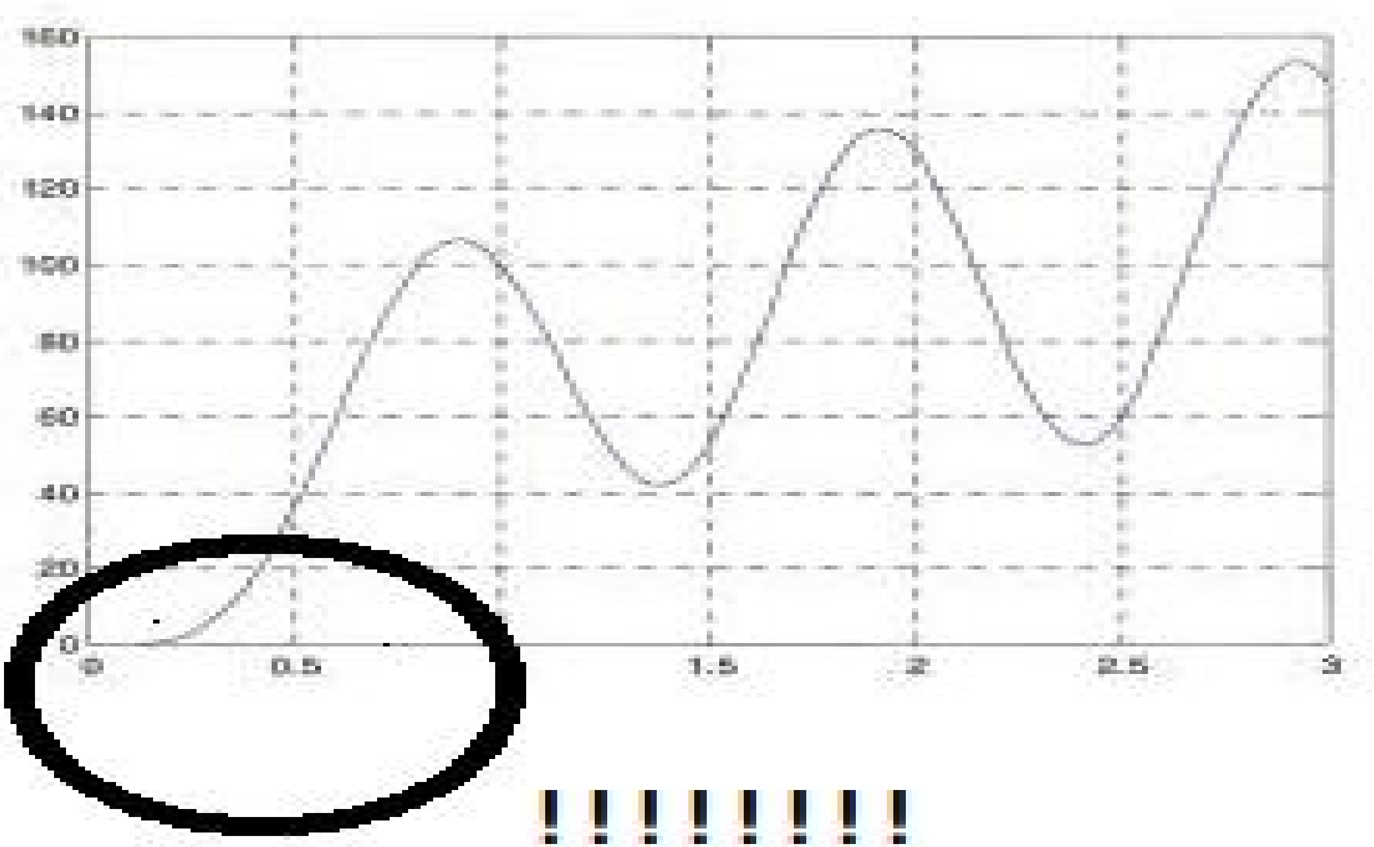


- GOOD designs have greater apertures
- Some claim this is a new revelation!
- Principle first published 1908 by Rudolph Rudenberg
- Ensure aperture does not touch ground or other objects

Why use resonant antennas?

- Resonant antennas have greater apertures!
- Field strengths relate to current
  - More current, more field strength
  - At resonance antenna 'Q' magnifies current
- 'You cannot make a small antenna act like a full size one – it all comes down to current distribution over linear spatial distance' – demonstrated in the next slide Quote - W8JI

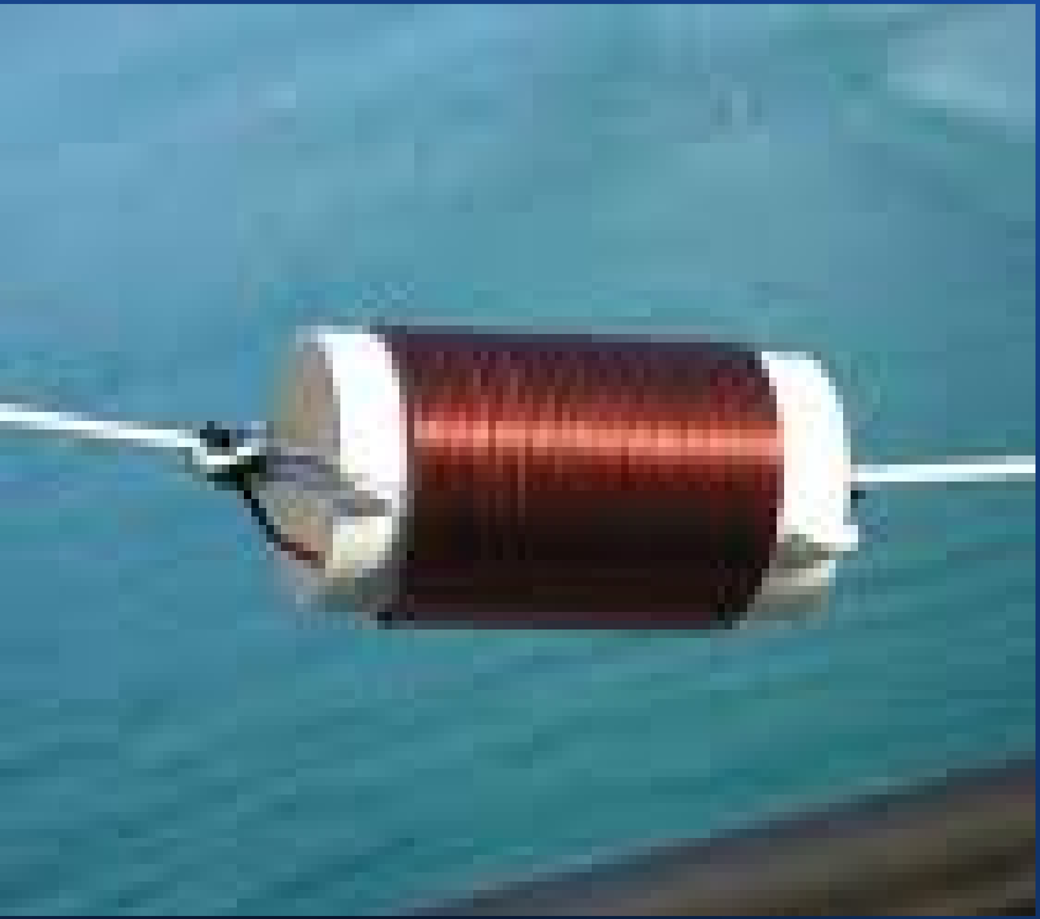
1A source, Watts/λ



How do we try to compensate ?

- We make current as uniform as possible over the length of the antenna by using as much capacitance as possible at the antenna ends.
- AND/OR

How do we compensate II



- We use low-loss loading such as optimum form factor (size, length, and diameter) loading coils.

How do we compensate III

- We make the antenna as large and as straight in a line as possible. We don't fold, bend, zigzag, or curve the antenna...... especially in the high current areas!
- We keep the high voltage points (the open ends) away from lossy things (such as lossy earth or wet foliage).
- We keep the high current areas away from other large lossy conductors.

Unfortunately, it all leads to losses

- And thus reduces efficiency:
- Eff = (100 x Rradiation) / (Rradiation + Rinductors + Rground + Rother losses
  - Where
  - Rradiation is the loss due to coupling with the universe.
  - Rinductors are the ohmic losses due to inductors in the system.
  - Rground are the various ground losses.
  - Rother losses are any remaining losses in the antenna system.

What's radiation resistance?

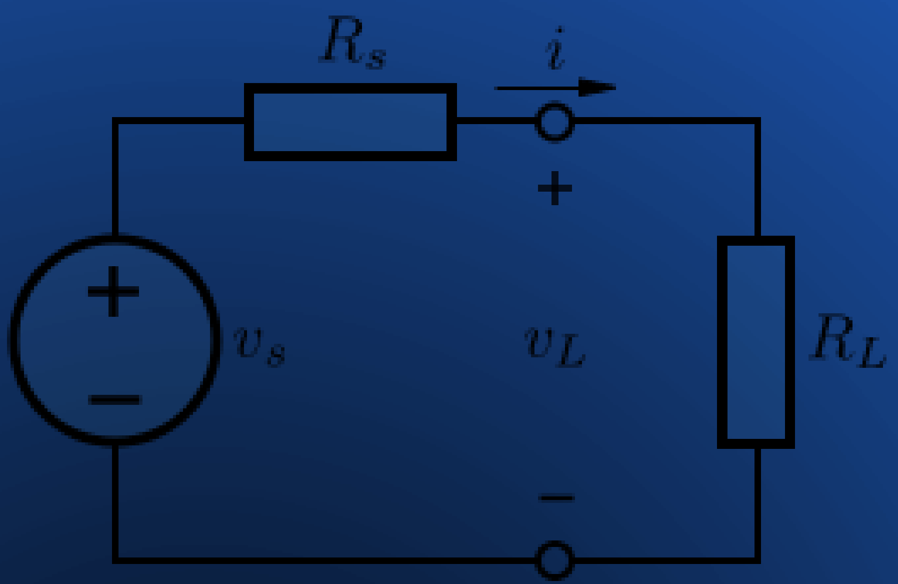
- It is usual to model antennas and their losses as an equivalent circuit
- Radiation Resistance is an element of the equivalent circuit with a value defined as:
  - The total power radiated in all directions divided by the square of net current causing the radiation.   It is:
  - The resistive part of an antenna's feedpoint impedance that is created solely by radiation from the antenna

Typical efficiencies?

- Dipoles can be very efficient, typically better then 95%
- A 60' highX100'flat-top TEE at 535kHz is about 11%
- The TEE is poor because its size is small compared to a half wave.
- Remember this?

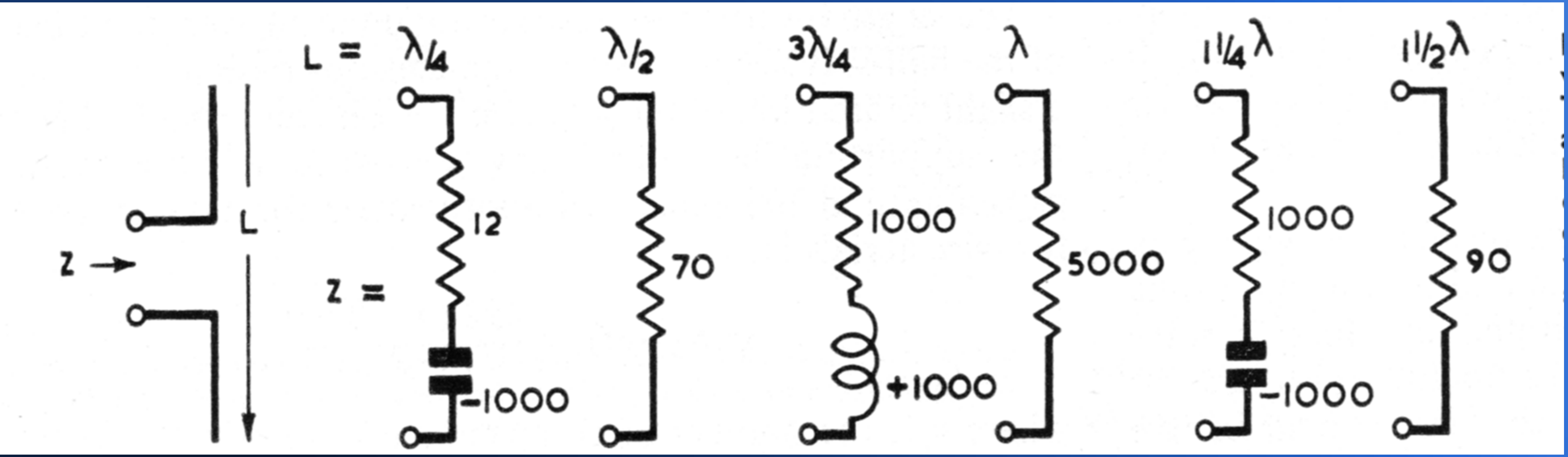
1A source, Watts/λ

Maximum power transfer theorem



- Max power is dissipated in the R_L when R_S=R_L
- If both are 25Ω, Power is 100W when v_s=100V
- 87W when R_L=50Ω
- 81W when R_L=10Ω

Z_{in} for different length dipoles



Aerials match – what to what?

- The transmission line to the impedence of free space
- 50Ω to 377Ω ??????
- This their real function!
- Feedpoint Z is NOT the average antenna Z!
- Z at any point=ratio of V to I standing waves

Matching to the antenna

- An ATU? Where shall I put it?
- NOT in the shack unless you are using tuned feeders – if your feeder is co-ax put it at the antenna feed-point!
- An ATU at the feed-point is a COUPLER
  - This is a pain because the feed-point could be remote – hence the many commercial auto-couplers on the market

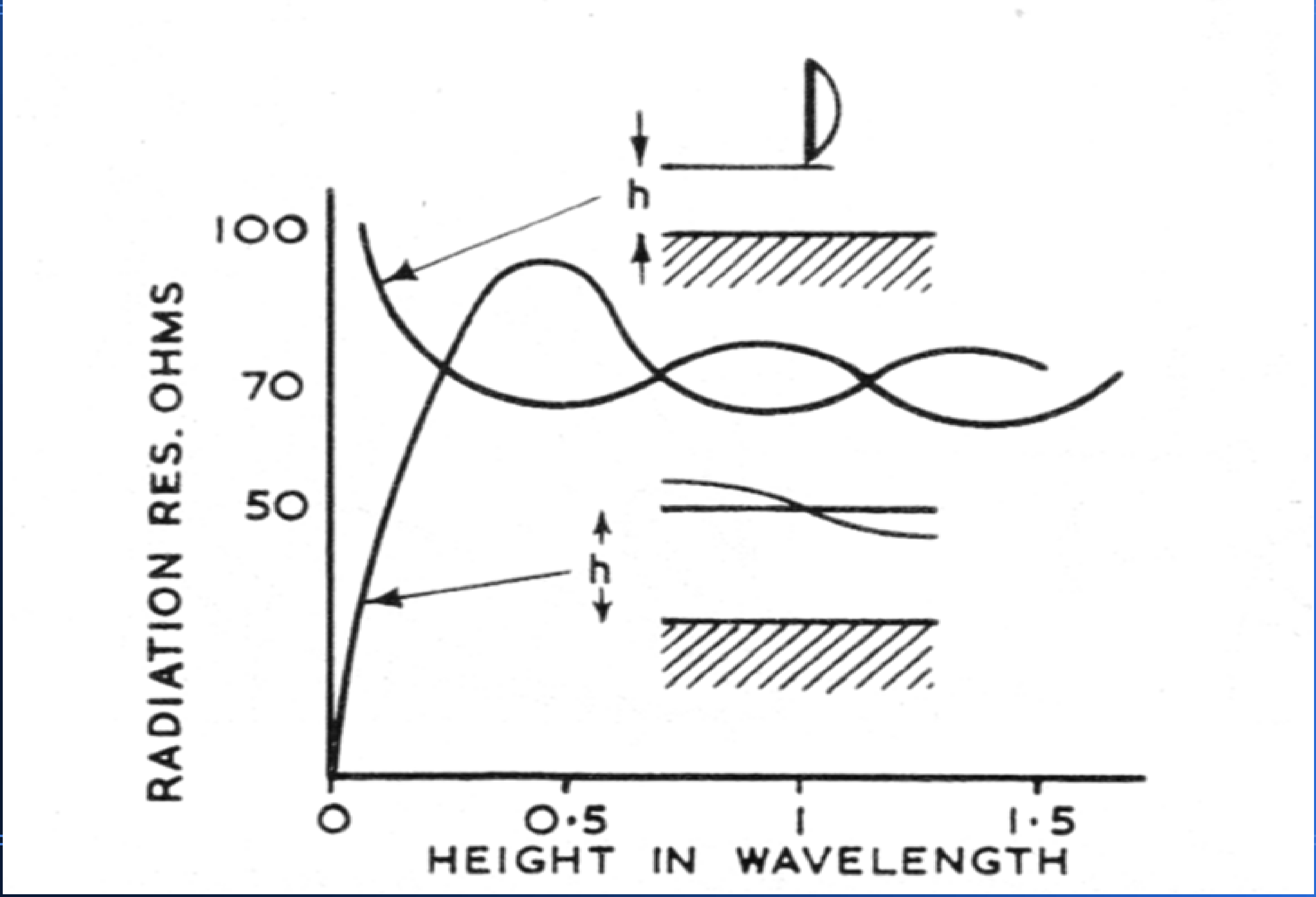
Coax, does it matter? YES!

Attenuation (dB per 100 feet)

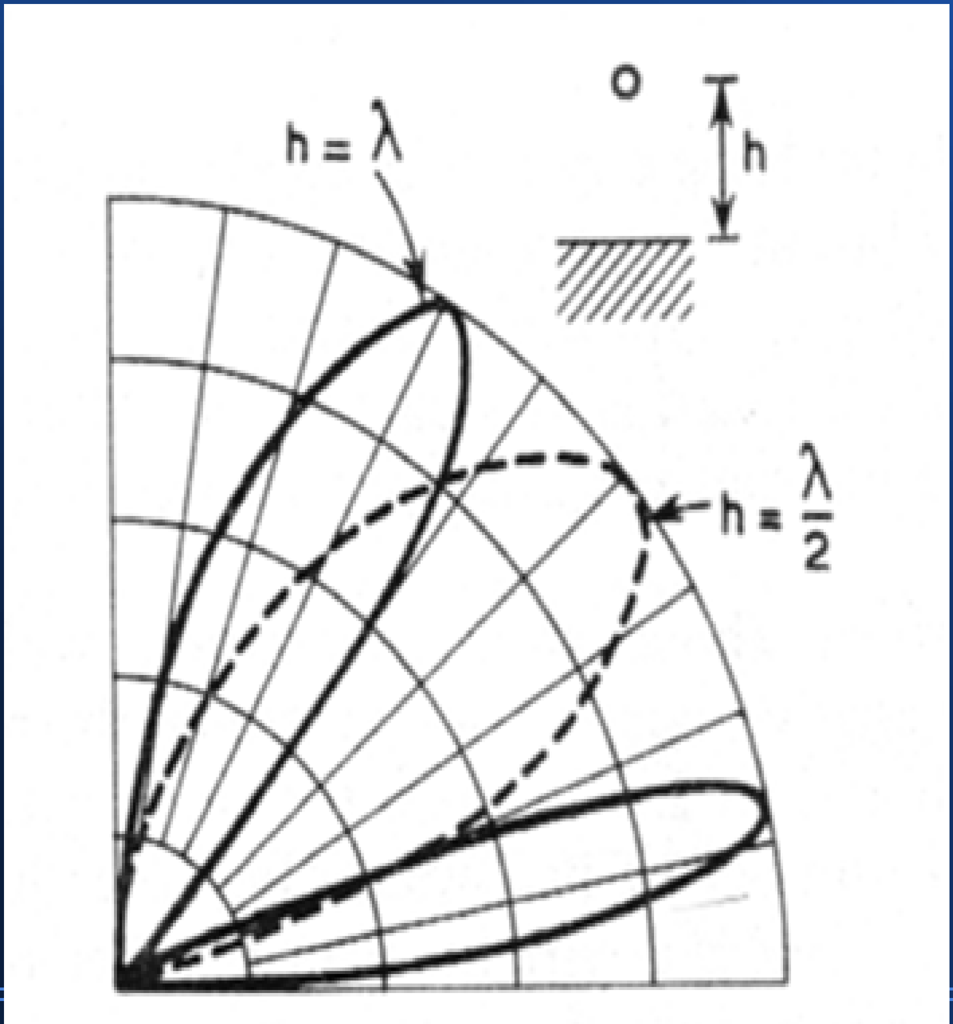
Coax Cable Signal Loss (Attenuation) in dB per 100ft*								
Loss*	RG-174	RG-58	RG-8X	RG-213	RG-6	RG-11	RF-9914	RF-9913
1MHz	1.9dB	0.4dB	0.5dB	0.2dB	0.2dB	0.2dB	0.3dB	0.2dB
10MHz	3.3dB	1.4dB	1.0dB	0.6dB	0.6dB	0.4dB	0.5dB	0.4dB
50MHz	6.6dB	3.3dB	2.5dB	1.6dB	1.4dB	1.0dB	1.1dB	0.9dB
100MHz	8.9dB	4.9dB	3.6dB	2.2dB	2.0dB	1.6dB	1.5dB	1.4dB
200MHz	11.9dB	7.3dB	5.4dB	3.3dB	2.8dB	2.3dB	2.0dB	1.8dB
400MHz	17.3 B	11.2dB	7.9dB	4.8dB	4.3dB	3.5dB	2.9dB	2.6dB
700MHz	26.0dB	16.9dB	11.0dB	6.6dB	5.6dB	4.7dB	3.8dB	3.6dB
900MHz	27.9 B	20.1dB	12.6dB	7.7dB	6.0dB	5.4dB	4.9dB	4.2dB
1GHz	32.0dB	21.5dB	13.5dB	8.3dB	6.1dB	5.6dB	5.3dB	4.5dB
Imped	50ohm	50ohm	50ohm	50ohm	75ohm	75ohm	50ohm	50ohm

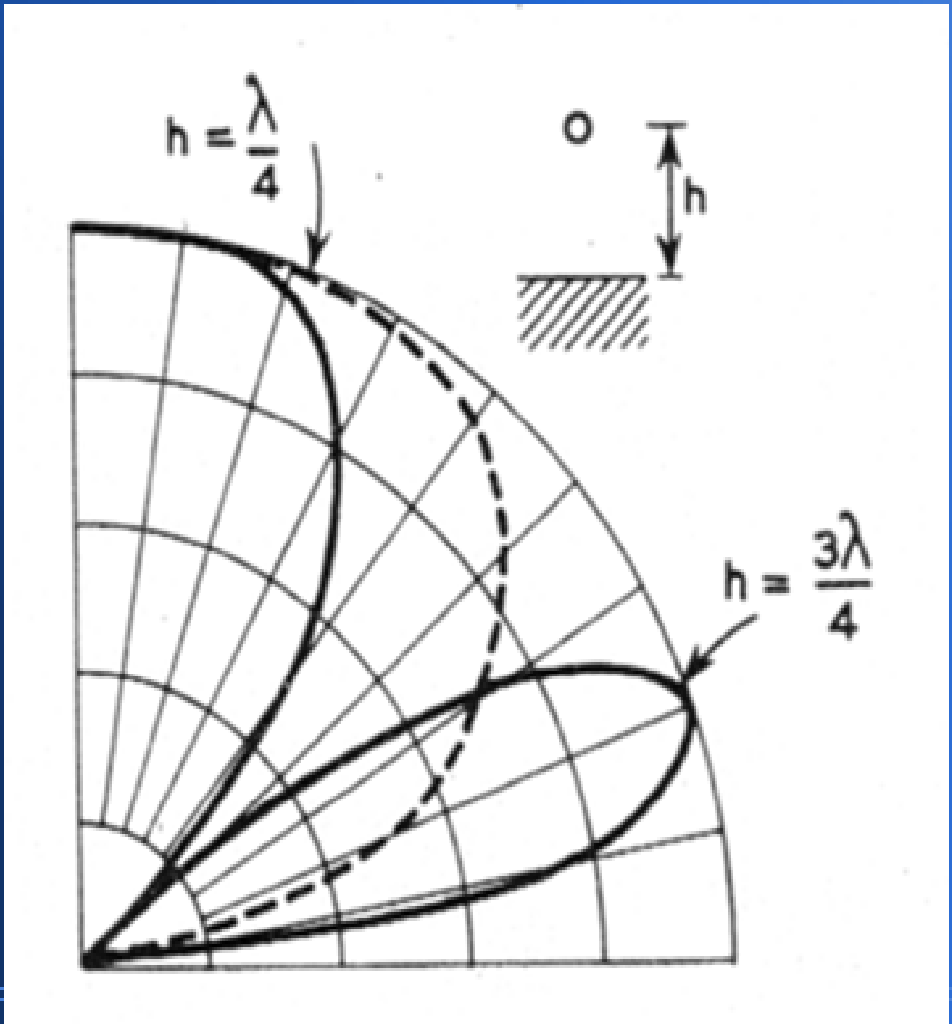
* **Note:** Coax losses shown above are for 100 feet lengths. Loss is a length multiplier, so a 200 ft length would have twice the loss shown above and a 50 ft length would have half the loss. This multiplier factor is why you should keep cable installation lengths between radios and antennas as short as practical!

Height – does it matter? YES!



Height -does it matter? II





How to do the best we can

- Choose a dipole based antenna:
  - e.g dipole, collinear,yagi,log-periodic,sterba,end fire array,W8JK,Cobwebb
- Match it to the line Z and use a Balun
- Use a genuinely low loss feeder like Westflex,RG213 etc
- Don't use an ATU at the shack end – use an autocoupler at the antenna base, if you must!

How to do the best we can II

- Get it up in the air! - 25' plus is good
- Don't bend it too much
- Keep the voltage ends away from things
- Don't use loading coils or capacity hats

It's tough to do it all

- So,
  - Just do what you can
  - Don't buy 'miracle antennas' – there is no such thing! Physics will not be cheated! If a manufacturer says you mustn't use a choke balun it's a very bad sign!
  - If you need to compromise, then you need to, e.g. for short antennas, coils,capacity hats, for multiband, traps etc. Just be aware of the losses.

......and finally

- Some have argued that heuristics are the way forward
- Heuristics – discover something for yourself
  - Alternative dictionary definitions
    - Guessing – jumping to conclusions
- Scientific – Build on the work of others, theorise and empiricise – deductive or inductive research method

Comparison

- A heuristic giant – Thomas Edison
  - Tin foil phonograph, a form of incandescent light bulb (Swann's was better!), DC power distribution, the kinetoscope.
- A Scientific giant – Nikola Tesla
  - AC power theory and distribution,transformers,fluorescent lamps,HF generators for radio,radio control, induction motor,the national grid,polyphase power systems and contributions to broadcast and communications radio,X-ray generation, radar,artificial lightning,robotics and more

Whose work has stood the test of time?

The End