

**PRACTICAL ANTENNAS**

**for the**

**LOW BANDS**

**RUDY SEVERNS N6LF**

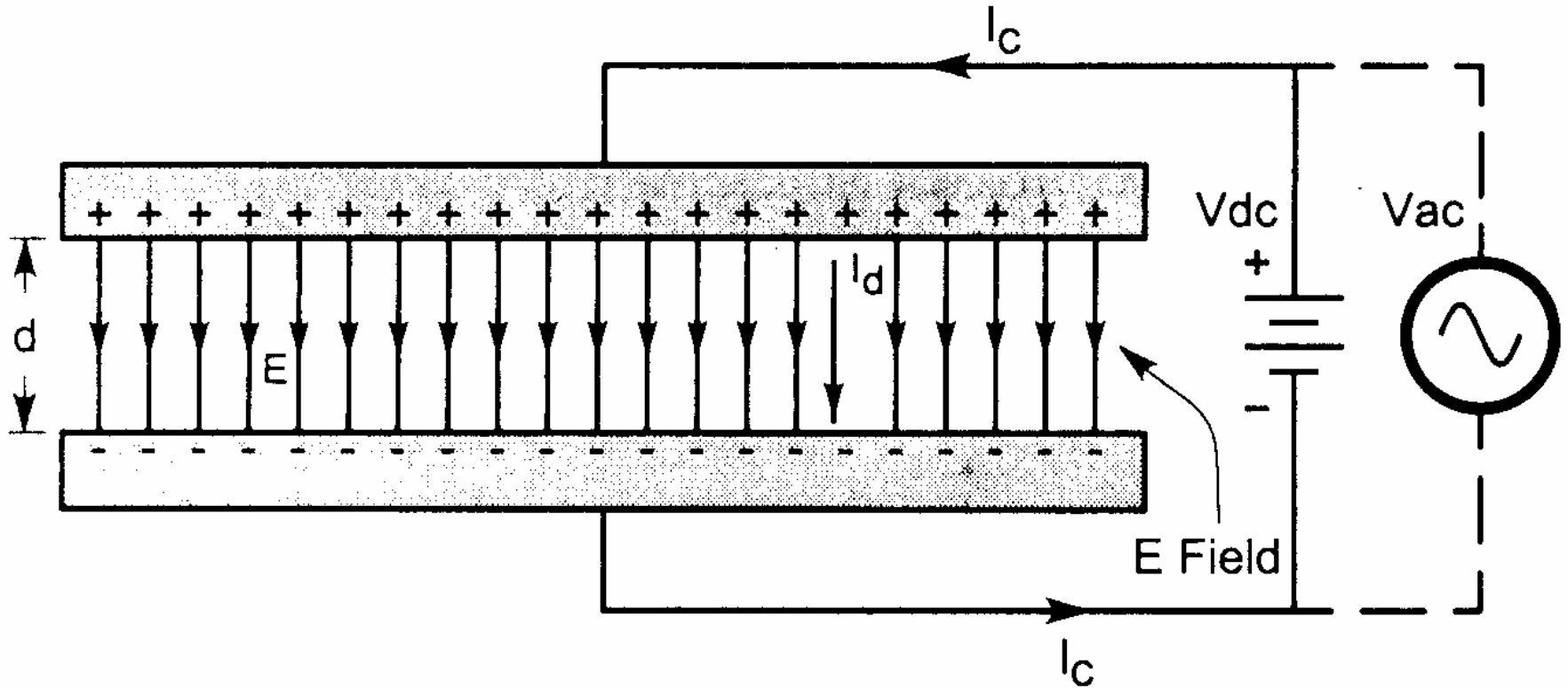
**Many of the antennas shown here are discussed in detail in articles on my web site:**

**[www.antennasbyn6lf.com](http://www.antennasbyn6lf.com)**

**But in the end take it all with a grain of salt!**

# The Electric Field (E)

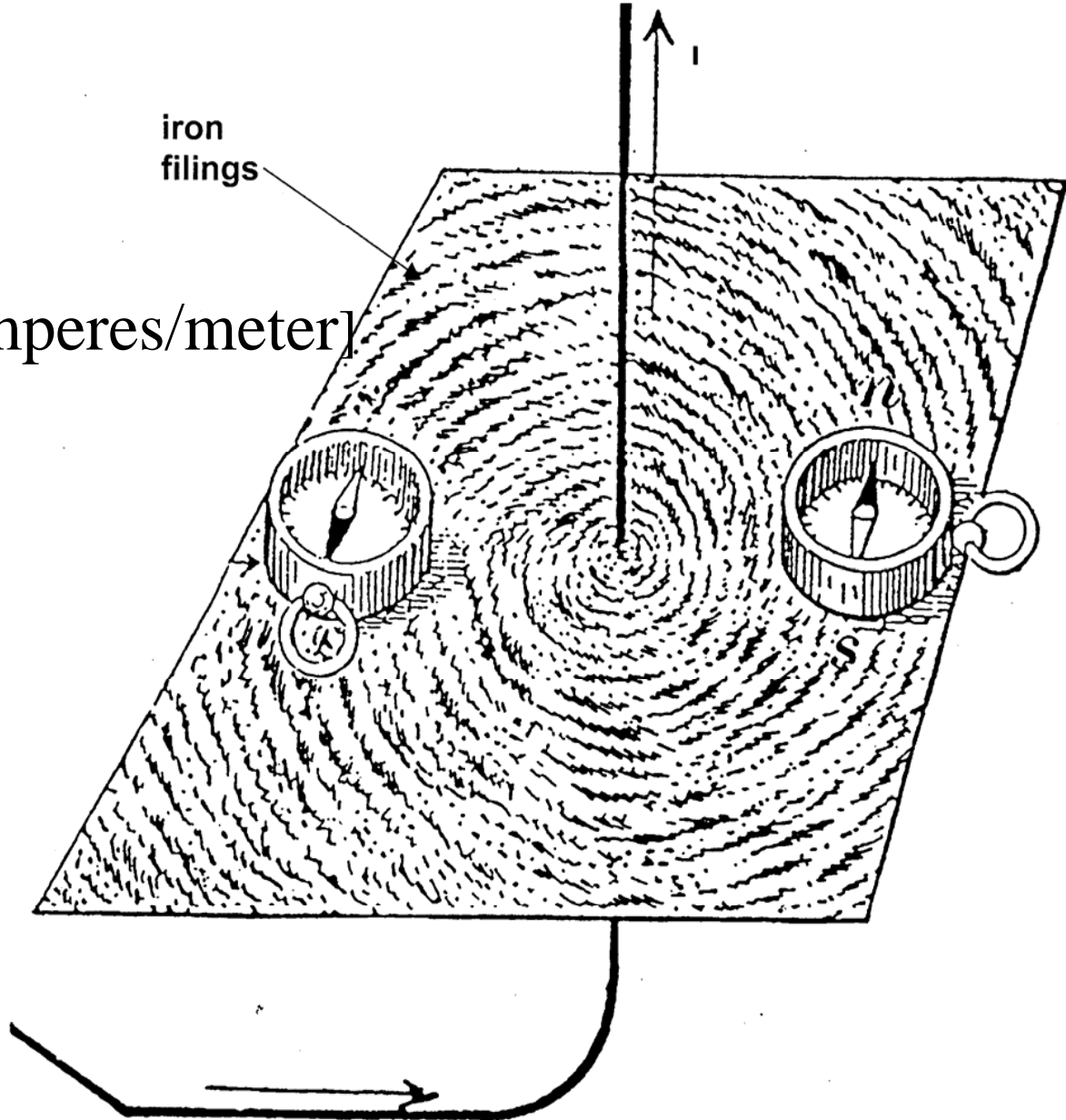
$$E = V/d \text{ [Volts/meter]}$$



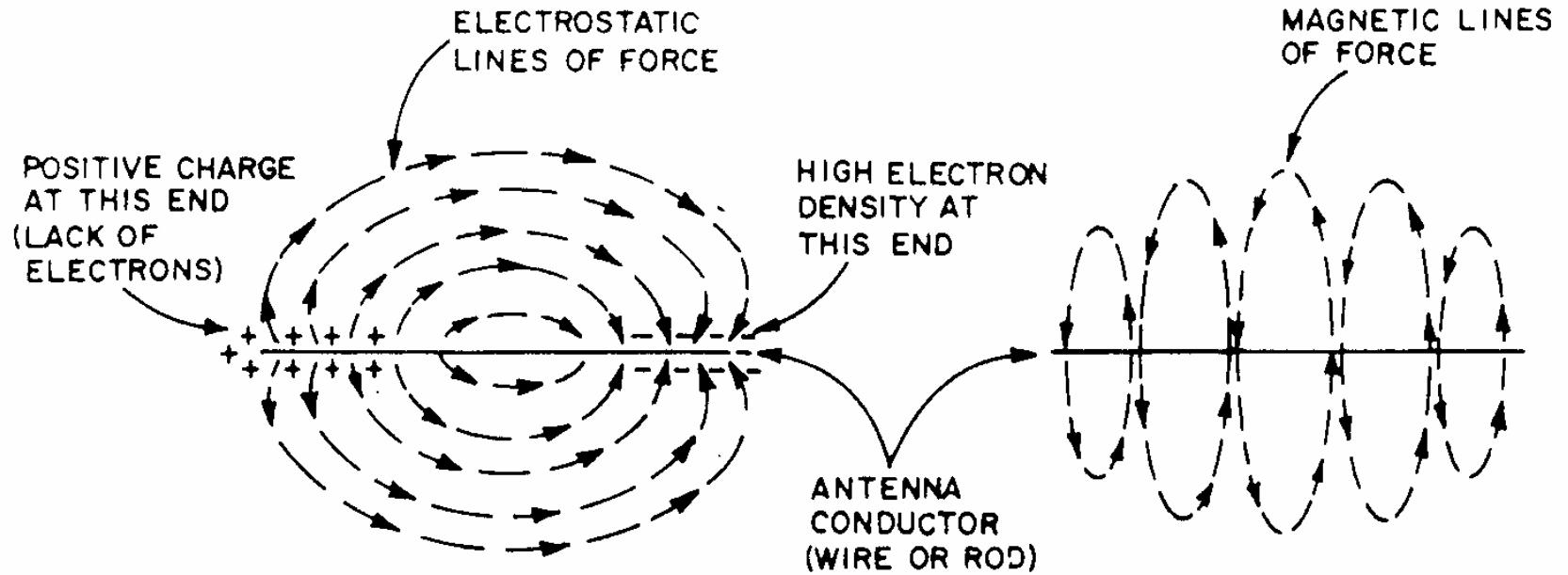
# The Magnetic field (H)

iron filings

$$H=I/d \text{ [Amperes/meter]}$$



# E and H Fields Around A Wire

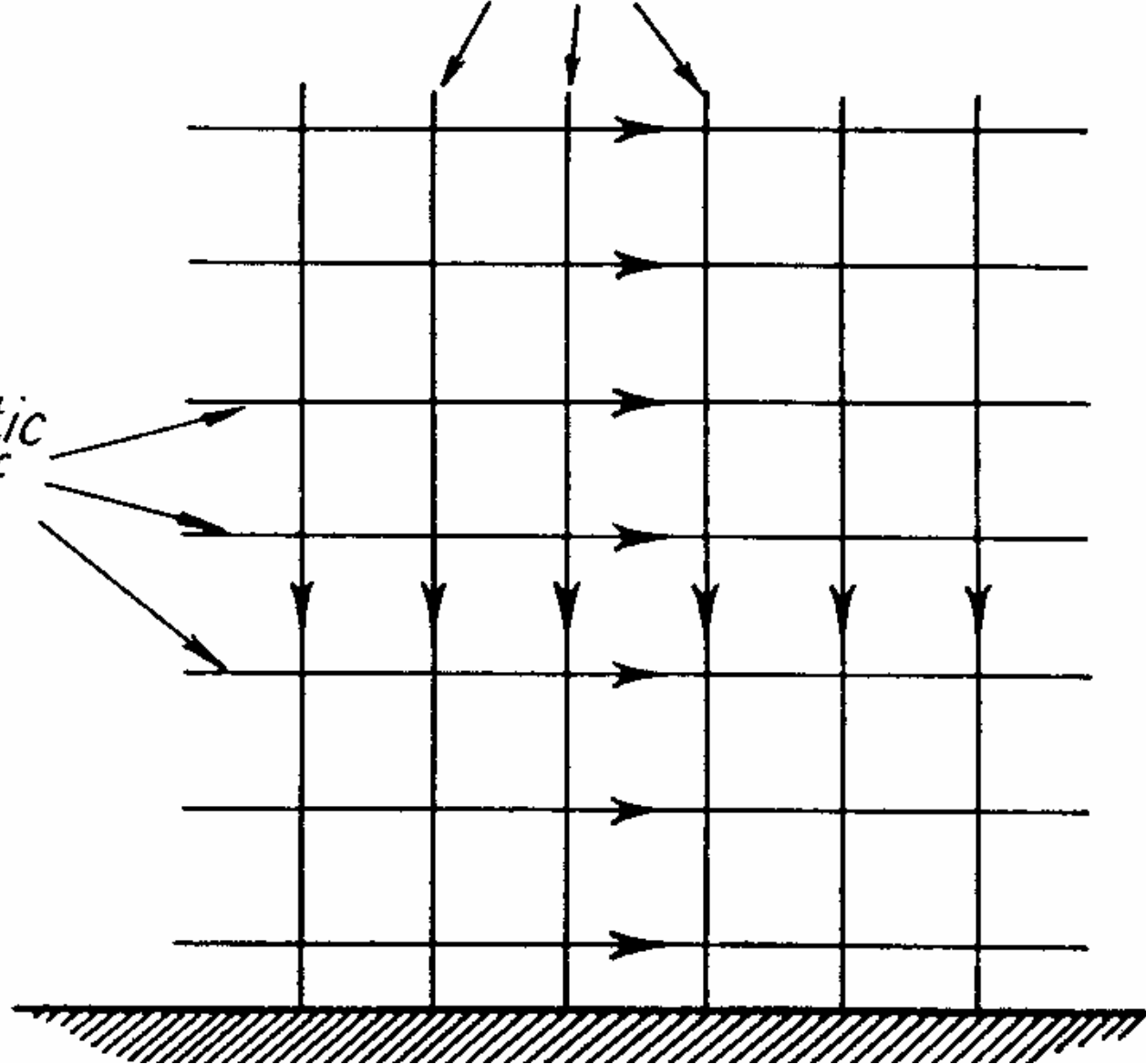


# EM Plane Wave

*Electric lines of Force*

$Z = E/H =$   
377 Ohm  
In vacuum

*Magnetic lines of Force*



# The Effect Of Ground

- **Antennas close to ground are profoundly affected:**
  - **$Z_{in}$  can be very different.**
  - **The radiation pattern is greatly modified.**
  - **All antennas have ground loss but for vertically polarized or low horizontal antennas, ground loss becomes a major consideration.**

# **FAR-FIELD PATTERNS**

**With vertical antennas the far-field pattern is dominated by the ground characteristics.**

**You can fix the near-field losses with a good ground system but there's nothing you can do about the far-field except to move to a better location.**

# Efficiency

- The ratio of the power radiated to the power input to the antenna is the efficiency :

$$\text{efficiency} = \eta$$

$$\eta = \frac{\text{power radiated}}{\text{total input power}} = \frac{R_{\text{radiation}}}{R_{\text{radiation}} + R_{\text{loss}}}$$

$$\eta = 90\% \Rightarrow -0.5dB$$

$$\eta = 80\% \Rightarrow -1dB$$

$$\eta = 50\% \Rightarrow -3dB$$

## Means for shortening

- **Just make the antenna short and feed it with a tuner!**
  - **This is a simple and direct approach but you have to accept the losses in the feedline and the tuner, i.e. higher  $R_{\text{loss}}$ .**
  - **$R_r$  will also be lower**
  - **There is no requirement that an antenna be resonant of itself.**

## Means for shortening

- **Use distributed capacitive loading:**
  - **most effective at the high voltage ends**
  - **but can also be placed down from the top but with lesser effect.**
  - **Generally the most efficient approach**

# Means for shortening

- **Use an inductor:**
  - at the base,**
  - near the center,**
  - distributed inductor**  
**(i.e. helical wound element)**
  - or**
  - linear loading.**
  
- **Use a combination of L and C.**

# Current distribution on a vertical

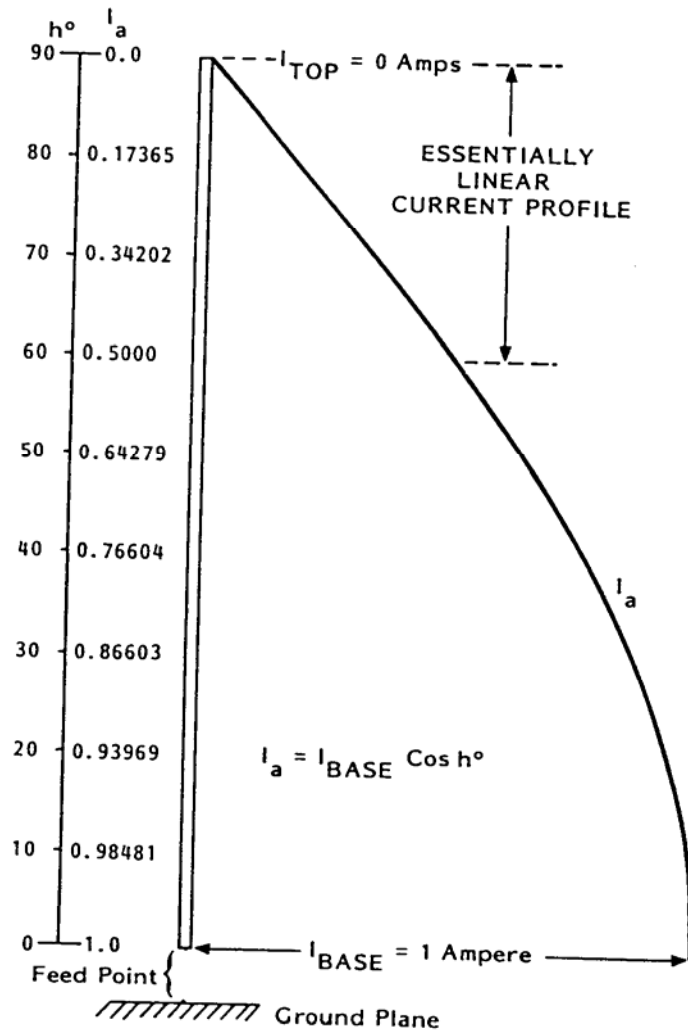


Fig 8—Relative current distribution on a vertical antenna of height  $H = 90$  electrical degrees.

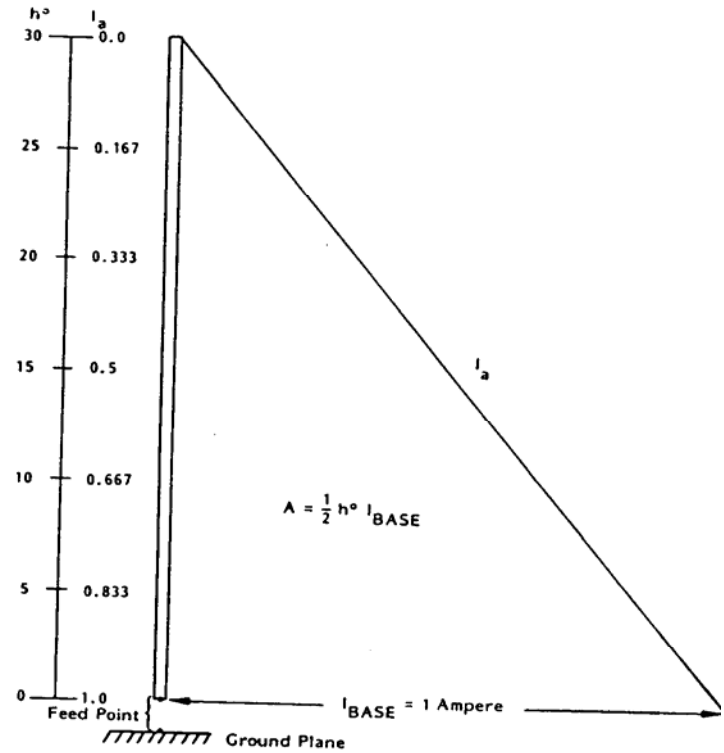
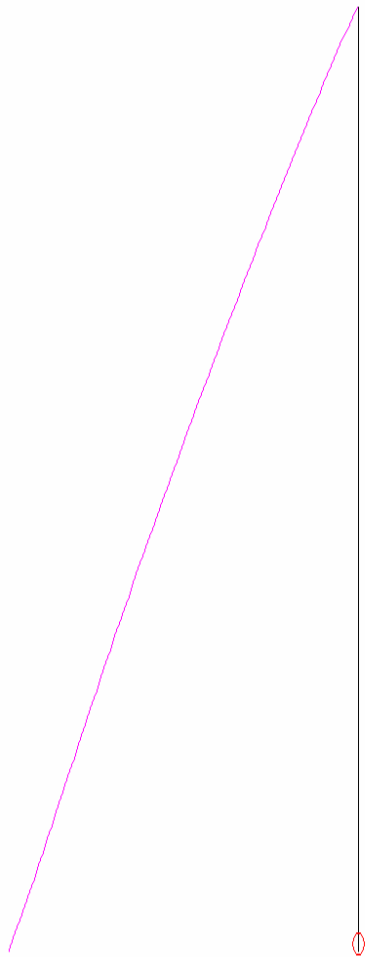


Fig 9—Relative current distribution on a base-loaded vertical antenna of height  $H = 30$  electrical degrees (linearized). A base loading coil is omitted.

# Current distribution on a 1/8-wave vertical

EZNEC/4

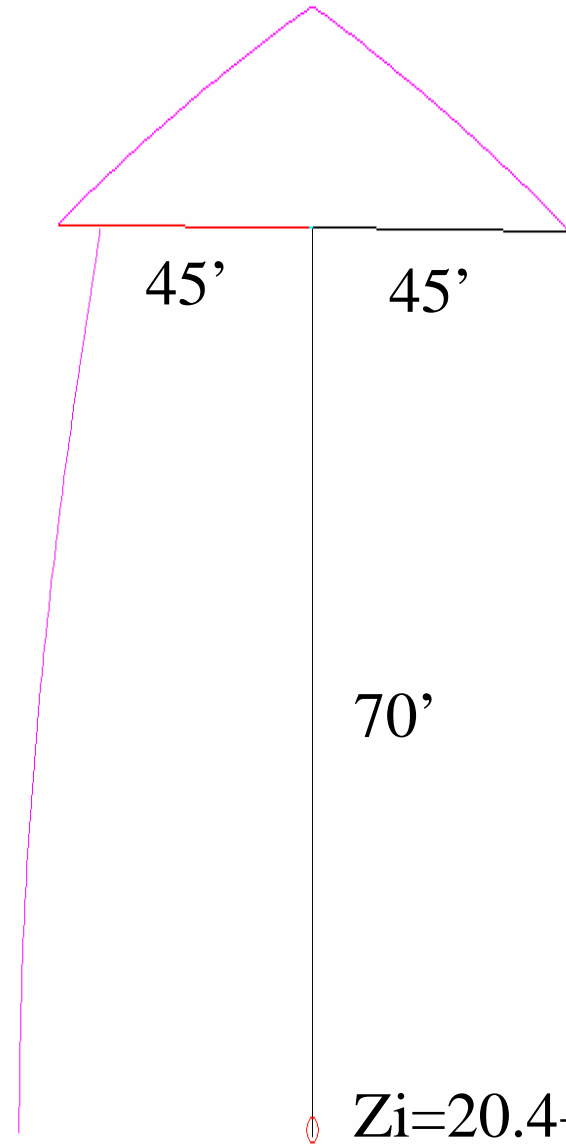
EZNEC/4



70'

Inductor series  
 $R = X_L / Q$

$Z_i = 7.1 - j511$   
1.8 MHz



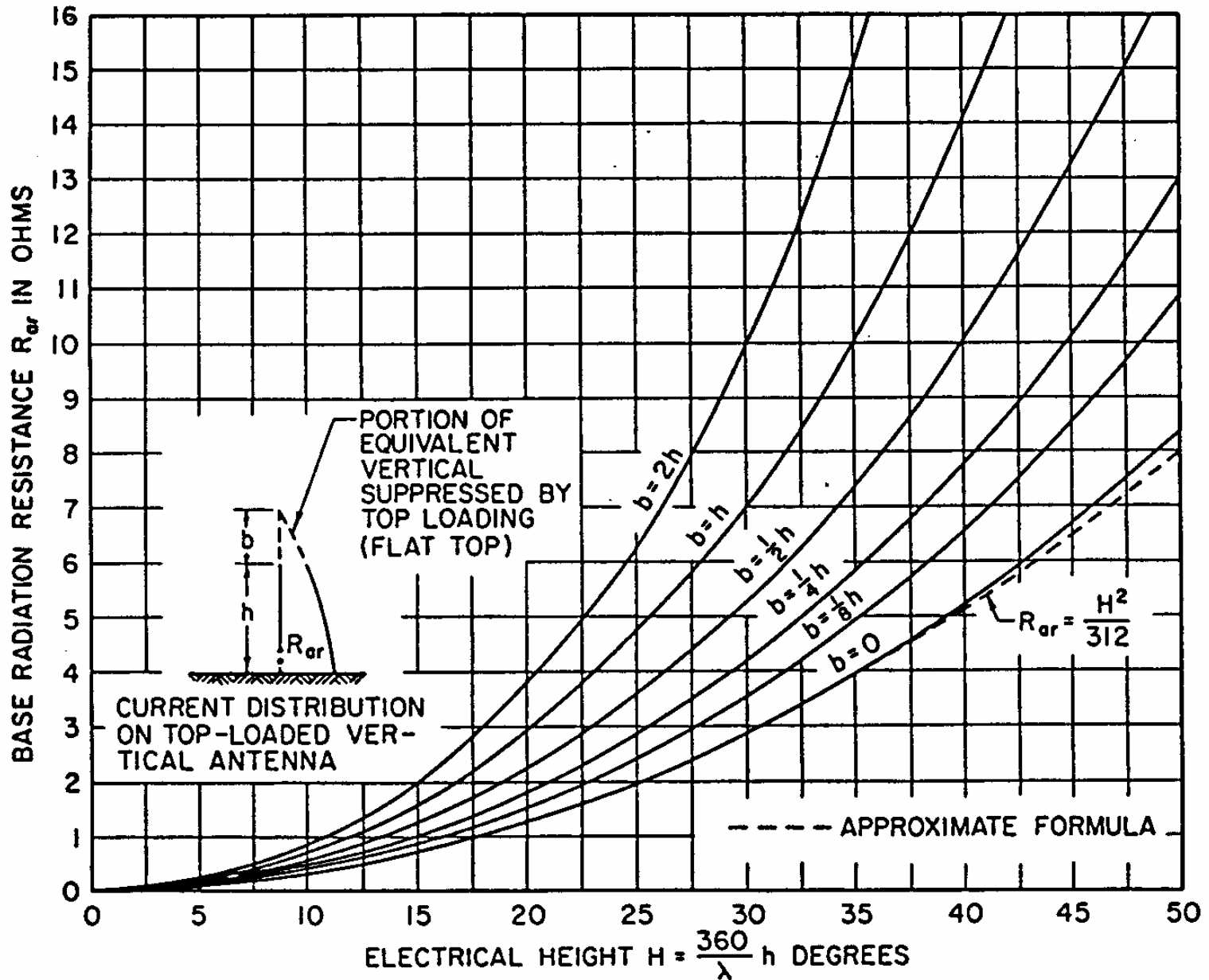
45'

45'

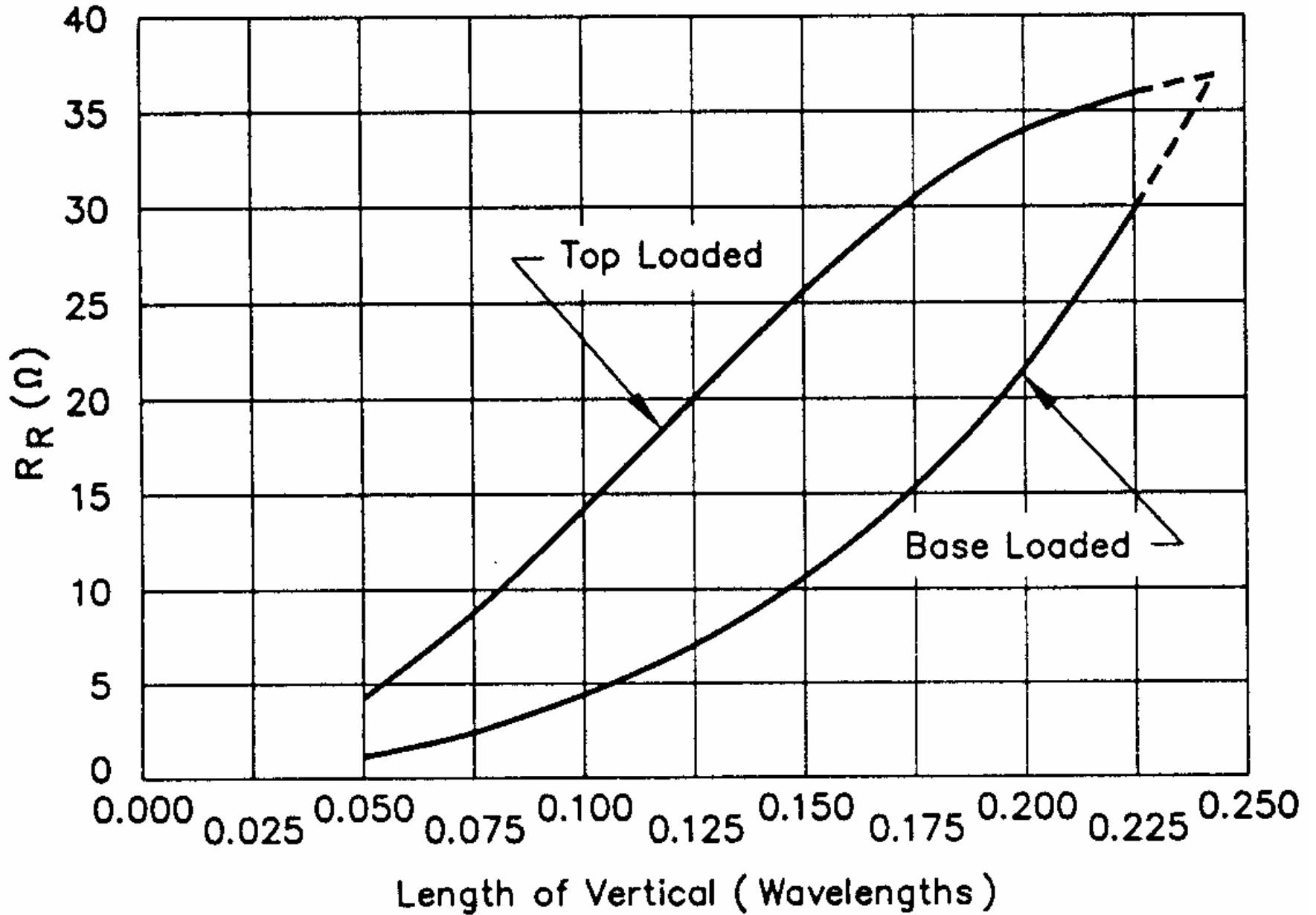
70'

$Z_i = 20.4 + j0$   
1.8 MHz

# Short Vertical Rr



# C Versus L Loading



# Advantages Of Capacitive Loading

- **Produces higher  $R_r$**
- **Very efficient**
- **Can usually be integrated into the support structure.**

# PRACTICAL MATTERS

**When I erect a short vertical I do the following:**

**If possible, I use enough capacitive top loading to resonate the antenna a little bit **above** the top of the band.**

# **PRACTICAL MATTERS**

**I then install a small inductor at the base to perform the following functions:**

- Resonate the antenna to the desired frequency and provide matching.**
- Usually this inductor will be small enough to have very little effect on efficiency.**

# **PRACTICAL MATTERS**

**Matching can be done by using the inductor as part of the matching network and/or, the inductor can be tapped and a relay used to vary the center frequency of the antenna to allow movement across the band.**

## **ANOTHER USEFUL TRICK**

**Add enough top-loading so that the antenna is resonant **below** the band.**

**This means that:**

**the input impedance will be inductive,**

**the resistive part of the input impedance will be larger and**

**you can resonate the antenna with a simple and efficient series capacitor at the input.**

# **ANOTHER USEFUL TRICK**

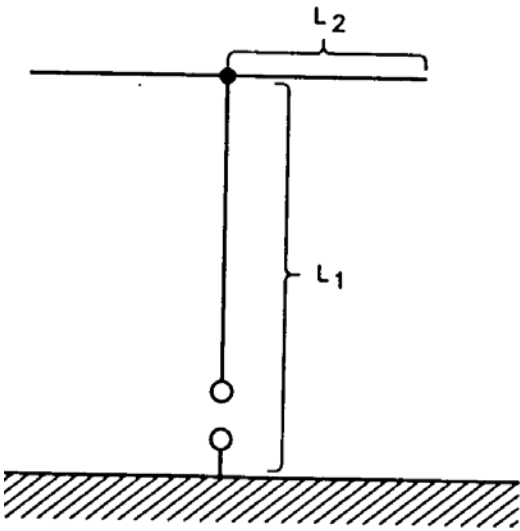
**In addition:**

**If you vary this capacitor you can tune the antenna across the band.**

**This is similar in concept to the hairpin match used in Yagies except that now you make the element a bit longer.**

**Sometimes this is called a “C” match.**

# 80 m "T" vertical

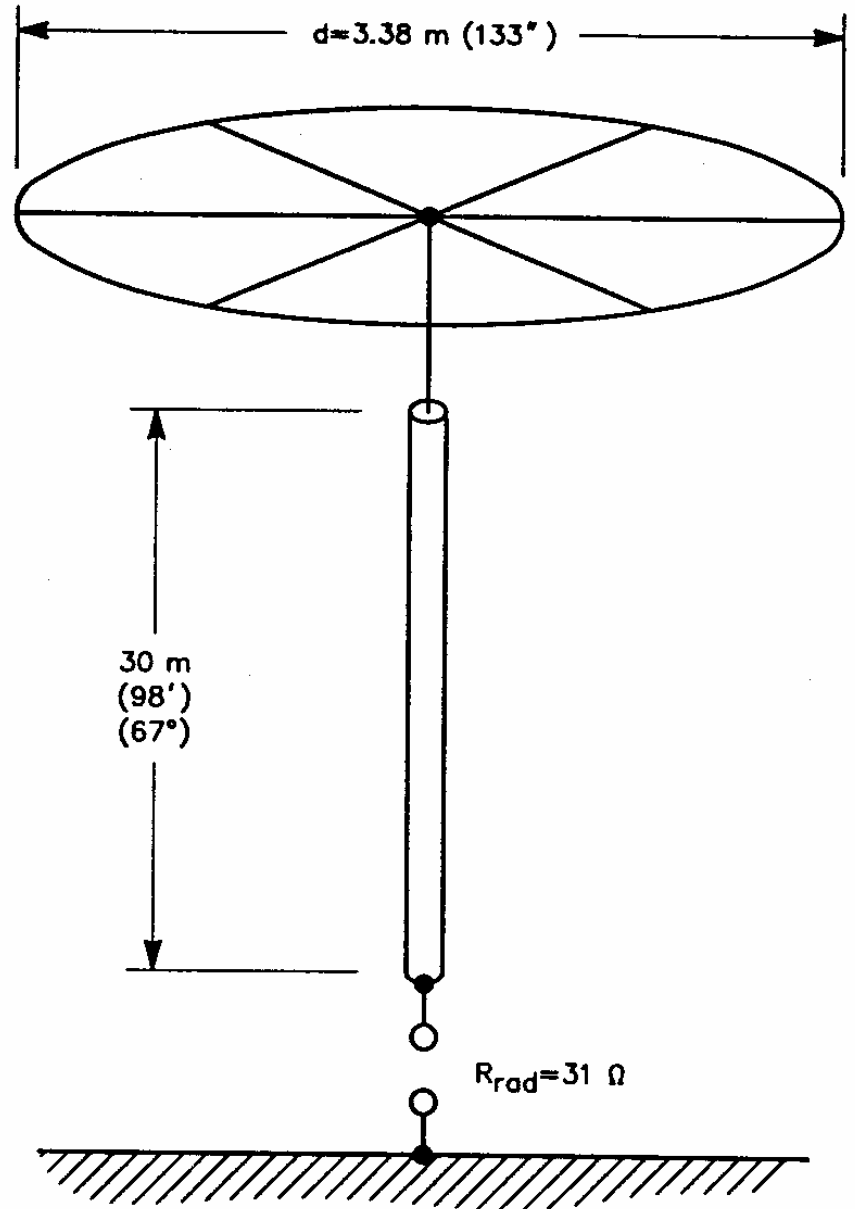
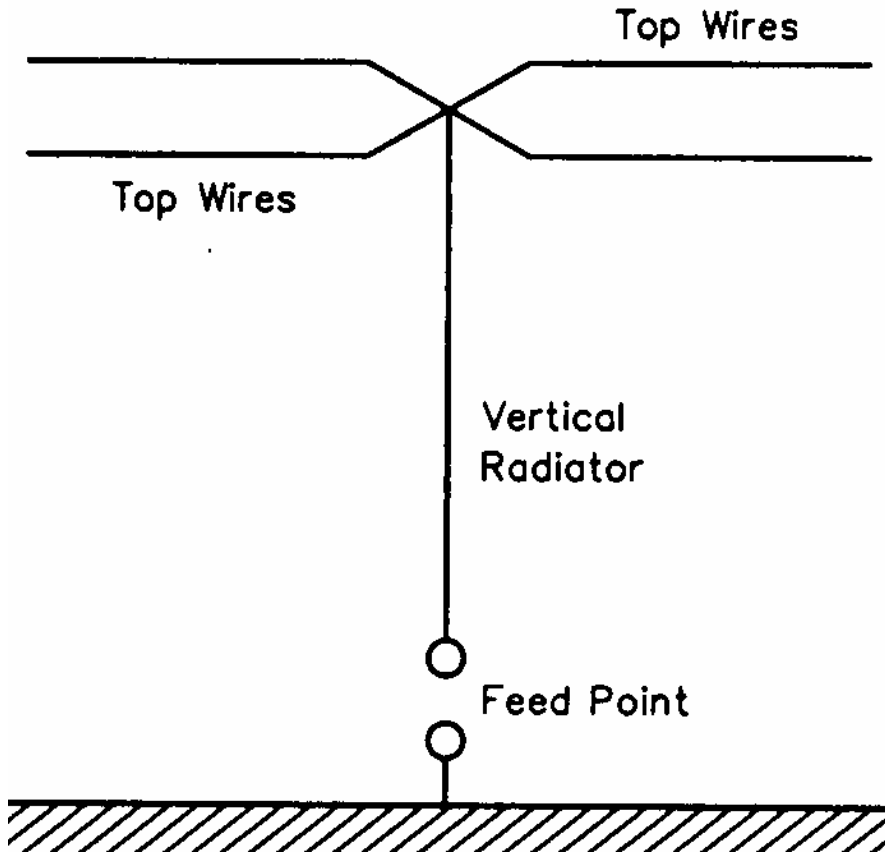


**Table 7**

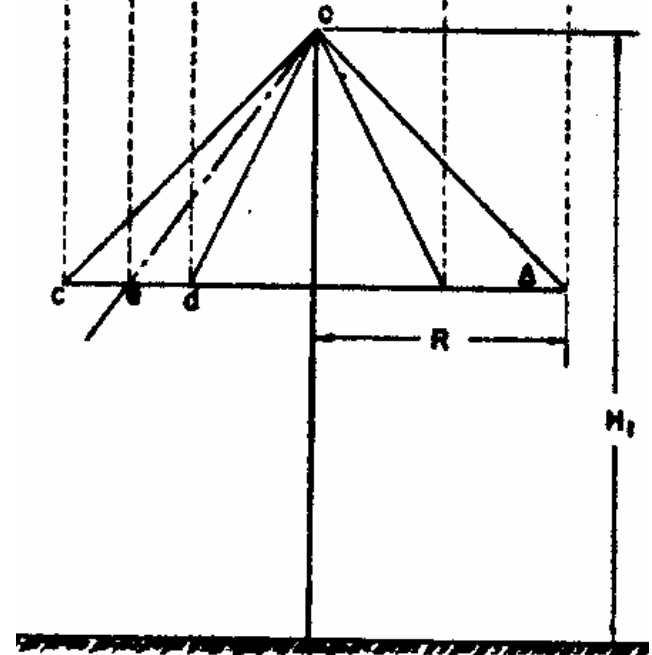
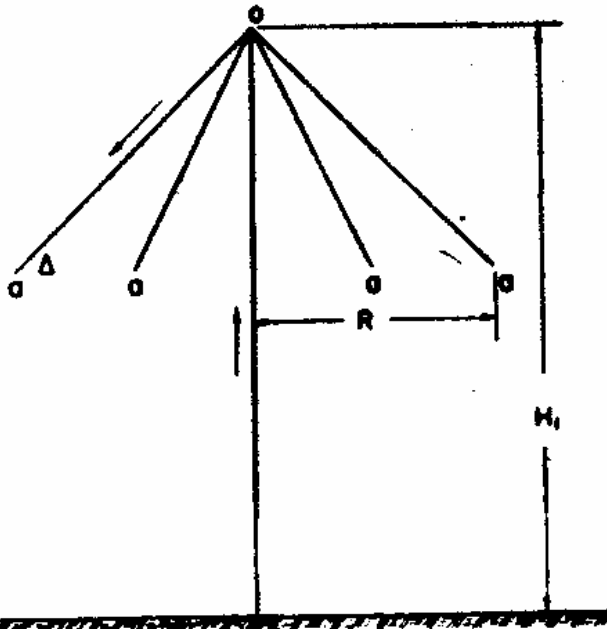
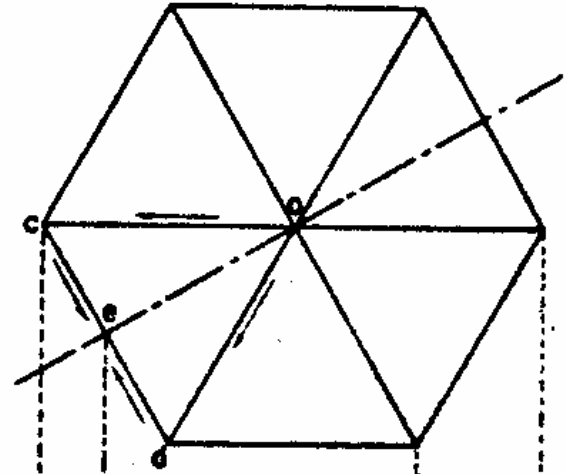
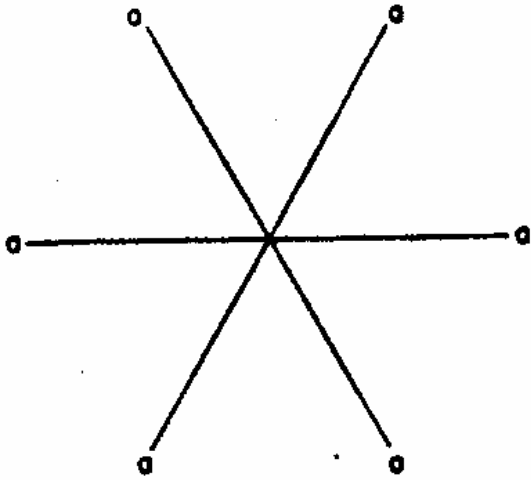
**Effect of Shortening a Vertical using Top Loading**

$L_1$ (feet)	$L_2$ (feet)	Length ( $\lambda$ )	$R_R$ ( $\Omega$ )
14.0	48.8	0.050	4.0
20.9	38.6	0.075	8.5
27.9	30.1	0.100	14.0
34.9	22.8	0.125	19.9
41.9	17.3	0.150	25.5
48.9	11.9	0.175	30.4
55.8	7.0	0.200	33.9
62.8	2.4	0.225	35.7

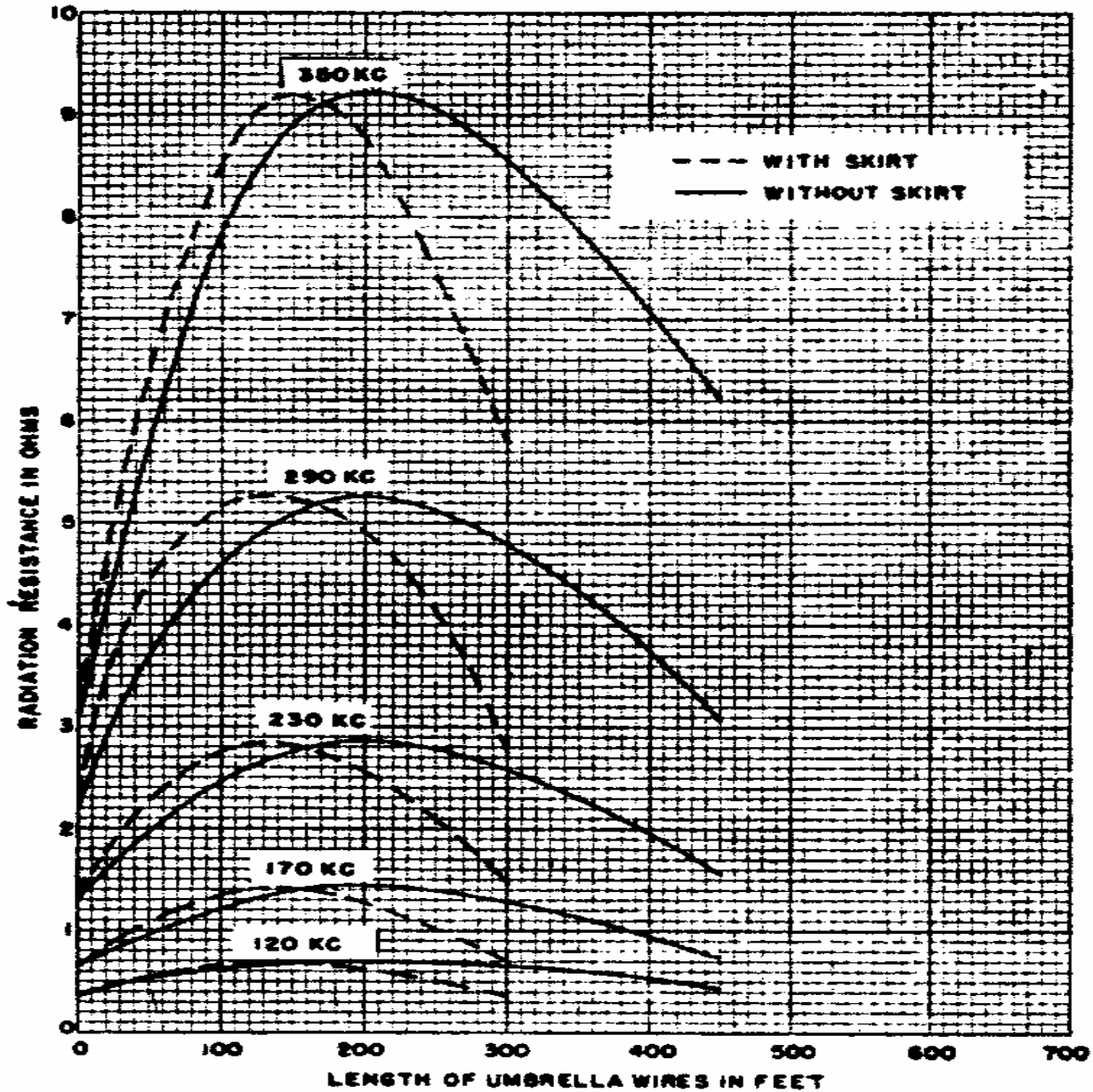
# Top Loading Examples



# Top loading with guys



# Optimum umbrellas



# **SLOPING TOP WIRES**

- **You can use two or more sloping top loading wires.**
- **The closer the angle to 90 degrees the better.**
- **The more wires you use the greater the loading but as you add more wires the additional improvement gets smaller.**

# **SLOPING TOP WIRES**

- **Usually four wires are plenty.**
- **Adding a skirt wire to a given number of sloping wires gives about the same maximum  $R_r$  but with shorter wires.**

# Loaded wire vertical

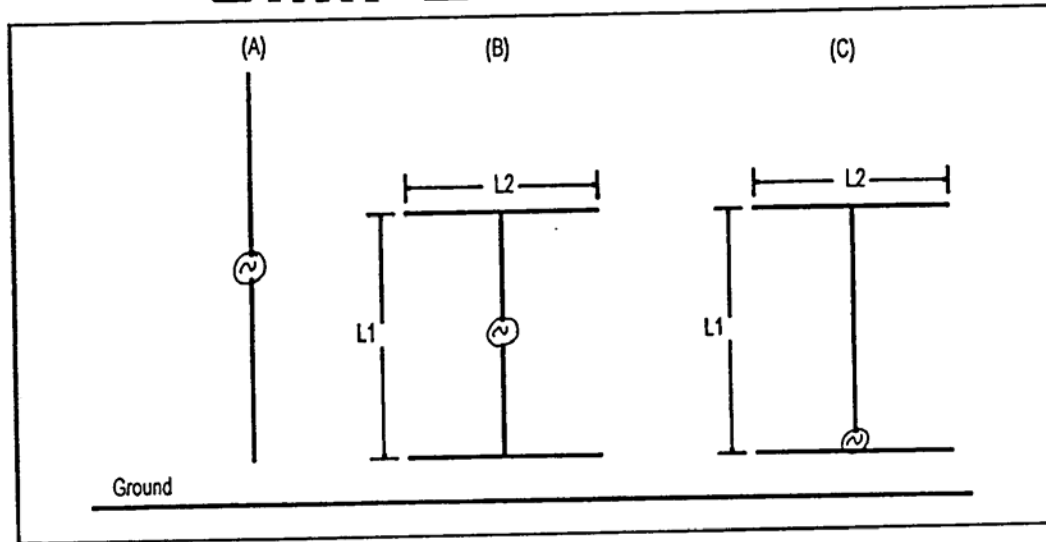


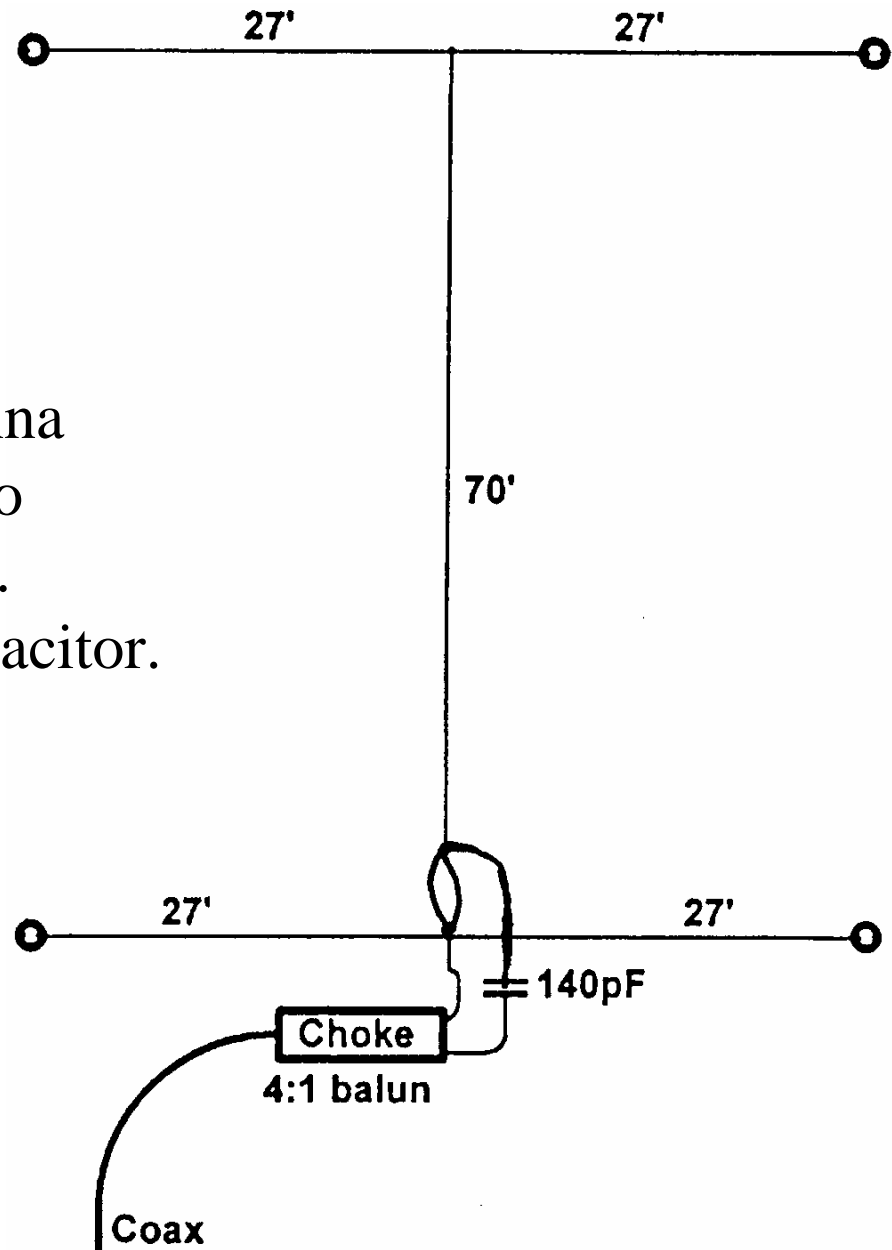
Table 1. Antenna Comparison at 3.510 MHz

ant	L1	L2	$Z_{\text{middle}}$ $\Omega$	$Z_{\text{end}}$ $\Omega$	peak gain, dB	peak angle $^{\circ}$	wire loss -dB	2:1 SWR Bw kHz
$\lambda/2$	137'	0	91	>5000	+.30	16	.08	270
lazy-H	120'	4.4'	96	1096	+.28	17	.02	280
"	100'	10.4'	94	384	+.12	19	.07	280
"	80'	17.4'	81.3	180	-.06	20	.08	260
"	69.8'	21.6'	71.2	127	-.07	21	.09	240
"	60'	26.3'	59.7	90.9	-.15	22	.10	200
"	40'	38.3'	33.7	40.8	-.38	24	.16	140
"	30'	45.6'	21.5	23.8	-.59	25	.23	100
$\lambda/4$ 2 radials	69.8'	—	—	38.8	.11/-.39	22	.15	200
$\lambda/4$ , 4 radials	69.8'	—	—	35.7	+.21	22	.13	175

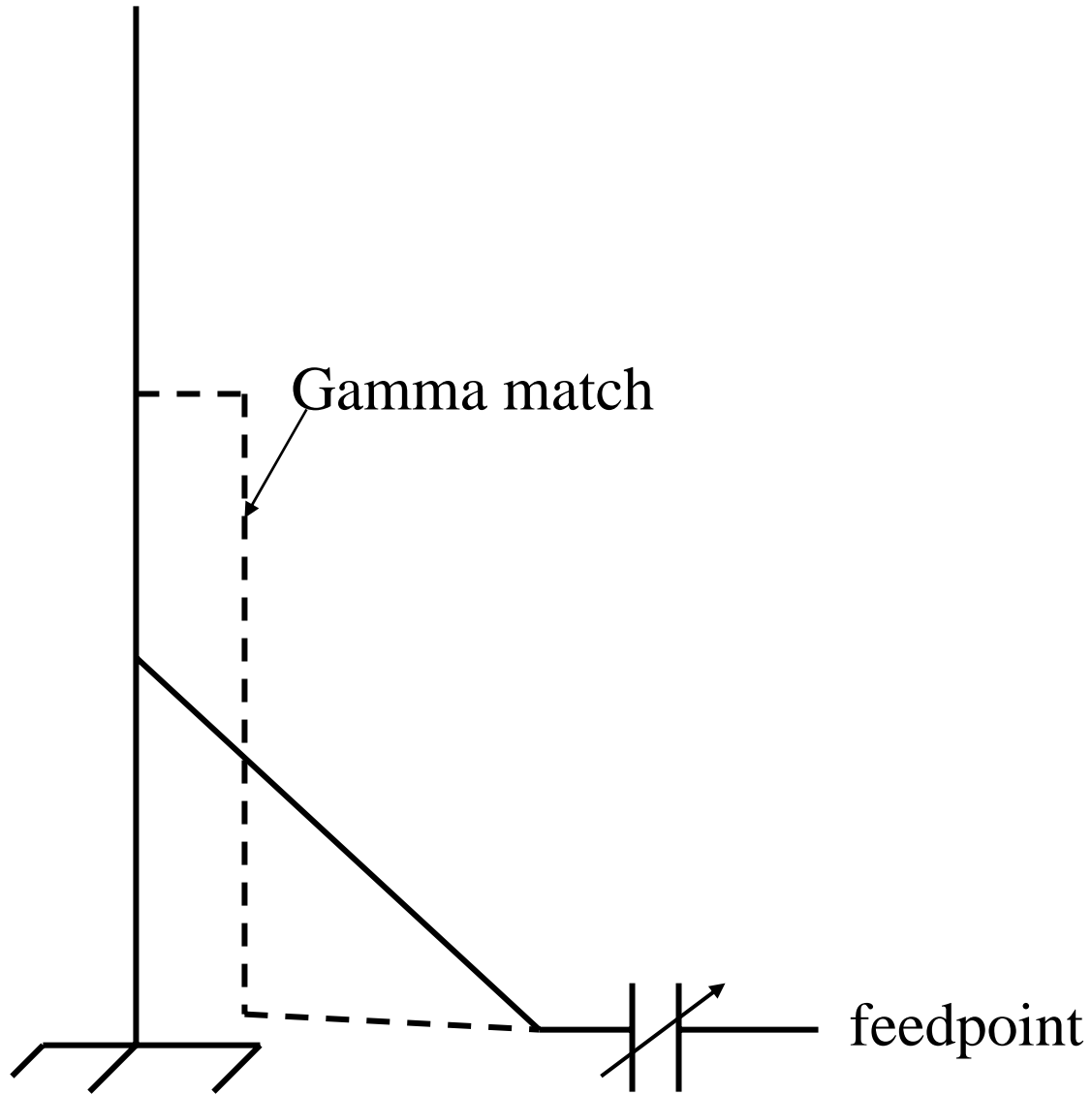
# 80 m example

As you go away from  
The current loop (maximum)  
The impedance rises.

As you “over-load” the antenna  
The feedpoint impedance also  
Rises and becomes inductive.  
You can then tune with a capacitor.

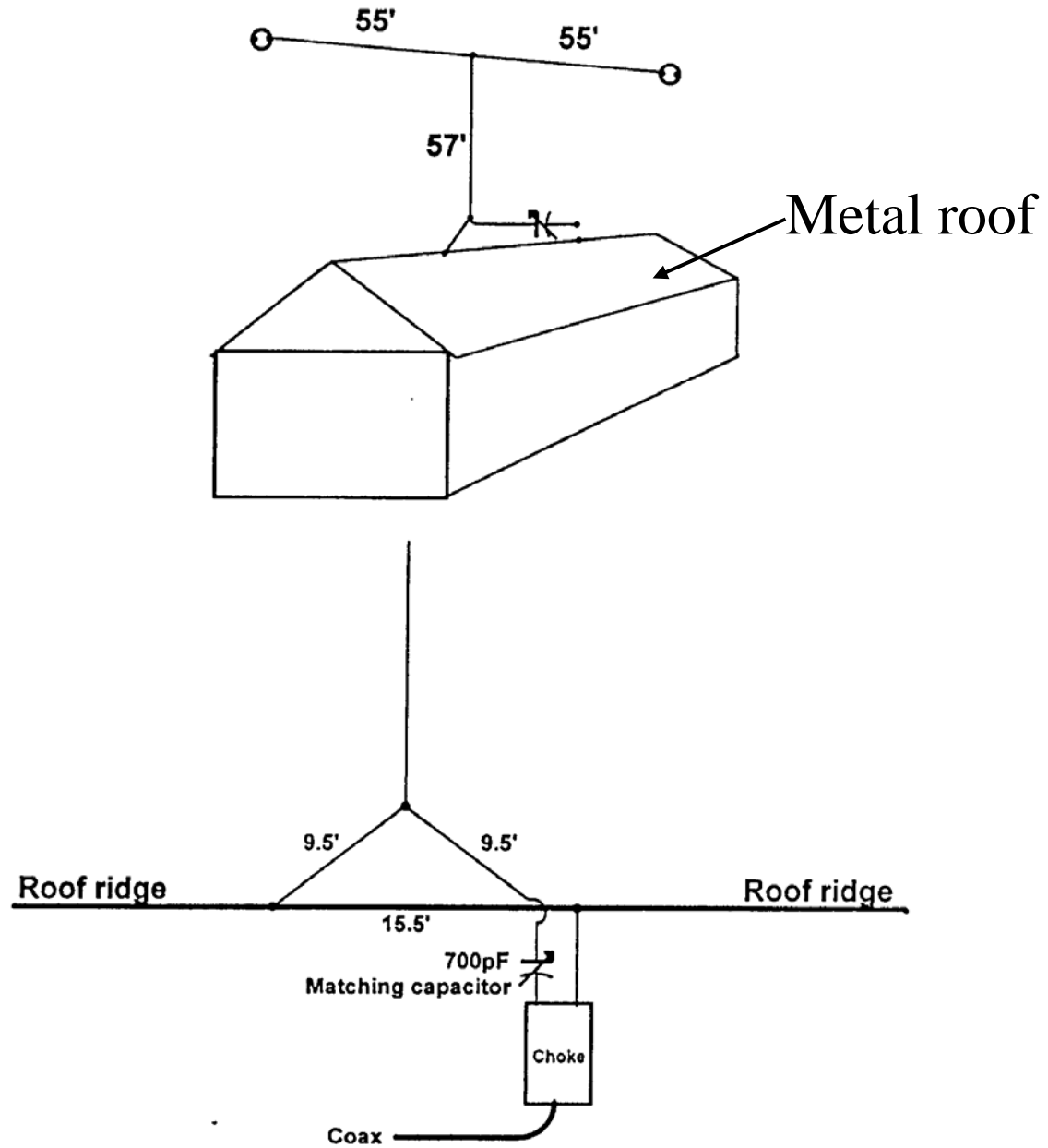


# Shunt feed



# Shunt-feed example

160 m



# Multiple vertical wires

Down leads arranged  
Symmetrically. If not  
then the currents won't  
share.

feedpoint

A schematic diagram showing a horizontal top line and a horizontal bottom line. Three vertical lines descend from the top line. The leftmost vertical line is the widest. The middle vertical line is the narrowest. The rightmost vertical line is of medium width. At the bottom of the rightmost vertical line, there is a horizontal line segment extending to the right, labeled 'feedpoint'.

# **Advantages of Multiple Wires**

- **One of the problems with short loaded wire antennas is conductor loss.**
- **Multiple wires can lower conductor loss.**

# Advantages of Multiple Wires

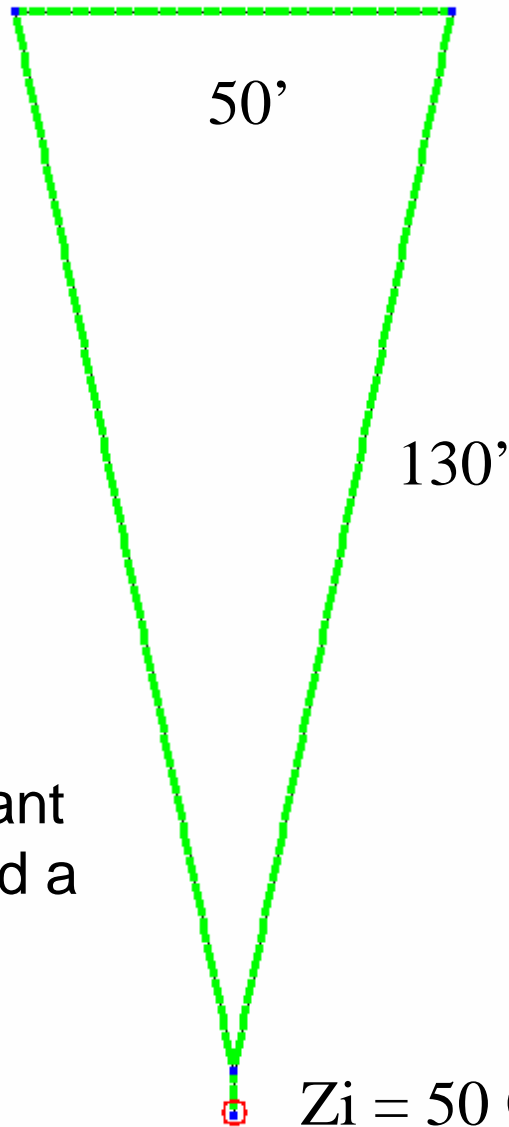
- **They may provide a wider match bandwidth.**
- **Larger diameter conductors or better yet, multiple spaced conductors, will have less reactance and the reactance changes more slowly with frequency.**

# **Advantages of Multiple Wires**

- **The feedpoint impedance when feeding one of the wires will increase by the square of the number of wires i.e. for three wires, the feedpoint impedance will be nine times that for a single wire.**
- **Multiple spaced top-hat wires increase the loading effect.**

# Another trick for improving bandwidth

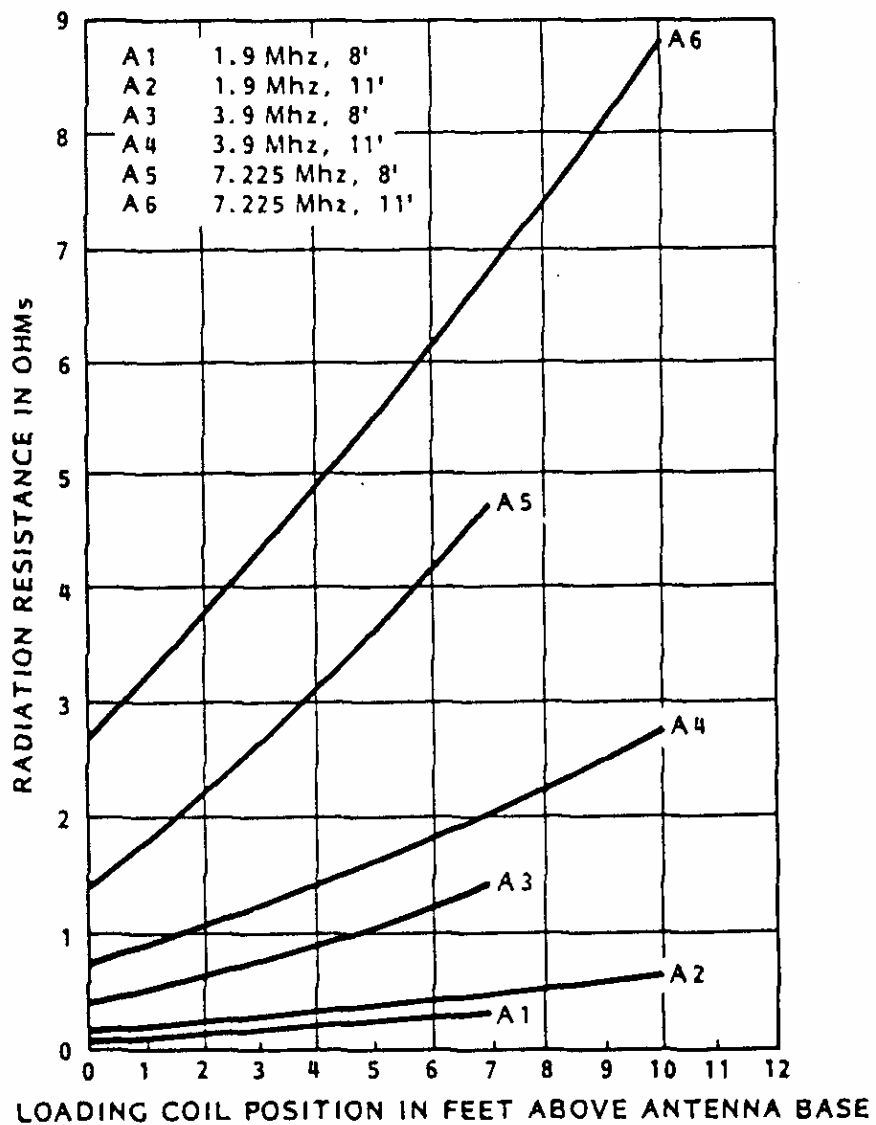
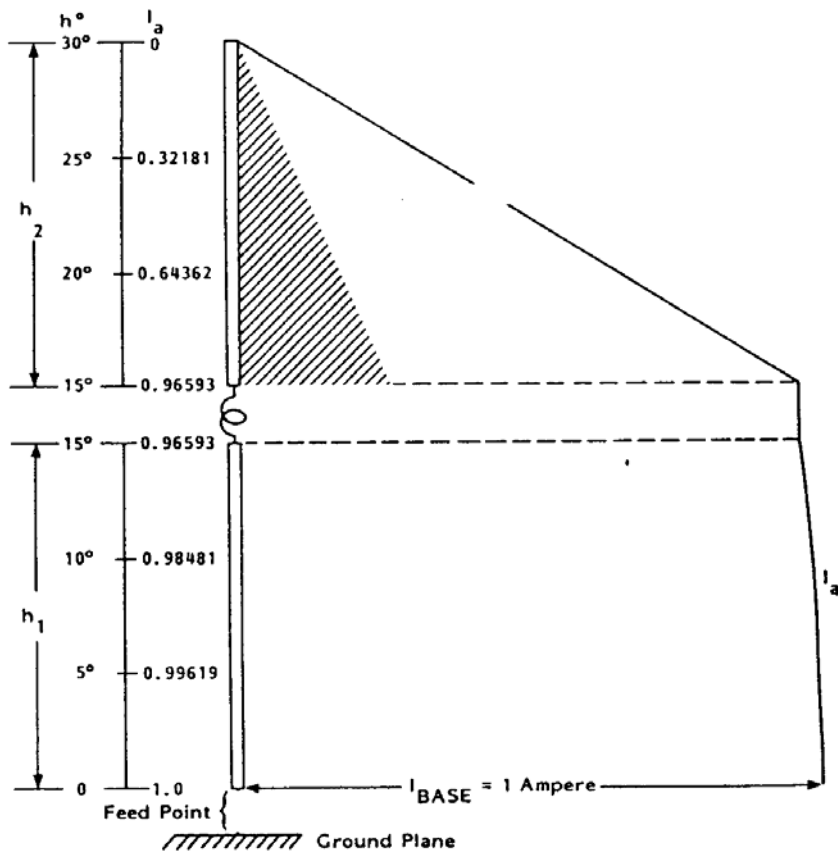
EZNEC/4



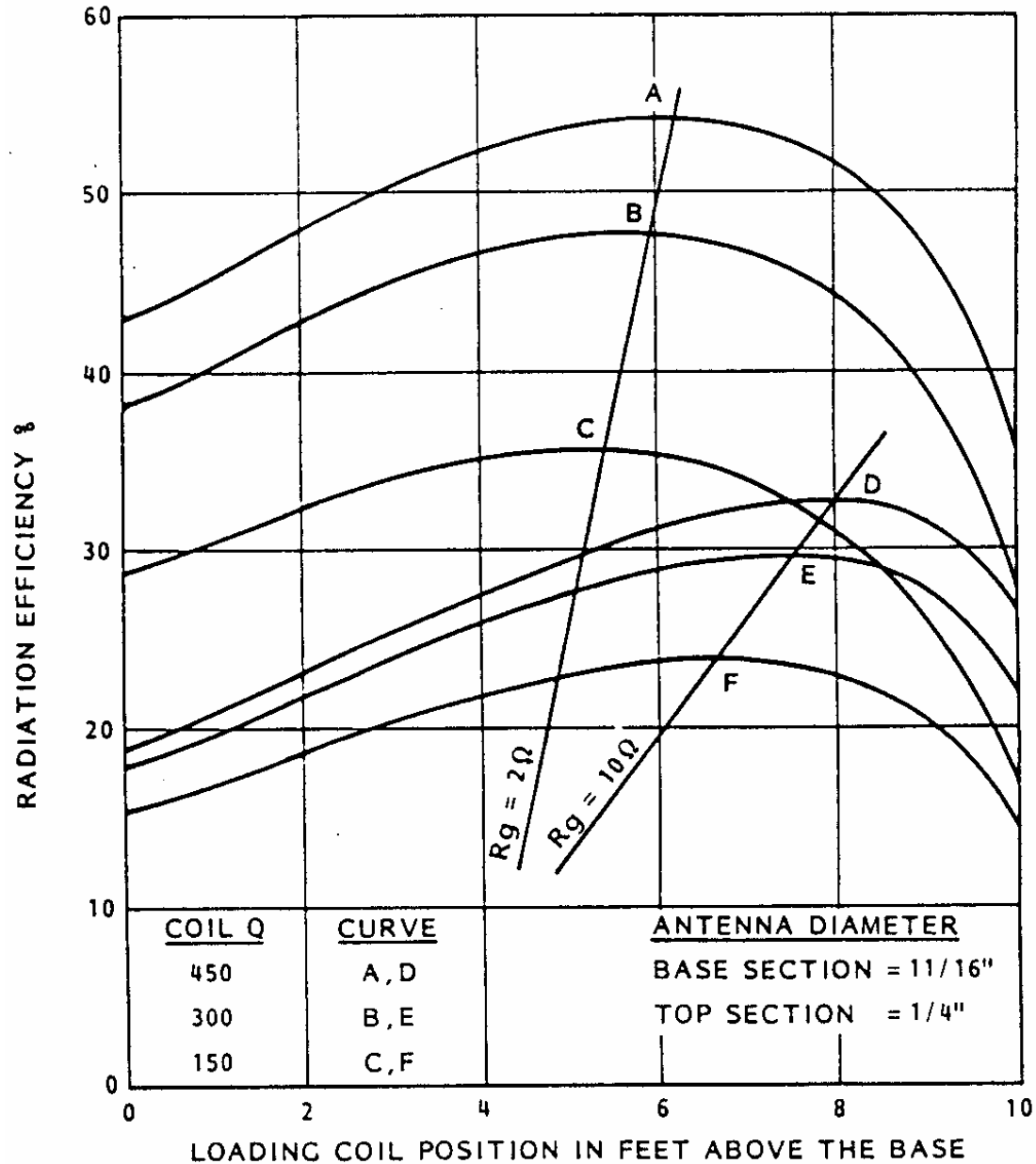
This antenna was resonant below the band, so I used a series C to resonate

$Z_i = 50 \text{ Ohm @ } 1.830 \text{ MHz}$

# Inductive Loading



# Efficiency And Coil Position



# Combining Capacitive and Inductive Loading

- You can combine both capacitive top loading and inductive loading.
- You would normally do this when it is not possible to erect sufficient top loading to reach resonance.
- With no top loading and given coil Q, the optimum coil location will be near the center.

# **Combining Capacitive and Inductive Loading**

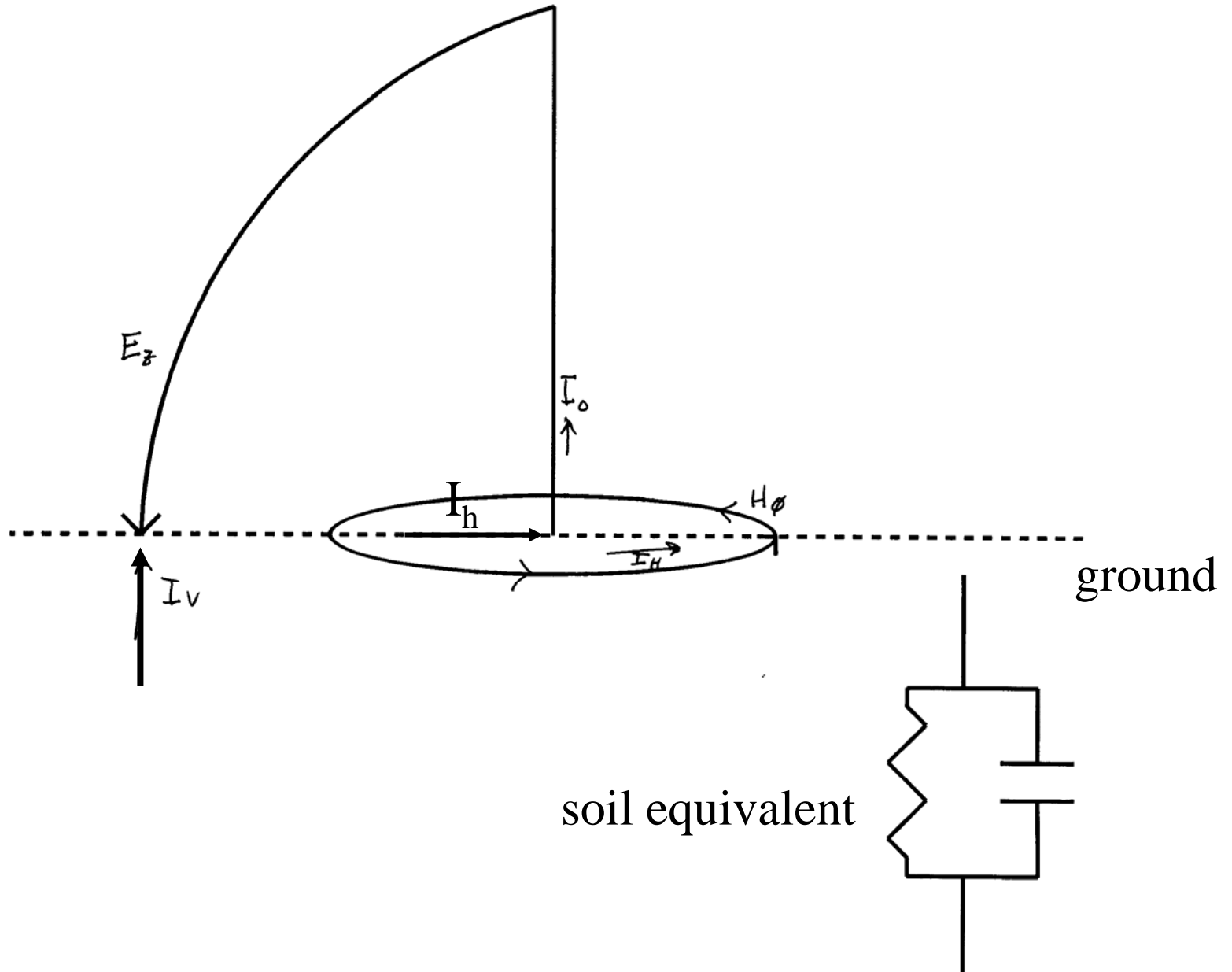
- As top loading is added, the optimum inductor location moves up towards the top.**
- However! With added top loading the effect of inductor location becomes much less critical and in fact for very much top loading it is more convenient to locate the inductor at the base.**
- This cost little in efficiency.**

# Tactics For High Efficiency

- **Maximize  $R_r$ :**
  - taller element
  - Capacitive end loading
  - move loading L up into the vertical
- **Minimize  $R_{\text{loss}}$ :**
  - Minimize conductor, loading coil and matching resistances
  - i.e. larger conductors, multiple conductors, higher Q inductors, etc
  - Minimize ground loss

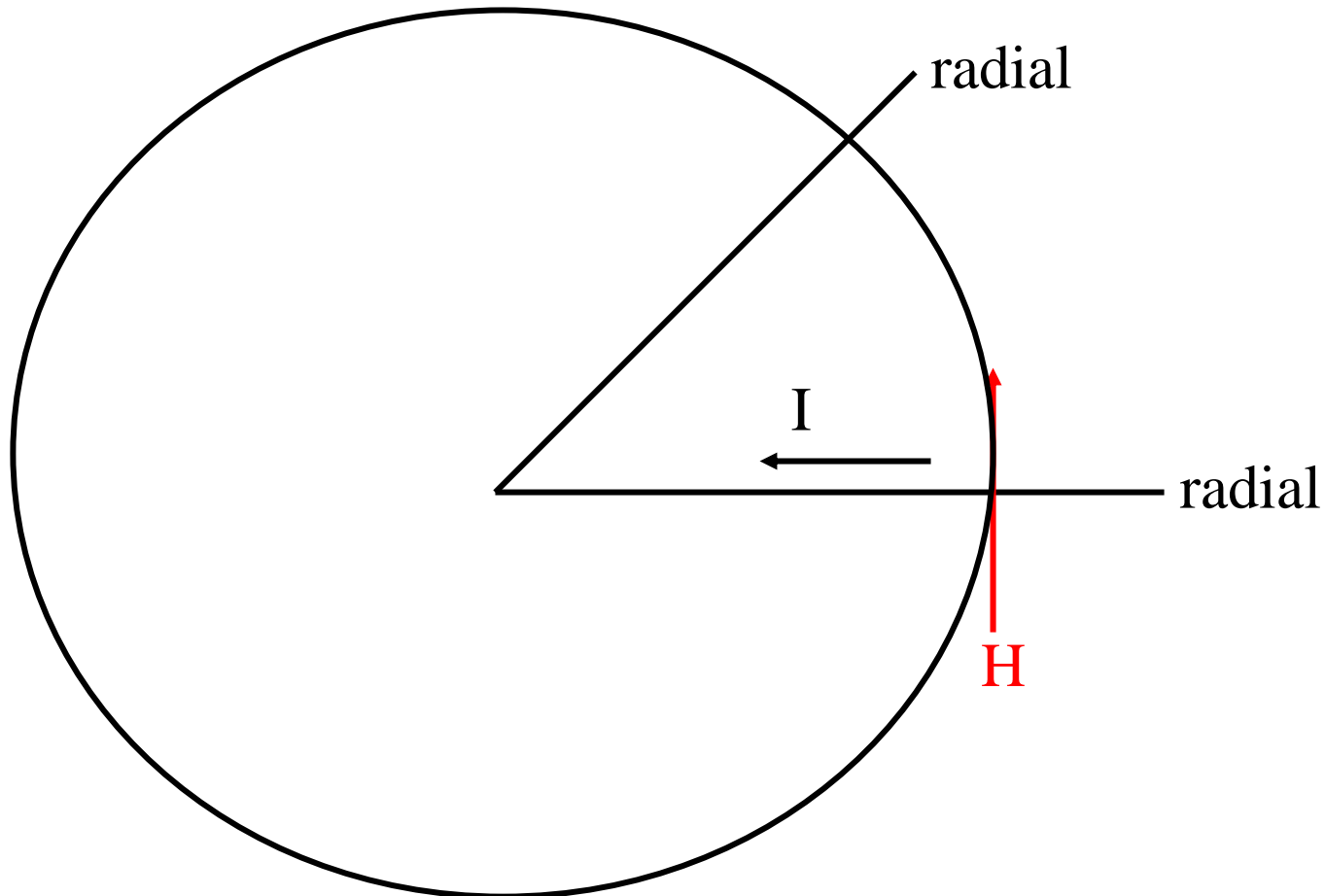
# Ground Currents

# E and H fields around a vertical



## H field and induced currents

- Current will be induced in the soil at right angles to the H-field.
- If a conductor is at right angles to the H-field then the maximum current will be induced in it. But if the conductor is parallel to the field then no current will be induced.



# GROUND LOSSES

- **The H-field will introduce horizontal ground currents.**
- **The E-field will introduce vertical ground currents.**
- **These losses are  $I^2R$  in nature, i.e. they vary as the square of the H and E-field intensities.**

# **GROUND LOSSES**

- **The ground losses for a given antenna are highly dependent on the electrical characteristics of the soil within a half-wavelength of the antenna horizontally and one skin depth vertically.**
- **The soil characteristics vary with frequency at HF.**
- **The function of the ground system is to reduce these losses to an acceptable limit.**

# Fundamental Limitation

The ground system around the antenna does nothing for the far-field pattern except to **increase the power radiated** for a given input power.

# ARRAY GROUND SYSTEMS

- **In a single element vertical, the radial wire ground system is by nature optimum in relation to the H-field orientation.**
- **In a multi-element vertical array if each element has its own radial system then radial wires are fine.**

# ARRAY GROUND SYSTEMS

- **However, if the radials are abbreviated so that they do not overlap as is standard practice, then in some areas the ground wires will not be optimally aligned and the ground losses will be higher.**
- **This can be overcome by using a grid ground system over at least part of the area near the antennas.**

# Soil Characteristics

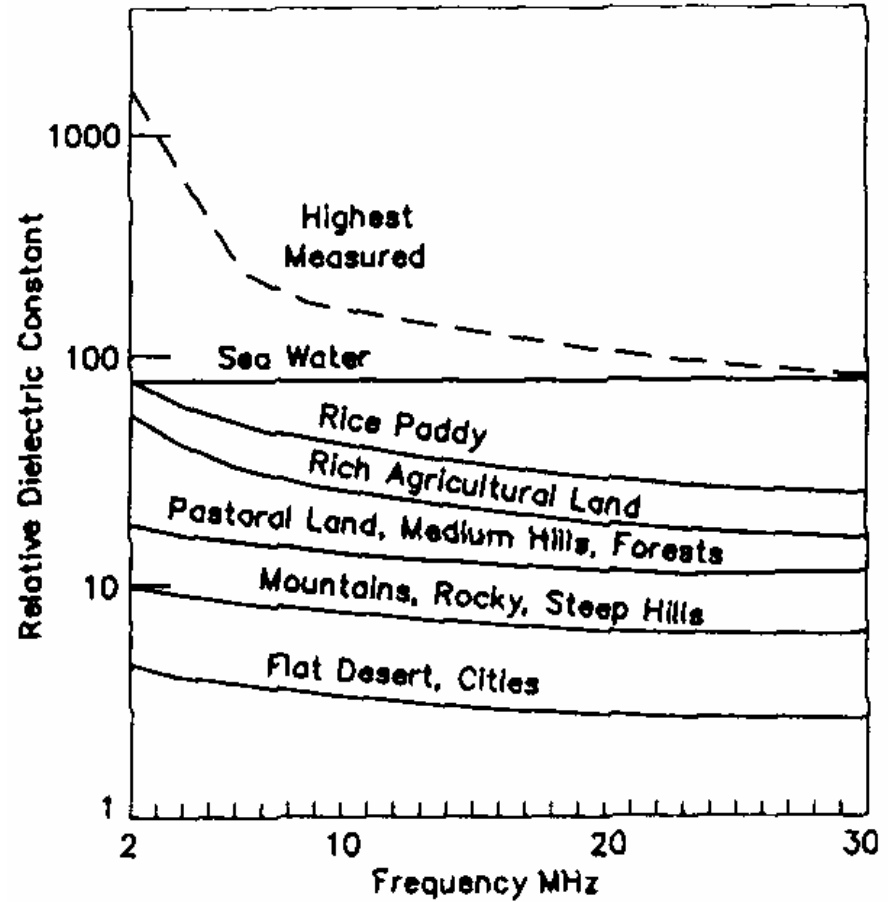
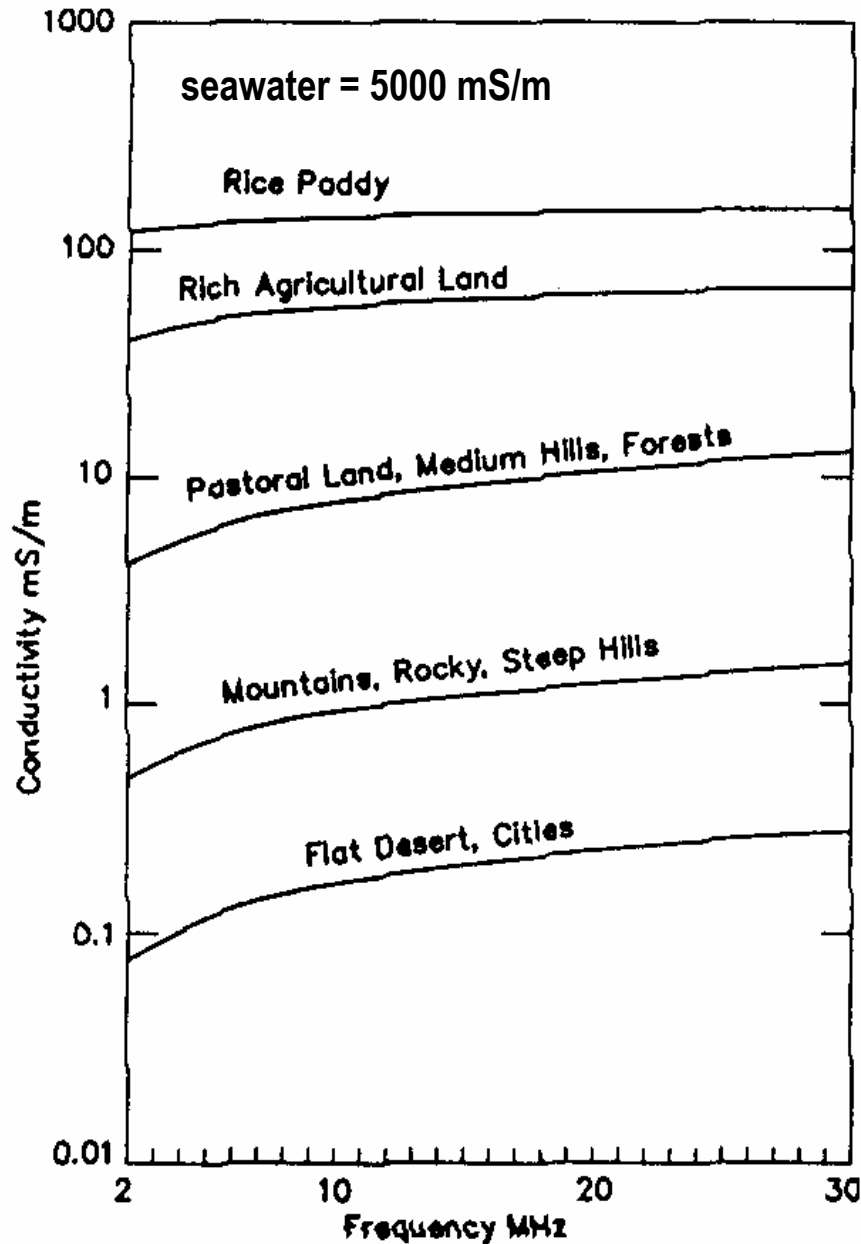
# Ground Parameters

- **Soil is characterized by its conductivity and permittivity.**
  - **the resistance of the soil for current flowing through it is inversely proportional to its conductivity with units of Siemens/meter (S/m).**
  - **higher conductivity means lower ground loss.**

# Ground Parameters

- the permittivity (dielectric constant) is related to the reactance of the soil for current flowing in it.
- permittivity has units of Farads/meter.
- we usually talk about the relative dielectric constant,  $\epsilon_r$ , which is 1 for air.

# Typical Ground Characteristics



# **Comment on Soil Charts**

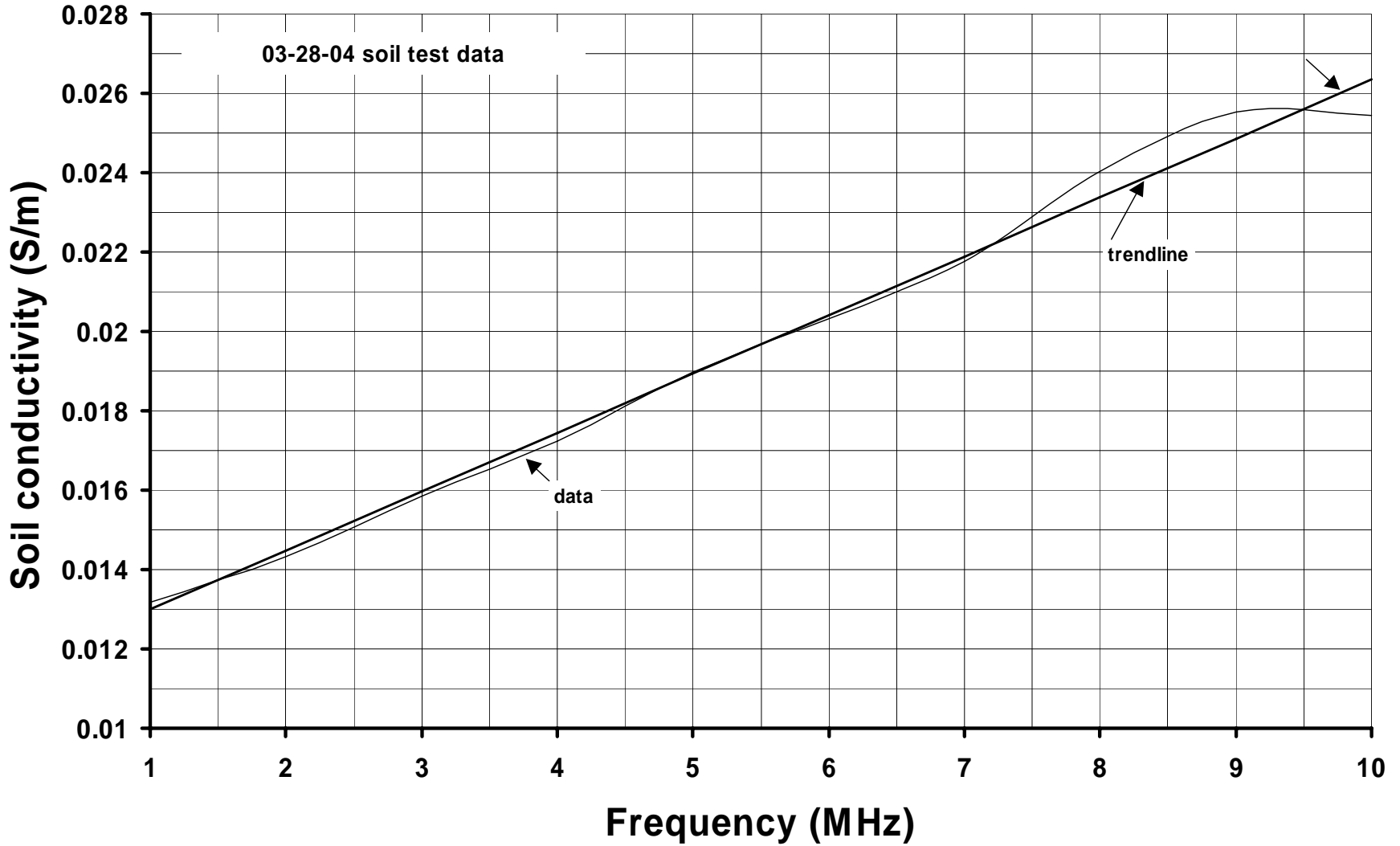
- **The typical soils listed in tables are for general guidance only.**
- **Most of the information is for BC frequencies and conductivity only.**
- **Your soil will almost certainly be different.**

## **Comment on Soil Charts**

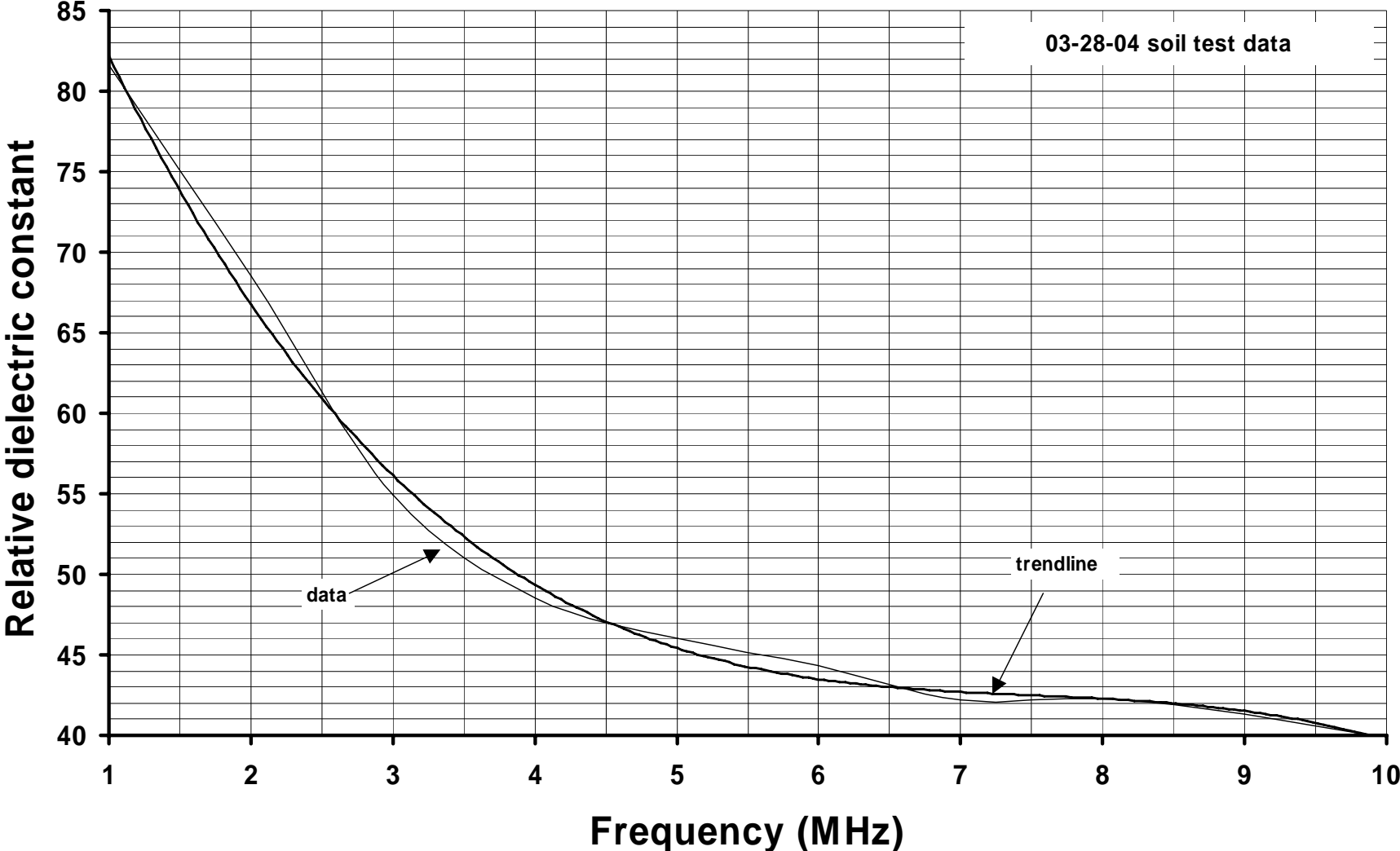
- **The soil parameters will vary both horizontally and vertically**
- **The soil parameters will also vary during the year depending on temperature, rainfall, etc.**
- **The best way to estimate your soil parameters is to directly measure them.**

**See QEX Nov/Dec 2006**

# N6LF Ground Conductivity



# N6LF Ground Permittivity



# Skin depth equations

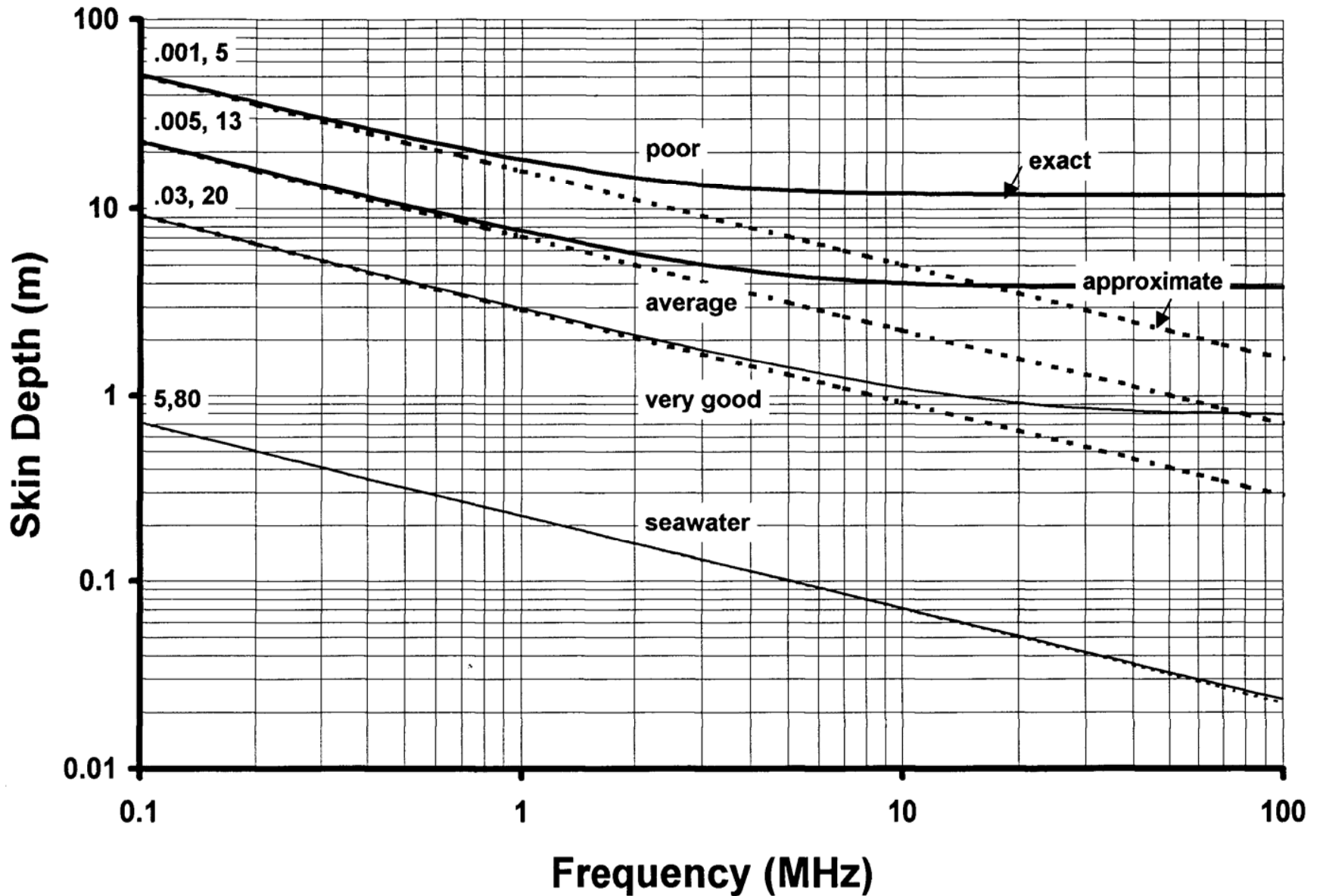
- Skin depth in an arbitrary material is given by:

$$\delta = \left( \frac{\sqrt{2}}{\omega \sqrt{\mu \epsilon}} \right) \left[ \sqrt{1 + \left( \frac{\sigma}{\omega \epsilon} \right)^2} - 1 \right]^{-1/2} \quad (1)$$

- Where:

- $\delta$  = skin or penetration depth
- $\omega = 2\pi f$ ,  $f$  = frequency
- $\sigma$  = conductivity [Siemens/meter, S/m]
- $\mu = \mu_r \mu_0$  = permeability
- $\mu_0$  = permeability of vacuum =  $4\pi \cdot 10^{-7}$  [Henry/meter]
- $\mu_r$  = relative permeability
- $\epsilon = \epsilon_r \epsilon_0$  = permittivity
- $\epsilon_0$  = permittivity of vacuum =  $8.854 \times 10^{-12}$  [Farad/meter]
- $\epsilon_r$  = relative permittivity

# Penetration Depth In Soil



## Wavelength in free space

$\lambda_o$  = wavelength in free space

$$\lambda_o = \frac{c}{f} = \frac{299.79}{f_{\text{MHz}}} \quad [m]$$

c = speed of light 299.79E6 m/s

f = frequency

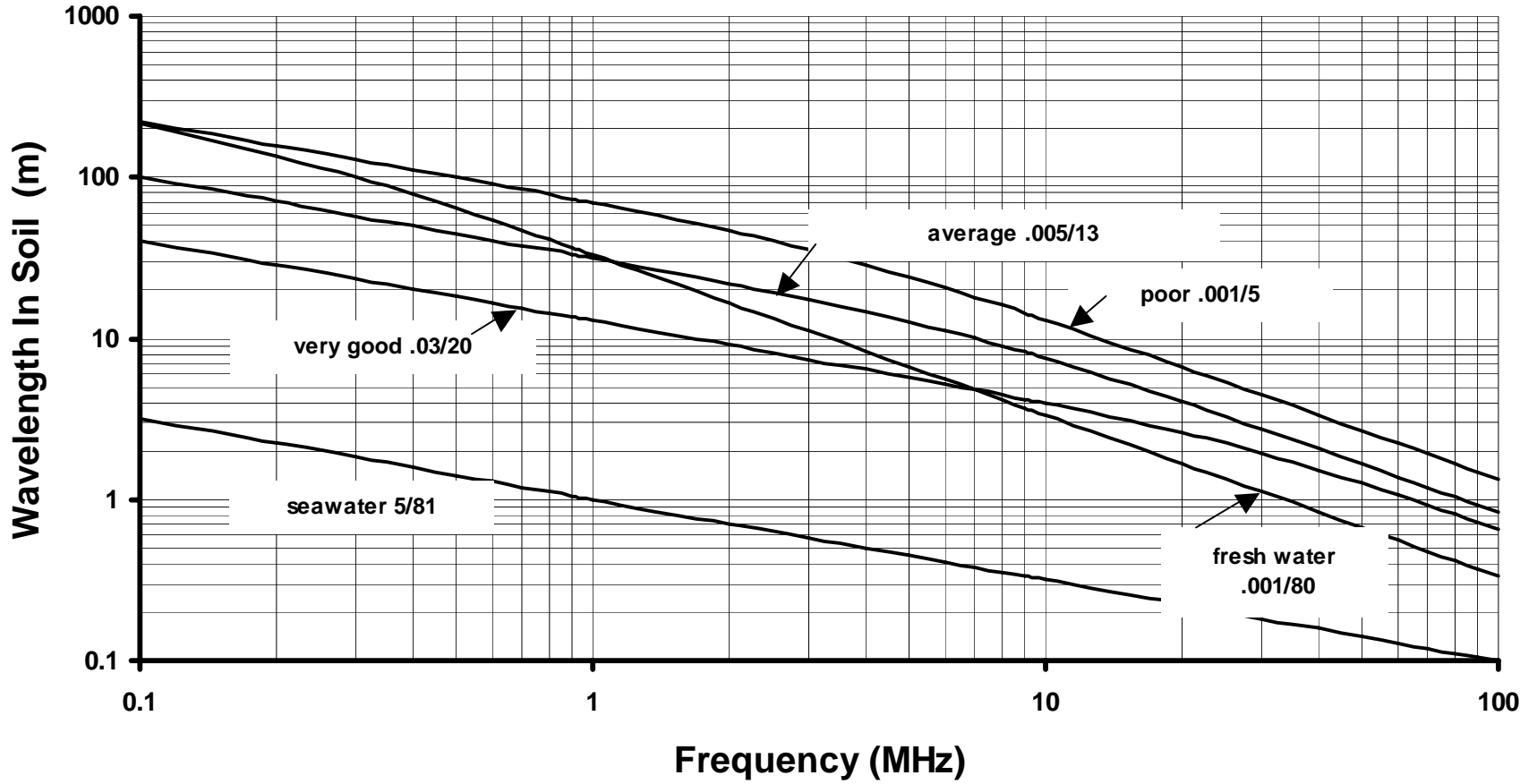
$f_{\text{MHz}}$  = frequency in MHz

## Wavelength in soil

- The wavelength in soil ( $\lambda$ ) will depend on  $\sigma$  and  $\epsilon_r$ :

$$\lambda = \frac{\lambda_0}{\left[ \epsilon_r^2 + \left( \frac{\sigma}{\omega \epsilon_0} \right)^2 \right]^{1/4}}$$

# Wavelength in soil



# **Ground Systems For Verticals**

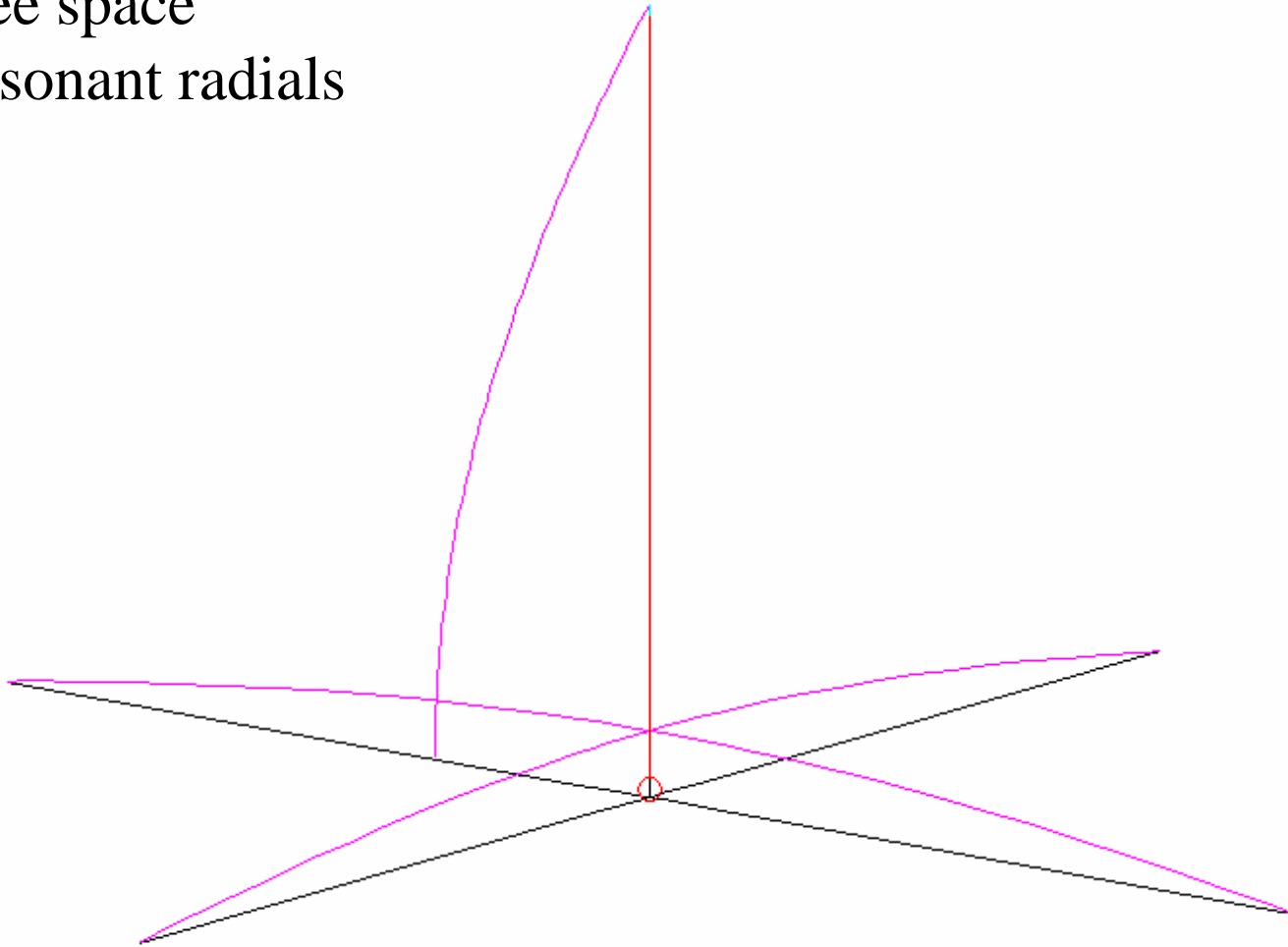
## **Choices for ground systems**

- **There are three categories of ground systems:**
  - **Elevated radials**
  - **Radials lying close to the ground surface**
  - **Buried radials**
  
- **Each of these behaves differently!**

# Radial currents

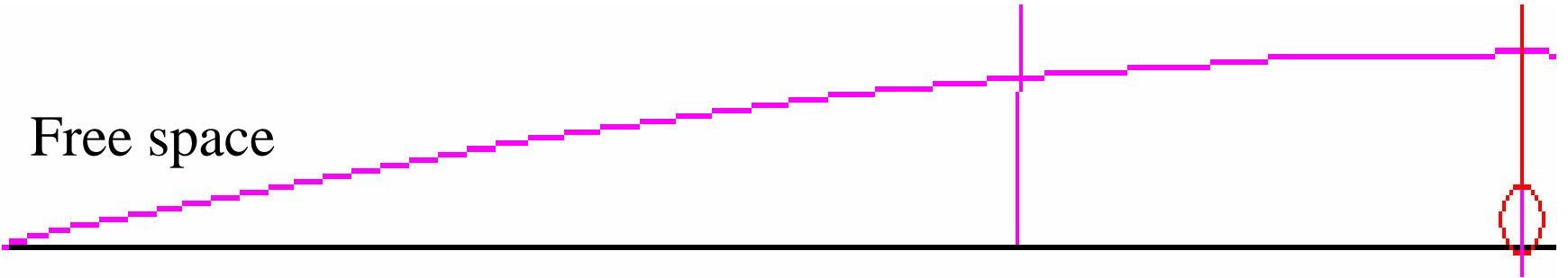
EZNEC/4

Free space  
Resonant radials

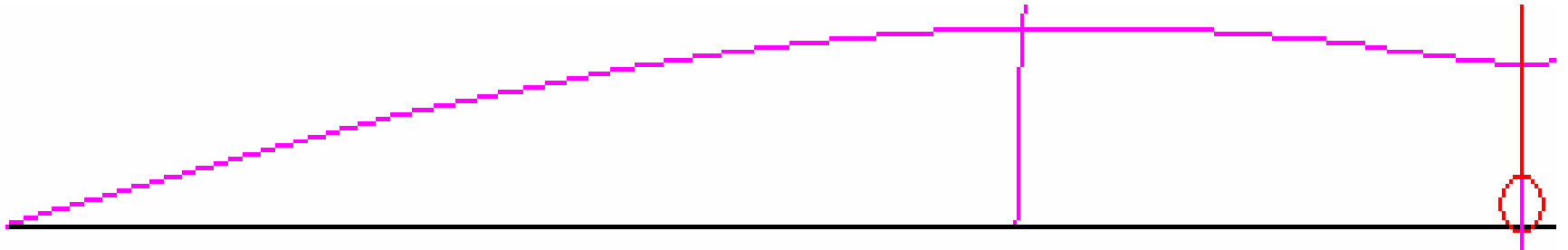


# Radial currents at three different heights

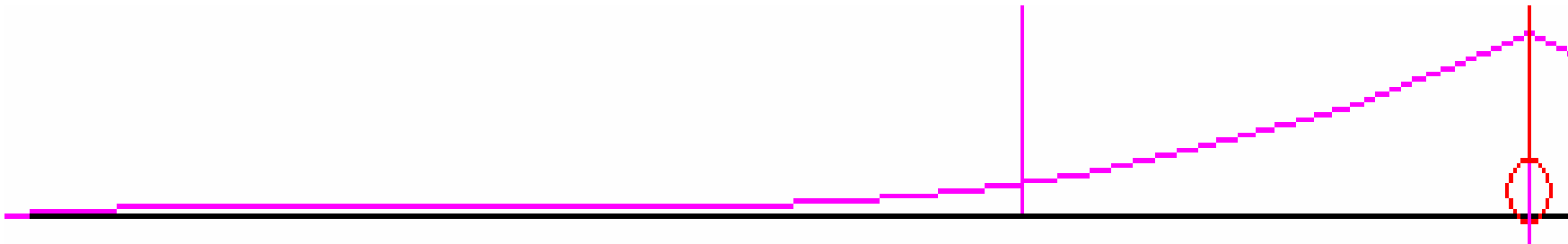
Free space



1" above average ground



12" below ground



# Measured radial currents

Arch Doty Measurements 160 m

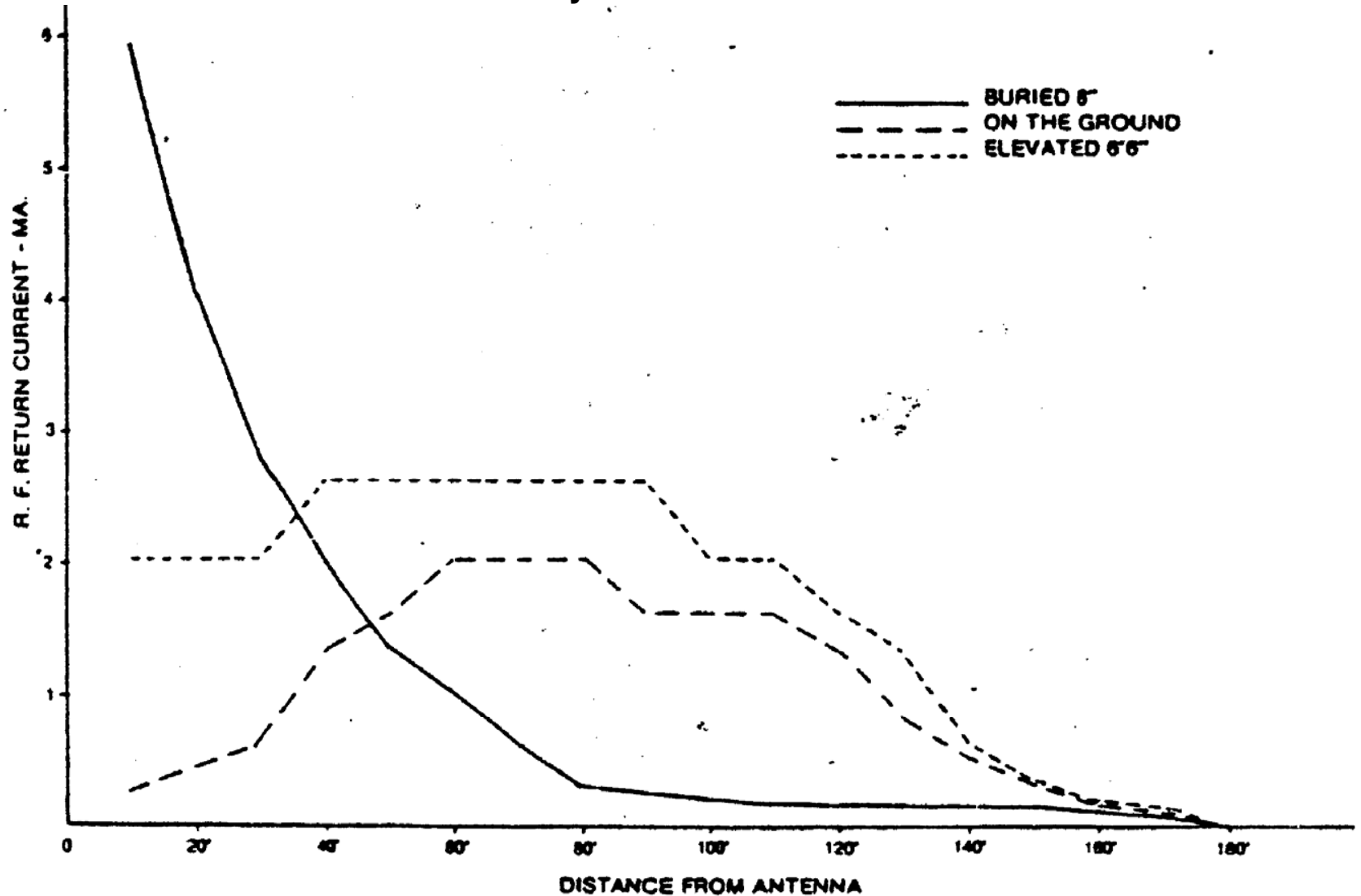
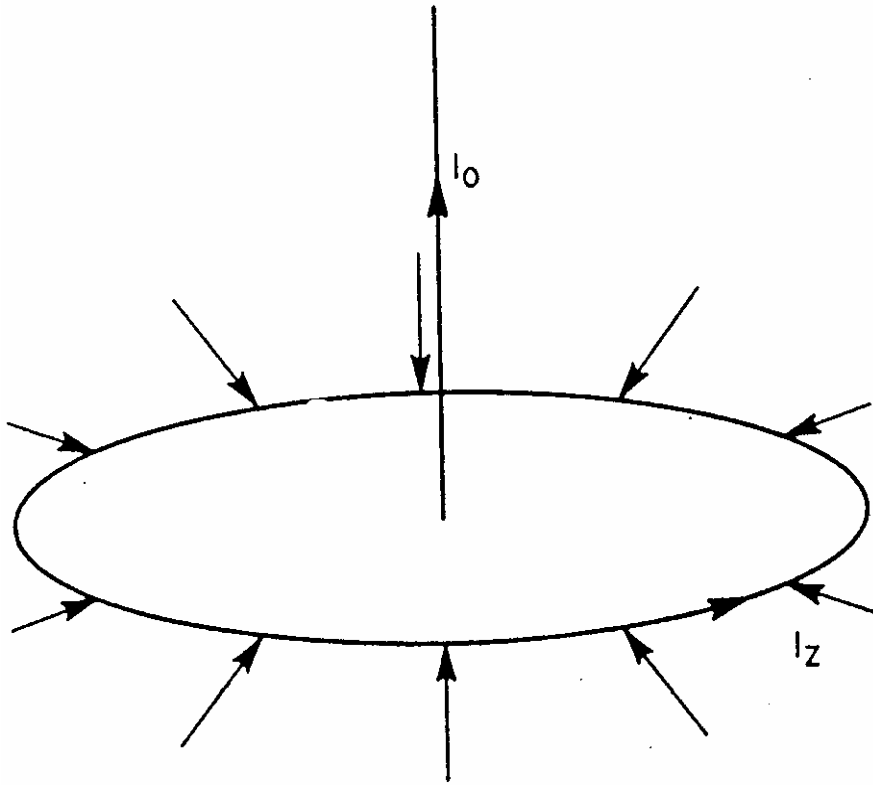


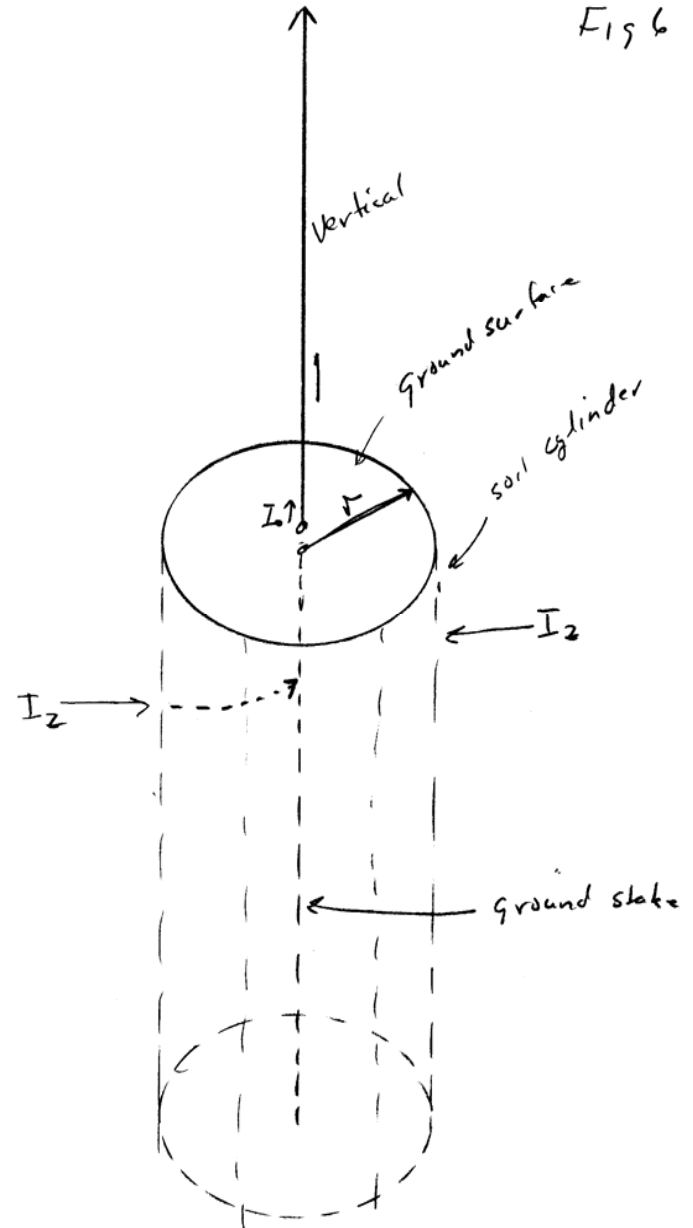
Fig. 7— The return current measured in 180' long radial wires.

# H-Field Currents Near A Vertical

Fig 6

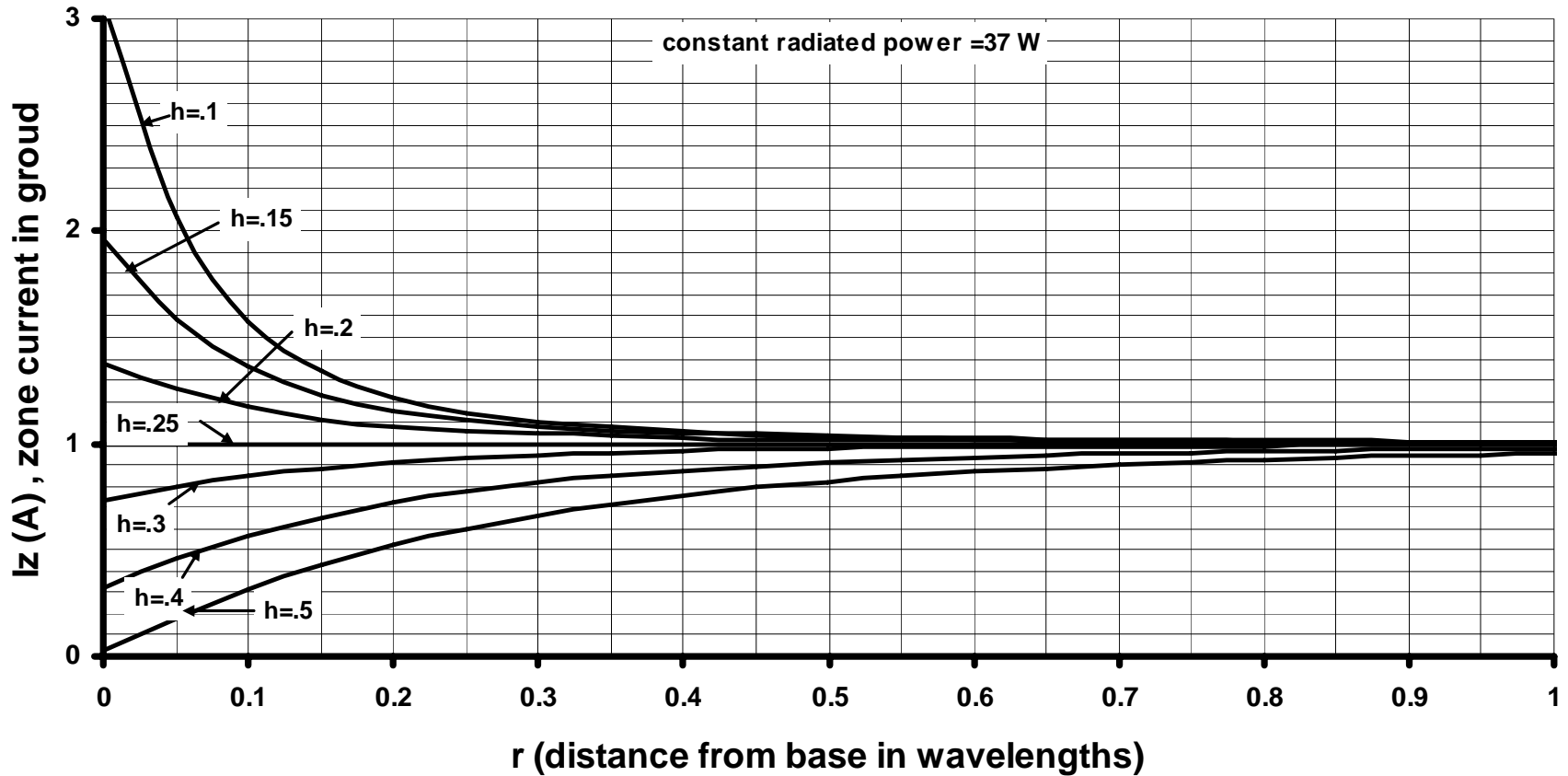


$I_z$  = zone current  
Induced by H-field

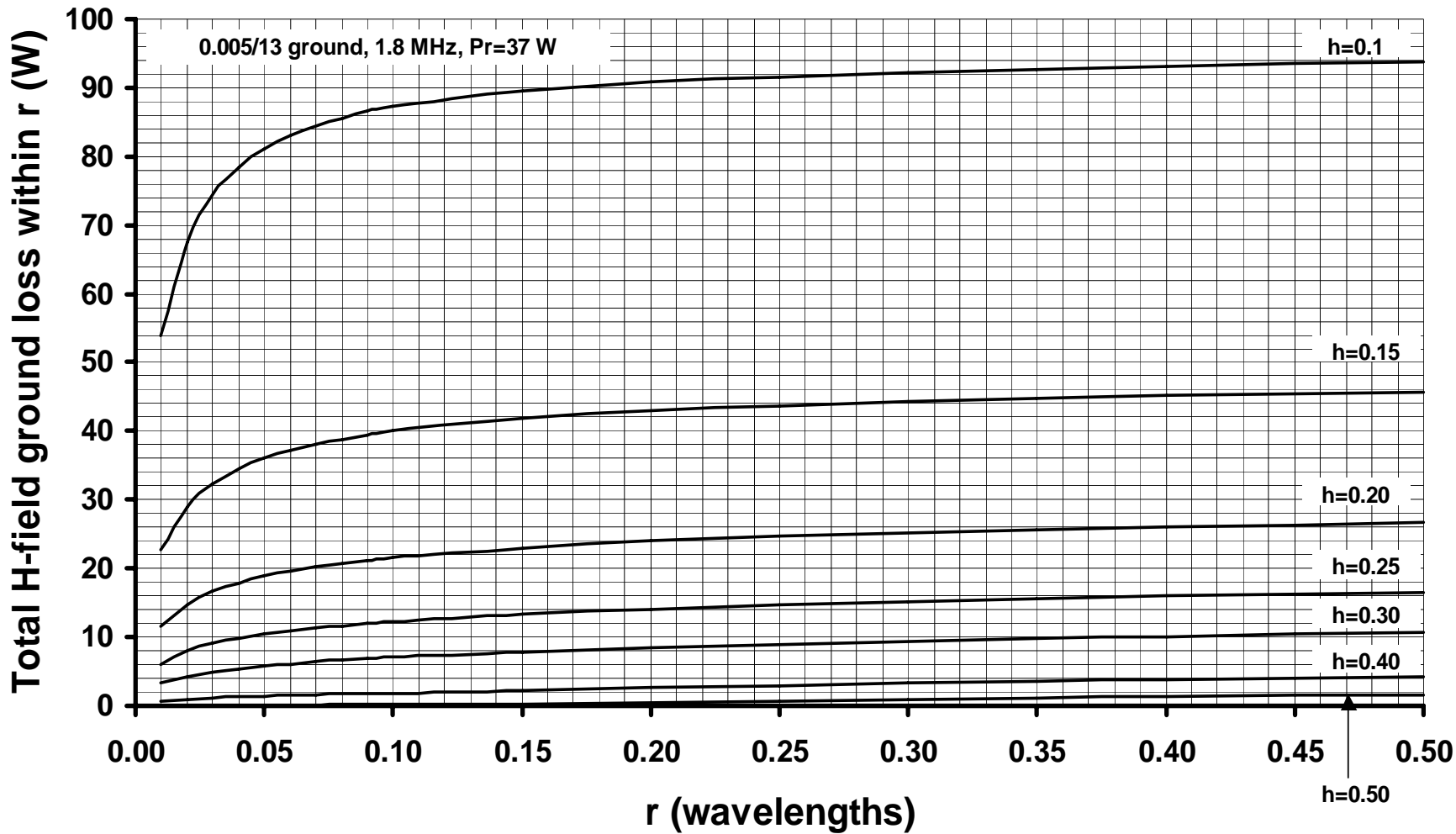


# Iz, zone current

Remember! Losses are proportional to  $I^2$

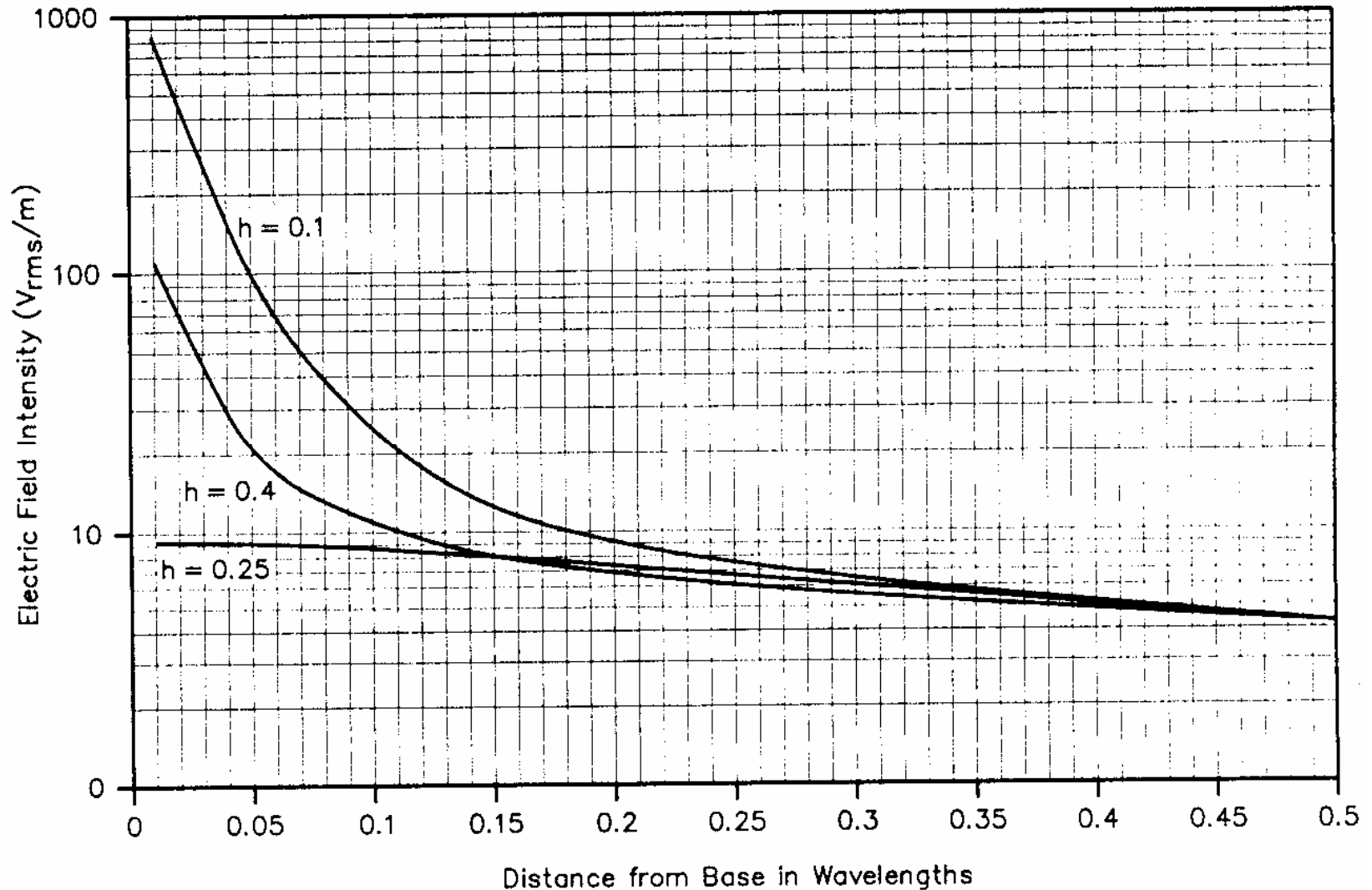


# H-Field Loss

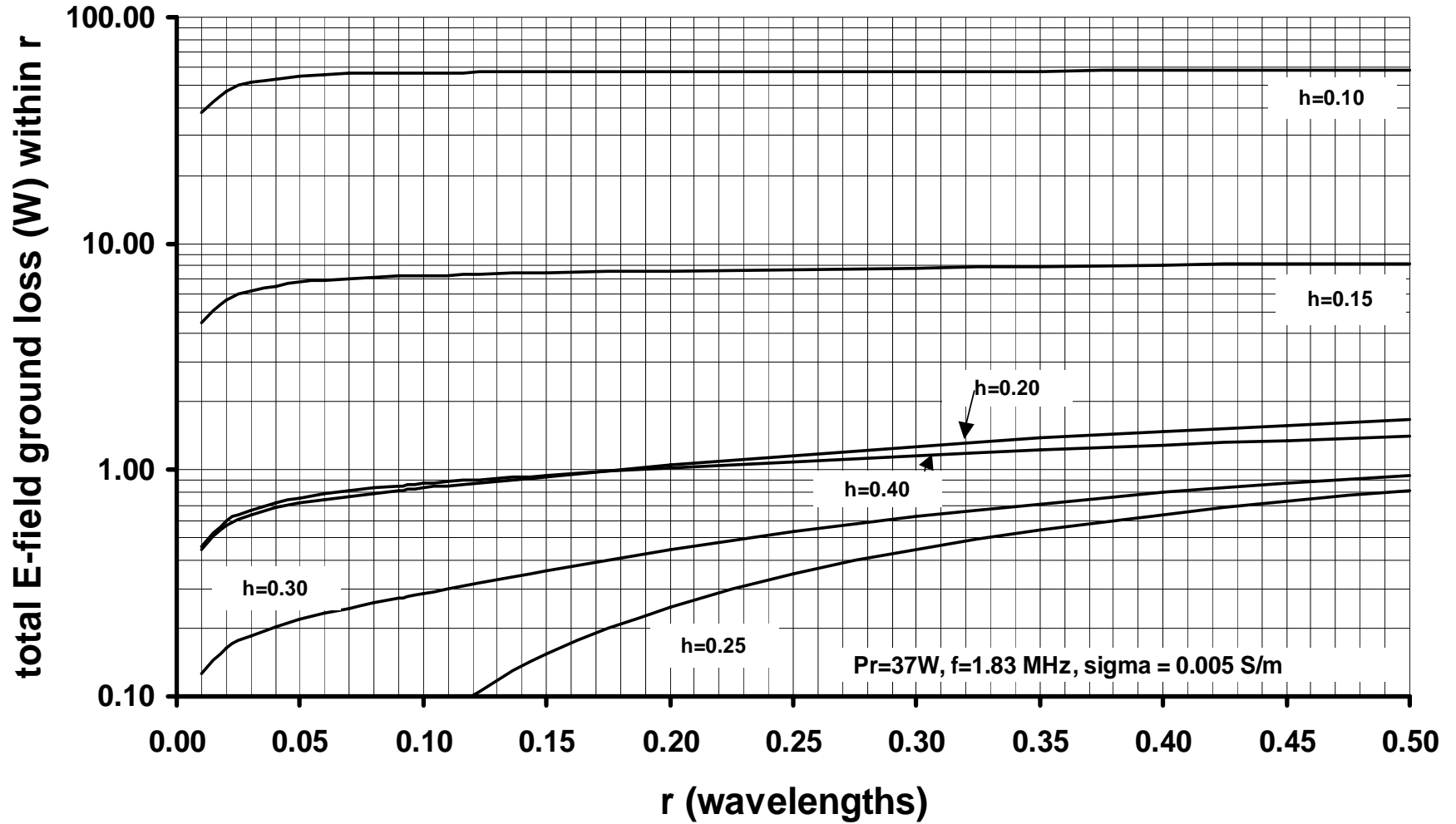


# Electric Field Intensity Near The Base

- $f = 1.8 \text{ MHz}$  and  $\text{Power} = 1500 \text{ W}$

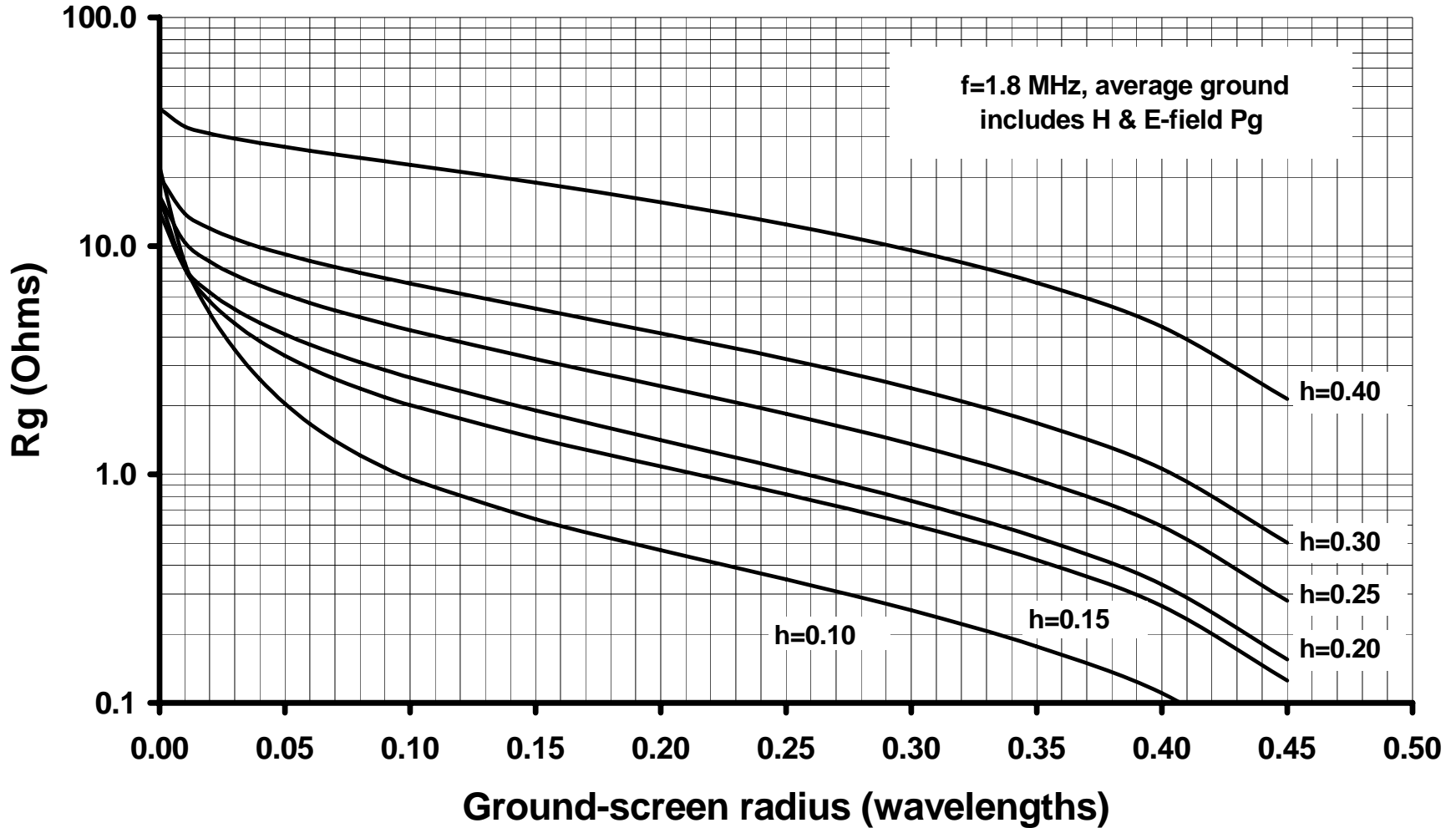


# E-Field Loss



# Rg With A Perfect Ground Screen

$$R_g = P_{\text{loss}}/I^2$$



# Variable $R_g$ with $h$ ???

- What's going on here.
- The conventional wisdom is that a given ground system, over a given soil, at a given frequency, will have some equivalent  $R_g$  independent of the antenna.
- **This isn't true!**

## Variable $R_g$ with $h$ ???

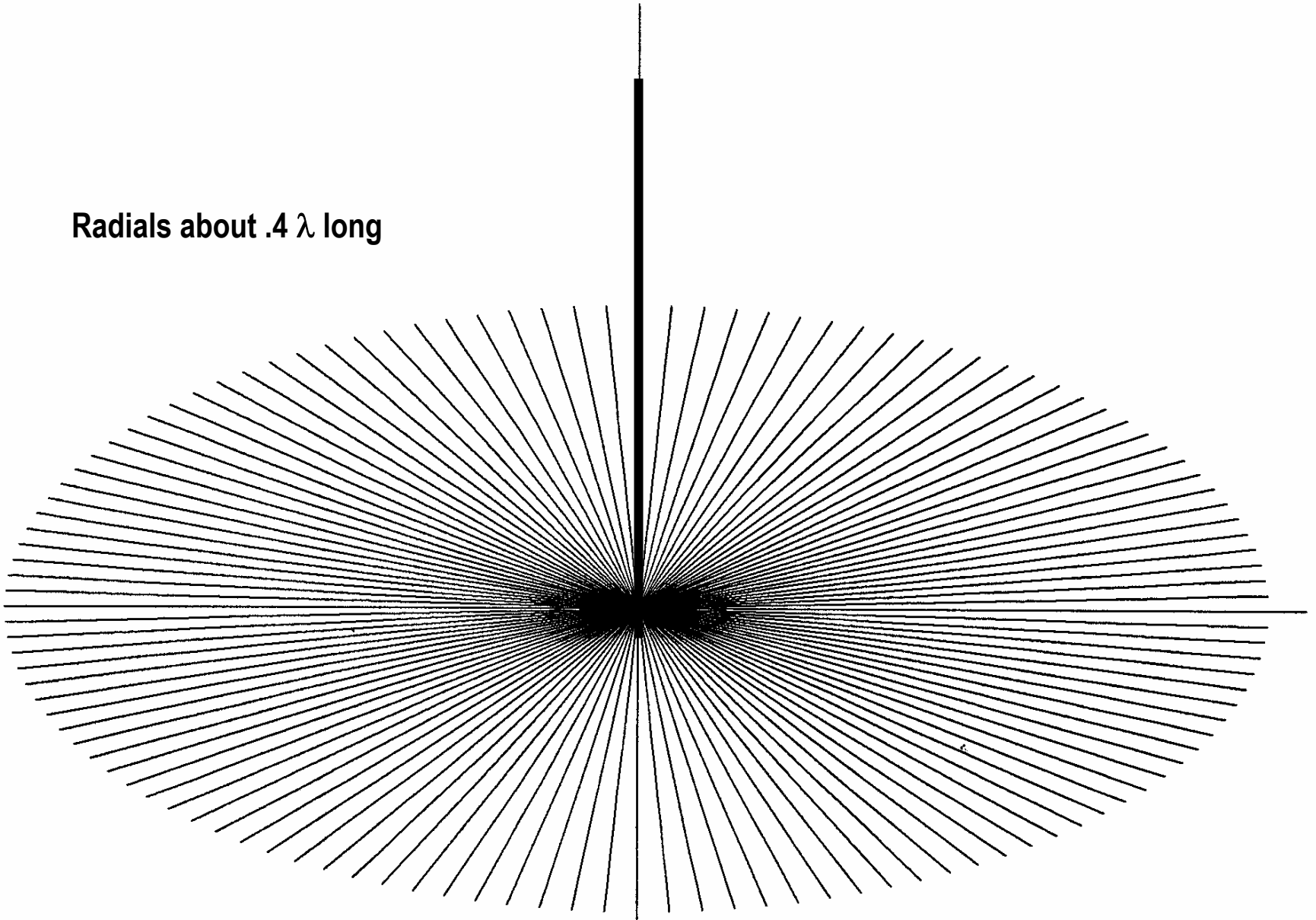
- $R_g$  represents the equivalent series resistance component of the input impedance that accounts for the ground loss ( $P_g$ ) for a given excitation current.
- As we reduce the height of the antenna,  $R_r$  goes down, so for the same power we have to jack up the current which increases the fields around the base.

# Variable $R_g$ with $h$ ???

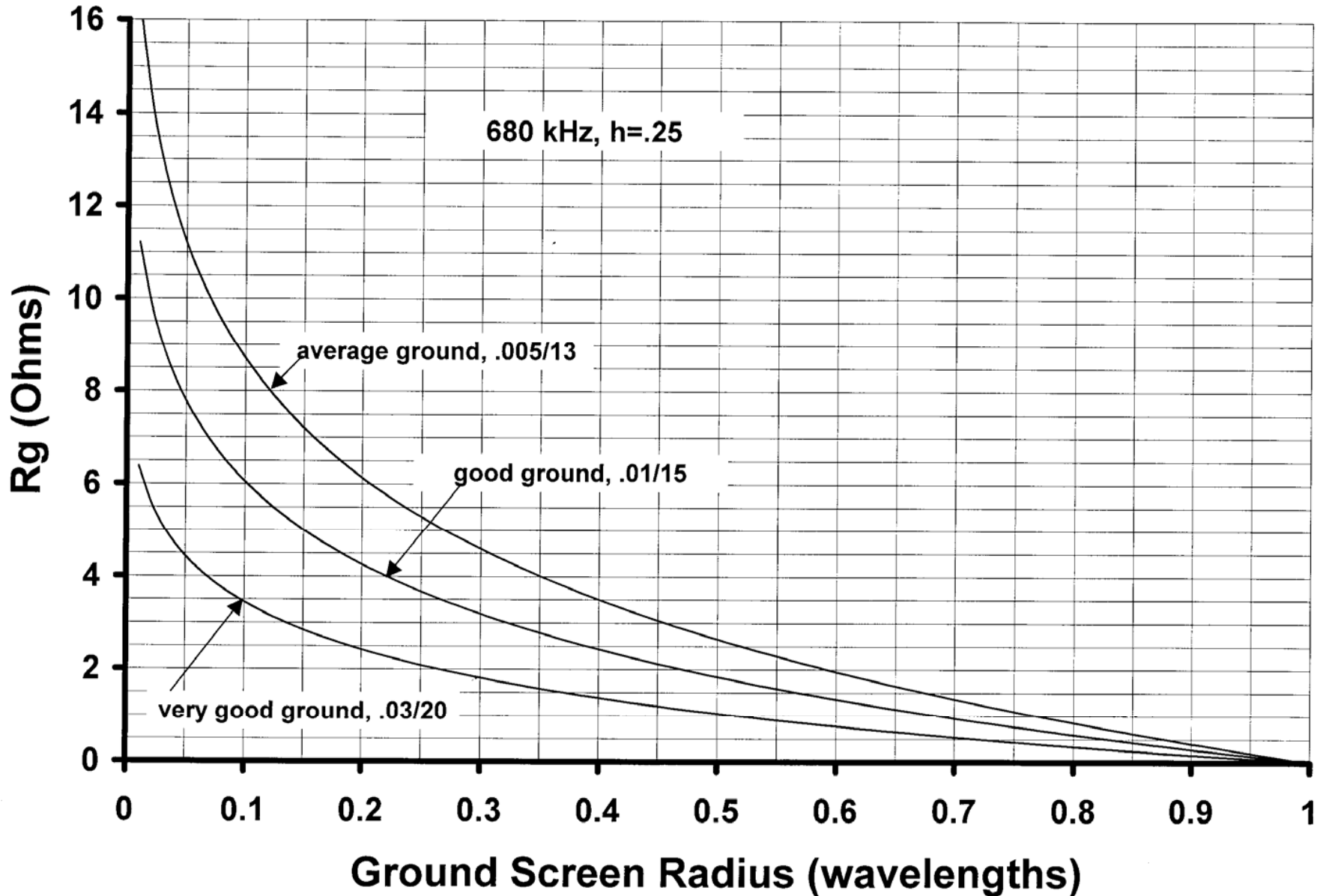
- **But the losses go as  $I^2$ !**
- **Yes, the ground loss does increase but the value for  $R_g$  actually goes down a bit.**

# CLASSICAL 120 RADIAL GROUND SCREEN

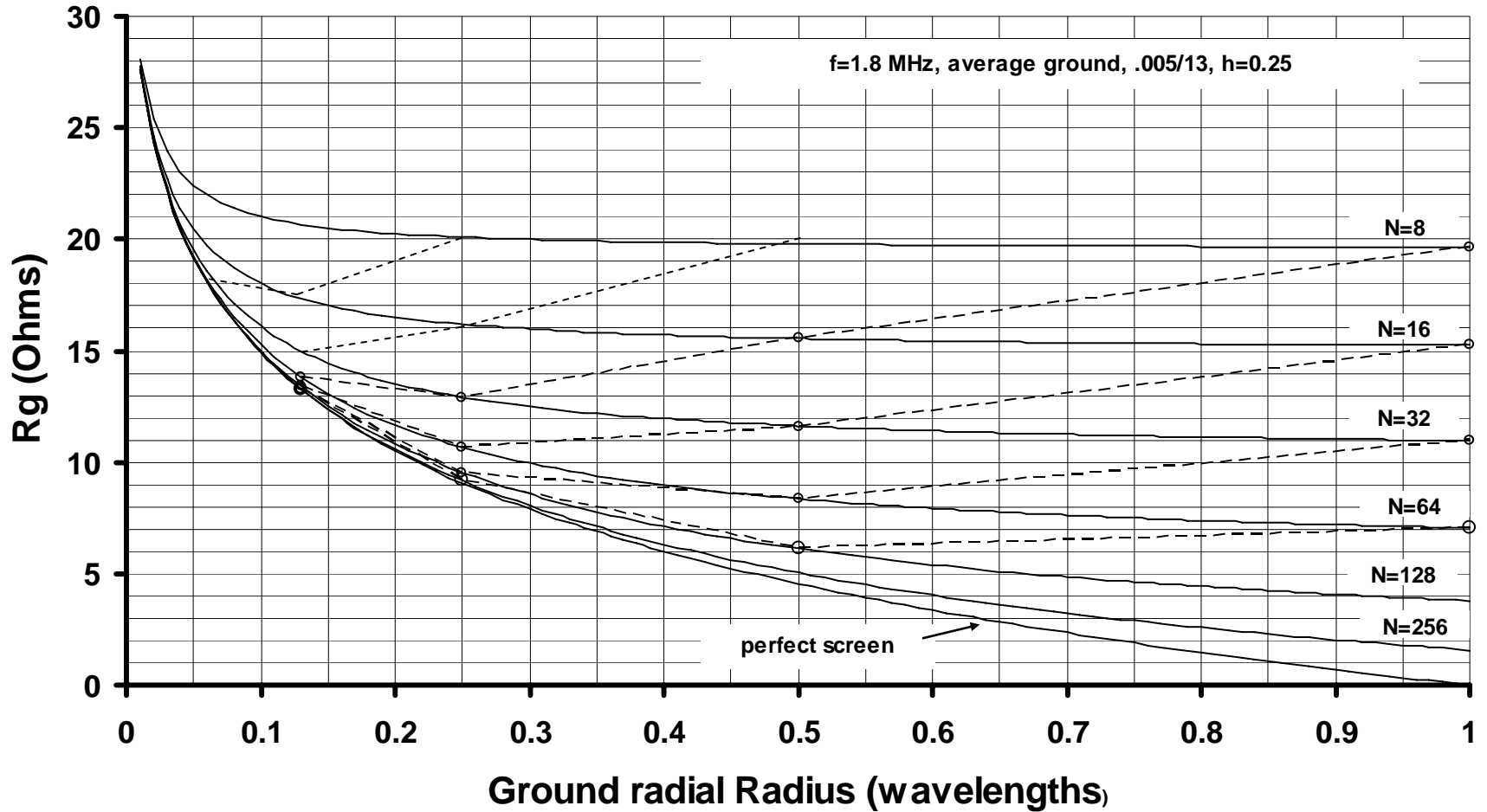
Radials about  $.4 \lambda$  long



# BC Frequency Rg Example

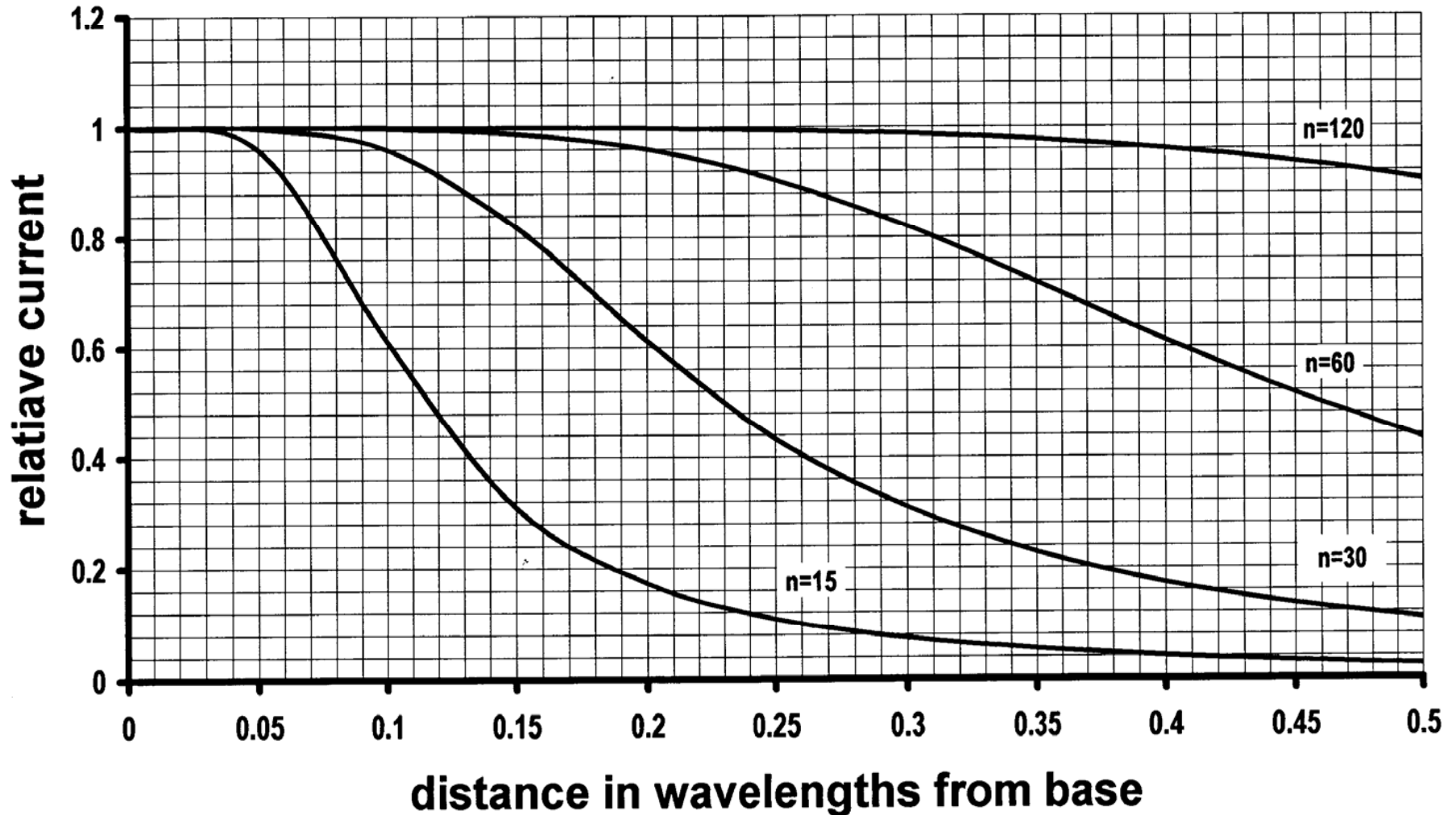


# Optimum Ground Wire Usage

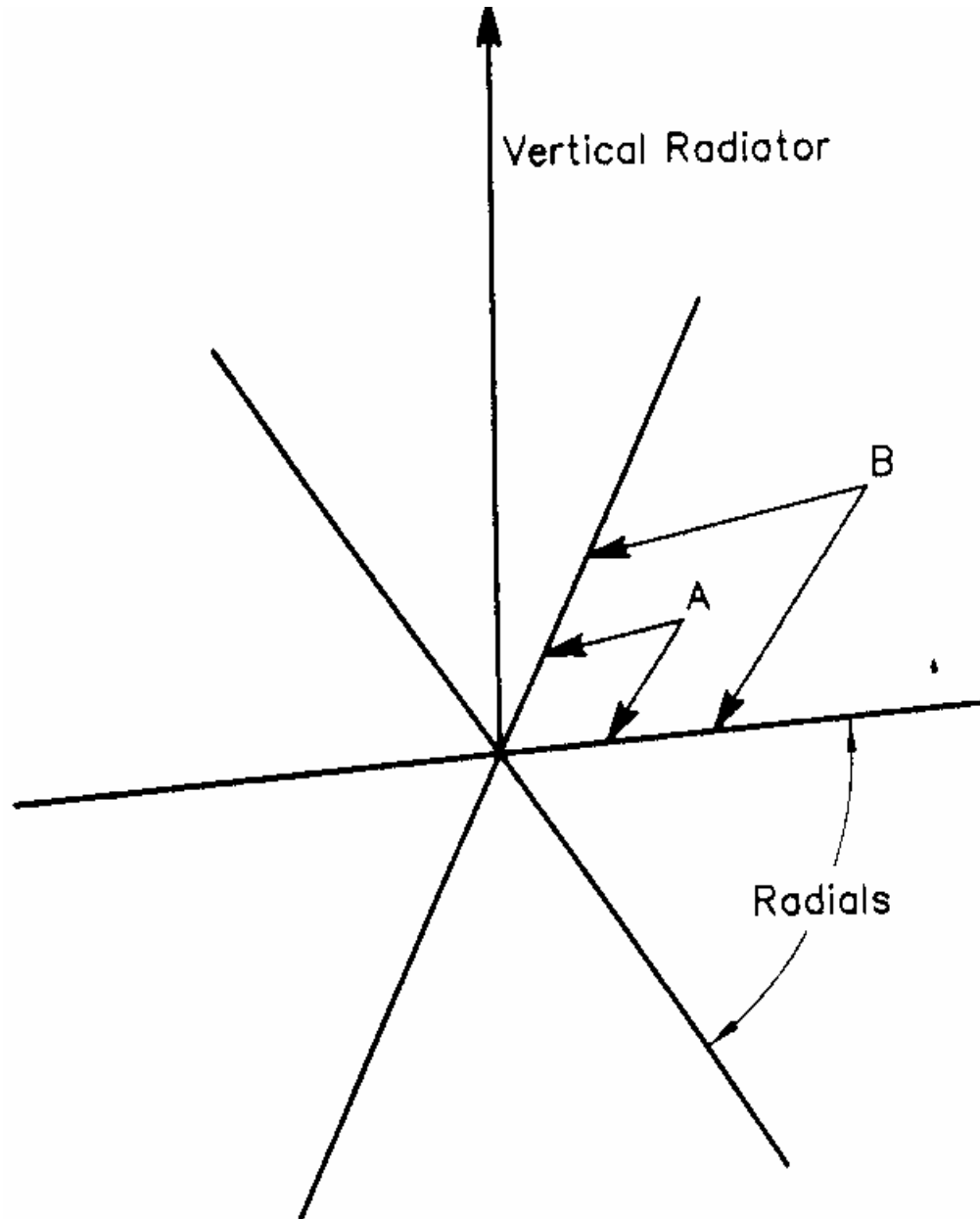


# Current In Radials

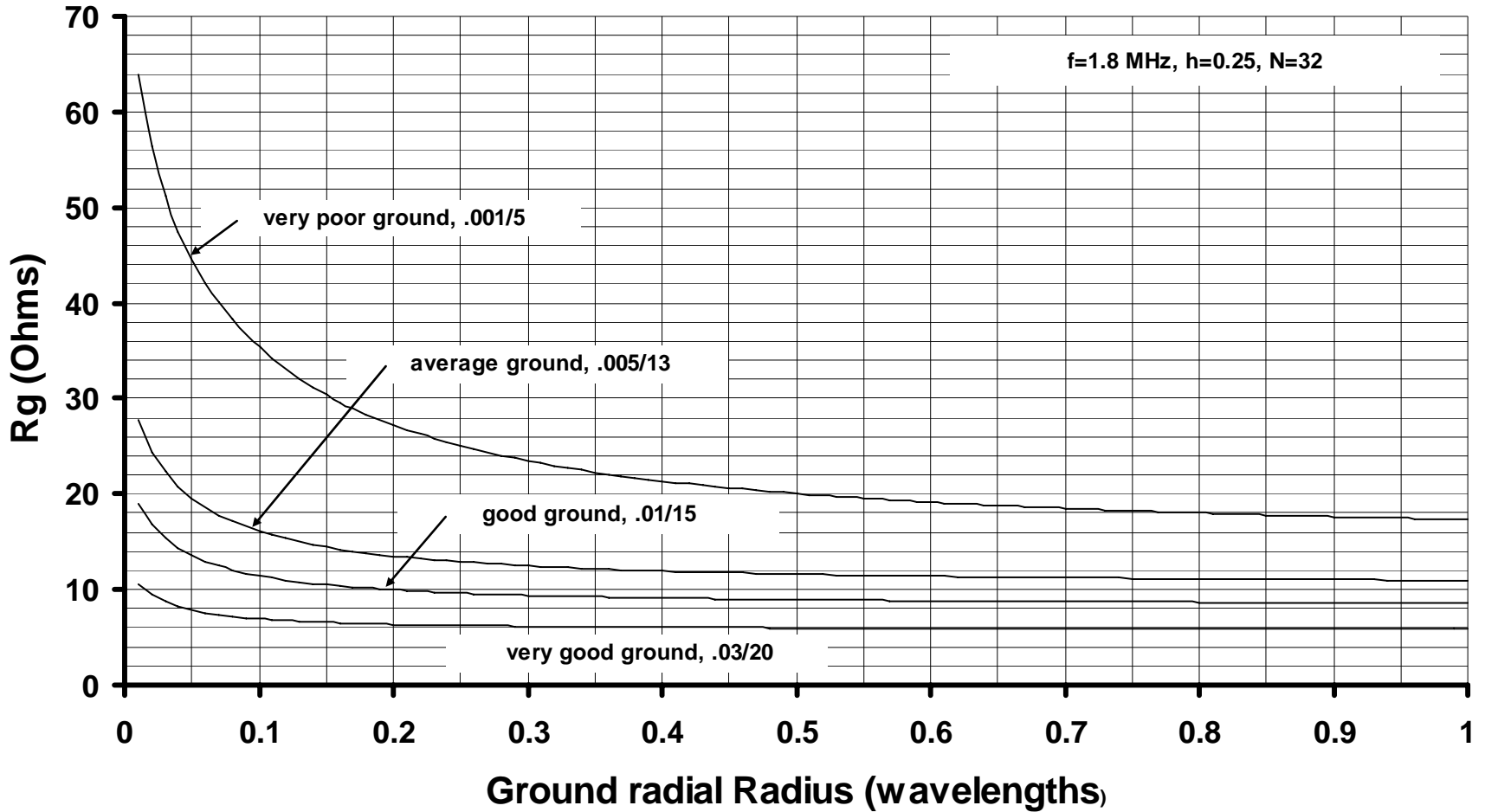
Current in the ground radials  
 $h=.25$ ,  $f=1.83$  MHz,  $g_{\text{cond}}=.005$  S/m



# Ground Current And Radials

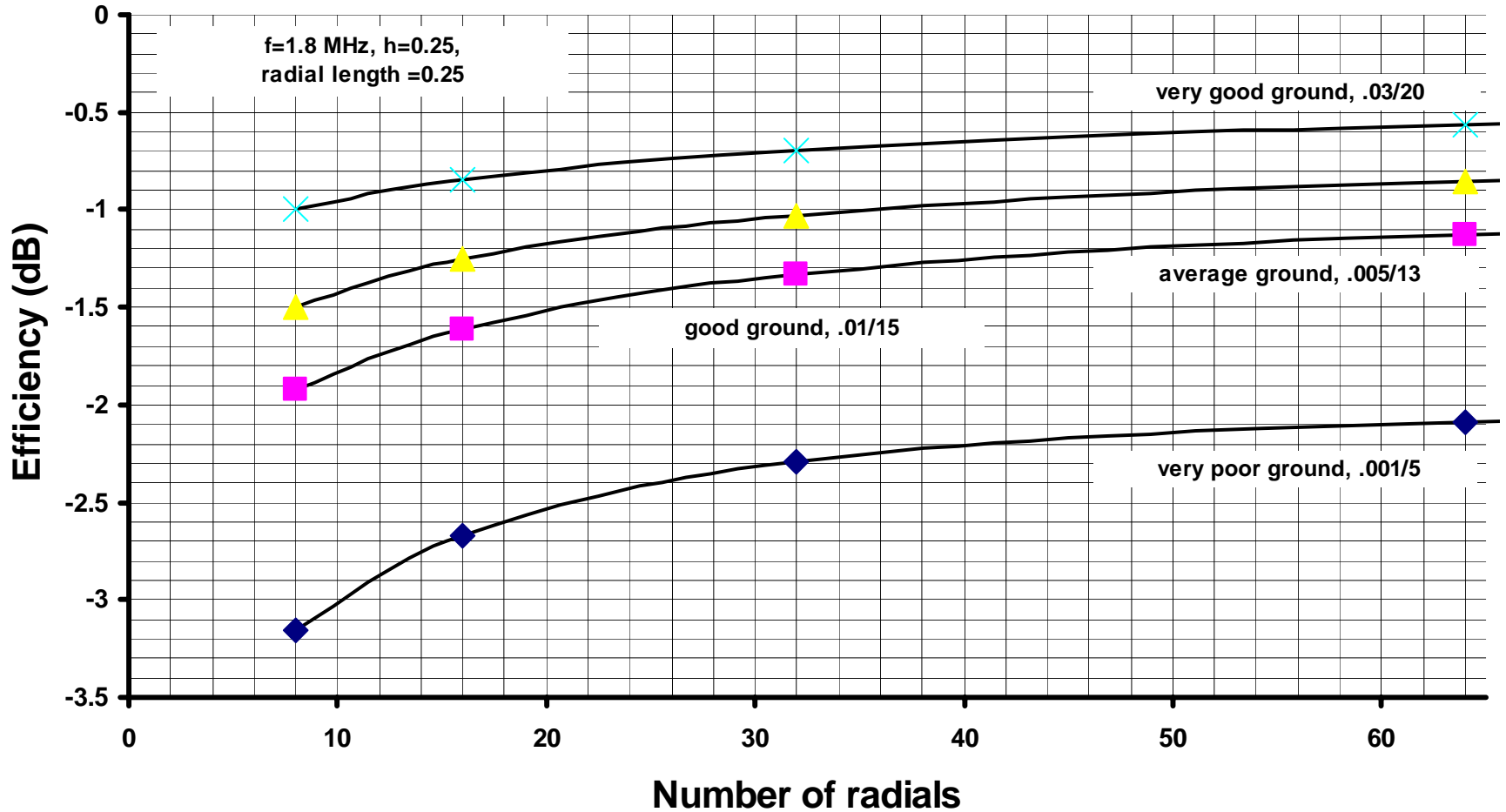


# Rg versus ground parameters

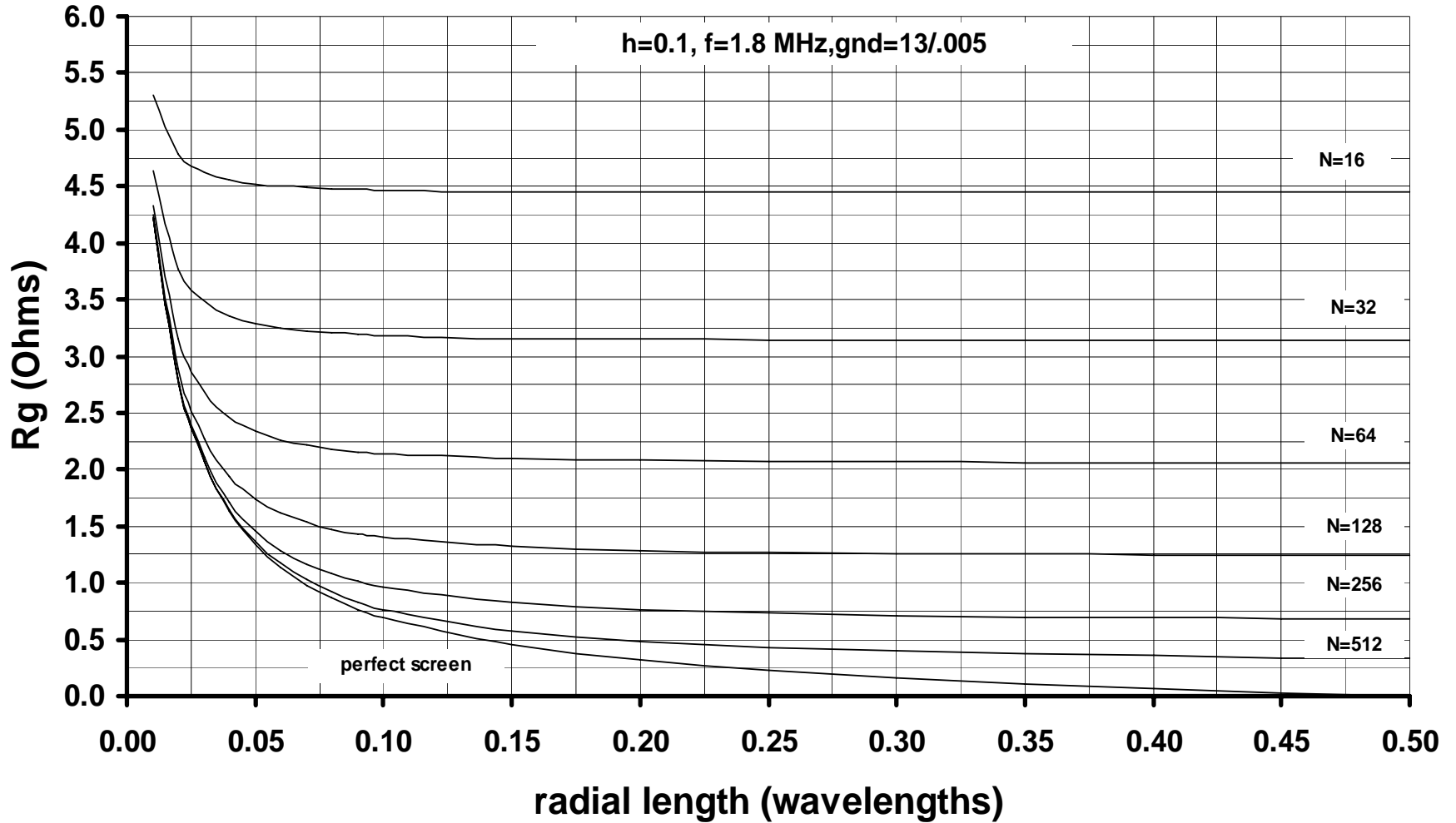


# Efficiency versus radial number

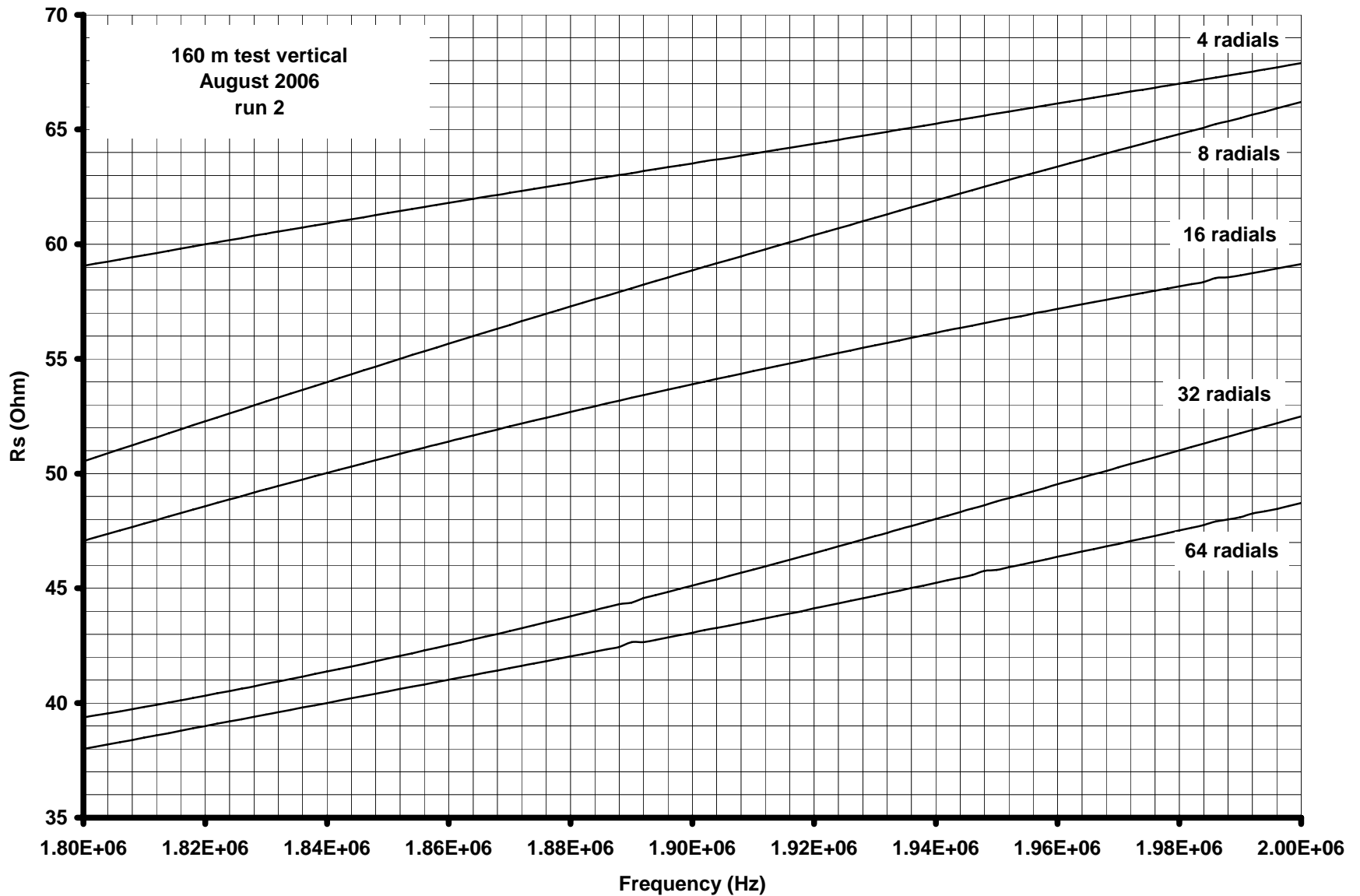
Assuming  $R_r = 36$  Ohms



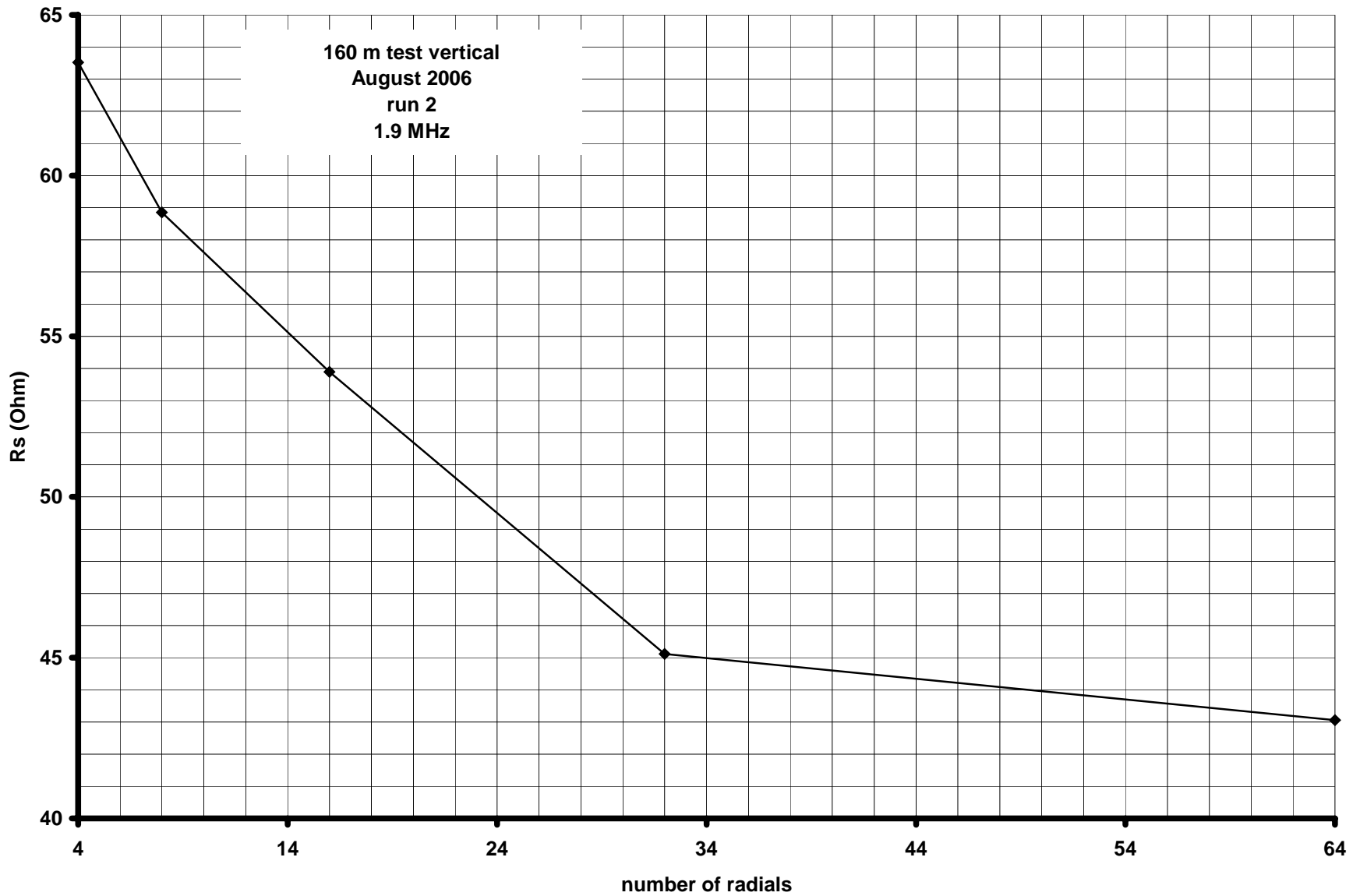
# Rg For h=0.1 Wavelength



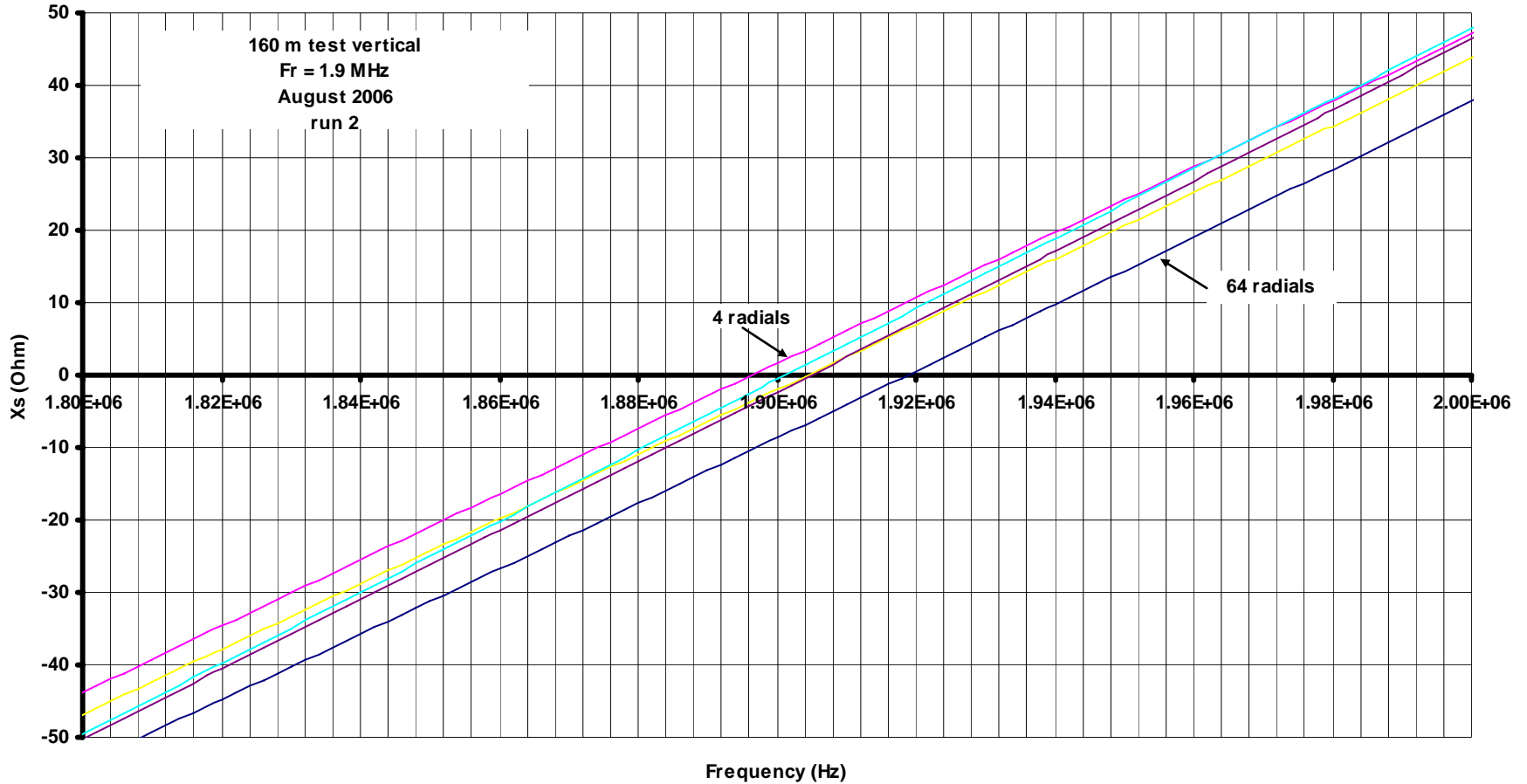
# Series base resistance (Rs)



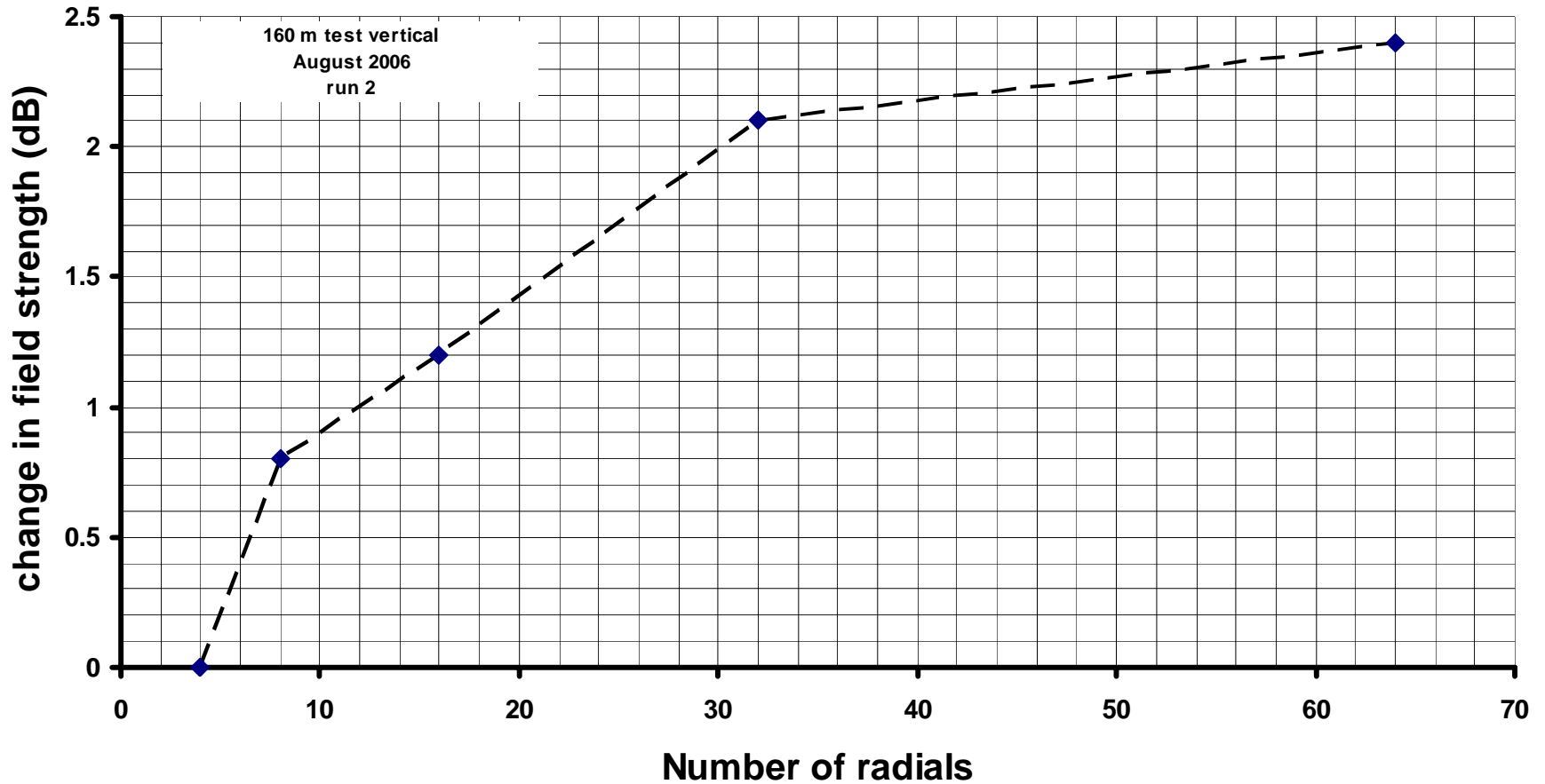
# Rs versus radial number



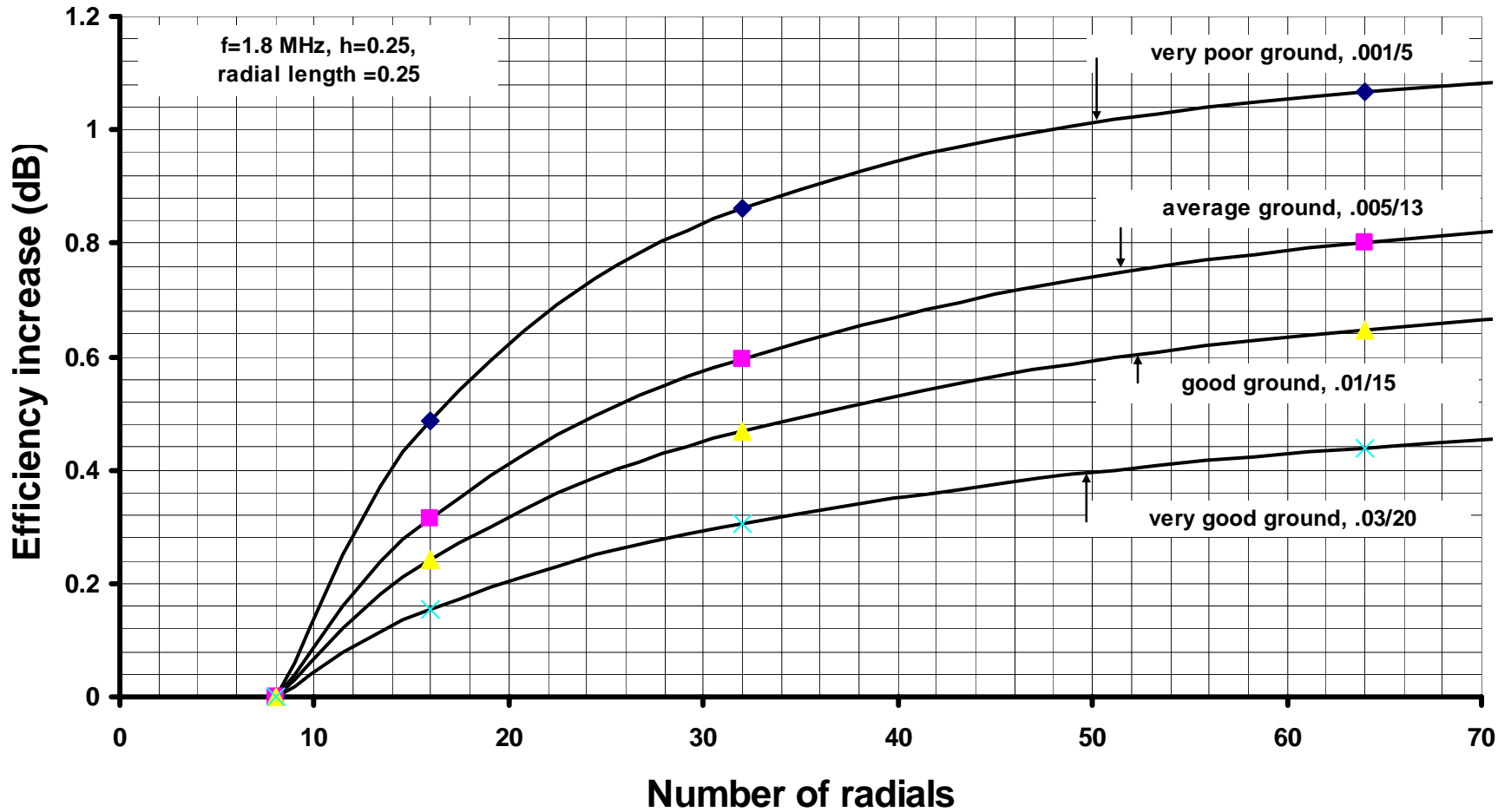
# Series base input reactance ( $X_s$ )



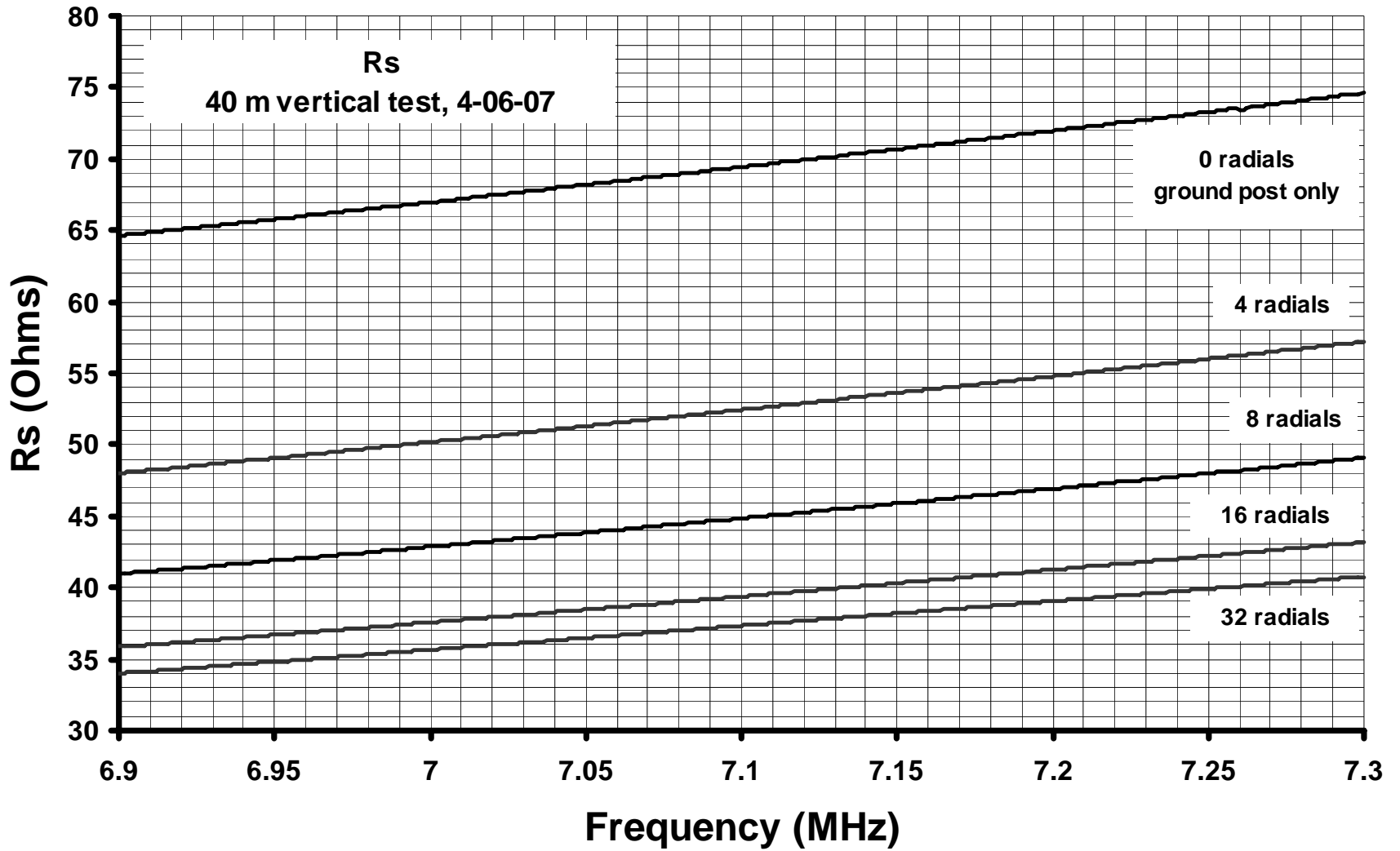
# Field strength versus radial number



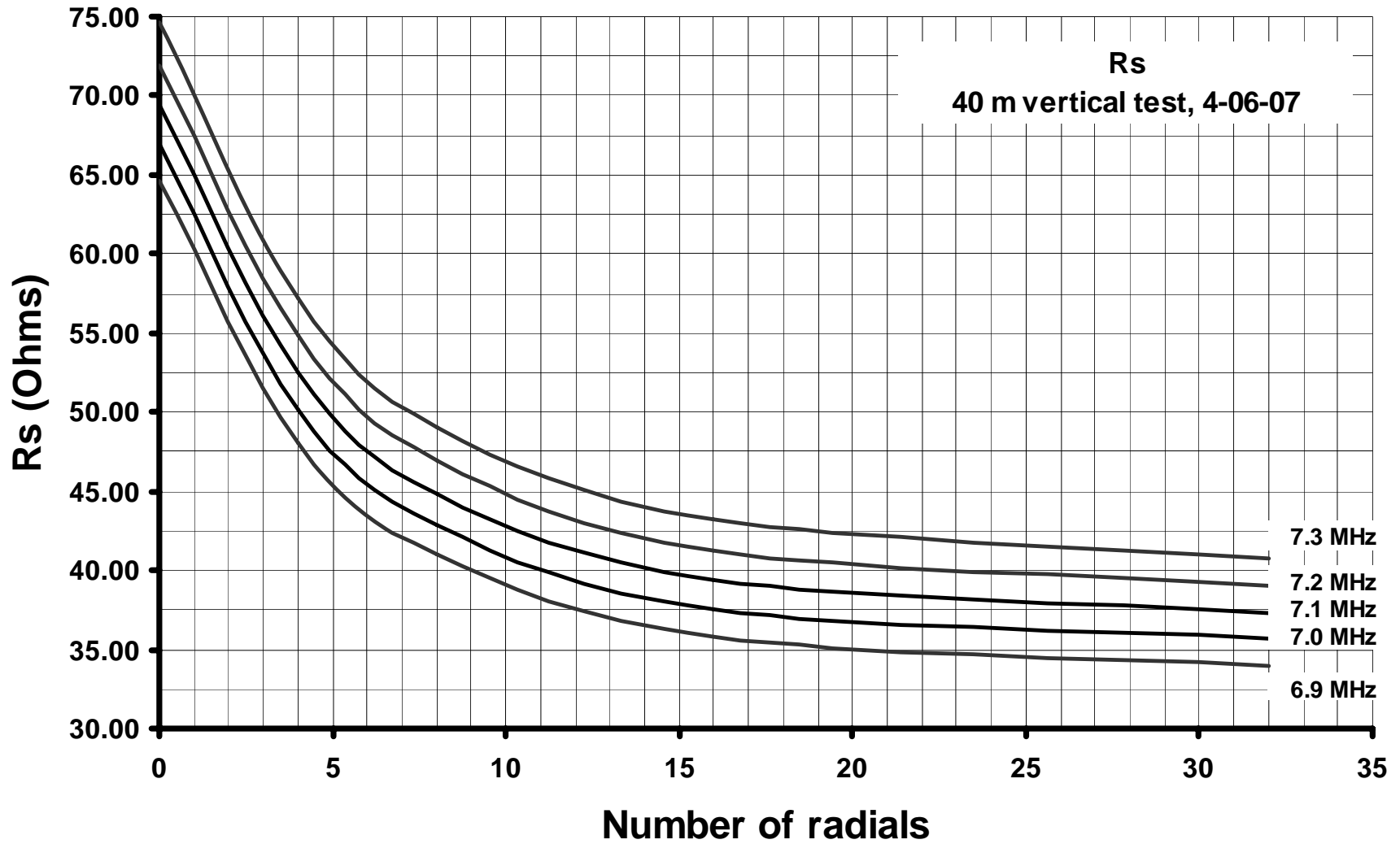
# Calculated change in field strength



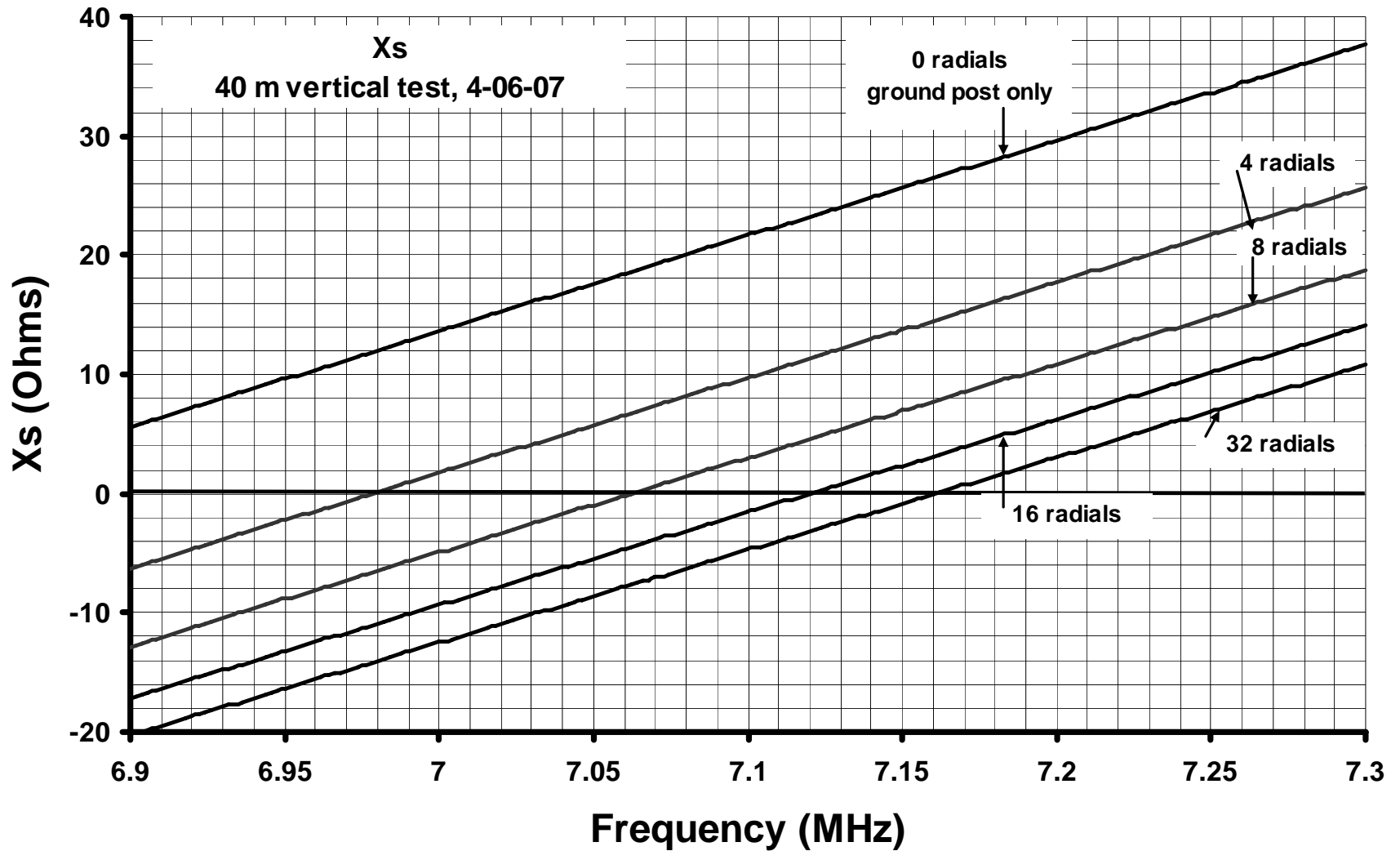
# Rs versus radial number and frequency



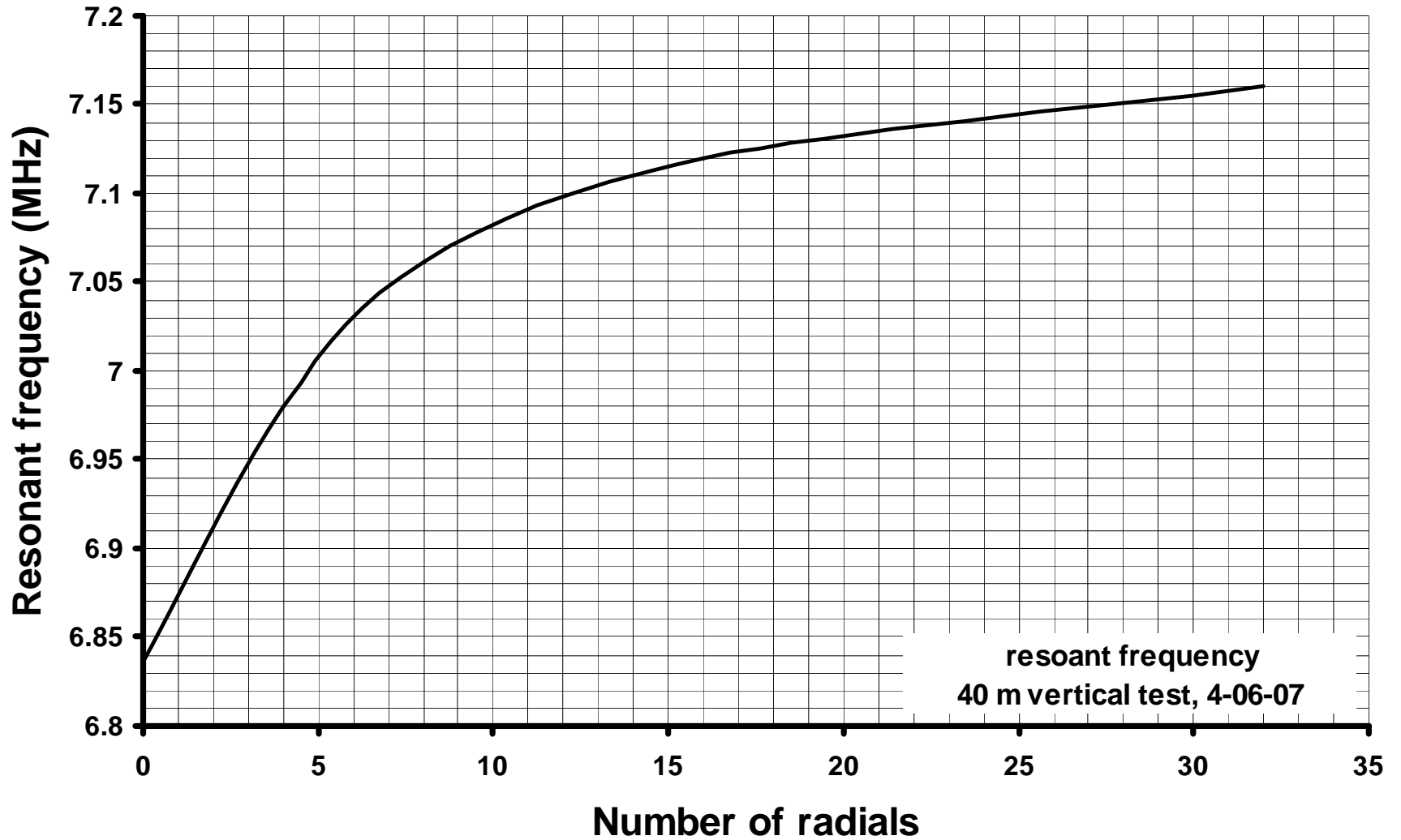
# Change in Rs with radial number



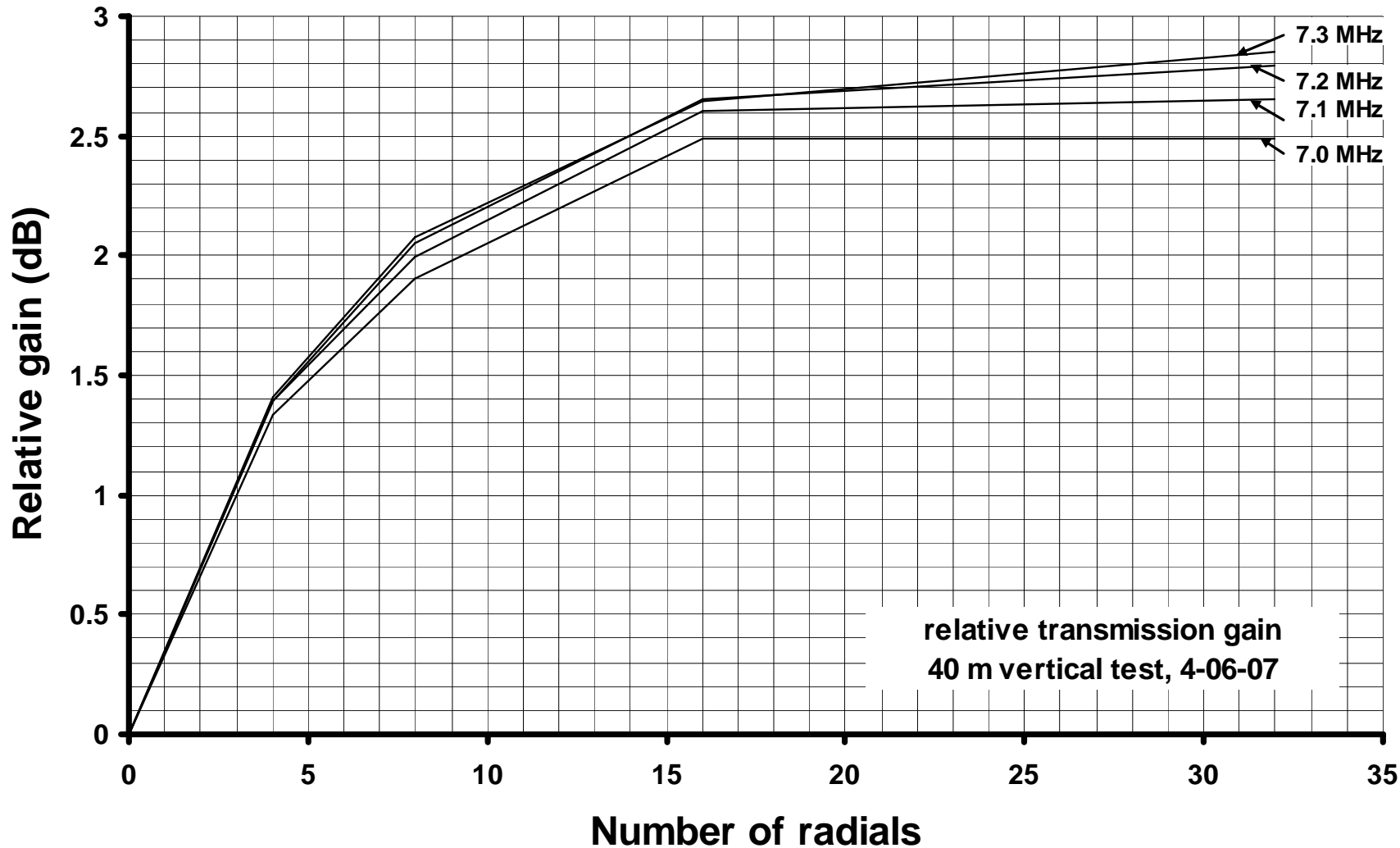
# Xs versus radial number and frequency



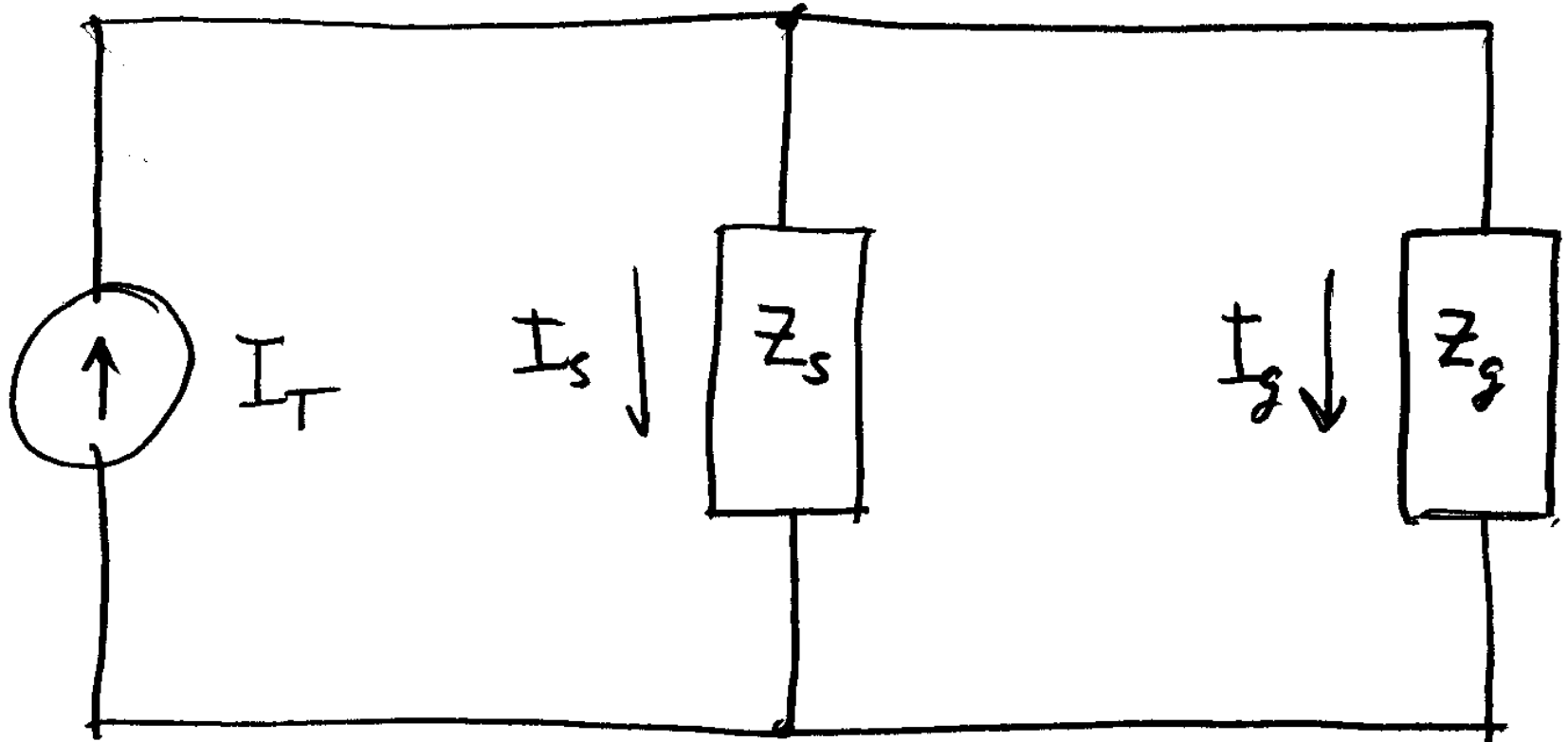
# Resonant frequency shift



# Relative gain versus radial number



# Wire grid ground systems



$Z_s$  = impedance of the soil

$Z_g$  = impedance of the grid or ground screen

$I_T$  = total current returning to the antenna

# Free space impedance

- What do we mean by the soil impedance? We know that the impedance of free space is the ratio of the E-field to the H-field components in an E-M wave and is given by:

$$Z_{space} = \sqrt{\frac{\mu_o}{\epsilon_o}} = 376.7 \text{ Ohm}$$

- Where:
- $\mu_o$  = permeability of free space =  $4\pi \cdot 10^{-7}$
- $\epsilon_o$  = permittivity of free space =  $8.854 \times 10^{-12}$

# Soil impedance

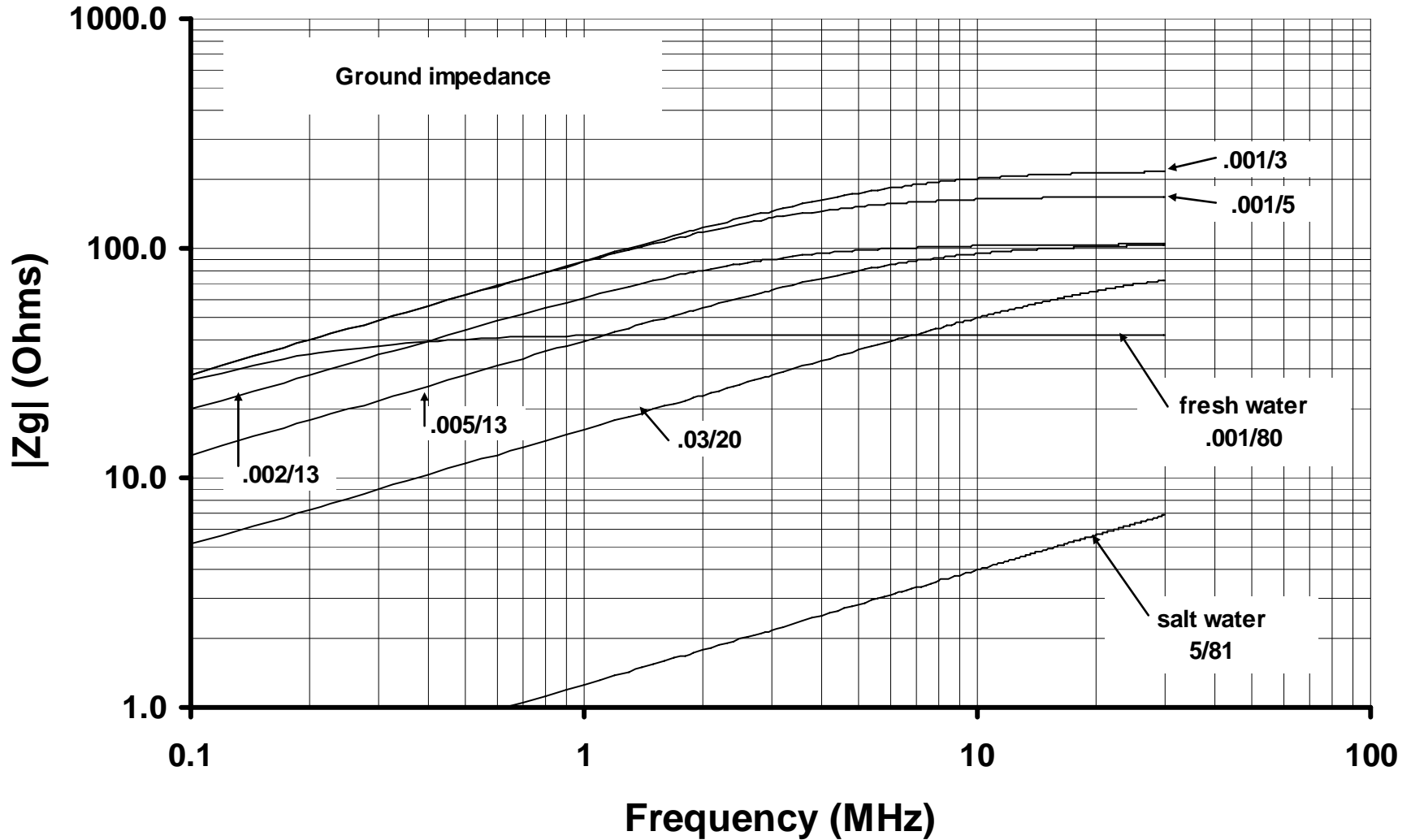
- We can extend this concept to soil by taking into account the conductivity and permittivity:

$$Z_s = \sqrt{\frac{\mu_o}{\epsilon_o}} \left[ \frac{1}{\sqrt{\epsilon_r - j \left( \frac{\sigma}{\omega \epsilon_o} \right)}} \right] = \frac{376.7}{\sqrt{\epsilon_r - j \left( \frac{\sigma}{\omega \epsilon_o} \right)}}$$

- Where:
- $\epsilon_r$  = relative permittivity
- $\sigma$  = soil conductivity in S/m
- $\omega = 2 \pi f$ , where f is the frequency in Hz.
- Note that  $Z_s$  can be complex.

# Ground impedance ( $Z_g$ )

Note: this is for constant parameters with frequency!



# Impedance of a grid

- We can also state the equivalent impedance for the grid:

$$Z_g = jf\mu_o d \ln\left(\frac{d}{2\pi a}\right)$$

- Where:
- $d$  = spacing of grid wires in meters
- $a$  = radius of grid wires in meters
- Note: this equation looks very much like that for a two wire transmission line!

# Typical grid calculation

- Let's see what  $Z_s$  is for average ground at 1.83 MHz.
- Plugging  $\epsilon_r = 15$  and  $\sigma = 0.005$  S/m into the equation for  $Z_s$ :

$$Z_s = 42.2 + j31.28 \text{ Ohms}, \quad |Z_s| = 52.6 \text{ Ohms.}$$

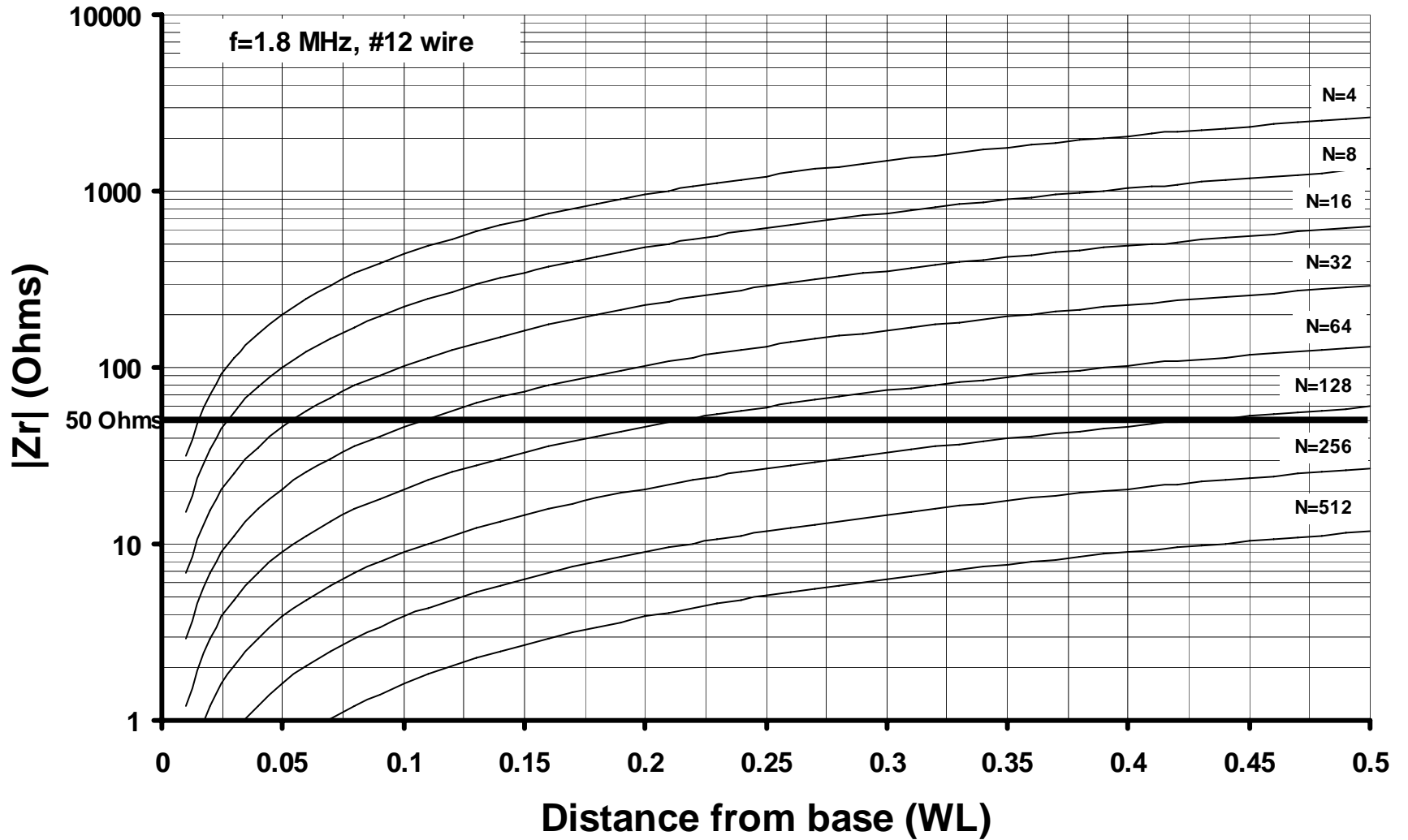
- If the ground screen is made with #12 wire spaced 24",  $Z_g = j6.41$  Ohms and  $|Z_g| = 6.41$  Ohms.

$$|I_s| = \frac{|Z_g|}{|Z_g + Z_s|} |I_T| = 0.113 |I_T|$$

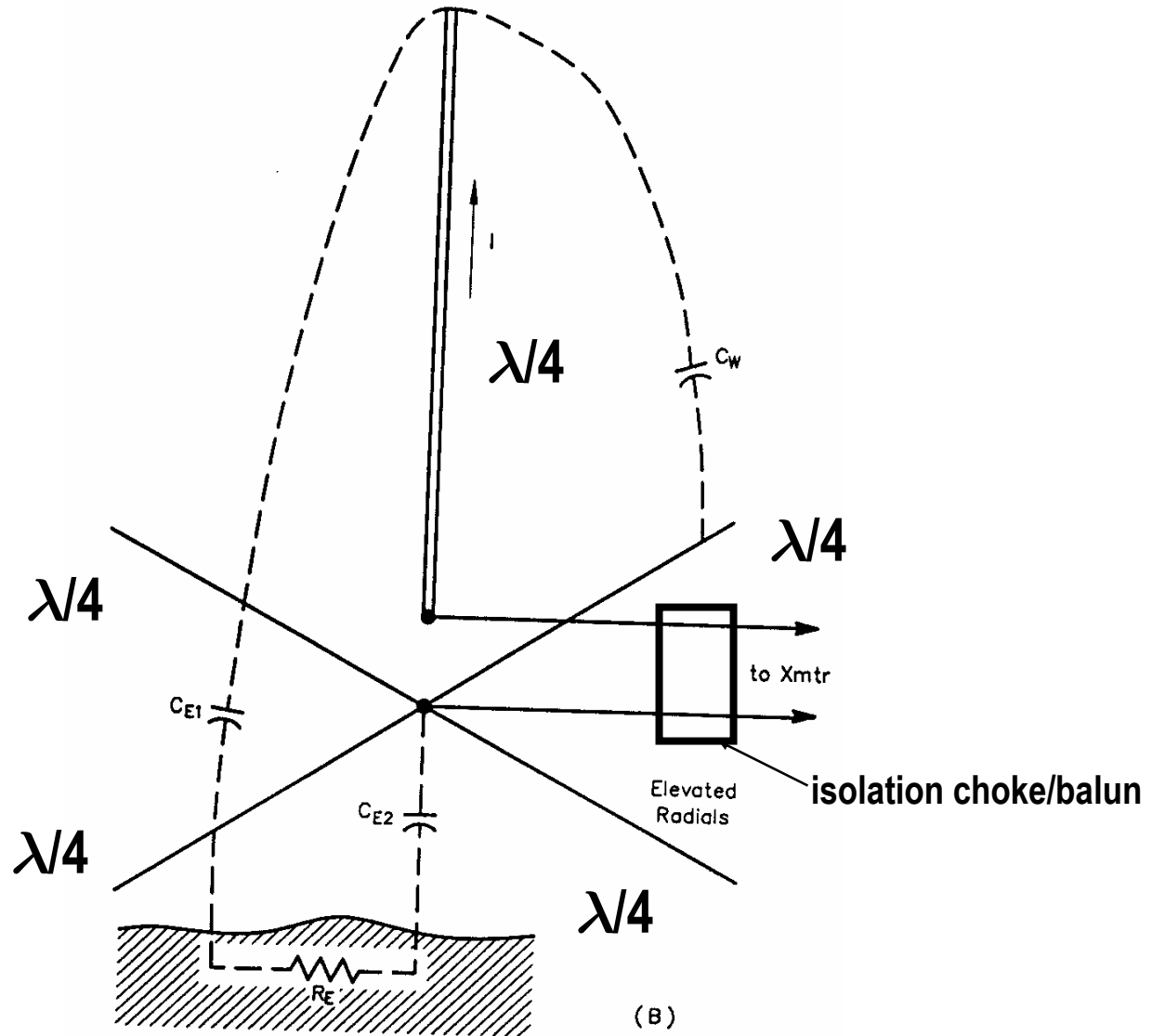
## Grid calculation

- **Loss is proportional to  $I^2$  squared!**
- **We see that for this ground characteristic and frequency, 24" spacing in the grid reduces the ground loss to about 1% of what it would have been without the screen.**

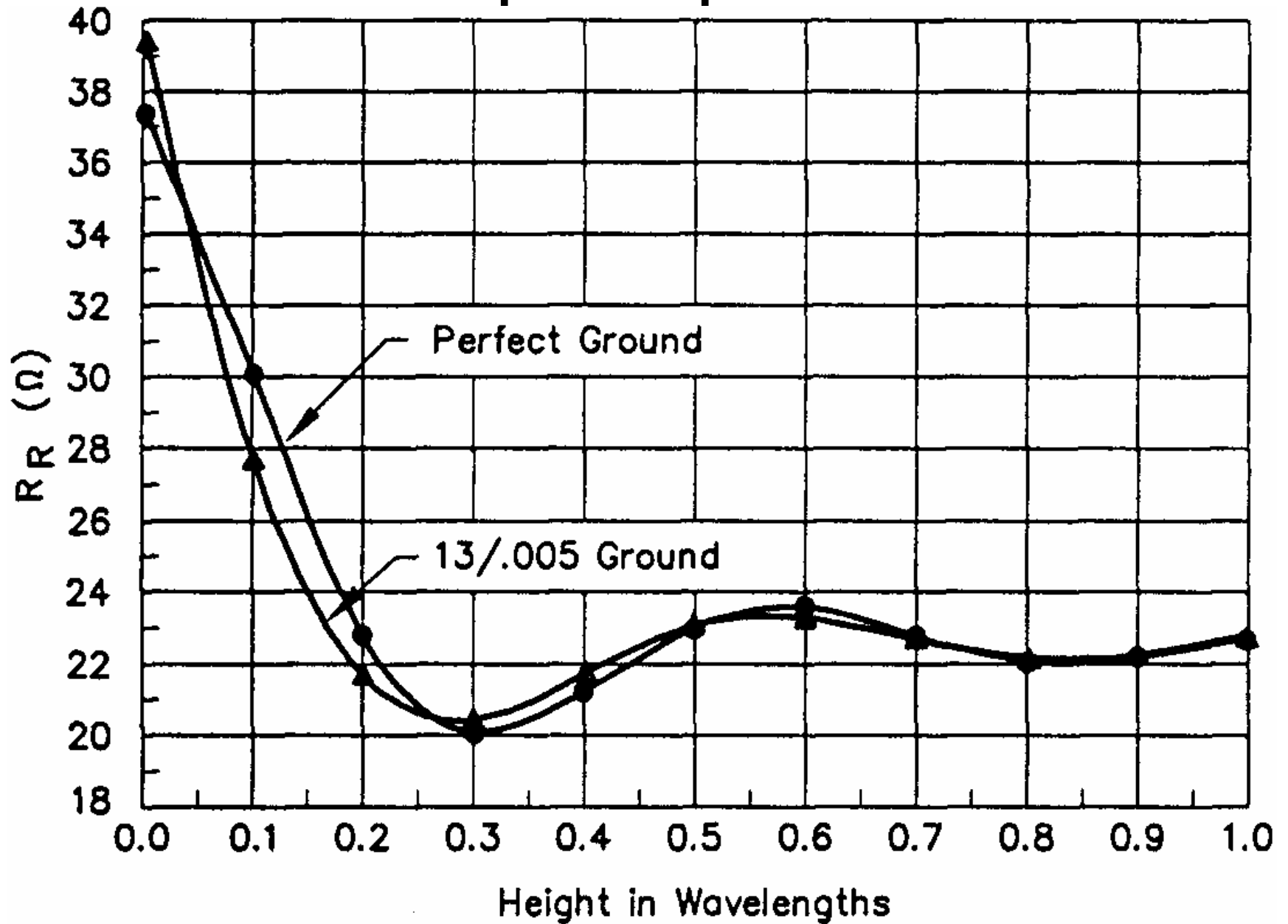
# Radial system impedance ( $Z_r$ )



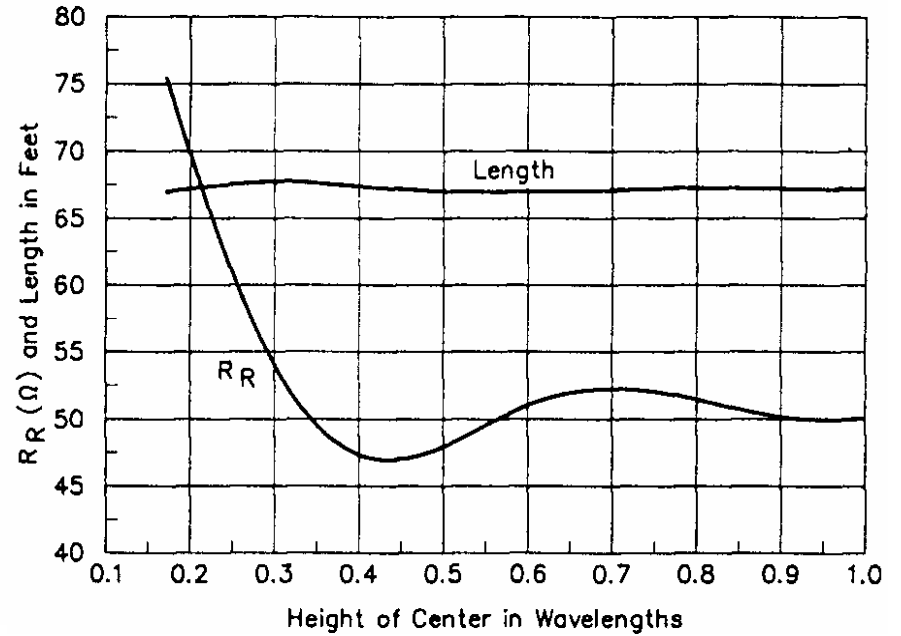
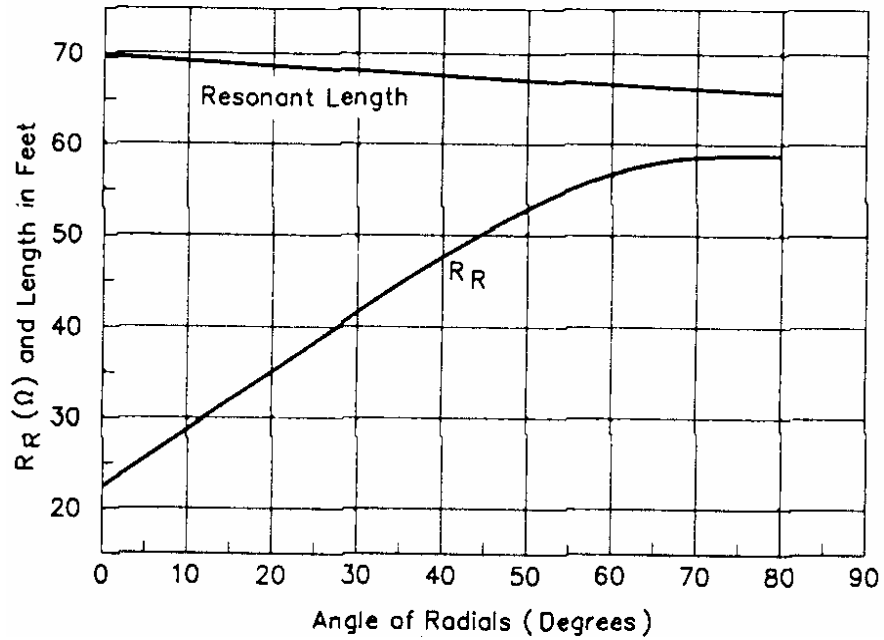
# Ground-Plane Antenna



# Feedpoint Impedance

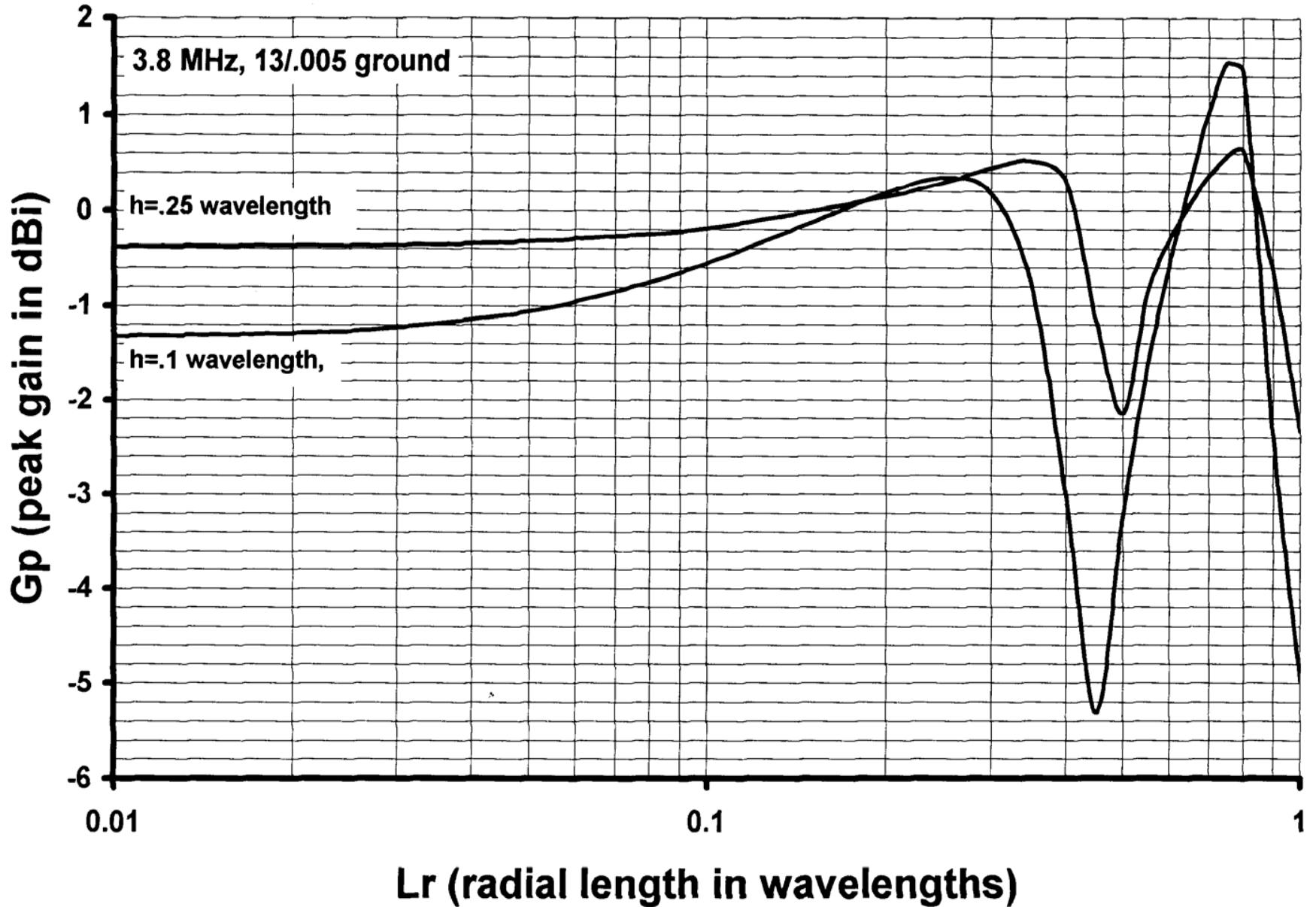


# Sloping Radials



45 degree sloping radials

# Effect Of Radial Length On Gain



## COMMENT

- **The electrical length for a resonant  $\lambda/4$  radial will depend on the height above ground.**
- **Radials very close to or actually lying on the ground will have to be much shorter than the free space length to be resonant.**
- **For radials near ground the high loss notch appears at much shorter lengths.**

# COMMENT

- **The high loss notch becomes much less pronounced as the number of radials is increased and the ground characteristics are improved.**
- **Buried radials can show the same problem in poor soil when there are only a small number of radials.**

# PROBLEMS WITH NON-IDENTICAL RADIALS

- **Unequal radial currents leading to asymmetrical radiation patterns**
- **Varying reactive and resistive components of the input impedance**
- **Increased ground loss**

## **Some Advice on Elevated Radials**

- Make all the radials as uniform as possible; same length, height over ground, wire size, tension (amount of droop) and maintain symmetry.**
  
- Keep the radials away from other conductors fences, buildings or other antennas.**

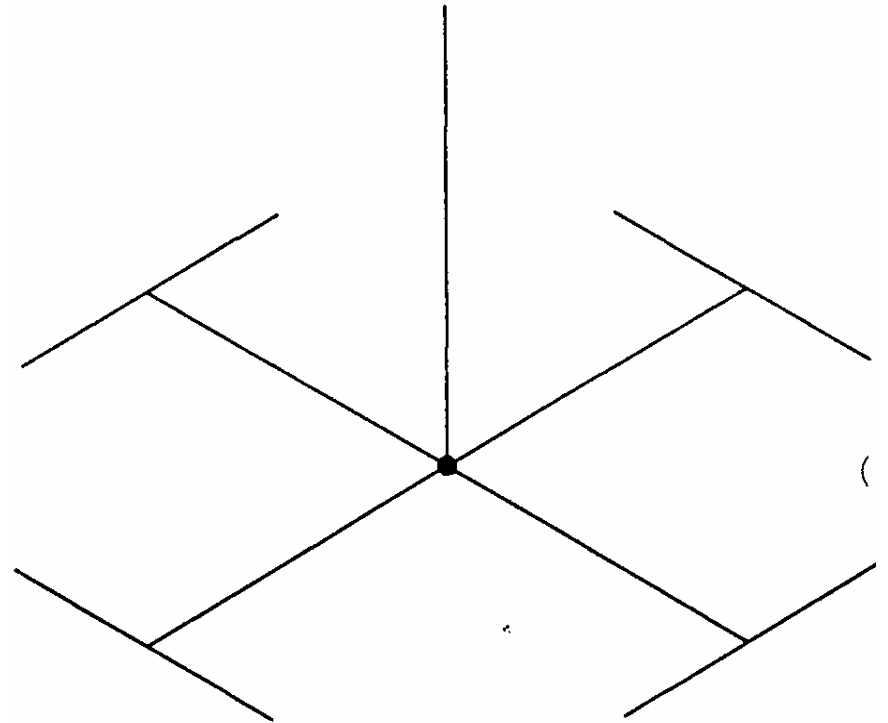
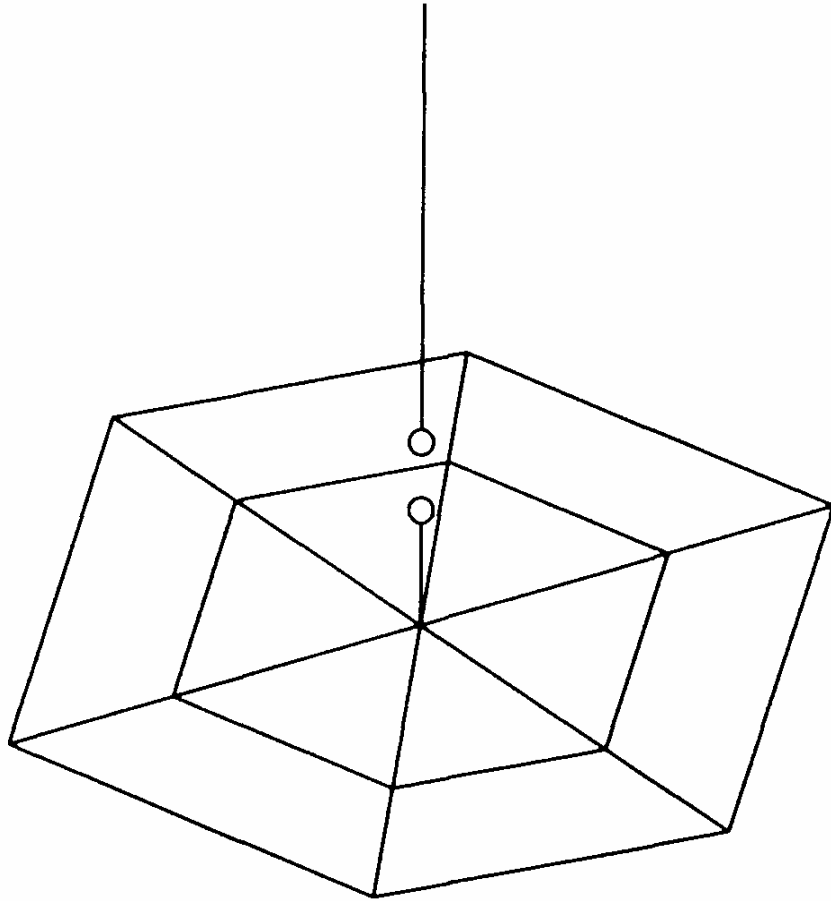
# Some Advice on Elevated Radials

- **Use as many radials as possible**
- **Place radials as high above ground as practical**
- **Make the radial lengths a bit longer or shorter than  $1/4$  wave**

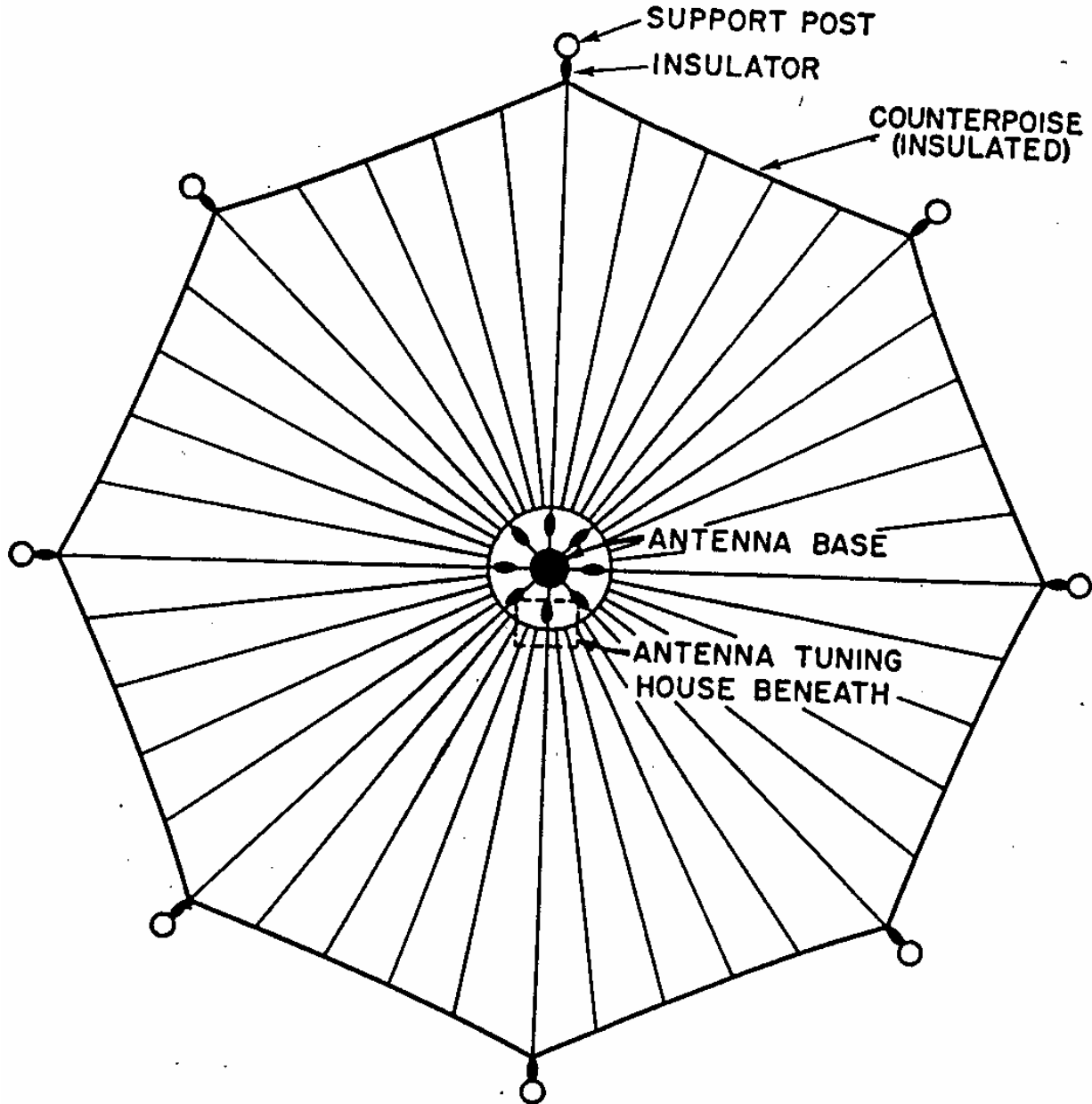
## **Some Advice on Elevated Radials**

- **If you make the vertical somewhat longer than  $1/4$  wave then you can use shorter radials and still be resonant.**
- **No installation will be perfect.**
  - **Measure the radial currents and make adjustments as needed.**
  - **Add small series L or change lengths.**

# ALTERNATE RADIAL SYSTEMS



# The Counterpoise



# DECOUPLING CHOKES

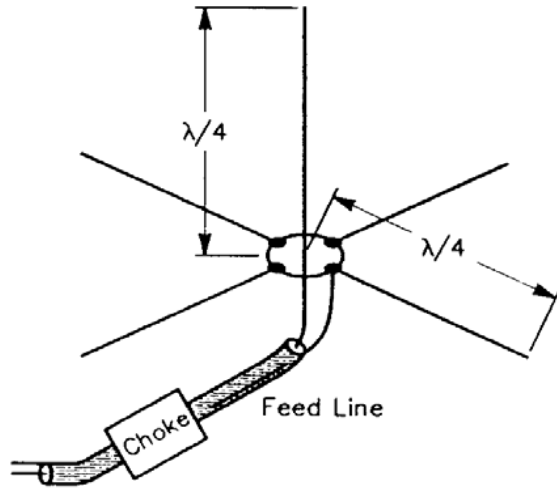


Fig 12—The ground-plane antenna. Power is applied between the base of the vertical radiator and the center of the ground plane, as indicated in the drawing. Decoupling from the transmission line and any conductive support structure is highly desirable.

