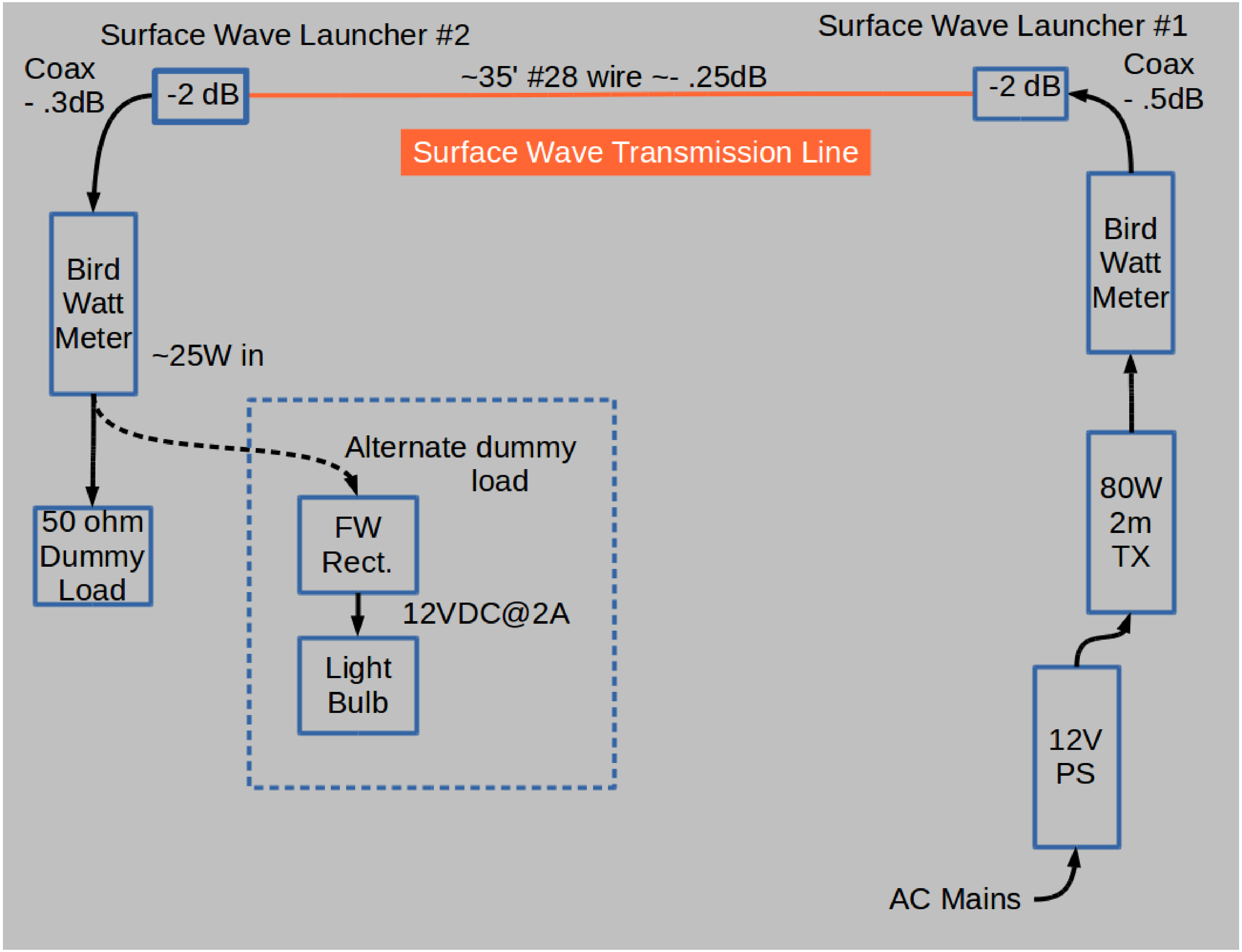
Pacificion 2016

# Another Look at Transmission Lines

Demonstration & Discussion

Glenn Elmore n6gn

# Demonstration



# Demo

As an alternative to a live demo, please view:

1st SWTL power transfer demo video.

100 m SWTL power transfer Demo

# Huh? Really?

You may have a few questions:

1)“Why doesn’t it act like an antenna?”

2)“Isn’t this just G-Line?”

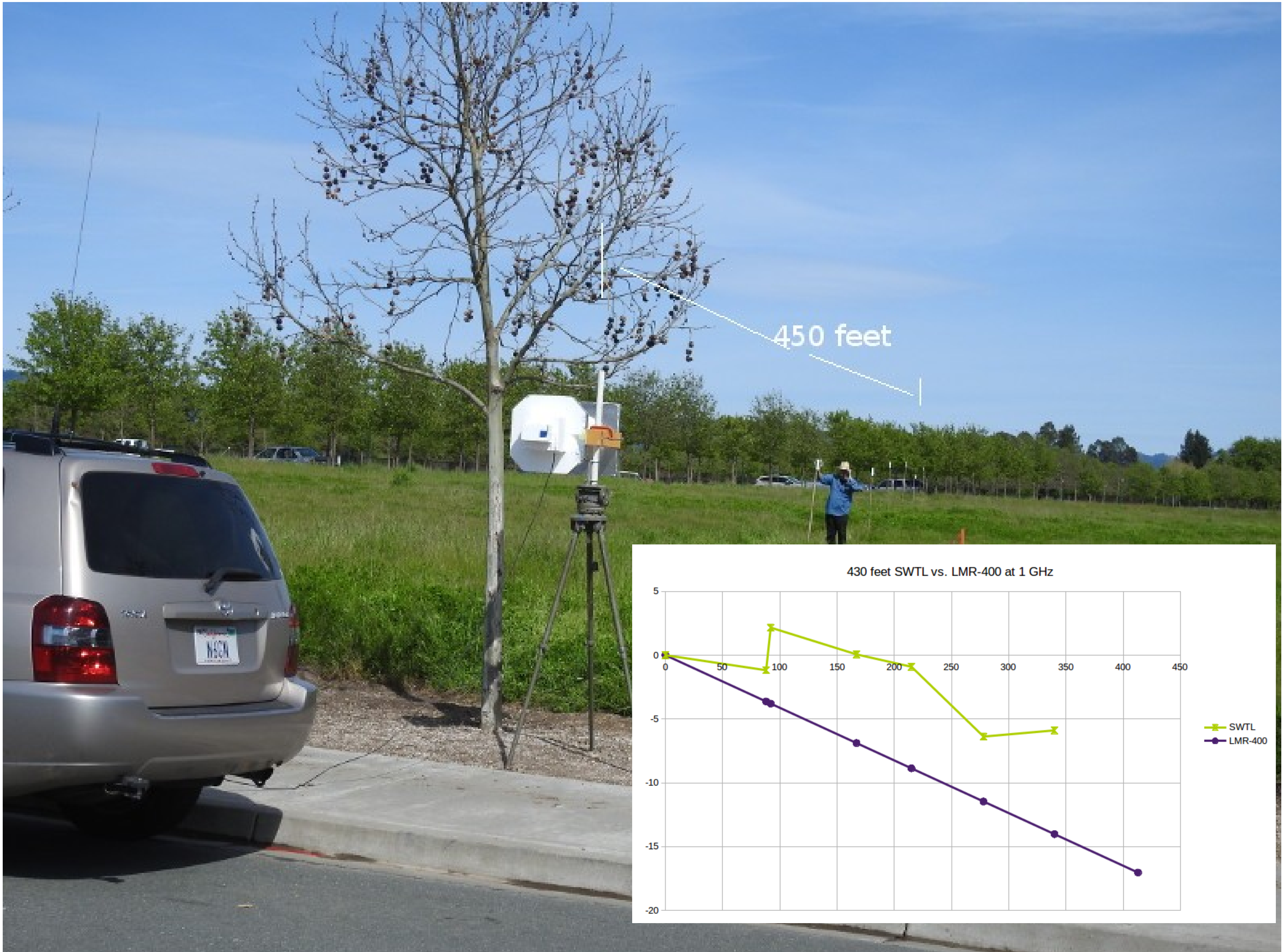
3)“Is this a trick?”

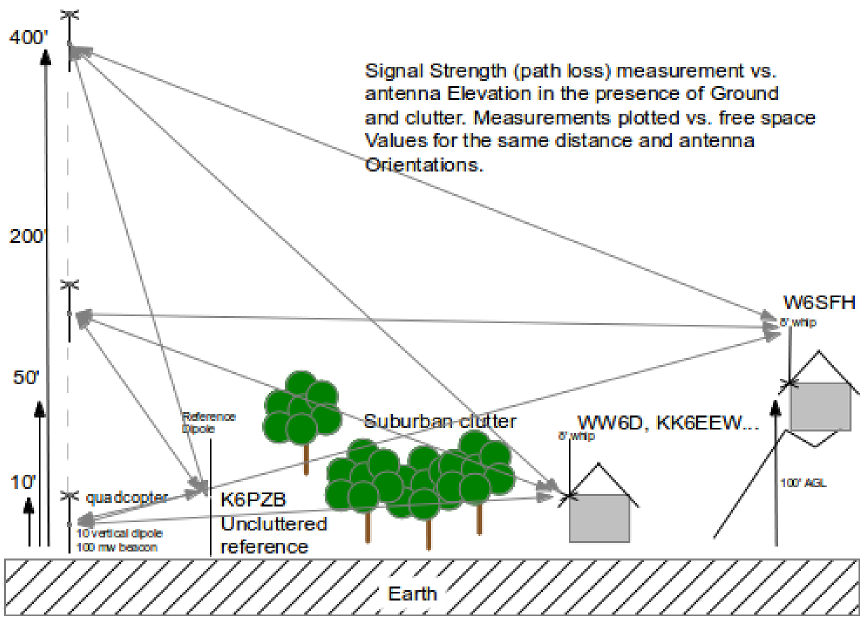
4)“What’s really going on?” (I want some theory and evidence)

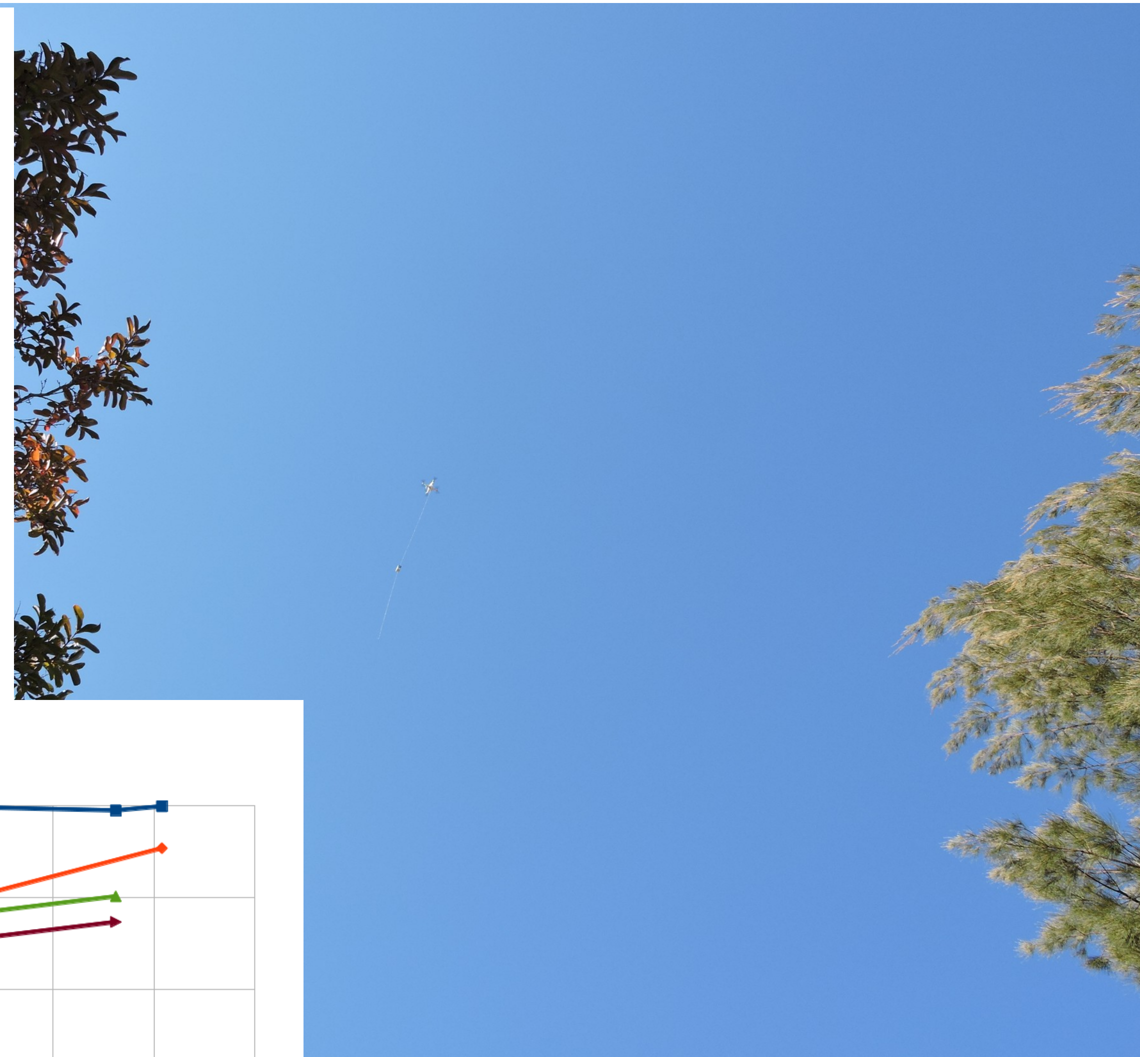
5)“If this really is such a fundamental mode, why hasn’t it been discovered before now?”

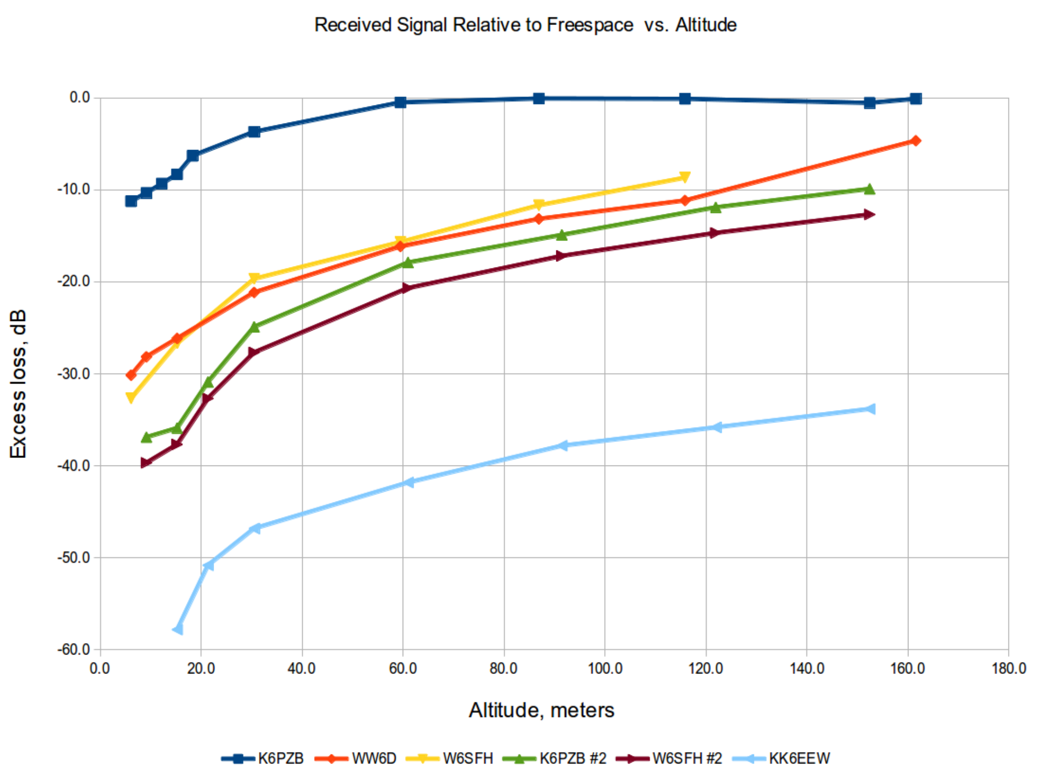
# Practical Uses

- Long, low loss feedlines
- Superb “height gain”
- Continuous powered quadcopter
- “Active Tower”
- ...
- Free to licensed amateurs worldwide for personal, non-commercial use under terms of license


450 feet
430 feet SWTL vs. LMR-400 at 1 GHz
5
0
-5
-10
-15
-20
0
50
100
150
200
250
300
350
400
450
SWTL
LMR-400

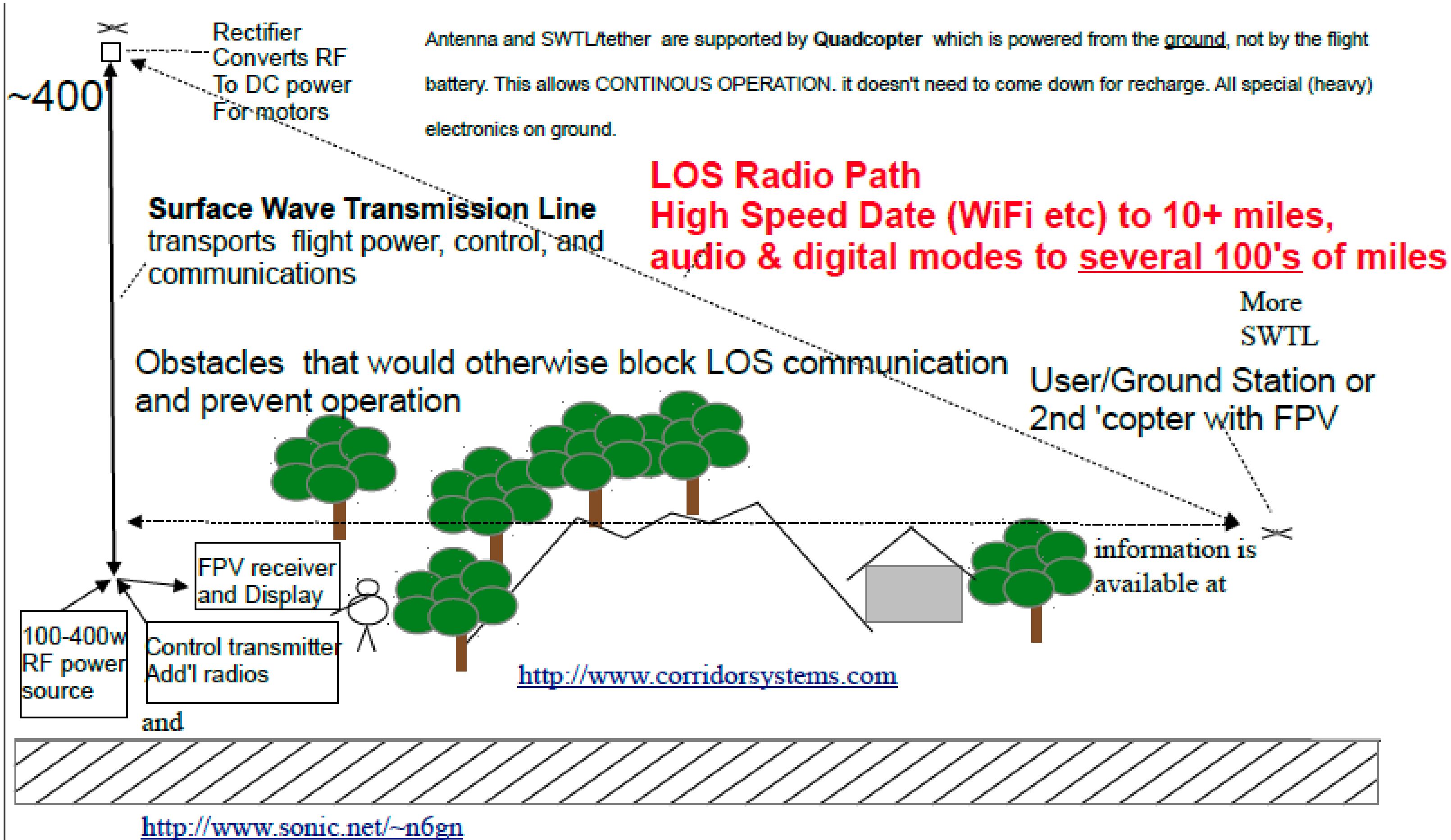





QEX Magazine May/June 2016

Balloon supported 2m halo at 160' AGL, connected to ground-mounted transceiver by AWG @28 SWTL




# SWTL method for Continuous non-LOS Communications

## "Active Tower"

# Thanks for listening!

- More details, examples and happenings available at http://www.sonic.net/~n6gn

# The End

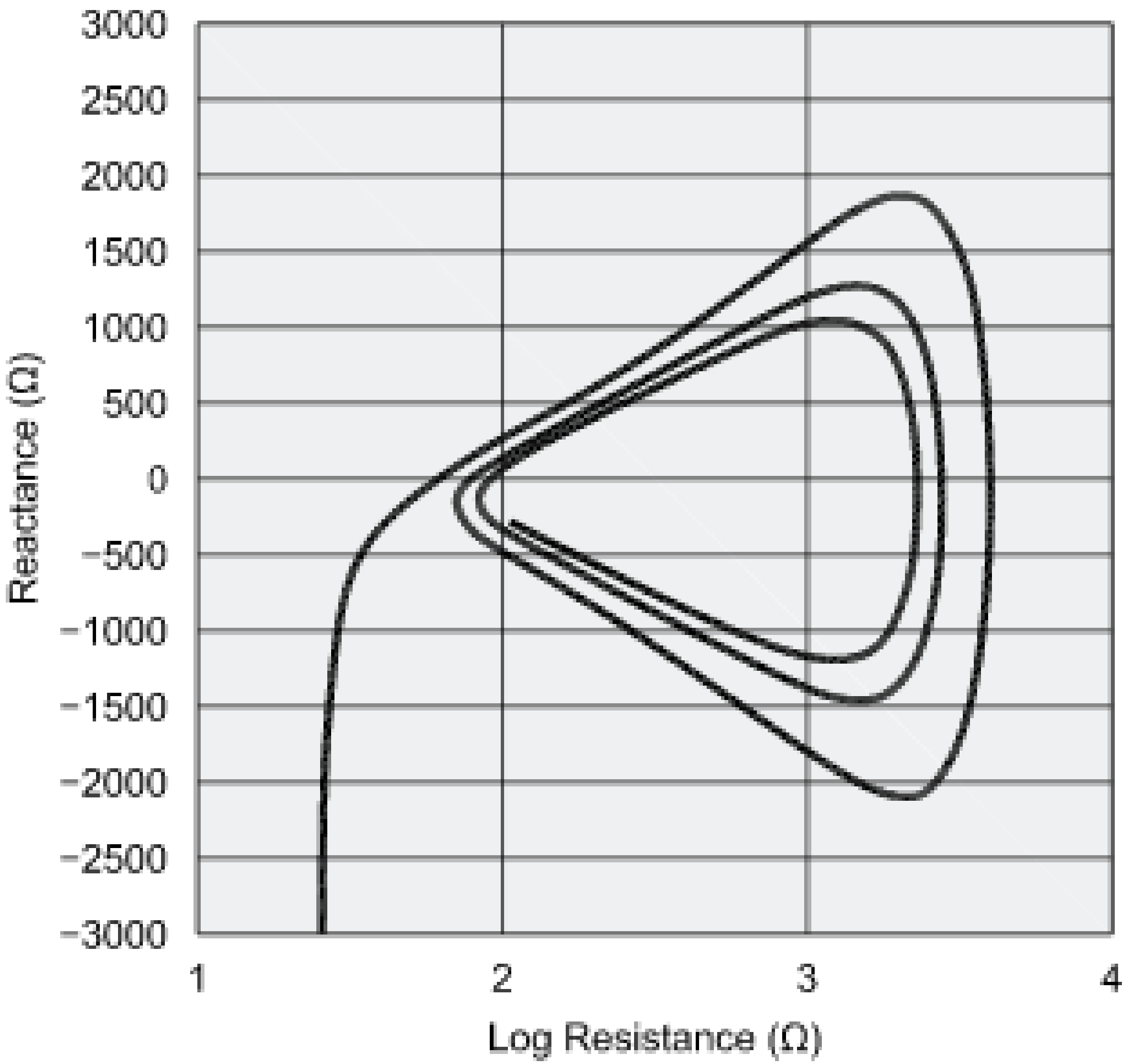
$\overline{\text{sk}}$ de n6gn

# Why isn't this an antenna?

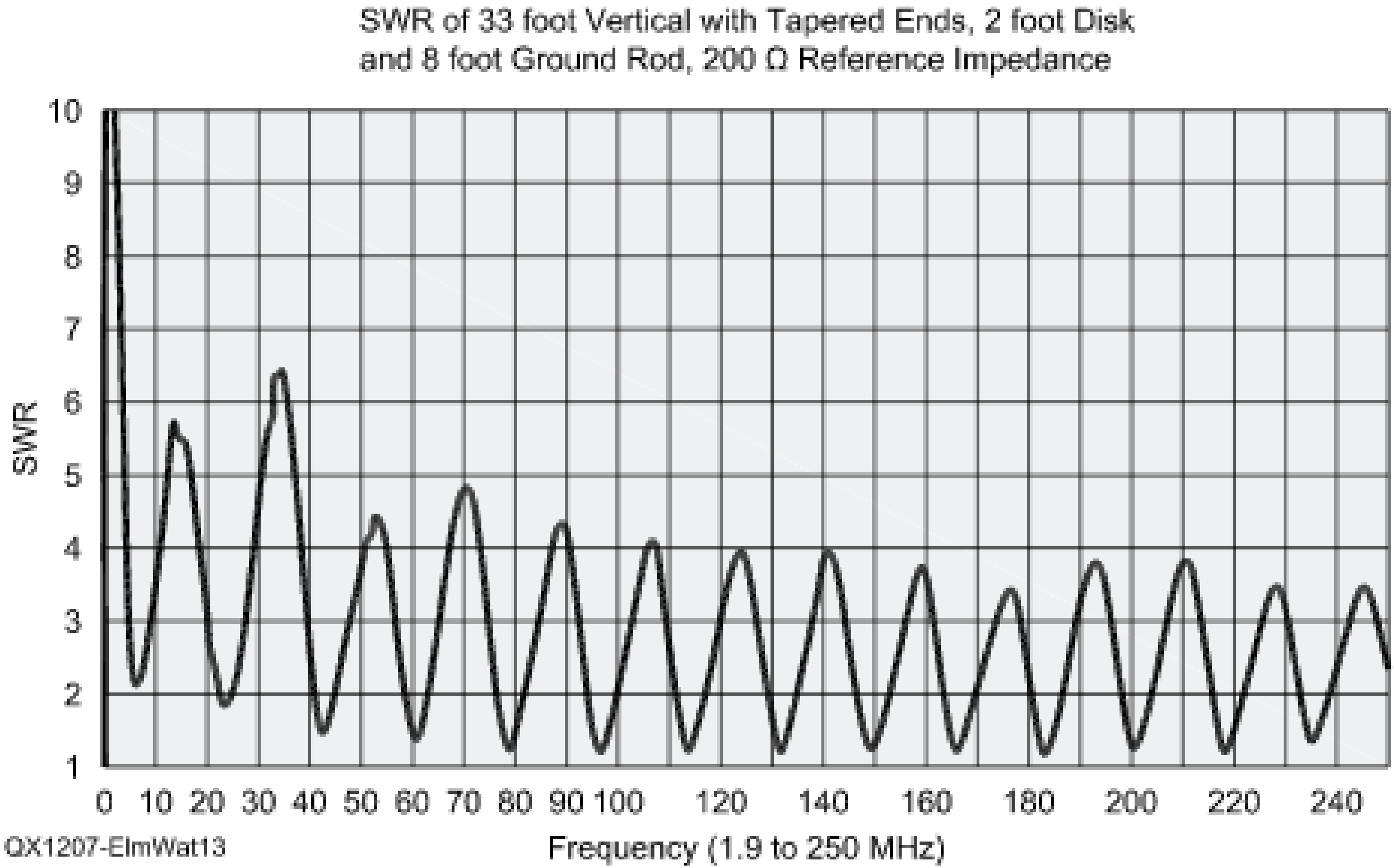
( Slides that follow excerpted from " A New Antenna Model" published in QEX July/Aug 2012)

Contrary to "common wisdom", current in a conductor is not synonymous with radiation - witness coaxial cable, balanced line and many other transmission line types for which symmetry provides cancellation in the far field. Coax outer conductor shields because it provides a balancing/negating current rather than because it "shields" the acceleration of charge (current) in the center conductor from being "seen" outside of the cable. Common mode current on coax with its attendant radiation is a deviation from this mode of operation.

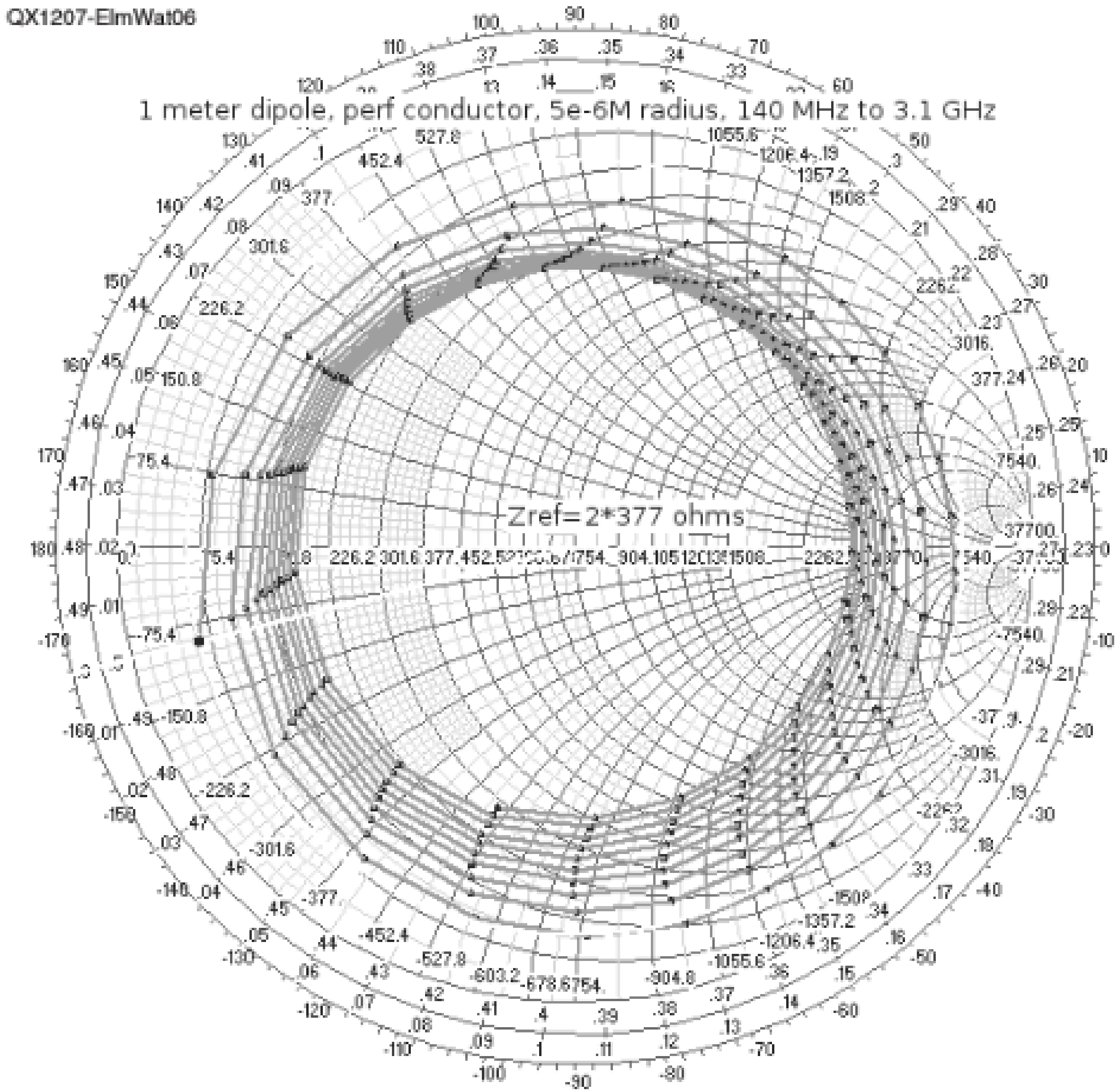
# ARRL Antenna Book "Long Wire"



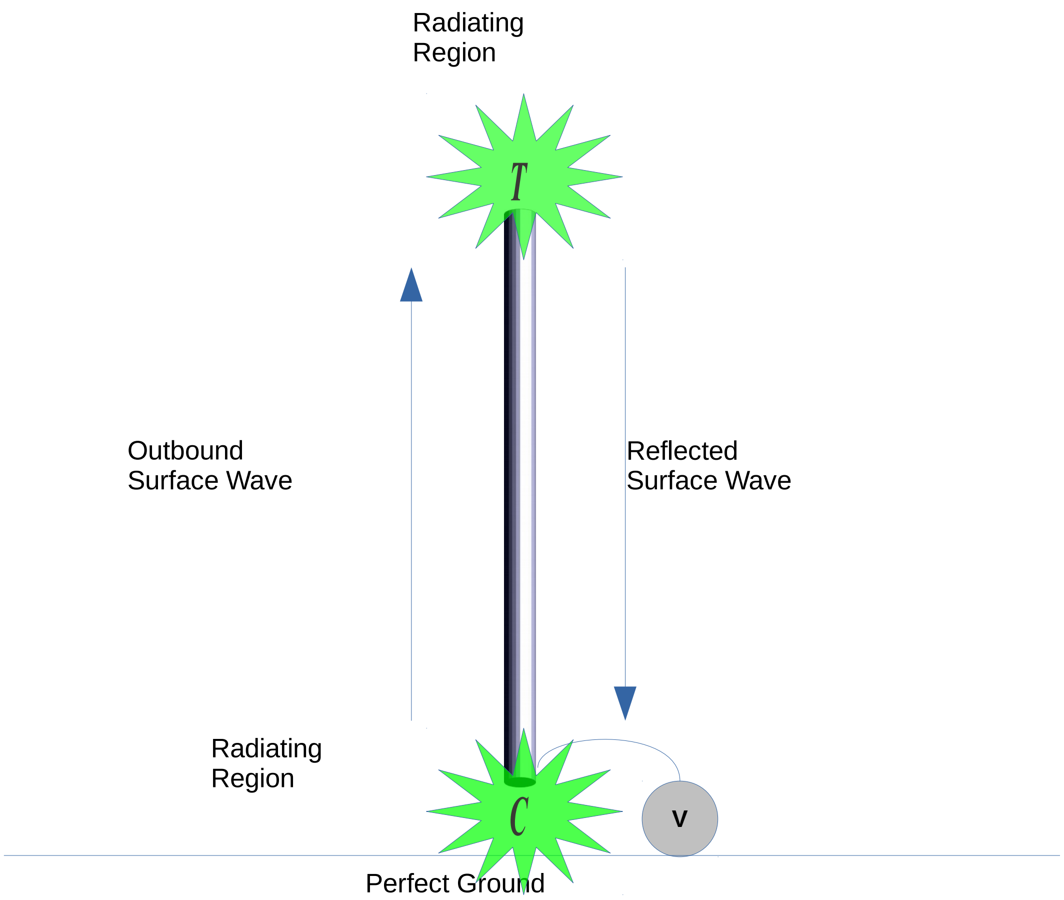
# “Long Wire” Acts Like a Transmission Line



# Dipole Over Broad Range



# In an antenna radiation occurs in space at the ends (and sometimes the center), not from the conductor itself




*A New Antenna Model*, QEX July/Aug 2012

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# Why Isn't This "G-Line"?

- Goubau *Required* slowing the wave down by means of insulation or special conditioning

  From US Patent #2685068 (1954):

  - "object of my invention is to provide a surface wave transmission line comprising elongated conductive means having its outer surface conditioned, or modified, so as to reduce the phase velocity of the transmitted energy to thereby concentrate the field of the transmitted wave adjacent the conductor."
  - "By means of the present invention the field of the surface wave is concentrated adjacent the conductor."

He thought an otherwise expanding wave front was made to "hug" the conductor if the conductor was made suitable. He did not recognize that there was actually a TM mode present, a solution to Maxwell's Equations, which did not have the constraints he put on G-Line.

He said G-Line needed:

- Reduced wave propagation velocity
- Special conductor, no bare wires (maybe "sort of" above 5 GHz)
- Launchers with mouths a considerable fraction of a wavelength
- Low frequency operation impractical

# Goubau Was Wrong

- **No** “concentration” of field is involved
- Conductor does ***not*** require conditioning
- A $TM_{00}$ wave is present that ***can*** travel at c
- Bare conductor ***can*** work well below 5 GHz, even HF
- Small launchers ***are*** possible

Almost certainly, Goubau’s invention was not operating the way he thought it was nor was it restricted in the ways he, and everyone else since, has thought and taught.

Multiple US and International patents have been granted which acknowledge these differences.

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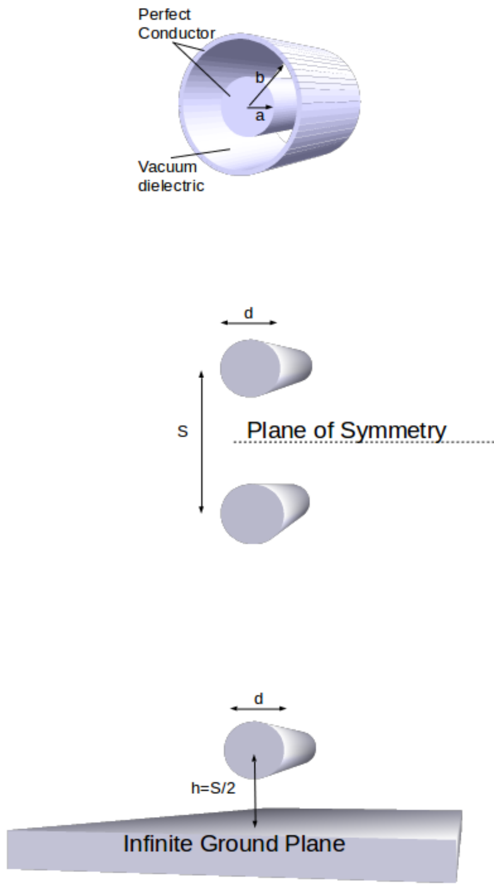



a. Coaxial Cable

b. Balanced Line

c. Wire-over-Ground

Fig. 1

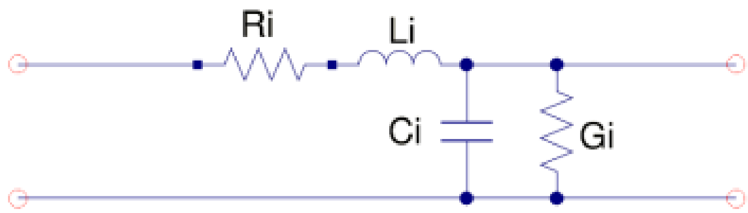
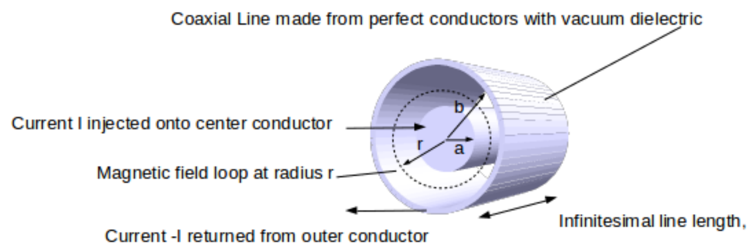



Fig.2




The enclosed current outside the coax is zero so within it at radius r, by Ampère's law

$$\oint \vec{\boldsymbol{B}} \cdot \partial \vec{s} = 2\pi r B = \mu_0 I_{enc} = \mu_0 I$$

where $\vec{B}$ is the magnetic field, $I$ the enclosed current and $\mu_0$ is the permeability of space

so within the coax vacuum $B = \frac{\mu_0 I}{2\pi r}$

The energy density per unit volume $u_B = \frac{B^2}{2\mu_0} = \frac{1}{2\mu_0}\left(\frac{\mu_0 I}{2\pi r}\right)^2 = \frac{\mu_0 I^2}{8\pi^2 r^2}$

Considering the volume within a short length of line, the energy is

$$U_B = \iiint u_B(\partial Volume) = \int_a^b \frac{\mu_0 I^2}{8\pi^2 r^2} \cdot 2\pi r\, l\, \partial r = \frac{\mu_0 I^2 l}{4\pi} \int_a^b \frac{1}{r} \partial r = \frac{\mu_0 I^2 l}{4\pi} \ln\left(\frac{b}{a}\right)$$

and energy per unit length is

$$U_{B,per\ length} = U_{B,i} = \frac{\mu_0 I^2}{4\pi} \ln\left(\frac{b}{a}\right)$$

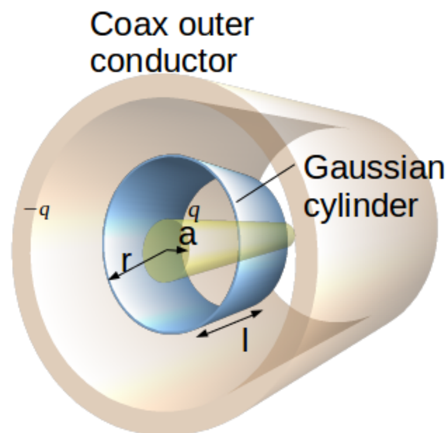
Stored energy is related to inductance and current by

$U_B = \frac{I^2 L}{2}$ which gives, inductance per unit length $L_i = \frac{2U_{B,i}}{I^2}$

so

$$L_i = \frac{2U_{Bi}}{I^2} = \frac{\mu_0}{2\pi} \ln\left(\frac{b}{a}\right)$$

Fig. 3




Considering a short section of coaxial transmission line made from perfect conductors,

a vacuum dielectric and a Gaussian surface at radius r with length l and with charge q and -q

on the conductors as shown, the charge/length = $\frac{q}{l}=\alpha$

Gauss' law gives magnitude of electric field, $\vec{E}$ pointed toward the center

$$\int \vec{E}\cdot\partial\vec{A}=\frac{q_{included}}{\epsilon_0}=\frac{\alpha l}{\epsilon_0}$$

$$E\,2\pi r\,l=\frac{\alpha l}{\epsilon_0}$$

$$E=\frac{\alpha l}{2\pi\epsilon_0 r l}=\frac{q}{2\pi\epsilon_0 r}$$

Referencing the outer conductor as one side of a capacitor with $V_b=0$

the voltage across that capacitor is the potential difference to the inner conductor

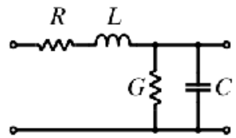
$$V_b-V_a=-V_{capacitor}=\int_a^b \vec{E}\cdot\partial\vec{r}=\int_a^b \frac{q}{2\pi\epsilon_0 r}\partial r=\frac{q}{2\pi\epsilon_0}\int_a^b \frac{1}{r}\partial r$$

$$V_{capacitor}=\frac{q}{2\pi\epsilon_0}(\ln(b)-\ln(a))=\frac{q}{2\pi\epsilon_0}\ln\left(\frac{b}{a}\right)$$

so the capacitance per unit length is

$$C_l=\frac{C}{l}=\frac{q}{lV_{capacitor}}=\frac{2\pi\epsilon_0}{\ln\left(\frac{b}{a}\right)}$$

Fig. 4



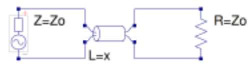

$\frac{dR}{dx}$, series resistance per unit length

$\frac{dL}{dx}$, series inductance per unit length

$\frac{dG}{dx}$, shunt conductance per unit length

$\frac{dC}{dx}$, shunt capacitance per unit length

Inserting Heaviside's model into a circuit with source (transmitter) and load




Using image parameter theory[1], a complex propagation constant

describes the line.

$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$

$\alpha =$ attenuation constant, nepers/meter ($\approx 8.69$ dB/meter) and $\beta =$ phase constant, radians/meter

for low loss line $\alpha \approx \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}}$ and $\beta \approx \omega\sqrt{LC}$

For the ideal, lossless case, R and G are zero so that the propagation constant becomes only imaginary.

$\gamma = \alpha + j\beta = 0 + j\omega\sqrt{LC}$

With sinusoidal (CW) drive from the source, the voltage at point l on the line is $\gamma = \alpha + j\beta = 0 + j\omega\sqrt{LC}$

$V = V_0 \sin(\omega t) e^{-\gamma l}$

The characteristic impedance is $Z_0 = \sqrt{\frac{L}{C}}$

The propagation velocity (phase velocity) of the voltage or current is $U_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$

Using the values derived in Figs 2,3 in the absence of any loss, dielectric or permeable material

The Velocity Factor is $V_r = \frac{U_p}{c} = \frac{1}{c\sqrt{LC}} = \frac{1}{c\sqrt{\mu_0 \epsilon_0}} = 1$

Whle the Characteristic Impedance is $Z_0 = \sqrt{\frac{L}{C}} = \frac{\sqrt{\frac{\mu}{\epsilon}} \ln(\frac{b}{a})}{2\pi} \approx 60 \ln(\frac{b}{a}) \approx 138 \log_{10}(\frac{b}{a})$

**Fig. 5**

[1] Matthei, Young,Jones, *Microwave Filters; Impedance-matching Networks, and Coupling Structures*,McGraw Hill 164, Chapter 3, p49 ff

with $c$ and $\mu_0$ defined as universal constants $\epsilon_0$ Is derived from them:

$c \equiv 299792458$ meter/second, speed of light in a vacuum

$\mu_0 \equiv 4\pi x 10^{-7}$ Henry/meter, permeability of space

$\epsilon_0 = \frac{1}{c^2 \mu}$ Farad/meter, permittivity of space

within classical physics, it has been accepted that a wave in free space propagates at

the speed of light, c, and that space itself sets a maximum impedance of

$Z_{space} = \mu_0 c = \sqrt{\frac{\mu_0}{\epsilon_0}} \approx 377$ ohms

Referring to Figs. 2-3 and Fig. 5, using Heaviside Telegrapher's Equation

Coax Impedance $Z_0 = \sqrt{\frac{L_i}{C_i}} = \frac{\sqrt{\frac{\mu}{\epsilon}} \ln(\frac{b}{a})}{2\pi}$ exceeds $Z_{space} = \sqrt{\frac{\mu_0}{\epsilon_0}}$ when

$\ln(\frac{b}{a}) > 2\pi$ which occurs at geometries where $(\frac{b}{a}) > e^{2\pi} \approx 535$

$C_i = \frac{2\pi\epsilon_0}{\ln(\frac{b}{a})}$ becomes less than $\epsilon_0$, the permittivity of space

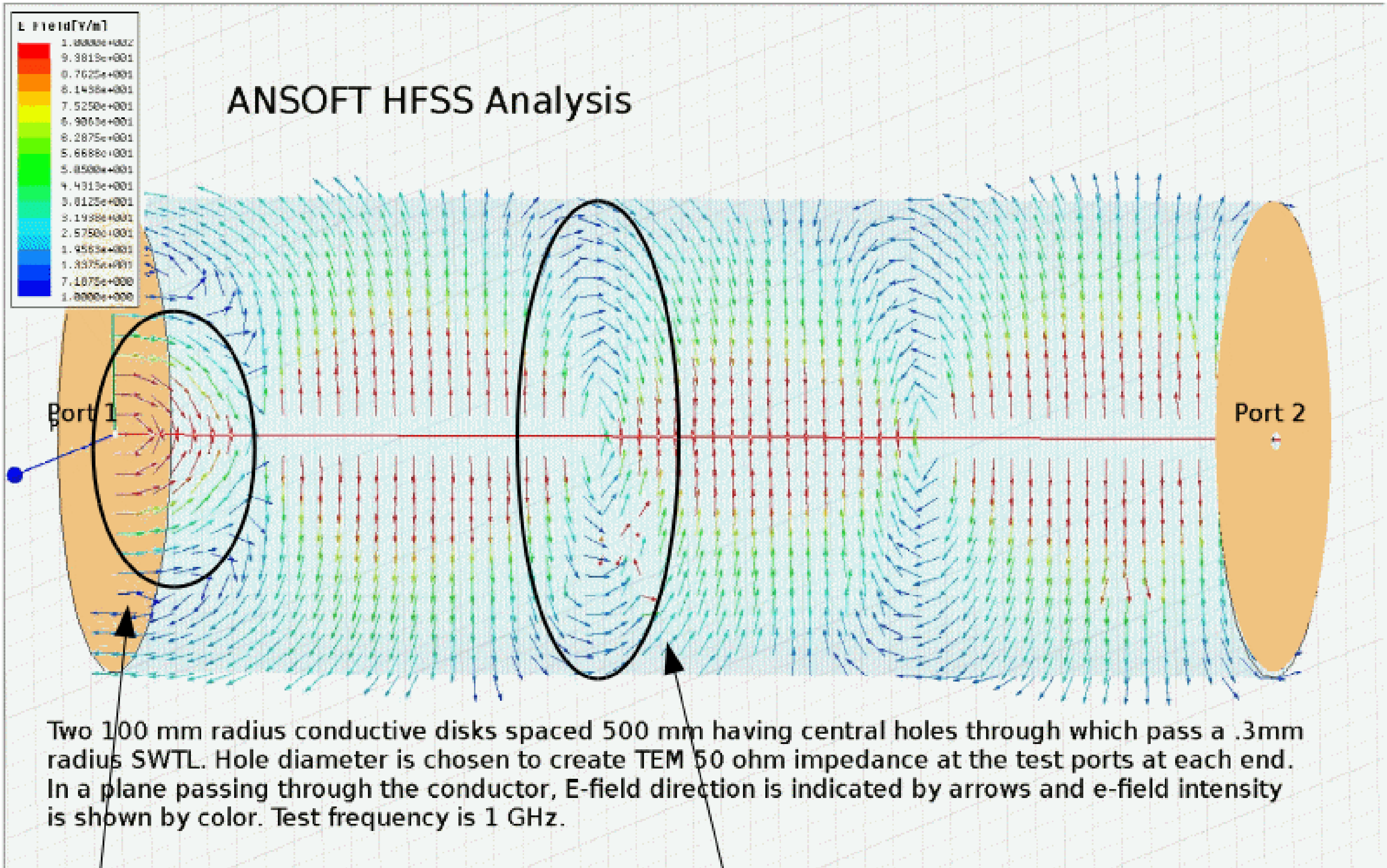
and

$L_i = \frac{\mu_0}{2\pi} \ln(\frac{b}{a})$ becomes greater than $\mu_0$, the permeability of space

so

$Z_0$ exceeds $\frac{\sqrt{\frac{\mu_0}{\epsilon_0}}(2\pi)}{2\pi} = \sqrt{\frac{\mu_0}{\epsilon_0}} \approx 377$ ohms which is the impedance of free space.

Fig. 6




Two 100 mm radius conductive disks spaced 500 mm having central holes through which pass a .3mm radius SWTL. Hole diameter is chosen to create TEM 50 ohm impedance at the test ports at each end. In a plane passing through the conductor, E-field direction is indicated by arrows and e-field intensity is shown by color. Test frequency is 1 GHz.

Near conductive plane, e-field lines return from the SWTL to the outer conductor of the test Port coax and are associated with a TEM wave witnin the coax.

Away from the Ports, longitudinal e-field lines return to the SWTL and are associated with a TM wave along the SWTL.

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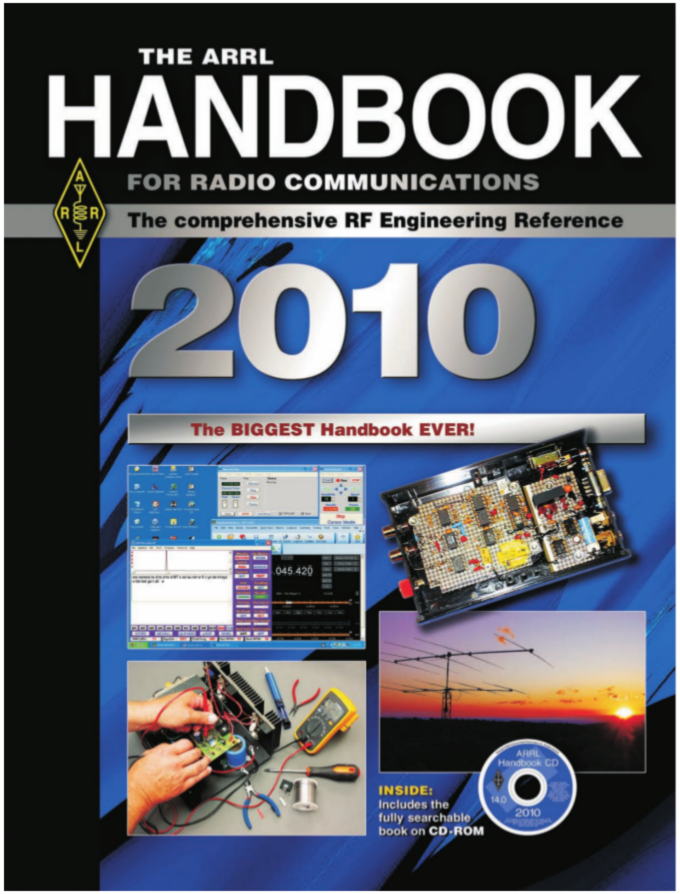
# Why Hasn’t This This Been Discovered Before?

This is the truly fun question

1) Theory recognized, practicality missed by Stratton (1941)
2) Theory missed, practicality obfuscated,  Goubau (1954) was WRONG.
3) Radiation not understood by anyone
4) Lumped Circuit model doesn’t accurately describe transmission lines
5) Our theory and models have been wrong.
6) DEEP issues here!



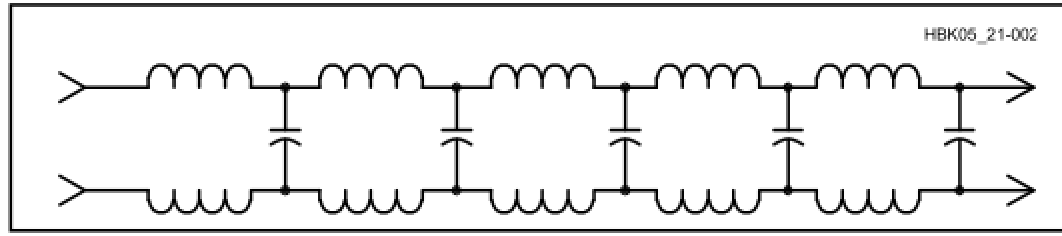
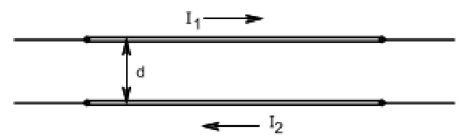




Fig 20.2 — Equivalent of an infinitely long lossless transmission line using lumped circuit constants.

(I)




The characteristic impedance of an air-insulated parallel-conductor line, neglecting the effect of the insulating spacers, is given by

$$Z_0 = 276 \log_{10} \frac{2S}{d} \qquad (4)$$

where

$Z_0$ = characteristic impedance
S = center-to-center distance between conductors
d = diameter of conductor (in same units as S).

The characteristic impedance of an air-insulated coaxial line is given by

$$Z_0 = 138 \log_{10} \left(\frac{b}{a}\right) \qquad (5)$$

where

$Z_0$ = characteristic impedance
b = inside diameter of outer conductors
a = outside diameter of inner conductor (in same units as b).

## 20.1.1 Fundamentals

In either coaxial or open-wire line, currents flowing in the two conductors travel in opposite directions as shown in Figs 20.1E and 20.1I. If the physical spacing between the two parallel conductors in an open-wire line, d, is small in terms of wavelength, the phase difference between the currents will be very close to 180°. If the two currents also have equal amplitudes, the field generated by each conductor will cancel that generated by the other, and the line will not radiate energy, even if it is many wavelengths long.

The equality of amplitude and 180° phase difference of the currents in each conductor in an open-wire line determine the degree of radiation cancellation. If the currents are for some reason unequal, or if the phase difference is not 180°, the line will radiate energy. How such imbalances occur and to what degree they can cause problems will be covered in more detail later.

# Our Handbooks are incomplete, coax and balanced Line aren't solely TEM

For b/a>535 in "regular old TEM coax", impedance becomes greater than that of free space.

The standing transmission line equation for coaxial cable where:

$$\gamma = \alpha + j\beta$$

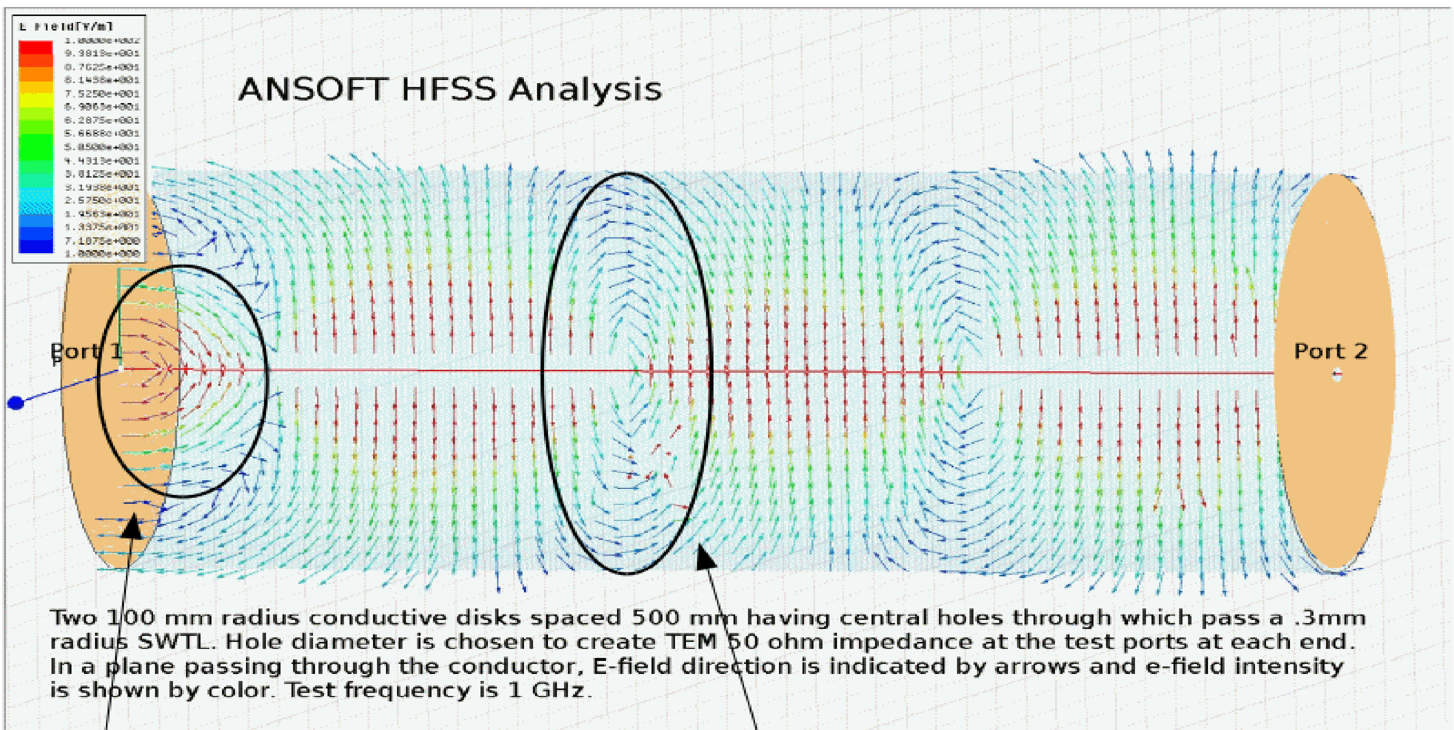
is the propagation constant. $\alpha$ describes the attenuation while $\beta$ describes the phase, per unit length of line. The propagation constant for the principle mode can be shown to relate to the components in Illustration 2 by

$$\alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{11}$$

Is WRONG!

# There's <u>Another</u> Mode!

Theory(*Julius Adams Stratton (MIT), *Electromagnetic Theory*, 1941) says that **<u>two</u>** principle modes are possible, TEM00 and TEM00. A TM00 mode not involving the outer conductor also exists in coax!

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