Coaxial Transmitting Chokes

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Don’t Bother Taking Notes

These slides (and a lot more) are at

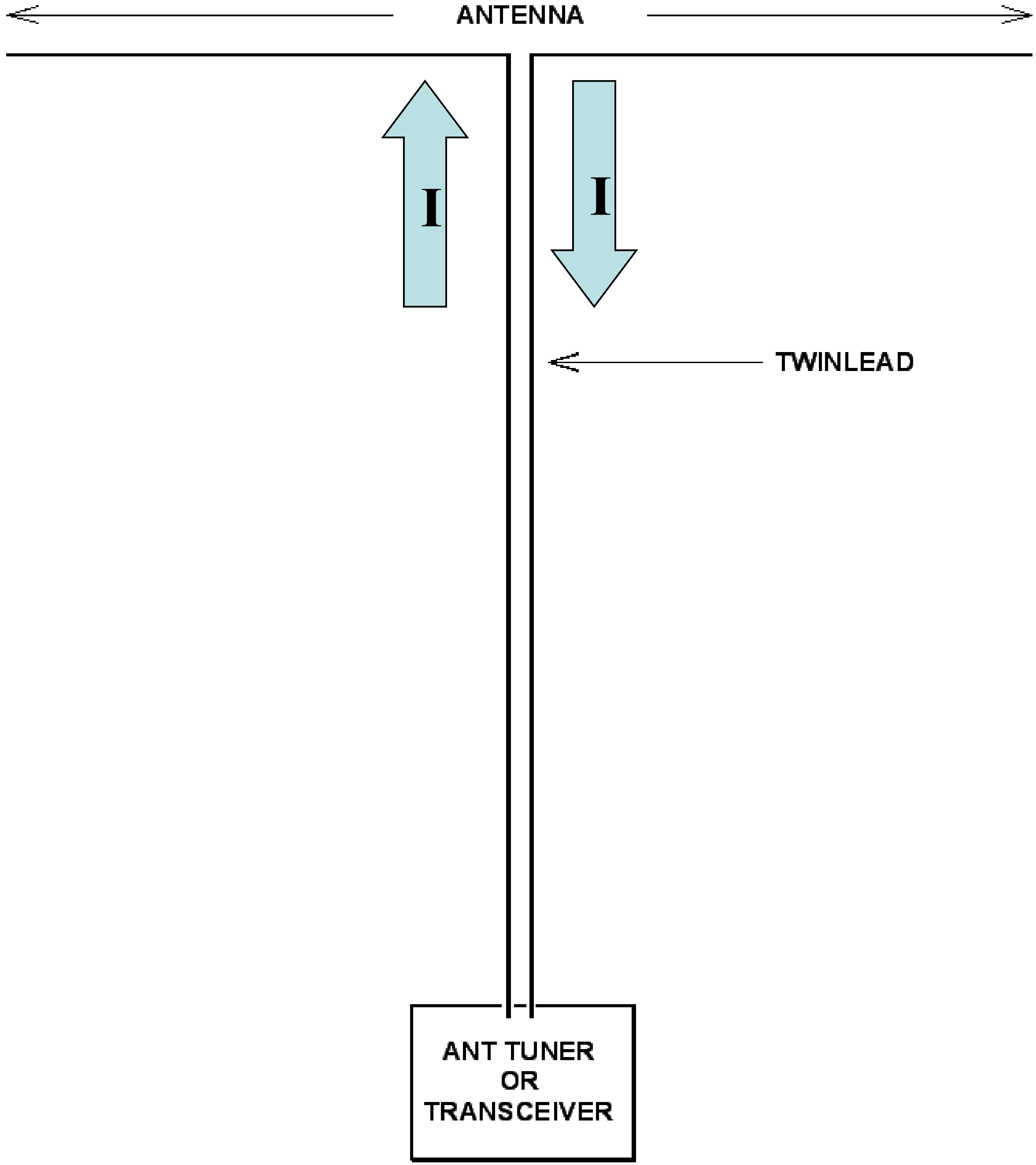
http://k9yc.com\publish.htm

Why Do We Need Chokes?

Understanding Common Mode and Differential Mode Currents on Transmission Lines

Differential Mode Current

- Transmission line carrying power from transmitter to antenna, or from antenna to receiver
- Signal is voltage <u>between</u> the two conductors
- Current flows out on one conductor and returns on the other
- Currents are <u>equal</u> and <u>opposite in polarity</u>



ANTENNA
I
I
TWINLEAD
ANT TUNER
OR
TRANSCEIVER

Differential Mode Current

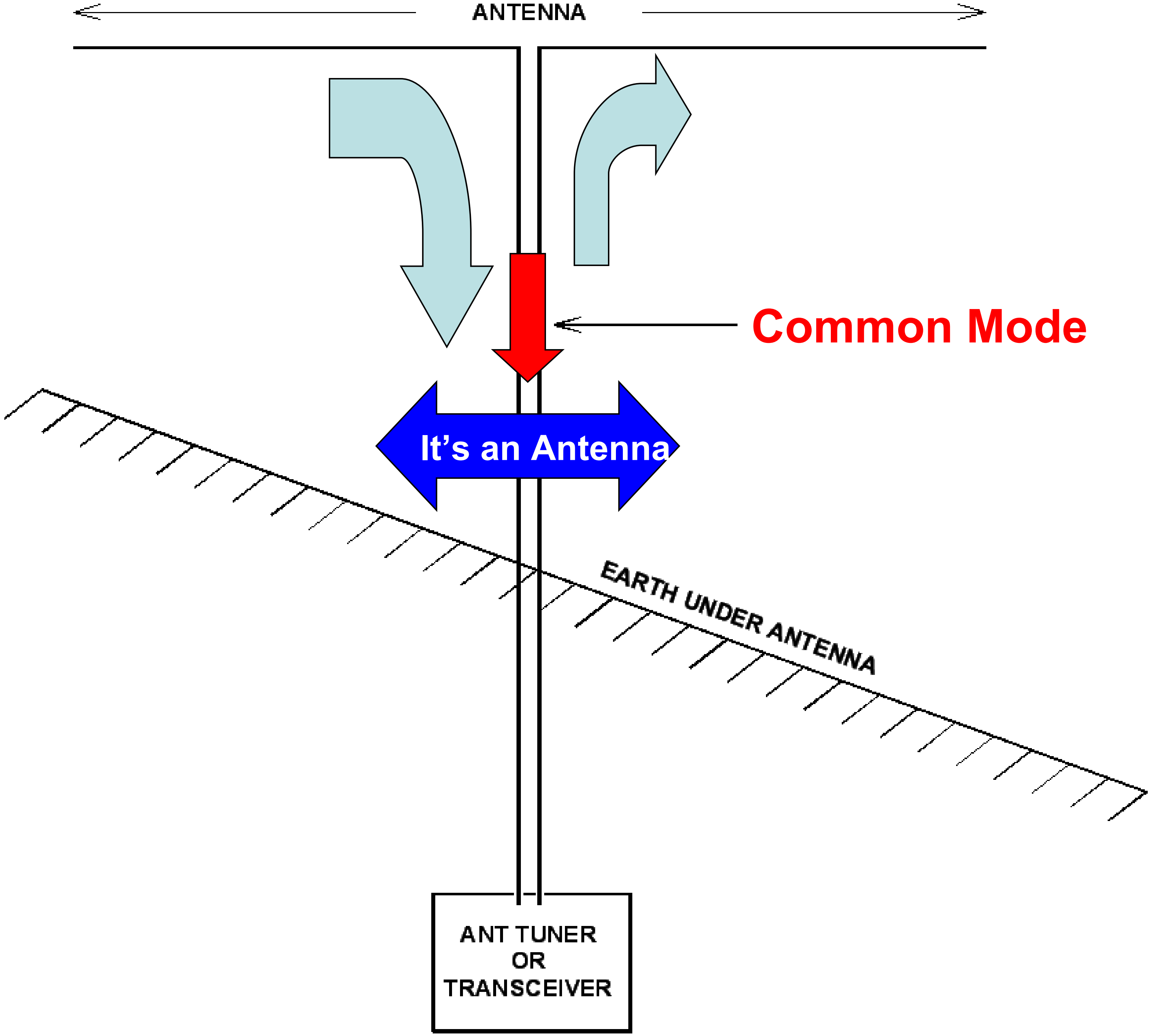
- **Transmission line carrying power from transmitter to antenna, or from antenna to receiver**
- **Signal is voltage <u>between</u> the two conductors**
- **Current flows out on one conductor and returns on the other**
- **Field exists <u>between</u> the two conductors**
- **No radiation from ideal line**
  - **At a distance, field of one conductor cancels field of the other conductor**

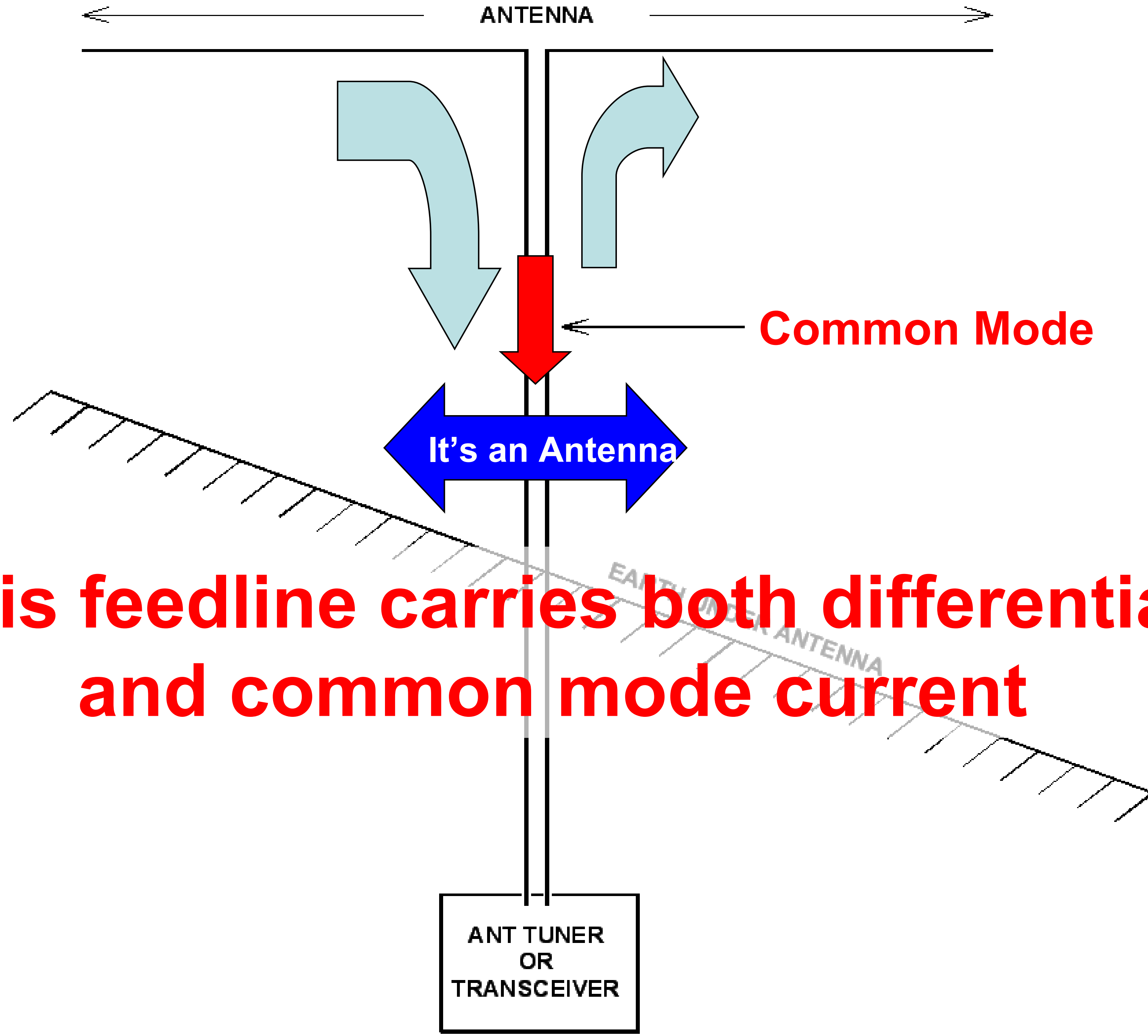
Differential Mode Current

- **Currents are <u>equal</u> and <u>opposite in polarity</u>**
- **Field mostly <u>between</u> the two conductors**
- **No distant radiation from ideal line**
  - **At great <u>distance</u>, field of one conductor cancels field of the other conductor**
- **In the near field of an ideal line, the fields do <u>not</u> cancel**
  - **Most observers will be slightly closer to one conductor than the other, so cancellation will not be perfect**

Common Mode Current

- Equal and flowing in the same direction on all conductors of the transmission line
- Current flows lengthwise on the line
  - No cancellation of one current by another, because they're in polarity
- Line acts as long wire antenna
  - It radiates and it receives


ANTENNA
Common Mode
It's an Antenna
EARTH UNDER ANTENNA
ANT TUNER
OR
TRANSCEIVER



This feedline carries both differential and common mode current

Ham Antennas and Balance

- **Most ham antennas are <u>unbalanced</u> by their <u>surroundings</u>, even when fed by a balanced source and line**

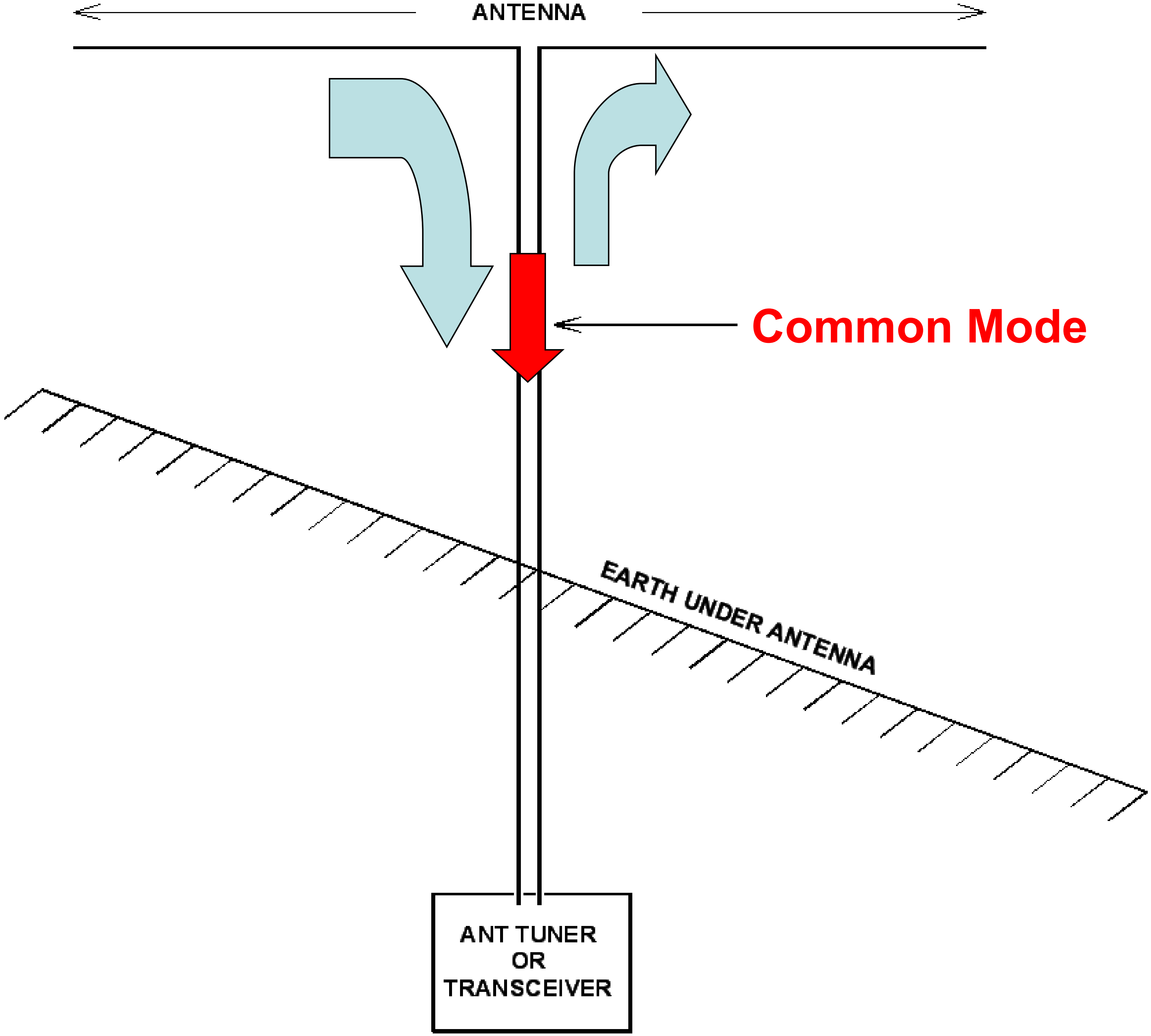
What Makes a Circuit Balanced?

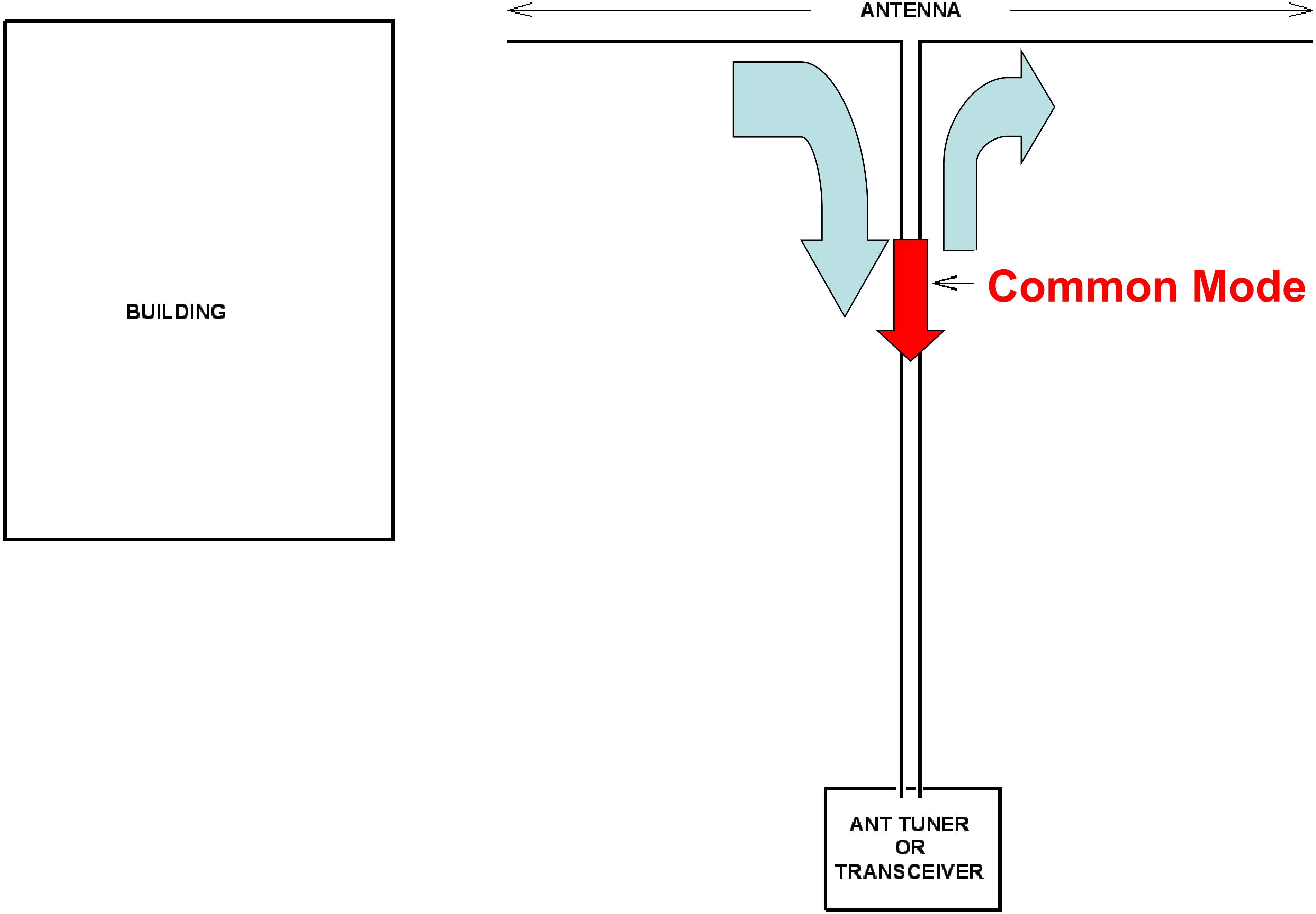
What Makes a Circuit Balanced?

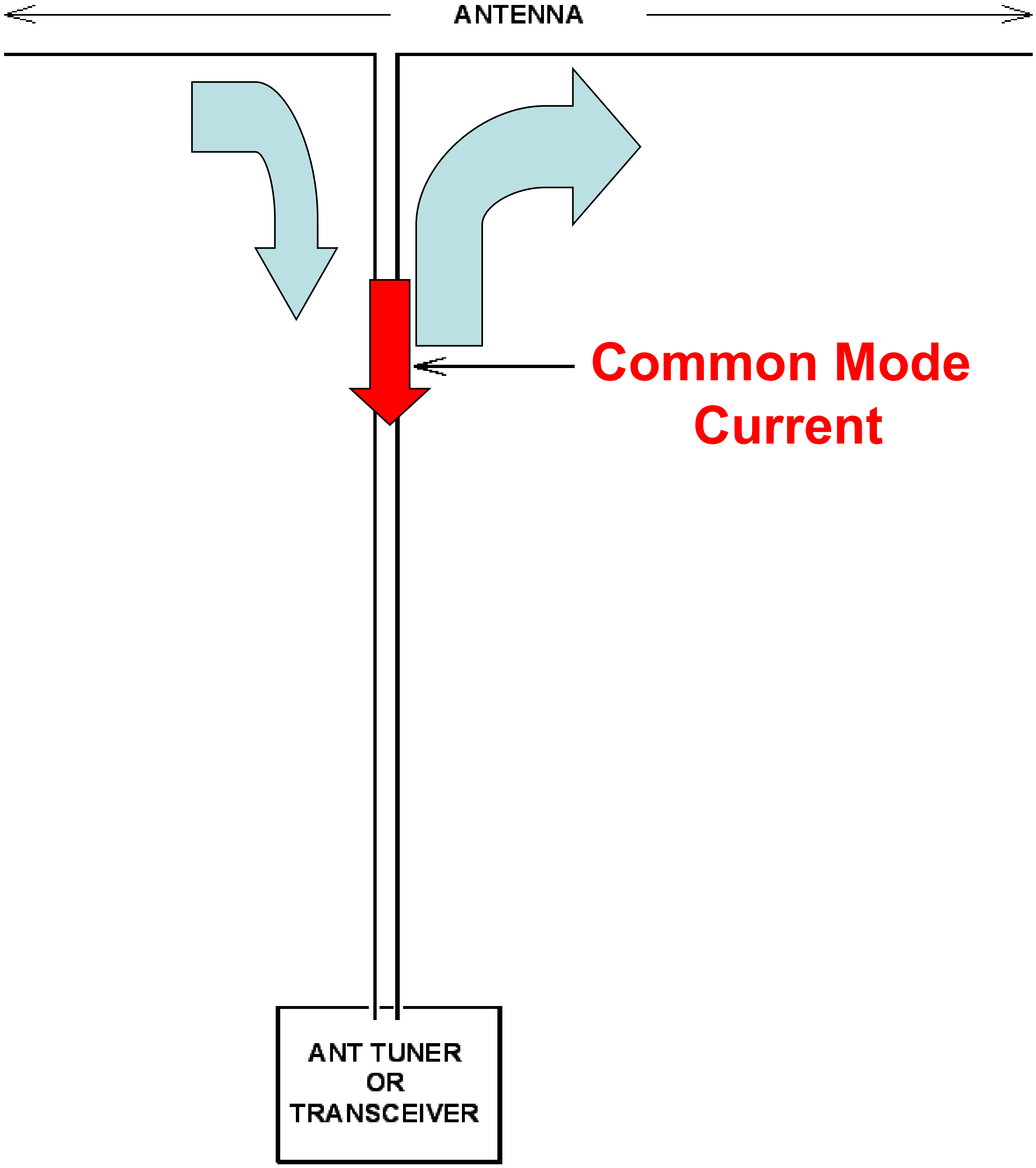
- The <u>impedances</u> of each conductor to the reference plane are equal
- Balance is <u>not</u> defined by voltage or current
- Imbalanced impedances <u>cause</u> unbalanced currents

Ham Antennas and Balance

- **Most ham antennas are unbalanced by their surroundings, even when fed by a balanced source and line**
  - Unequal capacitances to nearby conductors
  - Unequal inductive coupling to nearby conductors
  - Trees, buildings, towers, terrain
  - Feedline comes off at an angle
  - Coax is not a part of these imbalances


ANTENNA
Common Mode
EARTH UNDER ANTENNA
ANT TUNER
OR
TRANSCEIVER


ANTENNA
BUILDING
Common Mode
ANT TUNER
OR
TRANSCEIVER


ANTENNA
Common Mode Current
ANT TUNER OR TRANSCEIVER

Unbalanced Antennas and Lines

- **If the antenna is unbalanced**
  - **Unequal voltage and current to earth**
  - **Unequal currents on the feedline**
  - **The difference is common mode current, and it radiates from the line**
- **<u>Coax</u> did not cause the imbalance in these antennas!**
- **Coax simply adds to the imbalance**

The Fields around Coax and Twinlead are Very Different

Coax is Special

- **All the differential power (and field) is confined <u>inside</u> the coax**
- **All the common mode power (and field) is <u>outside</u> the coax**
- **<u>A ferrite core surrounding coax sees only the common mode power (and field)</u>**
- **<u>No</u> differential mode radiation**

Coax is Special

- **Skin effect splits the <u>shield</u> into two conductors**
  - **<u>Inner</u> skin carries <u>differential</u> mode current (the transmitter power)**
  - **<u>Outer</u> skin carries <u>common</u> mode current (the current due to imbalance)**

Now We Can Talk About Common Mode Chokes!

What's a Common Mode Choke?

- **A circuit element that reduces common mode current by adding a high impedance in series with the common mode circuit**
  - **Reduces <u>radiation</u> from the cable**
  - **Reduces <u>reception</u> by the cable**

Some Common Mode Chokes

- A coil of coax at the antenna
- A string of ferrite beads around coax (Walt Maxwell, W2DU)
- Multiple turns of transmission line through a toroid (Joe Reisert, W1JR) or stack of toroids (W1HIS, K9YC)
- Most 1:1 “baluns” are common mode chokes

Chokes you can buy (W2DU, W0IYH Baluns)

Much better chokes you can <u>build</u>

Much better chokes you can <u>build</u>

RG400 – Dipole Center Insulator

Teflon 12-2

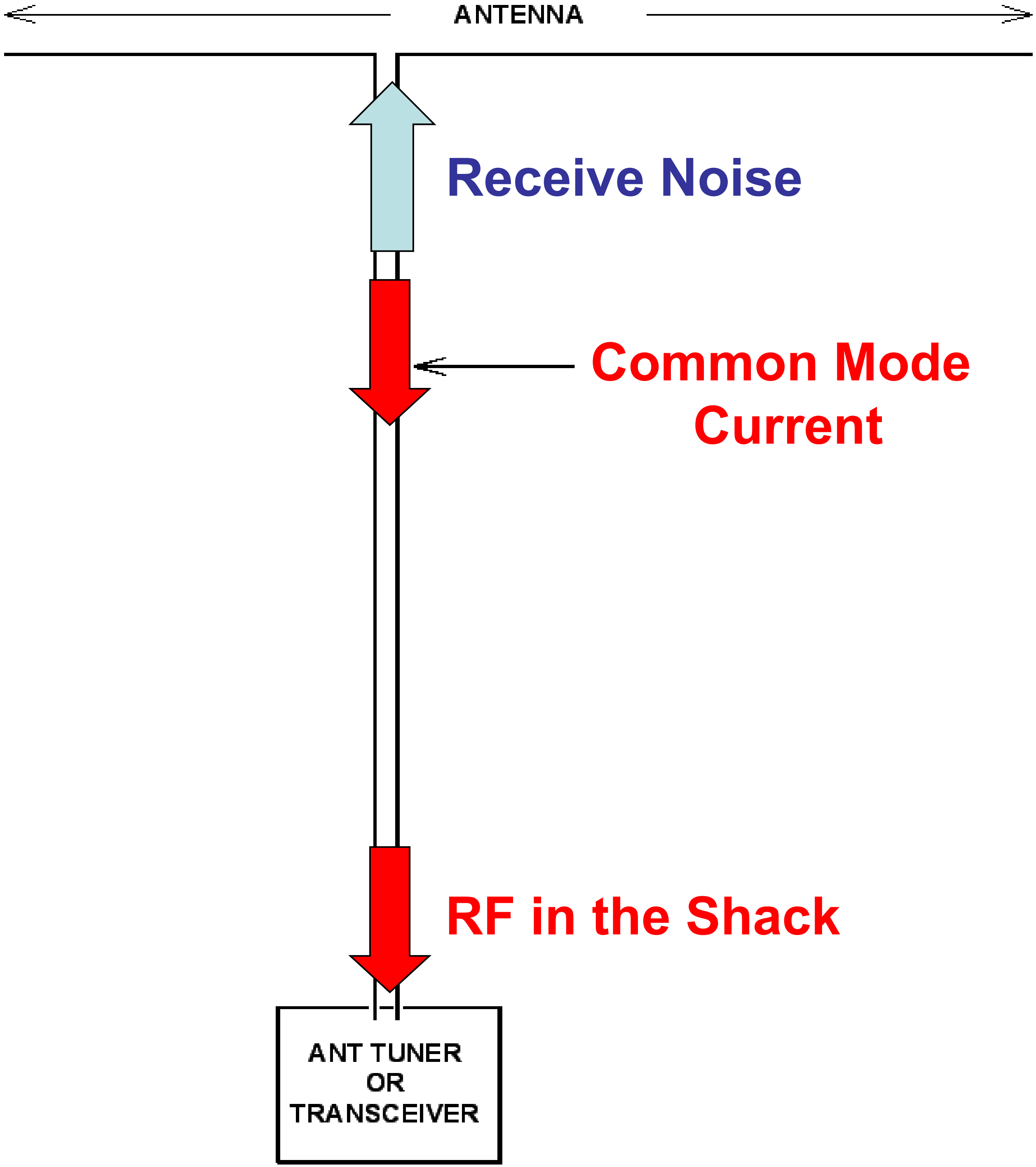
RG400

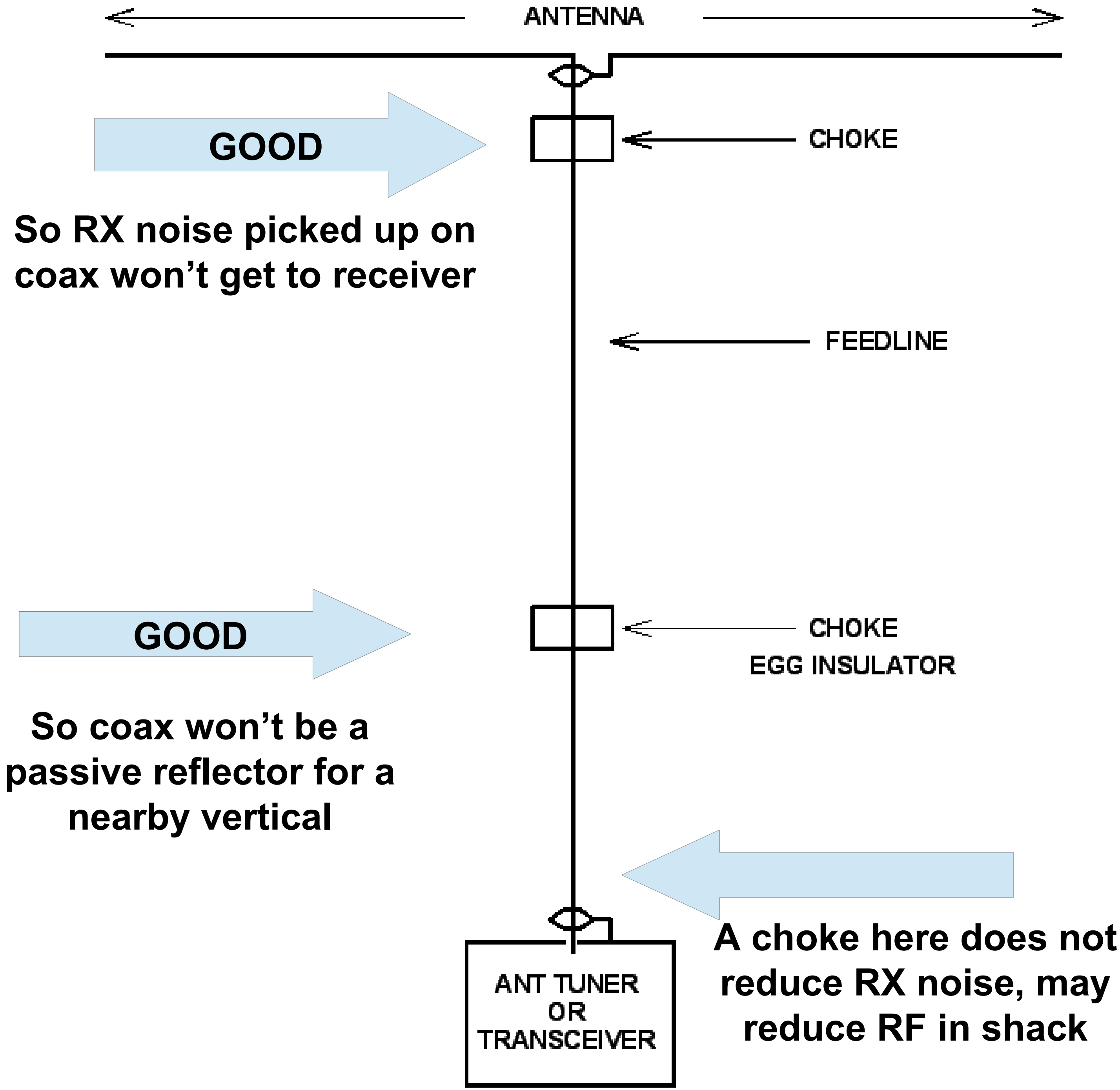
Some Common Mode Chokes

- Some 2:1, 3:1, and 4:1 “baluns” are also common mode chokes
  - Guanella balun
  - But the few I’ve measured aren’t very good common mode chokes

Why Transmitting Chokes?

- Isolate antenna from its feedline
- Reduce receive noise
- Keep RF out of the shack (and your neighbor's living room stereo)
- Minimize antenna interaction
  - Field Day, CQP Expeditions
  - SO2R, Multi-multi
  - Dipole feedline and vertical antenna


ANTENNA
Receive Noise
Common Mode
Current
RF in the Shack
ANT TUNER
OR
TRANSCEIVER


ANTENNA
GOOD
CHOKE
So RX noise picked up on coax won't get to receiver
FEEDLINE
GOOD
CHOKE
EGG INSULATOR
So coax won't be a passive reflector for a nearby vertical
ANT TUNER OR TRANSCEIVER
A choke here does not reduce RX noise, may reduce RF in shack

Design of Transmitting Chokes

- Higher impedance is better!
  - Reduces common mode current
  - Reduces noise
  - Reduces interaction
  - Reduces RF in the shack
  - Reduces dissipation (overheating)
- Resistance is better than reactance

Why is Resistance Better?

- **We want to reduce the current**
- **A cable shorter than λ/4 is inductive**
  - **Series inductance <u>reduces</u> the current**
  - **Series capacitance resonates with it and <u>increases</u> the current**
- **A cable longer than λ/4 (and shorter than λ/2) is capacitive**
  - **Series inductance resonates with it and <u>increases</u> the current**
- **Resistance <u>always</u> reduces current**

Why is a Simple Coil of Coax a Lousy Choke?

- **Because it's just an inductor**
  - **Can resonate with the line and <u>increase</u> the current**
- **Will resonate with its own stray capacitance (between turns)**
- **Above resonance it's a capacitor**
  - **Can resonate with the line and increase the current**

Ferrite Chokes are the Answer!

Why is Fair-Rite My Example ?

- Their published data is FAR better than any of their competitors
- You can study it and understand
  - How ferrites work
  - How one part is different from another
  - How one mix is different from another
  - How each part will work in your circuit
- The numbers I'm using are those that describe parts made by Fair-Rite

Why Is Fair-Rite My Example?

- **Most ferrites sold by ham distributors are actually <u>made</u> by Fair-Rite**
- **Ham distributors charge HUGE markups (typically 5X their cost)**
  - **Palomar, Amidon, Wireman, DX Engineering, etc.**
- **Industrial distributors have discounts for quantity!**
  - **Arrow, Allied, Newark, Kreger, Dexter Magnetics, Lodestone Pacific, Digikey**

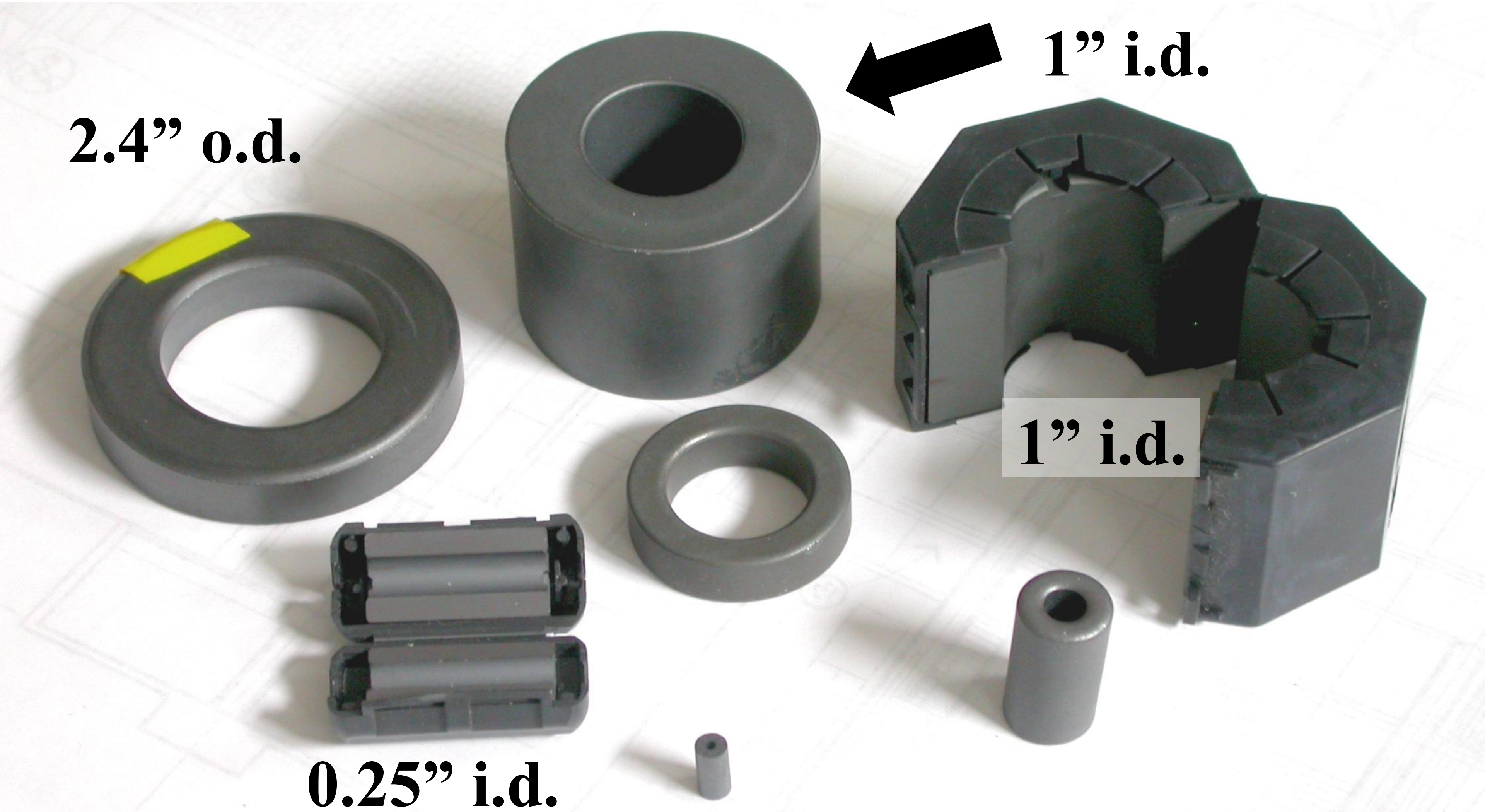
Why Is Fair-Rite My Example?

- Their parts are the most useful for ham applications
- They are easy to buy in North America
- They are the only manufacturer of #31 material or any material like it
- Stick to the industrial distributors listed on previous slide

What's a Ferrite?

- A ceramic consisting of an iron oxide
  - manganese-zinc
  - nickel-zinc
- Has permeability (μ) much greater than air
  - Better path for magnetic flux than air
  - Multiplies inductance of a wire passed through it
- Is increasingly lossy at higher frequencies

Different sizes and shapes



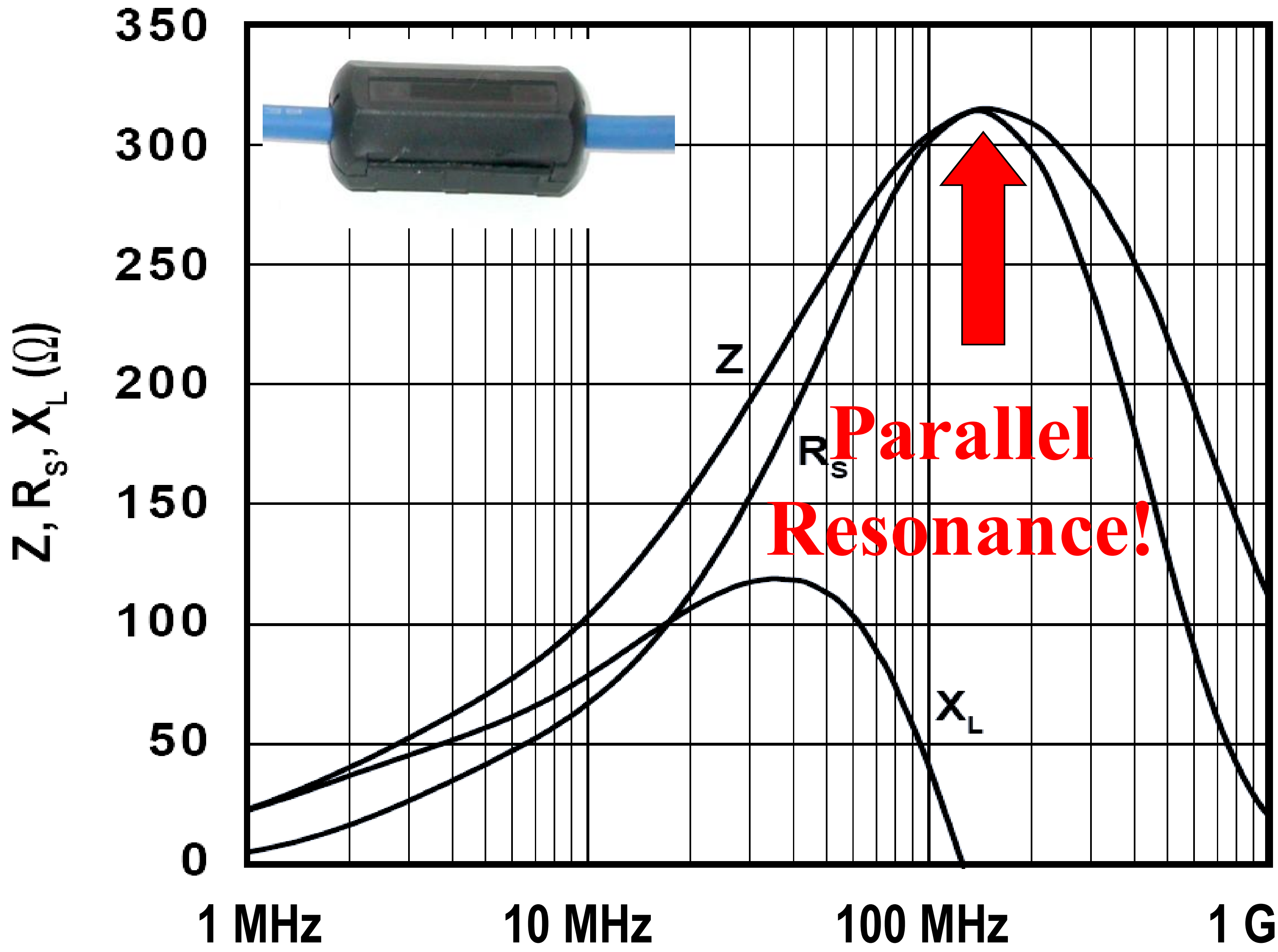
What's Do the Numbers Mean?

- **The "*MIX*" − the chemical formula of the iron oxide!**
- **A ceramic consisting of an iron oxide**
  - **manganese-zinc (MnZn) – 1-30 MHz (AM broadcast, hams) #31, #77, #78**
  - **nickel-zinc (NiZn) – 30 MHz-1 GHz (FM, TV, cell phones) #43, #61, #67**
- **#31 is a new MnZn *mix* that behaves like #43 at VHF, but #31 is much better on the HF bands**

A simple equivalent circuit of a wire passing through a ferrite

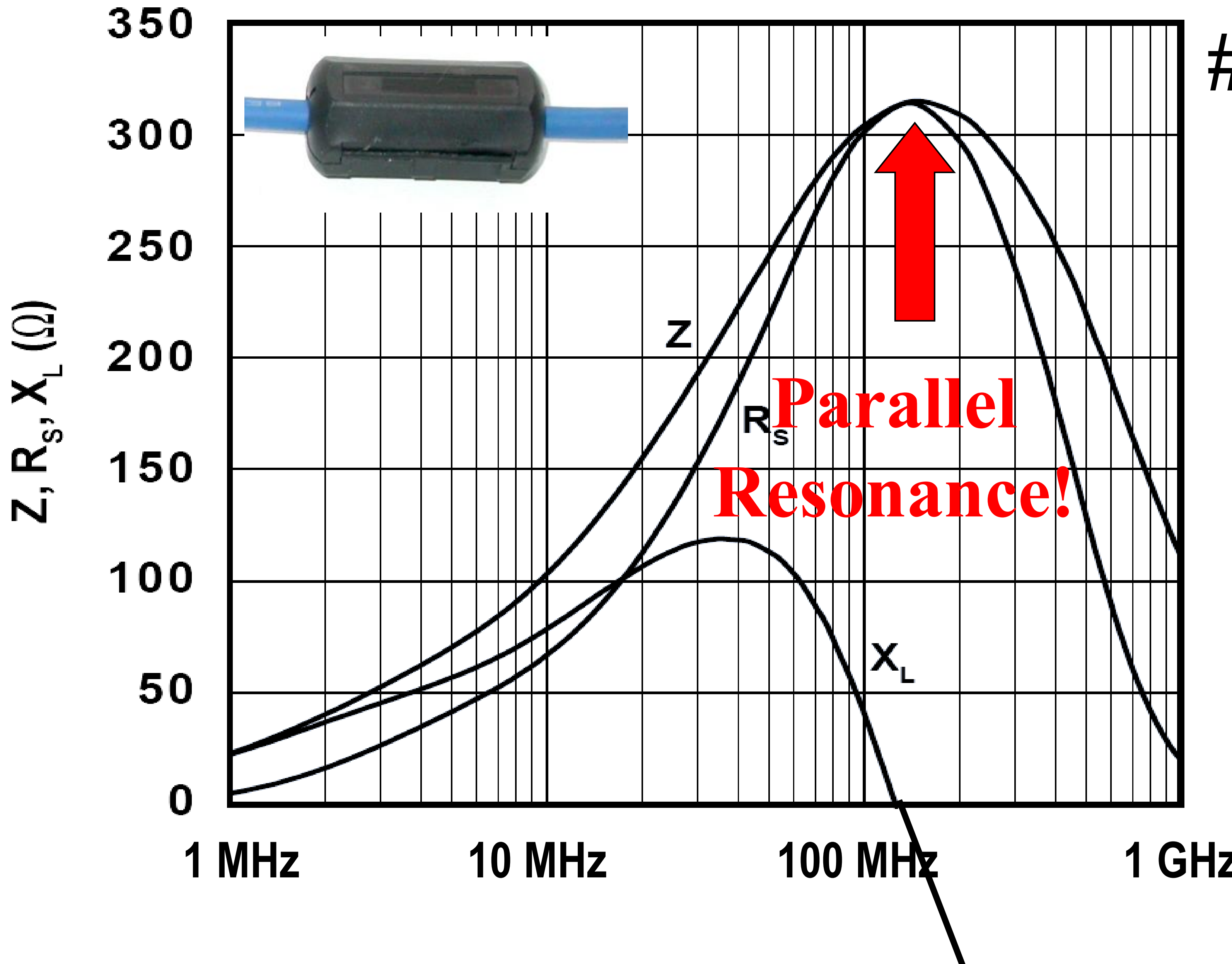
R_s and X_s vary with frequency!

#31



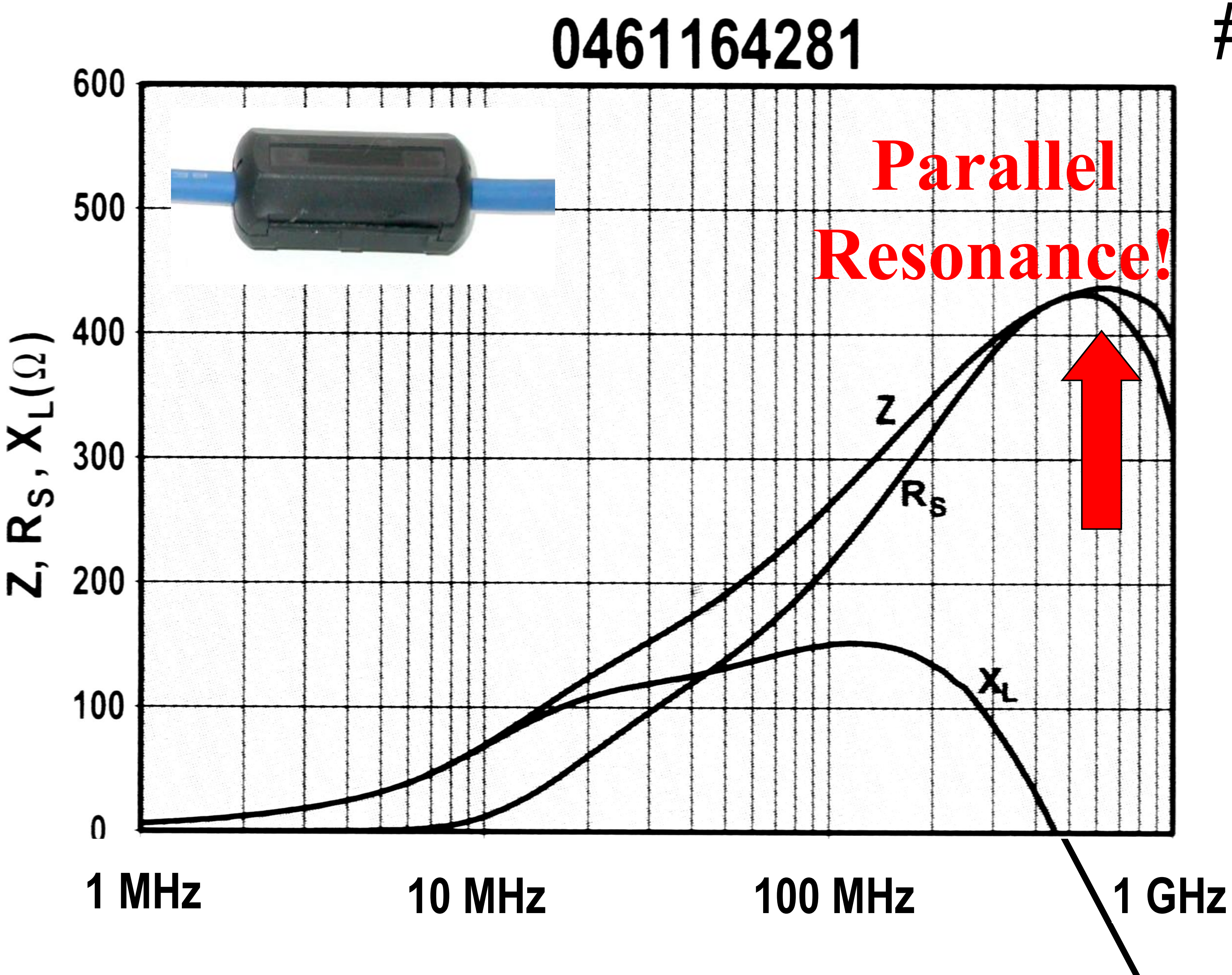
R_s and X_s vary with frequency!

#31



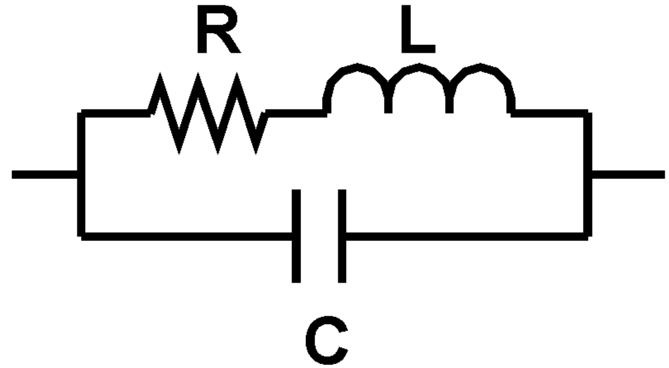
A Ferrite for UHF Suppression

#61

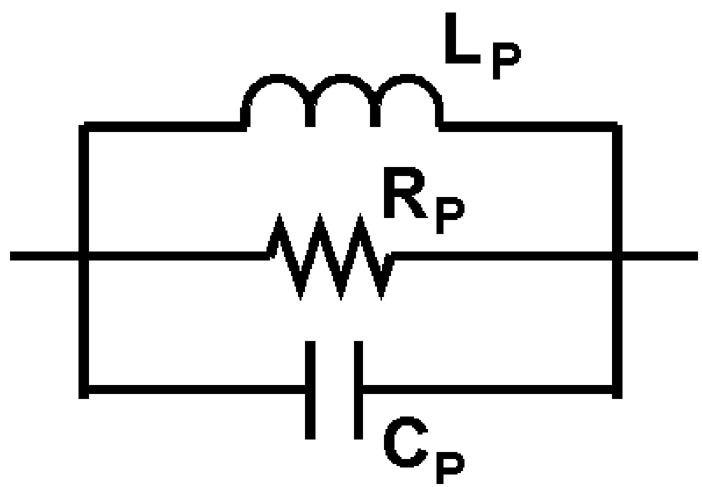


Equivalent Circuit of a Ferrite Choke

Low Frequencies

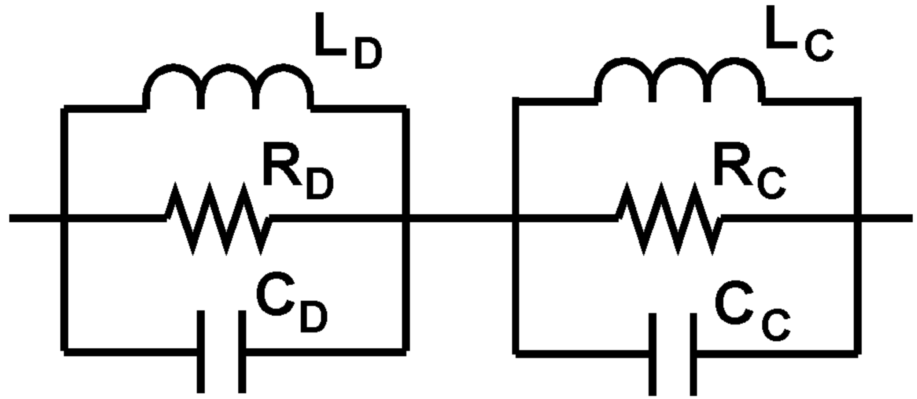


Mid-Frequencies



High Frequencies

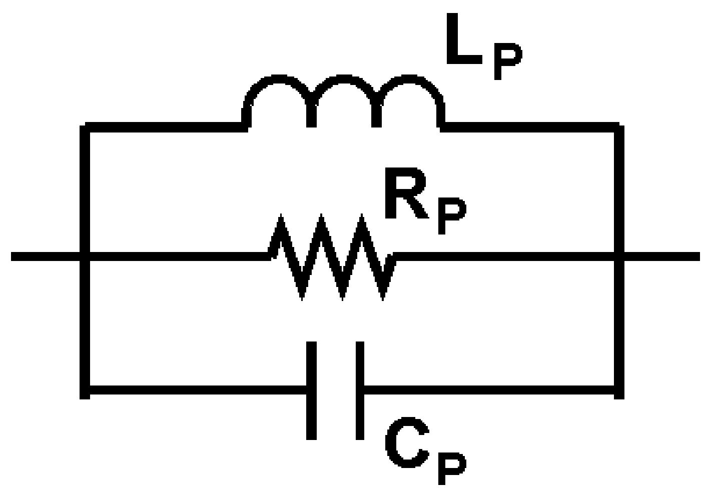
More General Equivalent Circuit

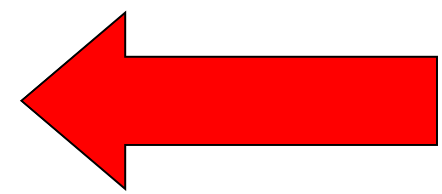


Including Dimensional Resonance

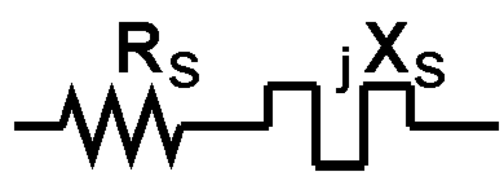
(more than we have time to talk about today)

We'll Use This Physical Equivalent Circuit to <u>Understand</u> the Choke

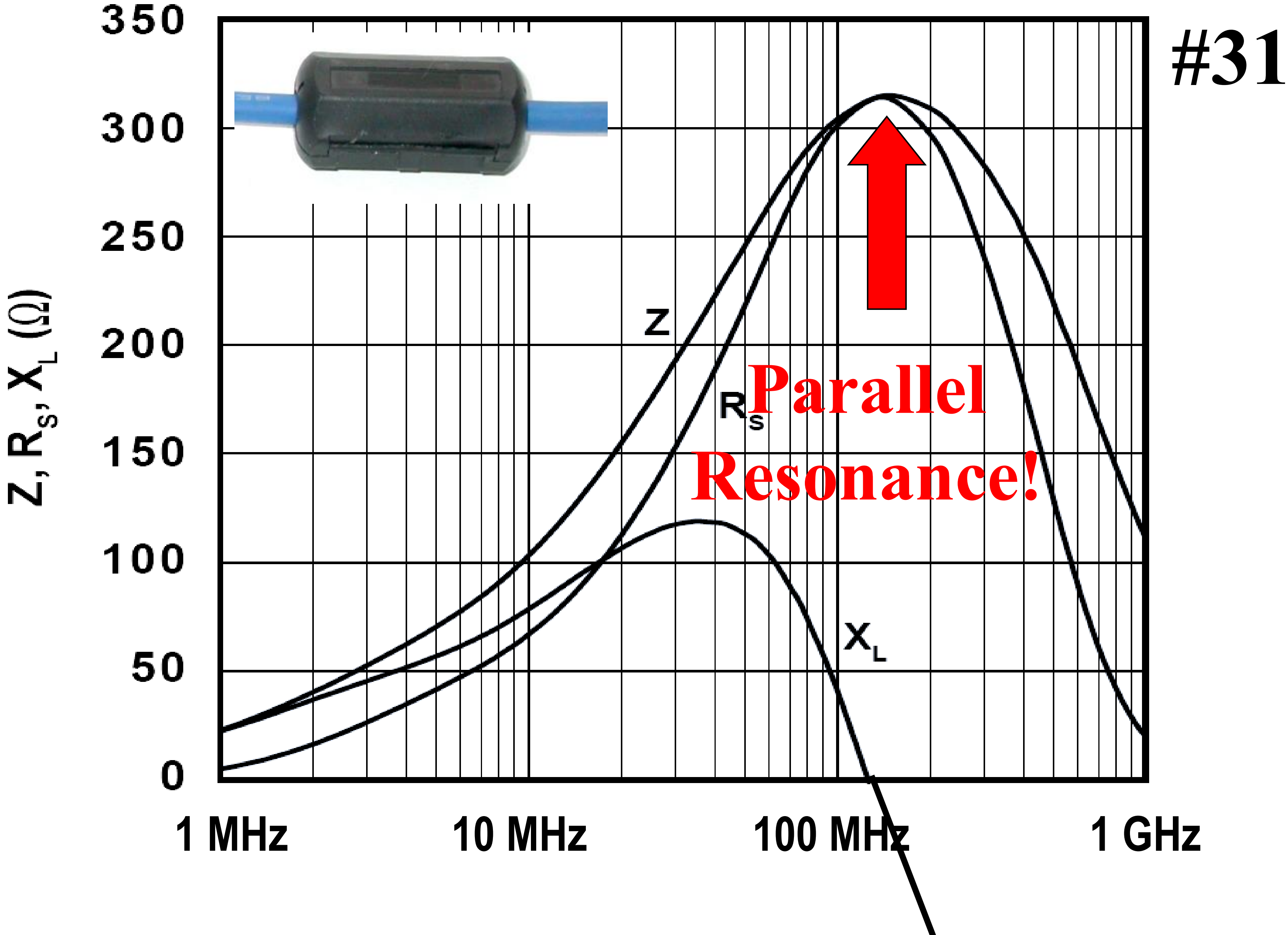




Data Sheets Use This Equivalent Circuit to Graph the Impedance



R_s and X_s vary with frequency!



Where's the Capacitance here?

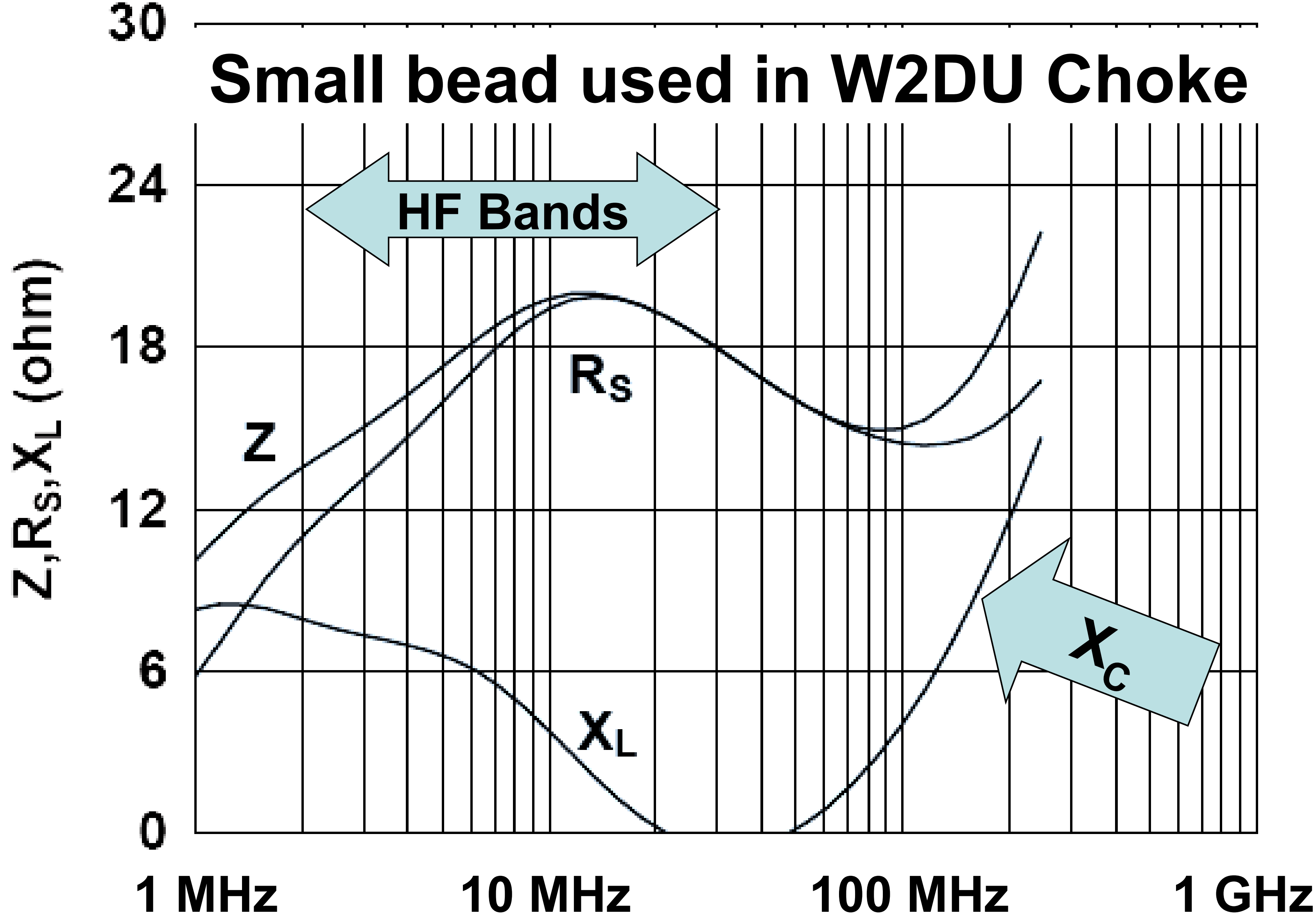
Where’s the Capacitance here?

From the wire at one end of the choke to the wire at the other end, through the permittivity of the ferrite (it <u>is</u> a dielectric!)

“Strings of Beads” (W2DU, W0IYH “Baluns”)

A String of Different Beads

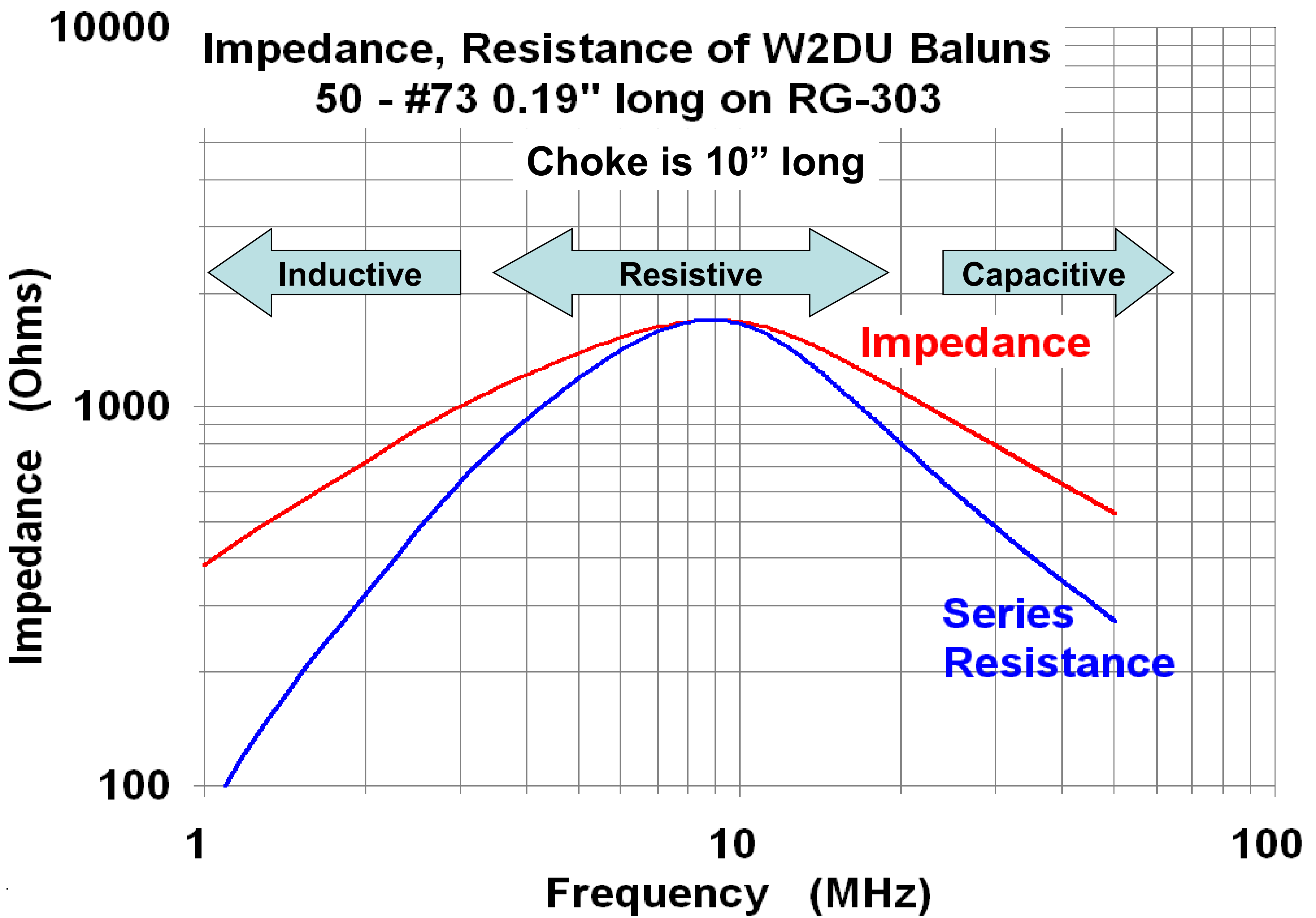
2673002402



30
Small bead used in W2DU Choke
24
HF Bands
18
R_S
Z
12
6
X_L
X_C
0
Z, R_S, X_L (ohm)
1 MHz
10 MHz
100 MHz
1 GHz

W2DU Choke

- **A “string of beads” choke**
  - **Impedances in series add**
  - **50 beads = 50 x Z of one bead**
- **W2DU used #73 mix (a very good choice)**
- **Increasingly resistive above 3 MHz**
  - **Less sensitive to feedline length**
- **Much better than bead of W0IYH choke**
- **<u>Many</u> more beads are needed**
  - **They’re small and cheap (good)**
- **#73 only made to fit RG58 or RG303**



Impedance, Resistance of W2DU Baluns
50 - #73 0.19" long on RG-303
Choke is 10” long
Inductive
Resistive
Capacitive
Impedance
Series Resistance
10000
1000
100
1
10
100
Frequency (MHz)
Impedance (Ohms)

Newer (and Inferior) Designs

- W2DU's design is 50 years old
- That's old fashioned -- certainly something newer must be better!
- He measured 50, 100, and 200 bead chokes
- 200 beads best, 4x impedance of 50 beads
  - Much better noise suppression, better power handling
  - Commercial W2DU balun only 50 beads (or less)
- W2DU's beads are tiny
- W0IYH tried something bigger
- BIG beads that fit on RG8

New Understandings of Chokes

- Before 2006, chokes were thought of as preventing pattern distortion from the imbalance caused by coax
  - 500Ω was considered “good enough”
- In 2006, W1HIS showed that a much higher choking impedance could prevent noise picked up on the coax from reaching the receiver
  - 5,000Ω was his recommendation
  - Chuck did not realize the significance of the resistive component of the impedance around resonance, and saw resonance as a problem

New Understandings of Chokes

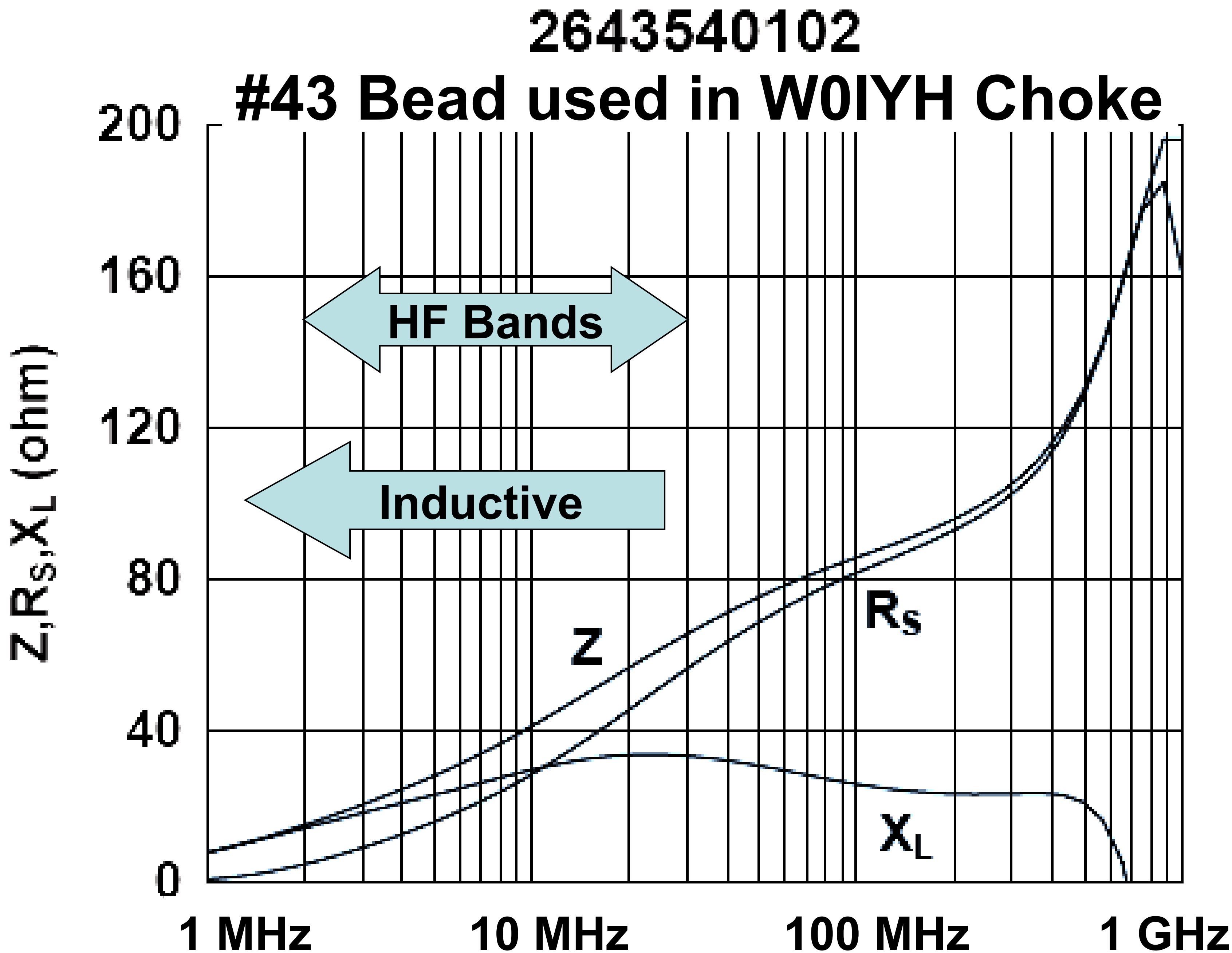
- **My 2005 AES paper on RF interference to audio systems** ***k9yc.com/AESPaperFerritesASGWeb.pdf***
  - **Cited E. C. Snelling's 1969 analysis of dimensional resonance in ferrite materials**
  - **Developed equivalent circuit for a ferrite choke as two parallel resonant circuits in series**
    - **Dimensional resonance**
    - **Circuit resonance of the winding around the core**
  - **Showed the importance of the resistive component of the impedance near resonance**
  - **Provided extensive measured data for small wire chokes wound on #31, #43, #61, #77, and #78 materials**

New Understandings of Chokes

- That 2005 AES paper included extensive measured data for small wire chokes wound on #31, #43, #61, #77, and #78 materials
  - For each material, chokes of 1 – 14 turns were measured, producing families of data for each material demonstrating both resonances
  - These data were produced by a collaborator with access to precision measurement gear in an engineering lab where he worked
  - That collaborator has chosen to remain anonymous

New Understandings of Chokes

- **My 2005 AES paper was the first to analyze Fair-Rite's #31 material**
  - **It was a relatively new material, developed after 2001**
  - **For that research, I obtained (in 2004) five samples from the first prototype run of 2.4-in o.d. toroids, and shared them with the collaborator who did the measurements**
- **The ham community was unaware of #31 material until my first RFI tutorial for hams in 2007** ***k9yc.com/RFI-Ham.pdf***



2643540102
#43 Bead used in W0IYH Choke
200
160
120
80
40
0
Z,RS,XL (ohm)
HF Bands
Inductive
Z
RS
XL
1 MHz
10 MHz
100 MHz
1 GHz

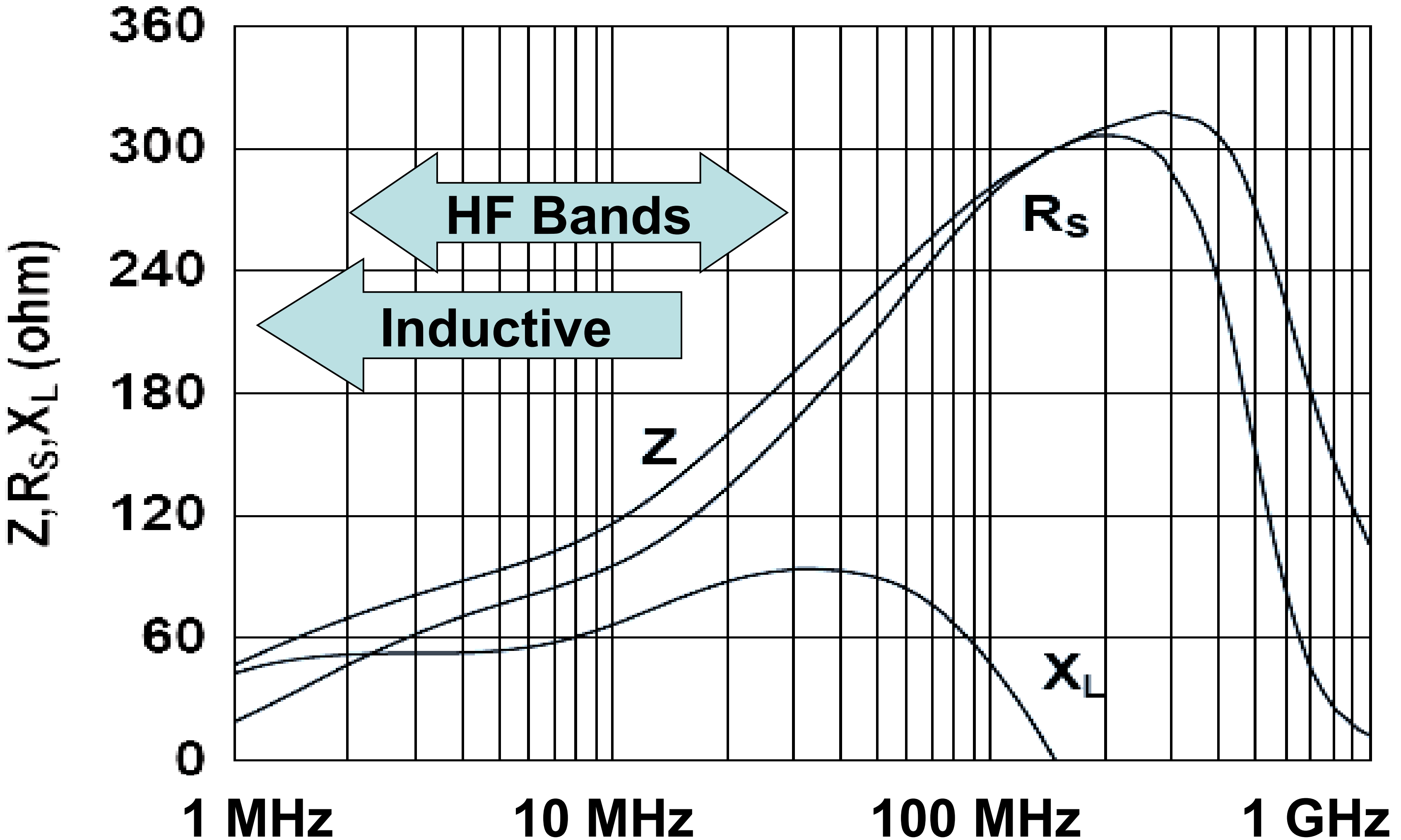
W0IYH Choke

- **Also a "string of beads" choke**
- **Predominantly <u>inductive</u> below 25 MHz**
  - **Very sensitive to feedline length**
  - **Inductance resonates with a capacitive line**
- **Increasingly resistive above 25 MHz**
  - **Much less sensitive to feedline length**
- **Not very effective below 15 meters!**

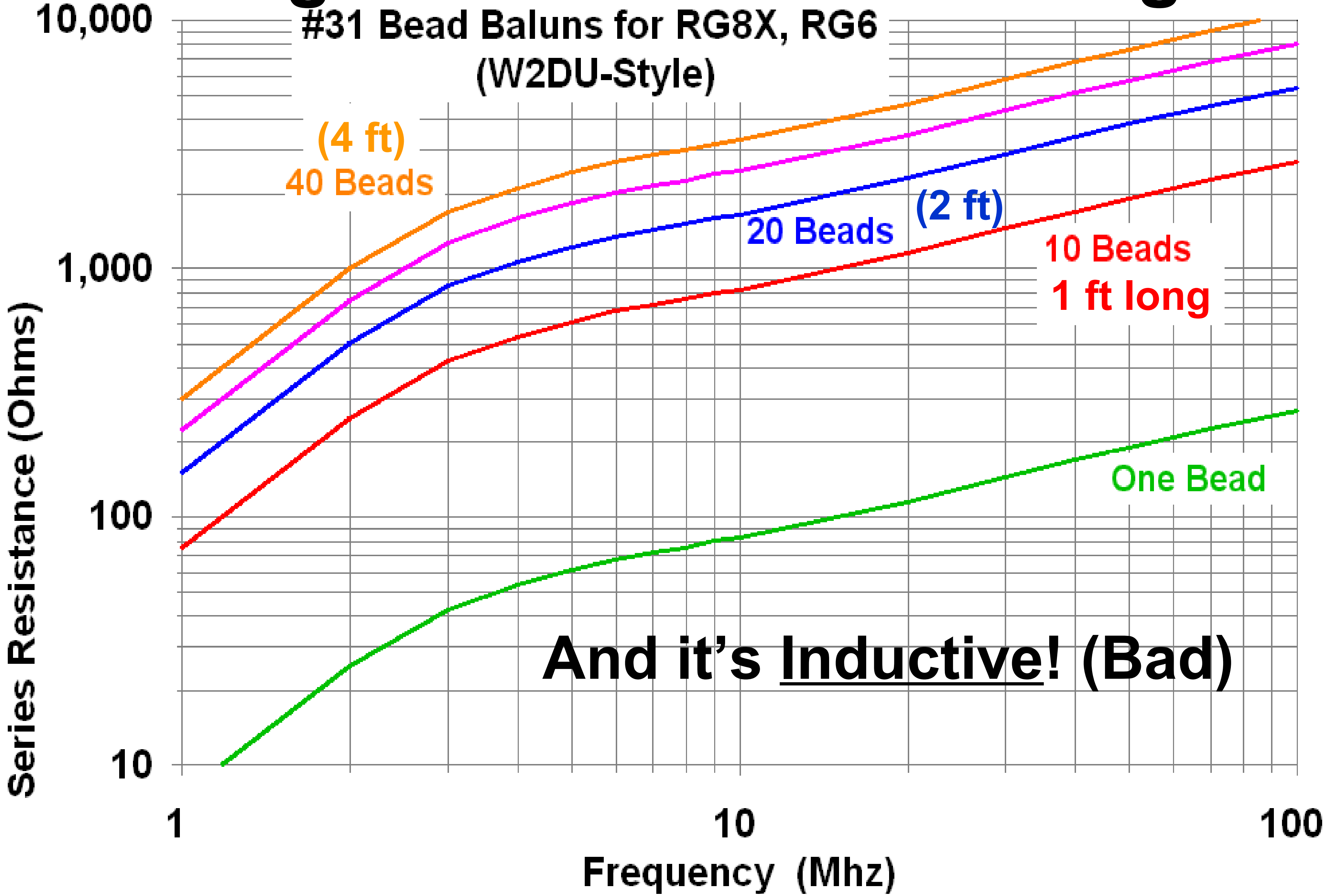
A #31 Bead for the String

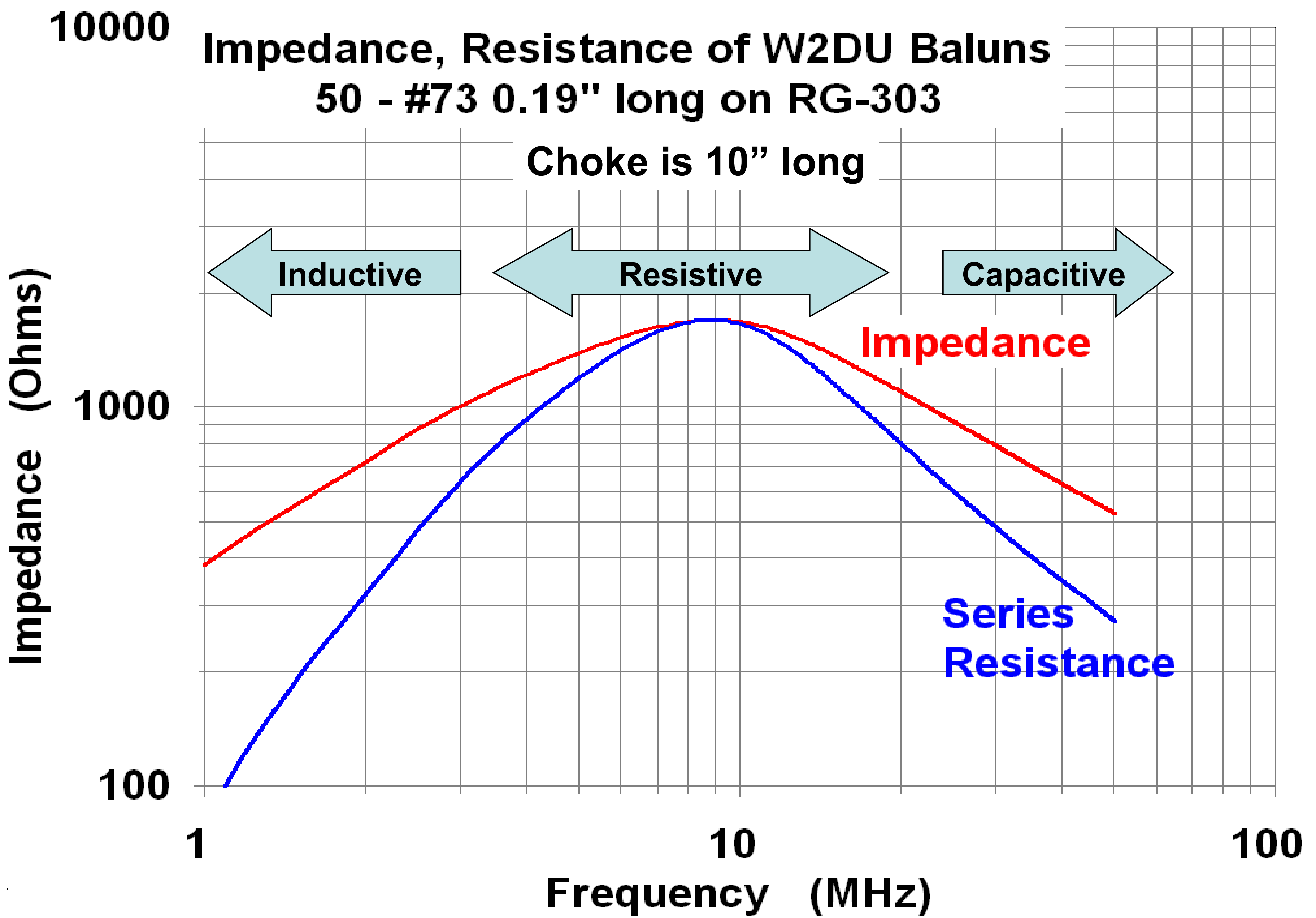
1" o.d. x 1.125" long (Fits RG8)

2631102002



Using #31 Beads in the String





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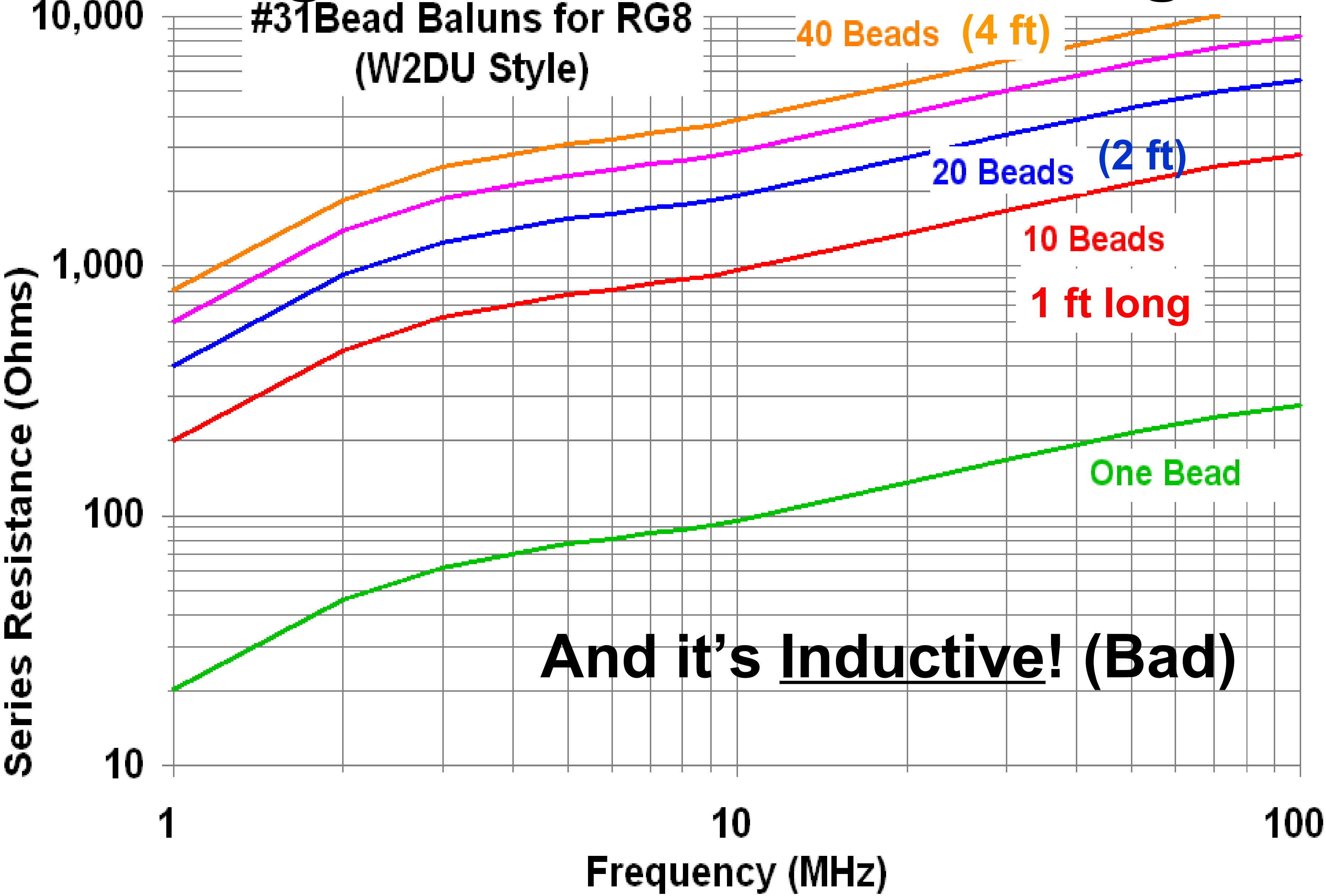
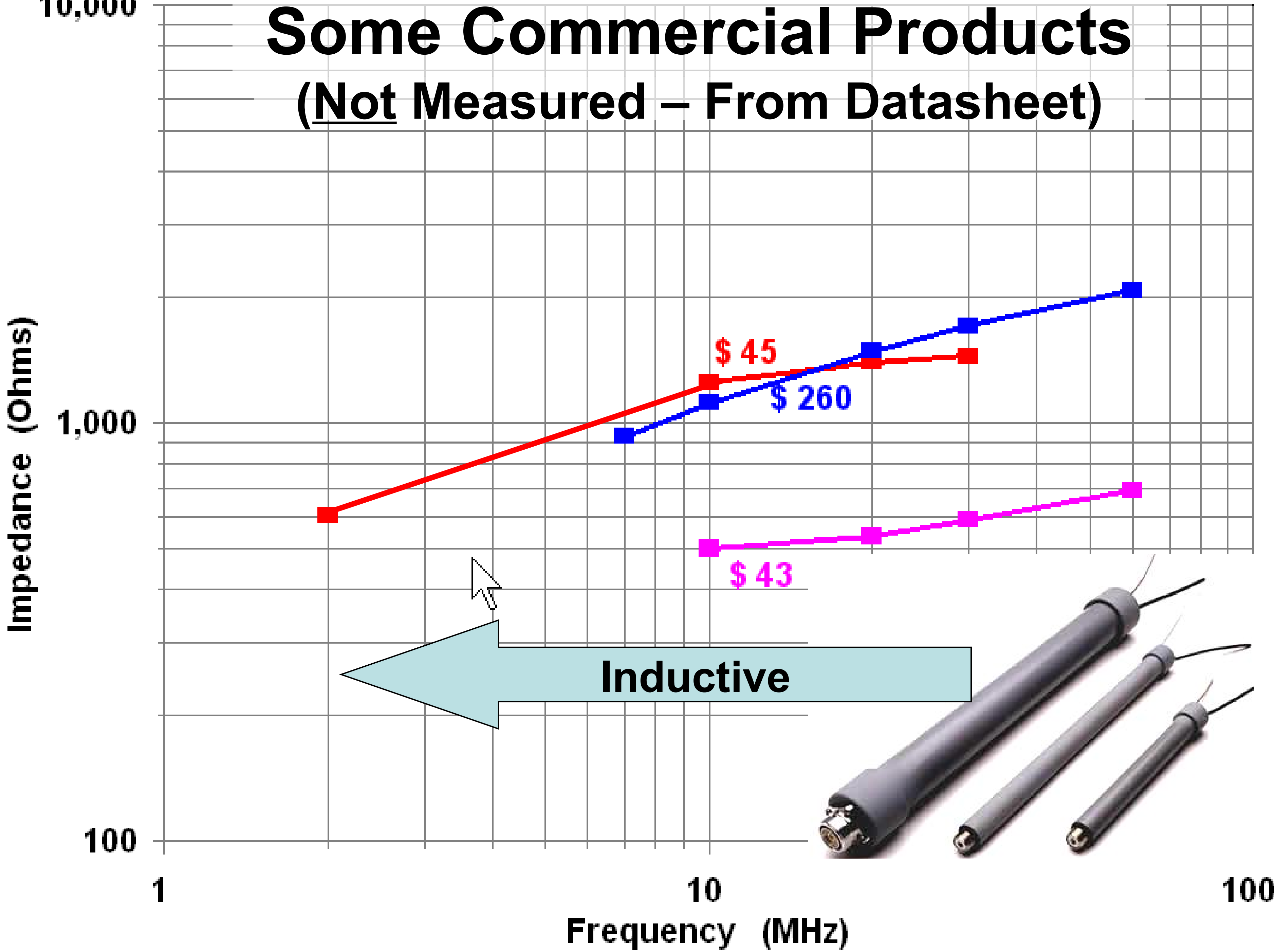
Frequency (MHz)

Using #31 Beads in the String



Some Commercial Products

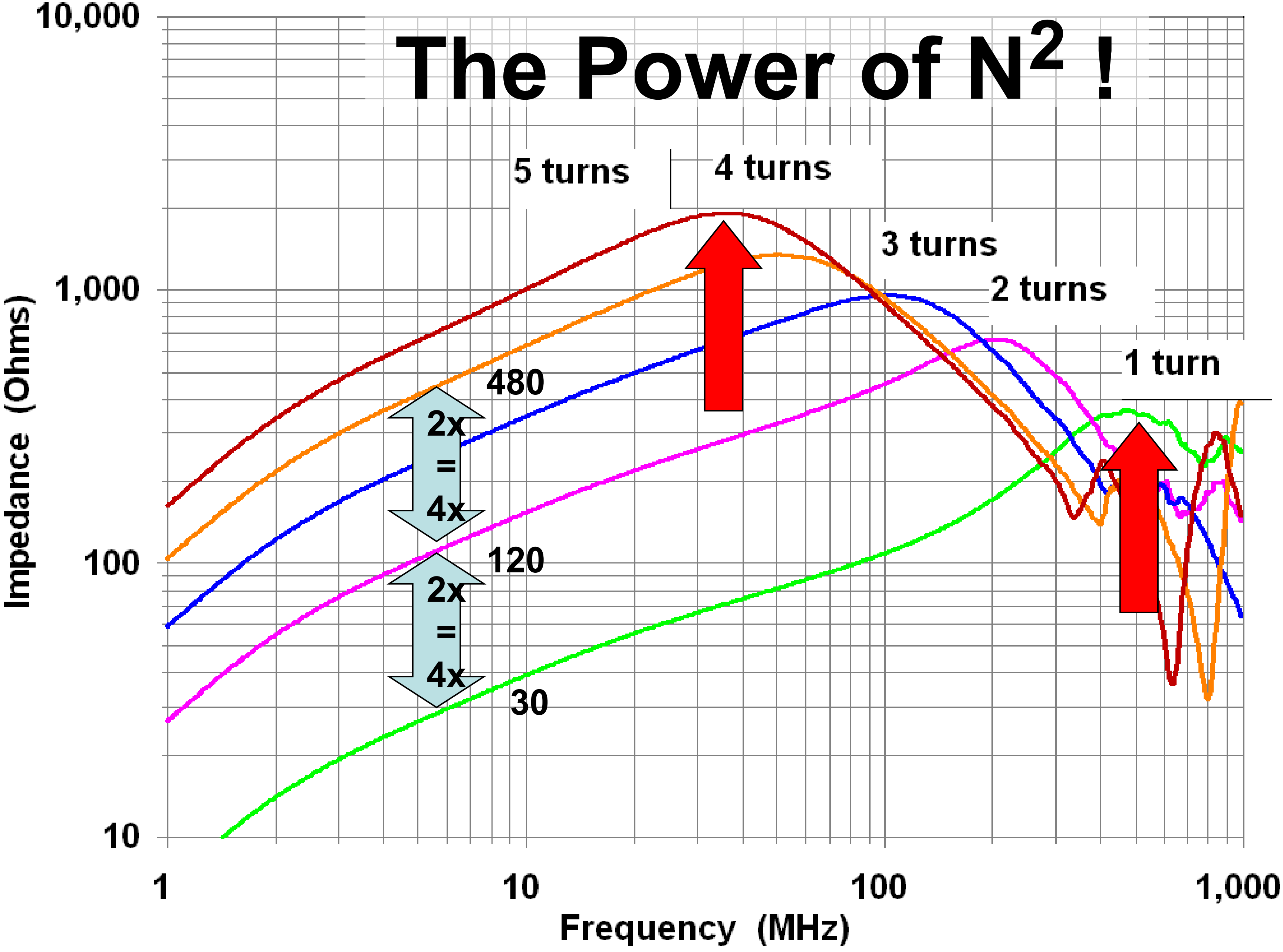
(Not Measured – From Datasheet)



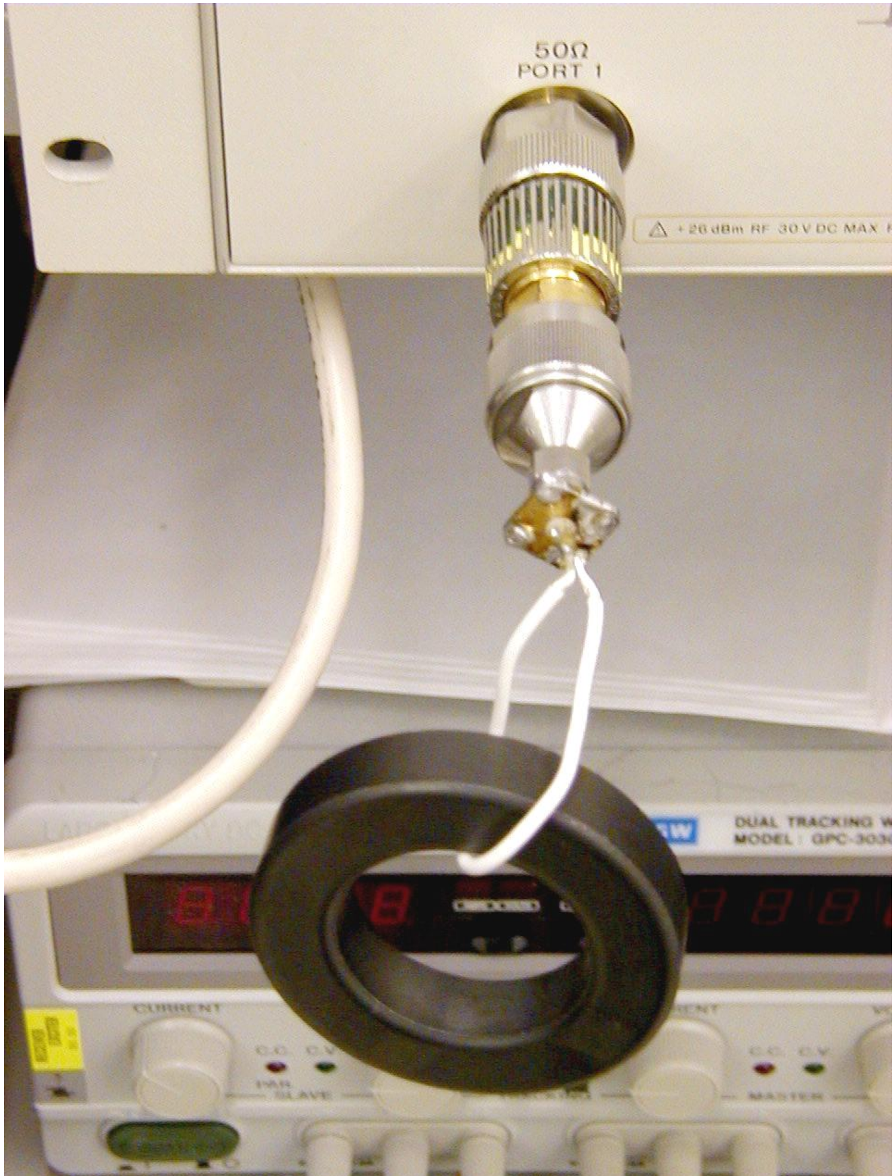
There's A Much Better Way to get Higher Impedance

- Inductance increases as N^2
- Inductively coupled resistance increases as N^2

Measured Data for #43 Toroid Chokes



HP8753C w/HP85046A S-parameter Test Set (by my anonymous collaborator)



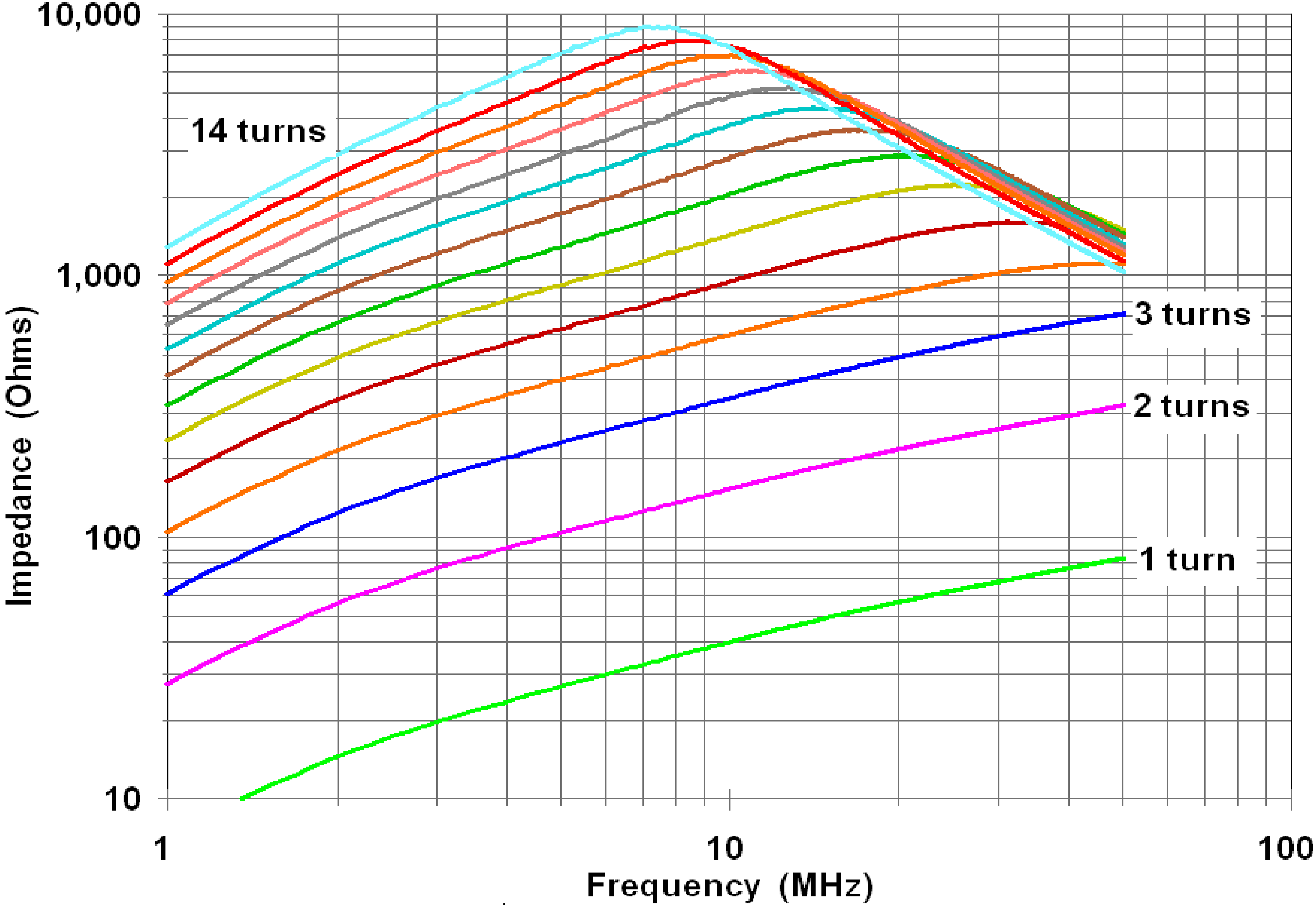
Why the Resonance Moves Down

- Inductance increases as N^2
- Inductively coupled resistance increases as N^2
- Capacitance increases with N
  - Capacitance between turns
  - Capacitance through the ferrite core
  - A bit more capacitance with much bigger wire (like coax)

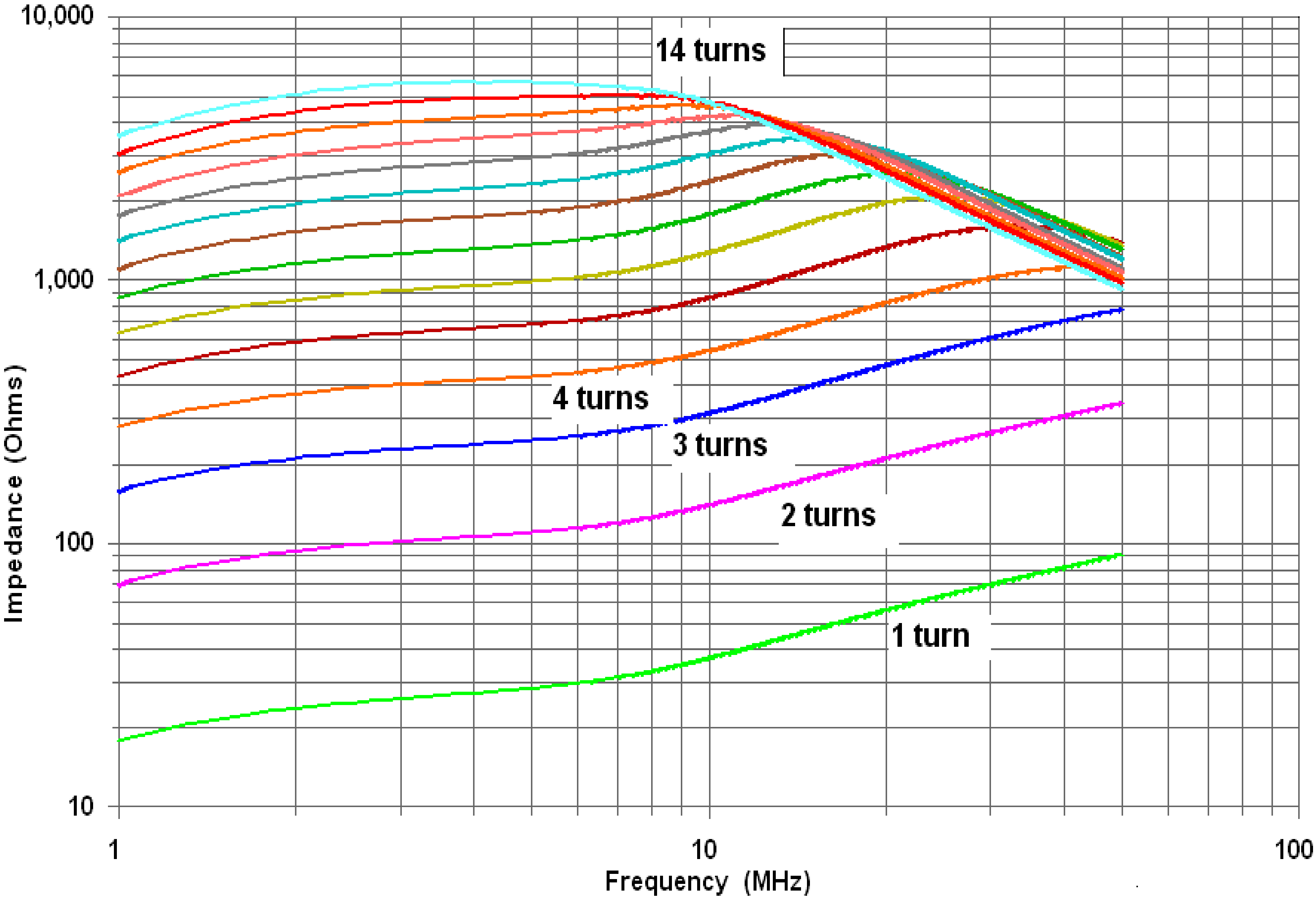
The Power of Turns at HF and MF

- Moves the resonance down from VHF to HF
  - More inductance
  - More capacitance
- Multiplies impedance at resonance
  - But not by N^2, because resonance has moved lower in frequency

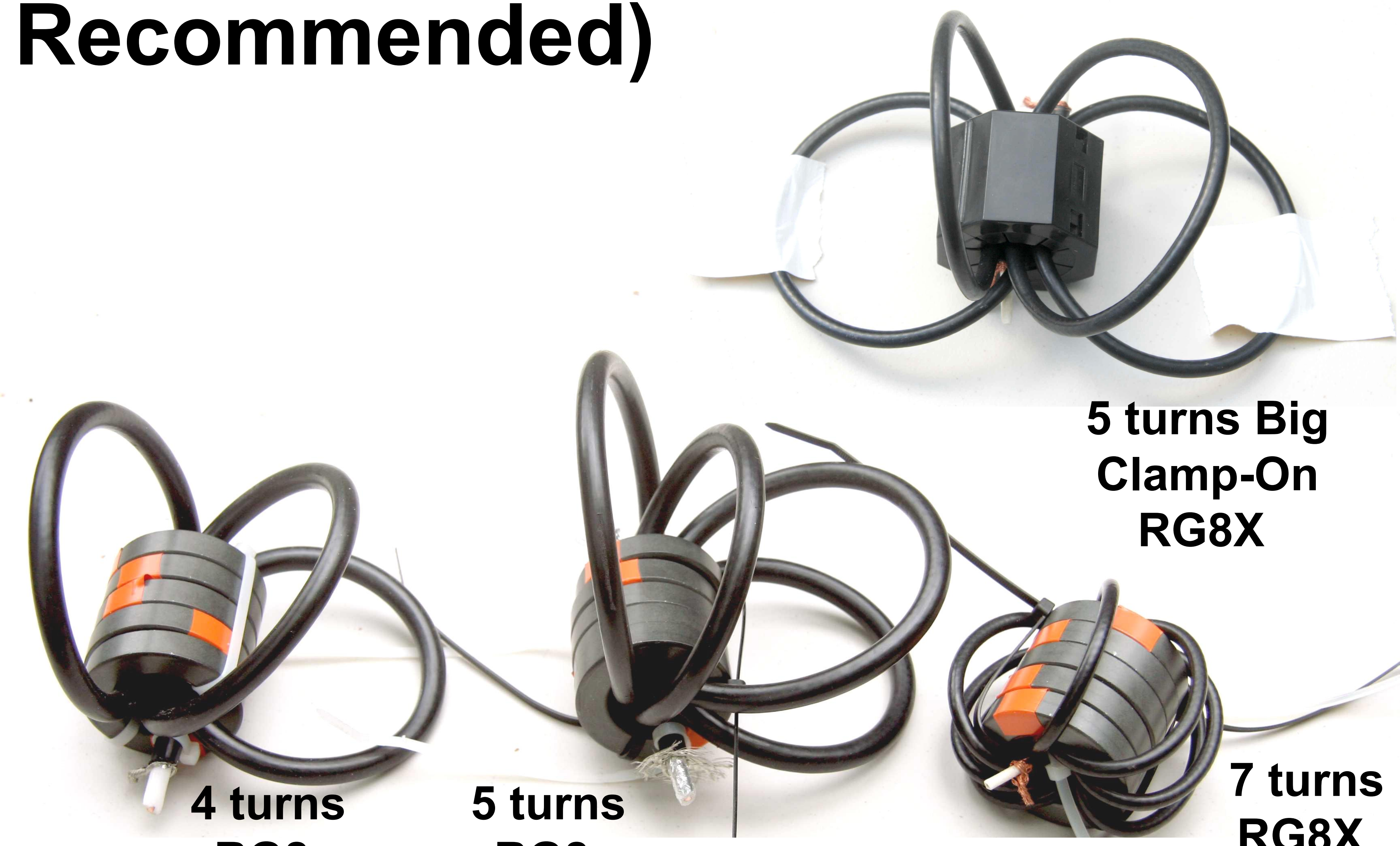
Measured Data for #43 Toroid Chokes



Measured Data for #31 Toroid Chokes



Earlier K9YC Chokes (No Longer Recommended)



Why No Longer Recommended?

- Poor repeatability due to variations in winding
  - Turn diameter
  - Turn spacing
  - Turns not wound in order cancel (“Cross-over turns”)
  - Coax diameter and dielectric affect both inductance and parallel capacitance

Let’s Talk About Dissipation (Heat, Power Handling)

Dissipation and Form Factor

- 1,500 W in 50 ohms = 275V @ 5.5A PEP
- Heat produced by the <u>average</u> power
  - With CW, ~ 3 dB less than PEP
  - SSB <u>without</u> speech processing or clipping ~ 14 dB less than PEP
  - SSB <u>with</u> heavy processing ~ 6 dB less than PEP
- Most power amps must be de-rated by 3 dB for RTTY, digital modes, FM, AM

Dissipation and Duty Cycle

- **We've got to listen sometime, so subtract another 3 dB (50% listening)**
- **Real world average ham power levels for intense contesting and DXing**
  - **~ 6 dB less than PEP for CW**
  - **~ 9 dB less than PEP for SSB**
  - **~ 6 dB less than PEP for RTTY, PSK, FM**

Heat in Common Mode Chokes

- **Heat (Power) is $I^2 R$**
  - **I and R are common mode values**
  - **Make R very large**
  - **I falls in proportion to R**
  - **P falls as I^2 so power (heat) falls twice as fast as R increases**
  - **Obtain current from the NEC model of the common mode circuit**

What About Heat?

- Heat is not a problem in coax chokes if R (the choking impedance) is large enough
- How large is enough?
- For an antenna with reasonably good balance, R = 10,000 ohms keeps dissipation low

Failures From Excessive Voltage

- $P = E^2 / R$
- Causes of excessive voltage
  - Antenna systems that make E very large
  - Feedline length near λ/2, λ, 3λ/2, 2 λ, etc.
  - Antenna tuners that step voltage up to high impedance lines
  - Severe imbalance
- Let’s study an example in NEC

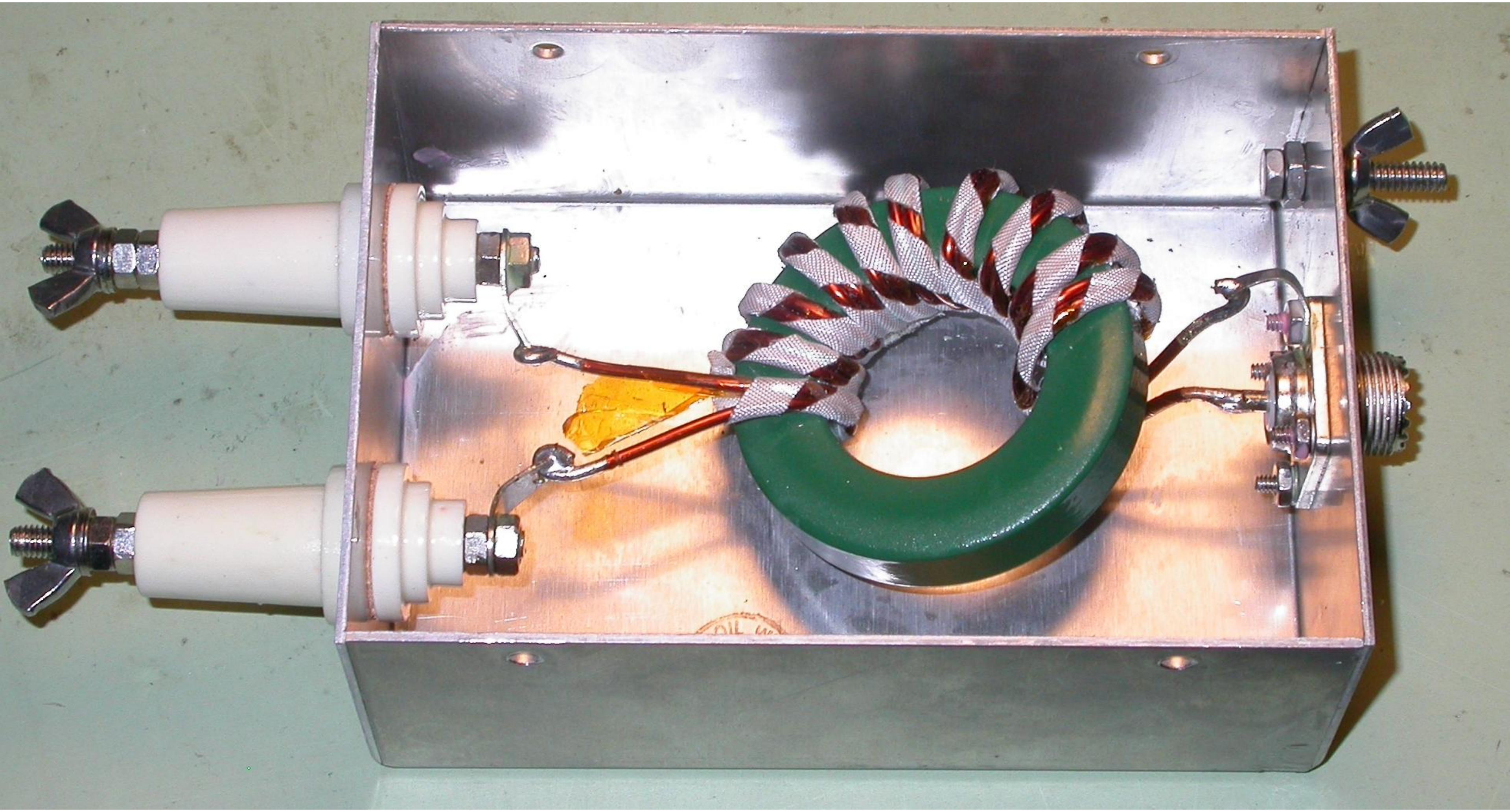
A Real Antenna, Unbalanced

- **NEC Model of 40M dipole, fed by 67 ft of coax (half wave), 5,000 ohm choke (Vf ~ 0.98 for common mode)**

	PEP		Constant CQing	
Legs (Ft)	Power	Volts	CW, FM, RTTY, PSK	SSB
30 - 36	30 W	387 V	8 W	4 W
27 - 39	80 W	632 V	24 W	12 W
24 - 42	150 W	866 V	40 W	20 W
20 - 46	253 W	1125 V	80 W	40 W

Chokes Must Be Exposed to Air Flow For Good Power Handling

A choke in a closed box is much more likely to overheat



Causes of Choke Failures

- Feedline near λ/2 combined with strong antenna imbalance
- Insufficient air circulation
- Choking impedance too low

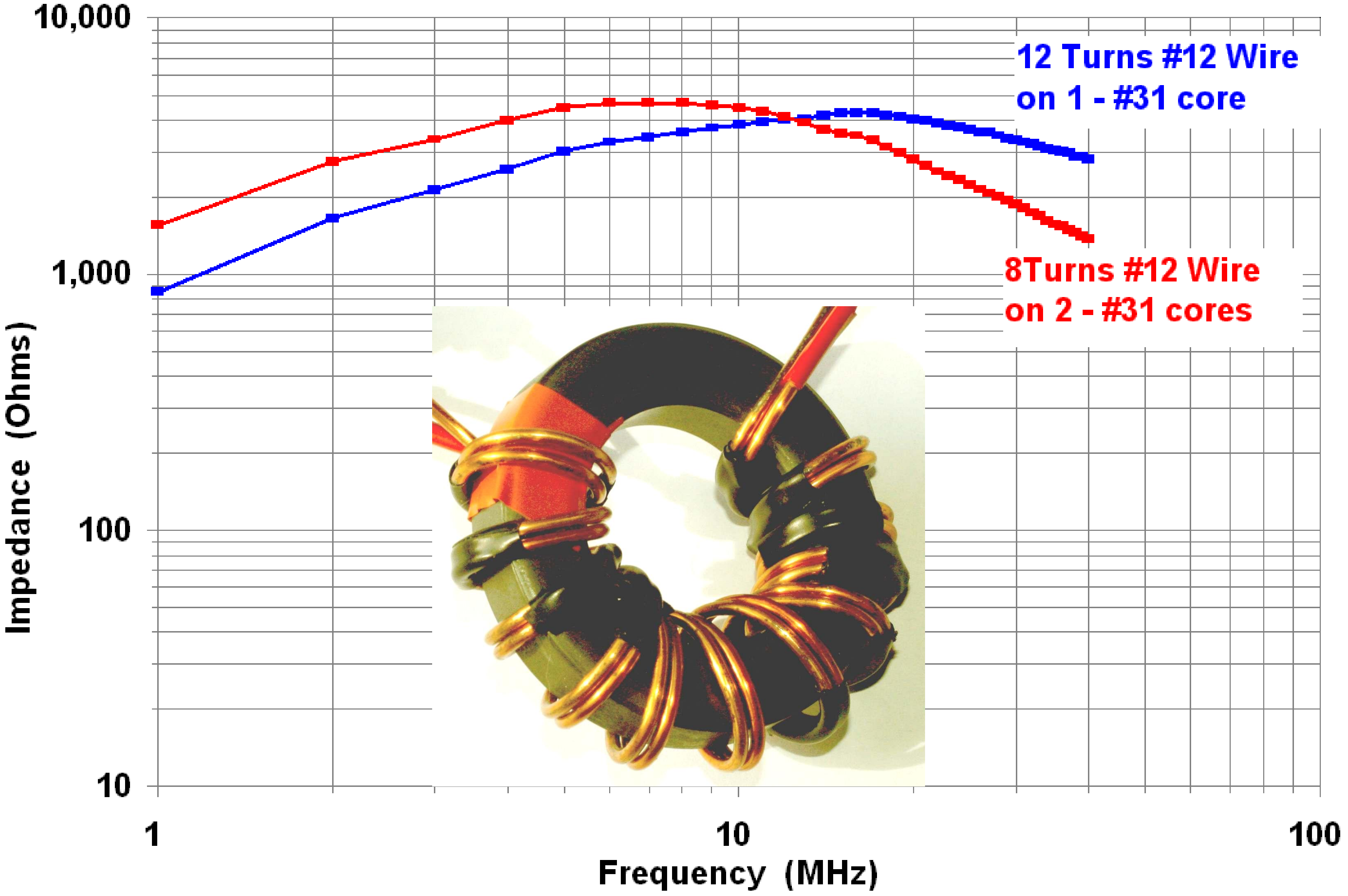
How Much Choking Z is Enough?

- **If your antenna is well balanced, 10,000Ω is plenty**
- **If your antenna has severe imbalance, 30,000Ω may not be enough**
- **Chokes on Windom and other Off-center fed antennas are notorious for failing**

What About Bifilar Chokes?

- **These bifilar chokes are wired simply as a short section of balanced line wound around one or two cores**

Bifilar chokes on #31 (lossy) toroid

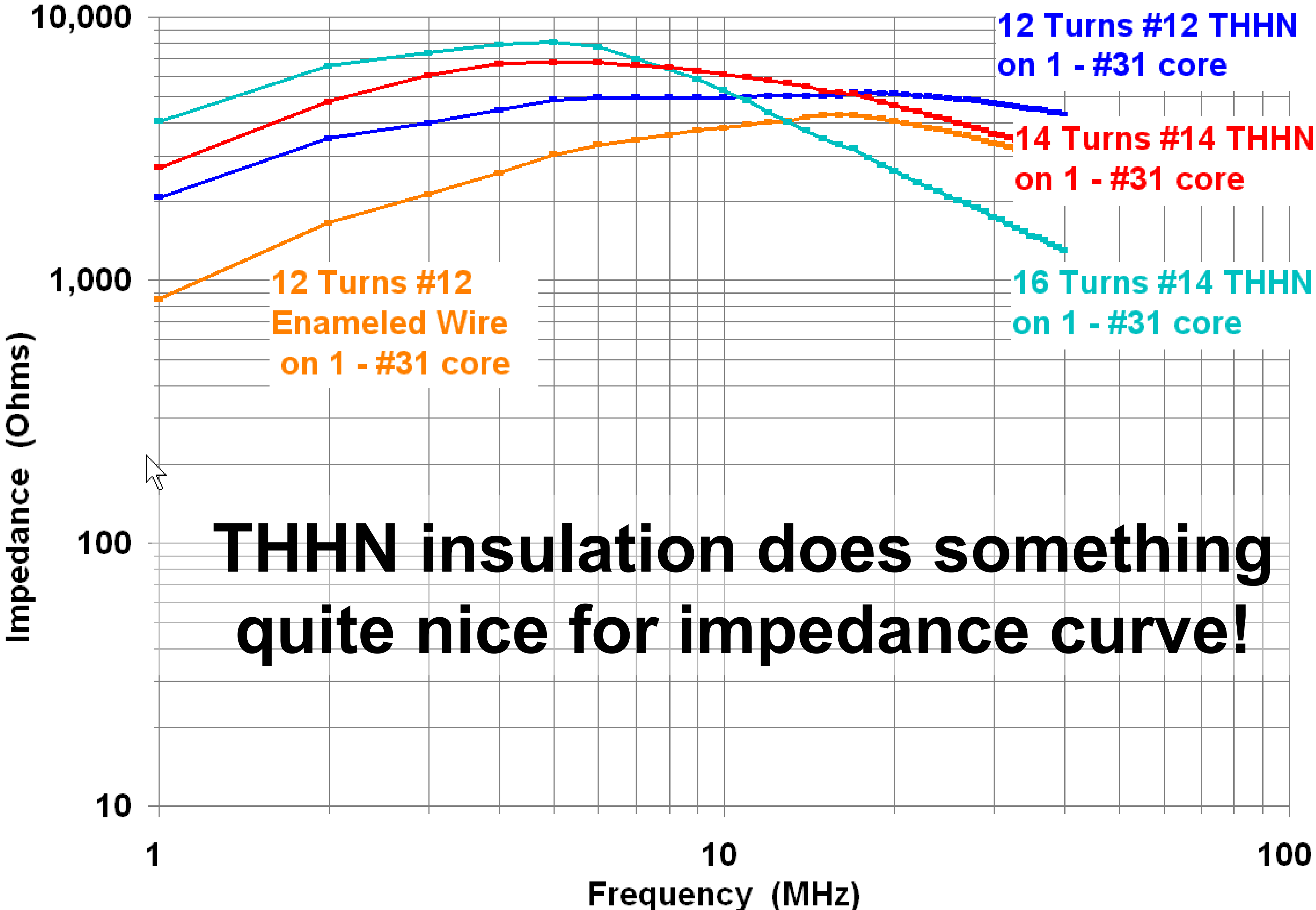


Bifilar Chokes

- I was looking for a low cost choke that anyone can build cheaply
- Enameled wire is hard to find and not cheap
- Voltage rating depends on enamel coating, varies widely
- How about THHN? (House Wire)

Chokes wound with #14 THHN (ordinary house wire)

Bifilar chokes on #31 (lossy) toroid



Z_O of Bifilar Windings

- **Winding is a 2-wire transmission line**
- **Z_O depends on spacing, wire size, and dielectric**
- **Z_O For #12 - #14 wire**
  - **Close spaced enameled wire ~ 50 ohms**
  - **Close spaced THHN ~ 100 ohms (Sevick)**
- **Study k9yc.com/2018Cookbook.pdf for detailed recommendations**

Impedance of THHN Windings

- Does the mismatch matter?
- It’s a short length of line
  - 12 turns ~ 30 inches of line
    - Less than λ/20 at 14MHz, λ/10 at 28 MHz
  - 16 turns ~ 40 inches of line
    - Less than λ/50 at 4 MHz
- These small mismatches don’t affect loss, easily matched by antenna tuner
- A small price to pay for high choking impedance and bandwidth!

Can They Handle High Power?

- Patched in series with my Titan amp at 1.5kW, they barely got warm!
  - Choke saw only differential power
  - All the heat was in the wire <u>where it was wound around the core</u>
  - No heating in the core itself!
  - No heating in the wire <u>away</u> from the core
- Like any other choke, dissipation due to common mode will be small if the antenna has reasonable balance

Bifilar Chokes

- **Leakage flux is quite small with a good bifilar winding**
  - **Very good symmetry and uniformity**
- **Loss shows up as heating in the <u>wire</u>, not the core**
  - **Large wire (#14, #12) for high power**
- **Use same cores and winding guidelines as for small wire**

How Much is Current Reduced?

- **NEC Model of 80M dipole @ 129 ft, fed with 129 ft of coax (Near half wave – Vf ~ 0.98 for common mode)**
- **Without choke, feedline current is 1/3 of antenna current (-10 dB)**
- **Adding 5,000 ohm choke reduces feedline current by an additional 24 dB**

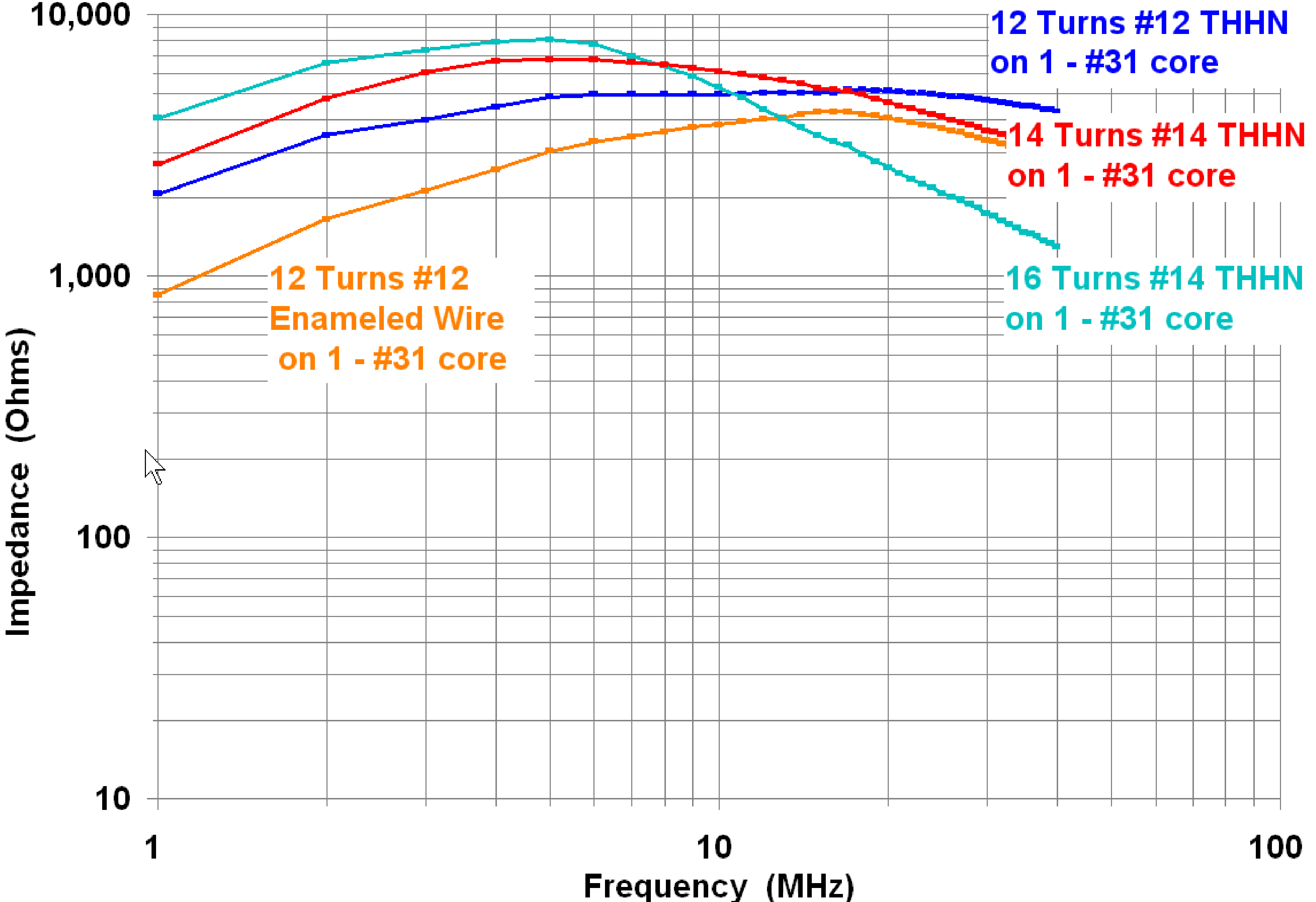
How Much is Current Reduced?

- NEC Model 80M dipole @ 66 ft, fed with 66 ft of coax (near quarter wave)
- Without choke, common mode current at TX end is 1/12 of antenna current (-22 dB), -38 dB at feedpoint
- Adding 5,000 ohm choke has no effect on feedline current

Bifilar Chokes Work in Coax Lines

- Much lower cost, much more compact
- See k9yc.com/2018Cookbook.pdf for detailed recommendations per band
  - #12 THHN solid pair
  - #12 Teflon stranded silver-coated copper
  - RG400 (50Ω, silver coated stranded copper center, double silver-coated copper braid shield)

Bifilar chokes on #31 (lossy) toroid



See K9YC's New Choke Cookbook

http://k9yc.com/2018Cookbook.pdf

How About Commercial Products?

We Can Build At Least as Good As We Can Buy, and for the cost of the cheapies!

- We must stock up on the right parts, buying in quantity

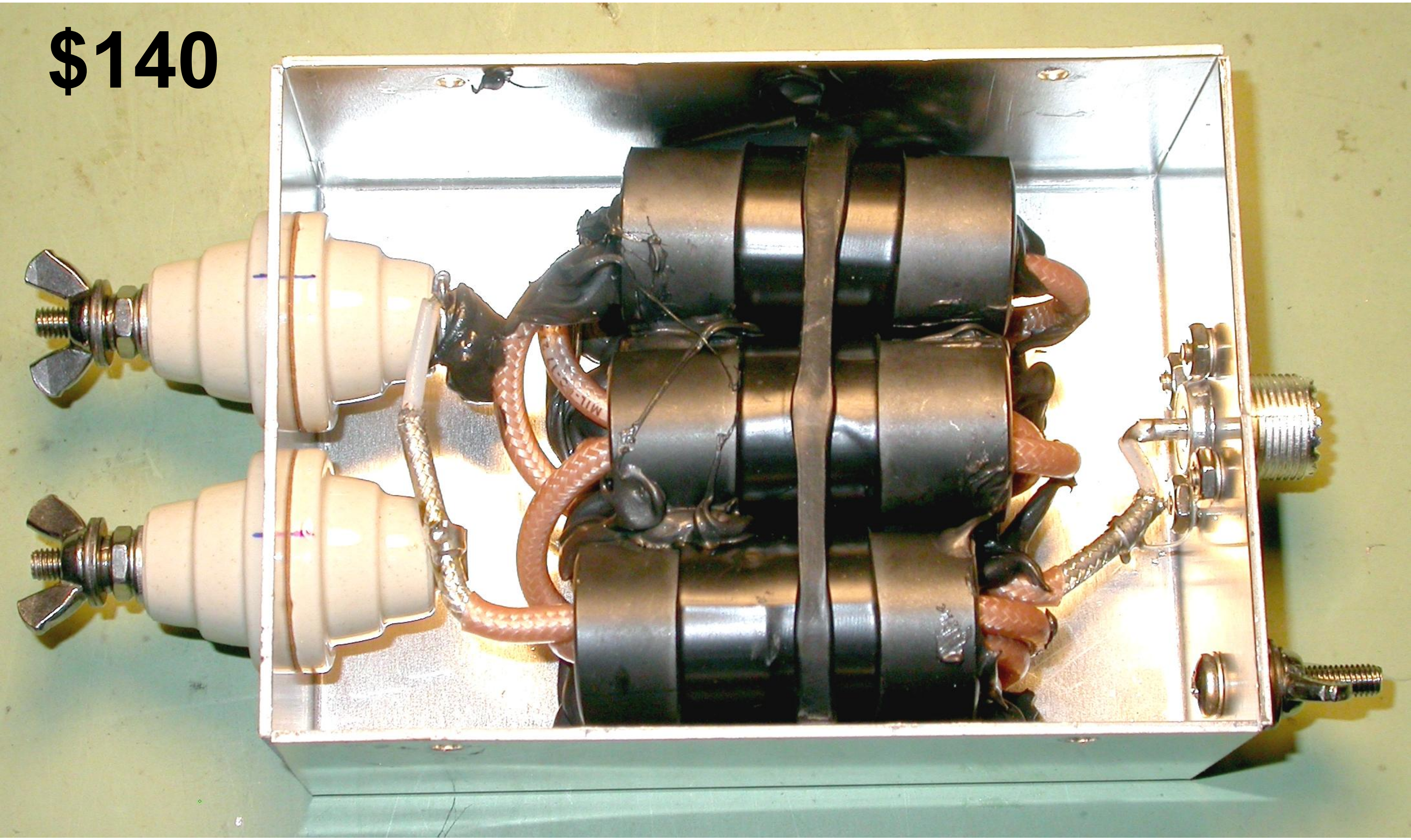
Who Makes Ferrites?

- **Most ham ferrite parts are made by Fair-Rite**
  - **A big company in upstate NY**
- **Ham distributors simply resell them**
  - **Disguised by invented part numbers (FT240-61)**
  - **<u>Very</u> high markups (typically 3-5x cost)**
  - **Palomar, Amidon, The Wireman**
  - **Often the “wrong” parts for best performance!**

How to Buy Ferrites?

- Get part numbers from my tutorial
  - http://k9yc.com/2018Cookbook.pdf
  - http://k9yc.com/KillingReceiveNoise.pdf
- Buy in <u>quantity</u> from distributors listed on the Fair-Rite website
  - Arrow, Newark, Allied, Lodestone Pacific, Kreger, Dexter Magnetics
- Don’t be a cheap ham
  - Think big – it costs more to think small!
  - Spend your money <u>wisely</u>

DX Engineering 50Ω Choke Balun

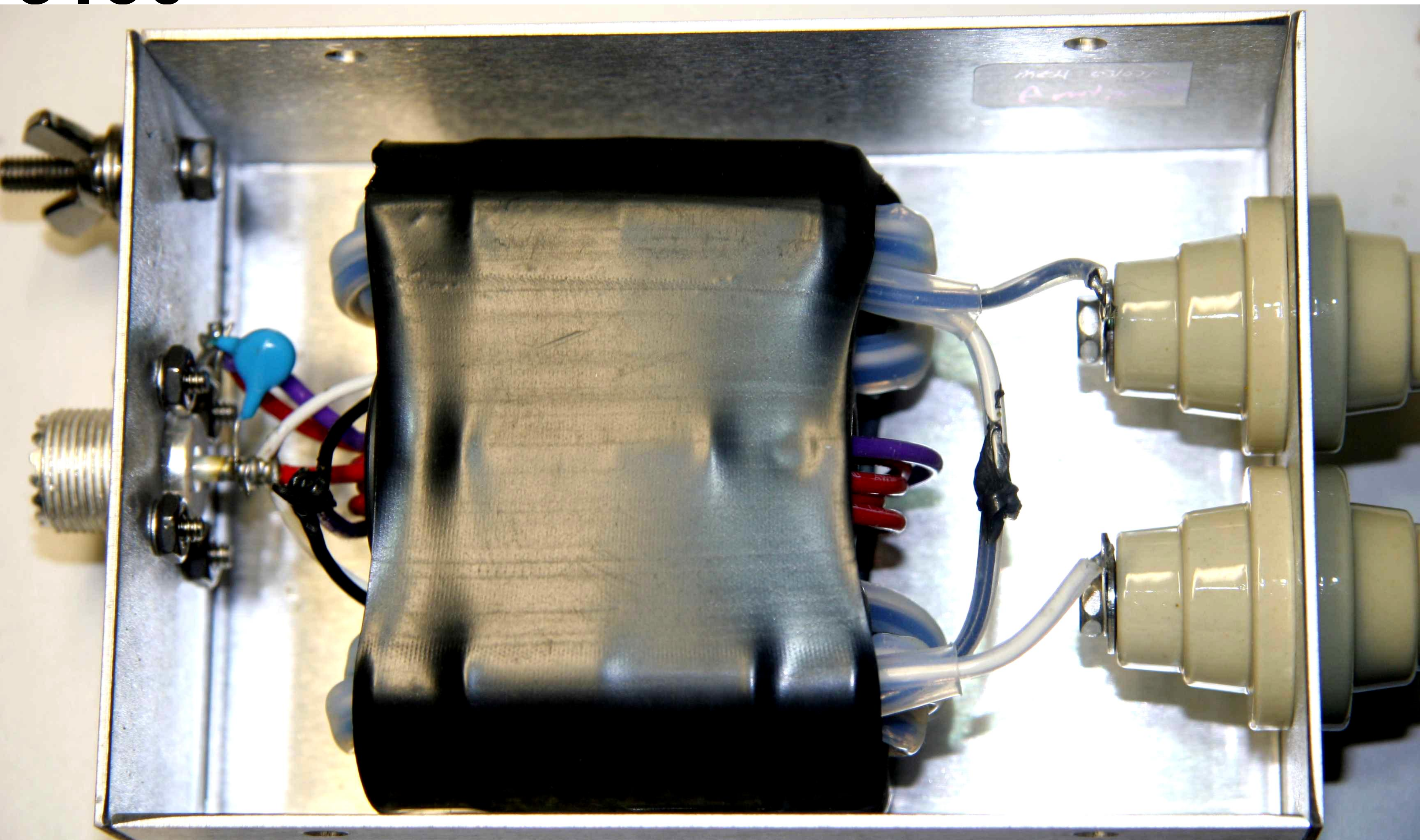


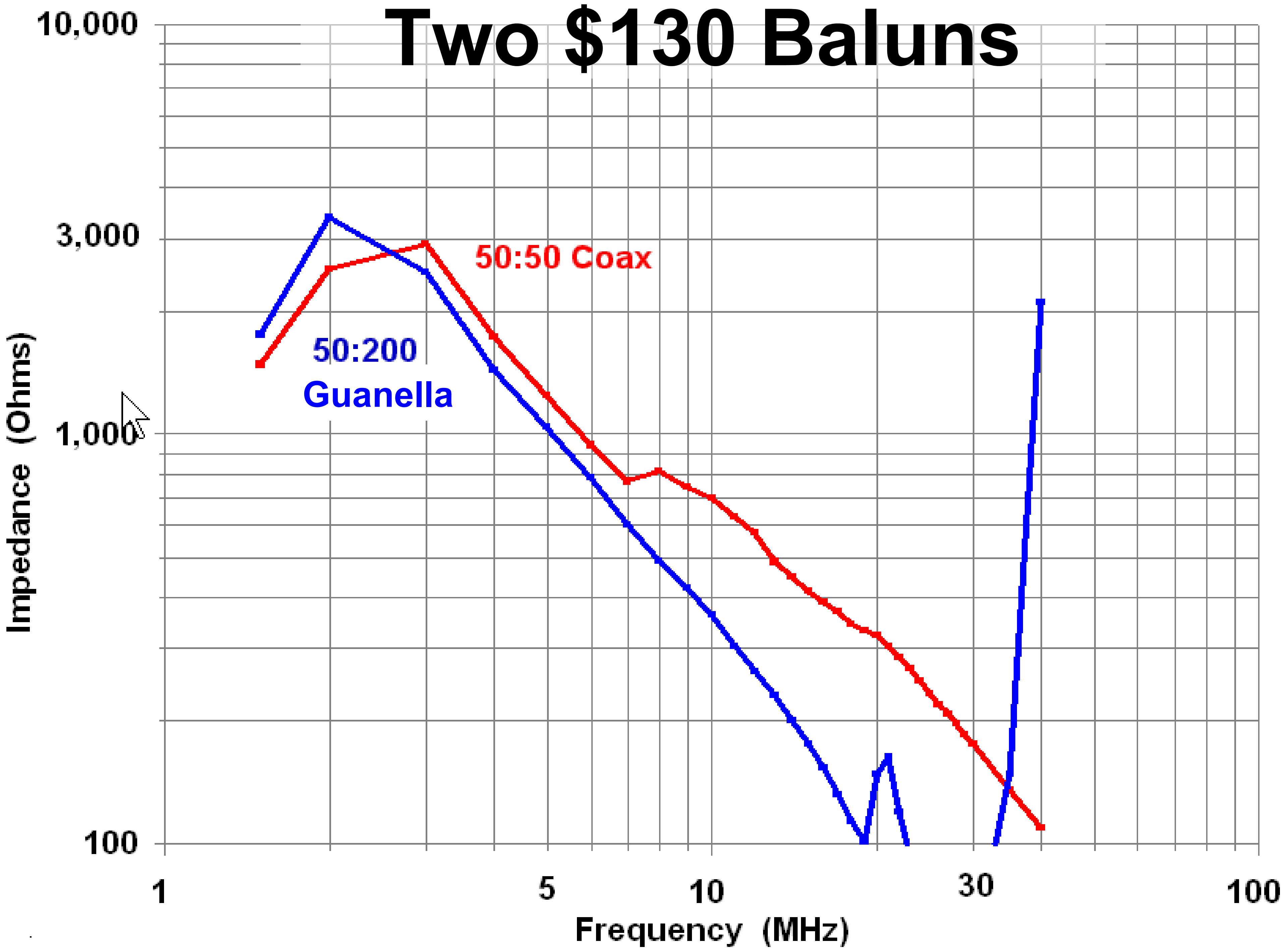
DX Engineering 200Ω – 50Ω Bifilar Choke Balun

$130

DX Engineering 300Ω – 50Ω Bifilar Choke Balun

$130

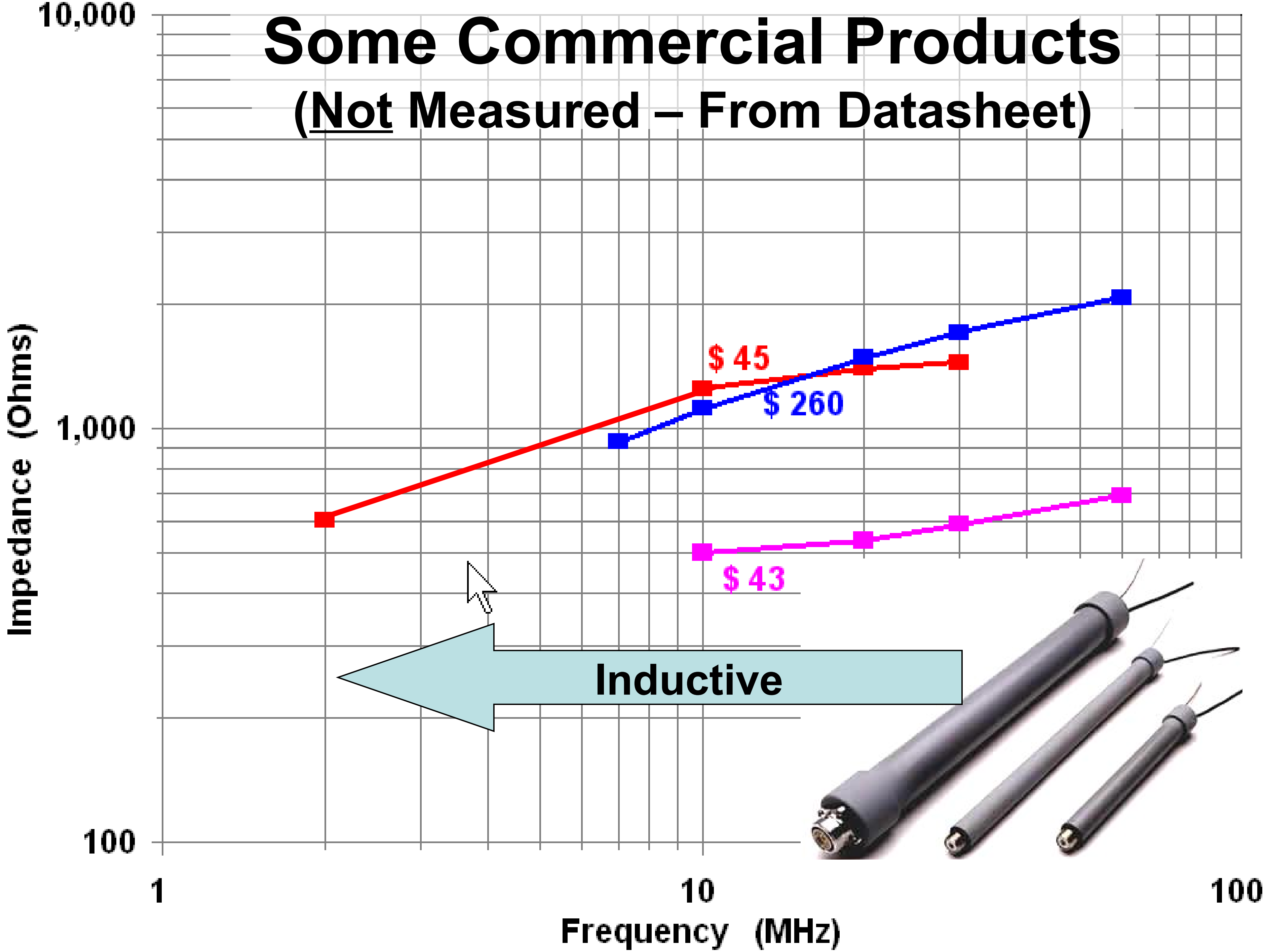




Two $130 Baluns
10,000
3,000
1,000
100
Impedance (Ohms)
50:50 Coax
50:200
Guanella
1
5
10
30
100
Frequency (MHz)

Some Commercial Products

(Not Measured – From Datasheet)



See K9YC's Choke Cookbook for specific recommendations

http://k9yc.com/2018Cookbook.pdf

The Measurement Problem

Measuring Coax Chokes

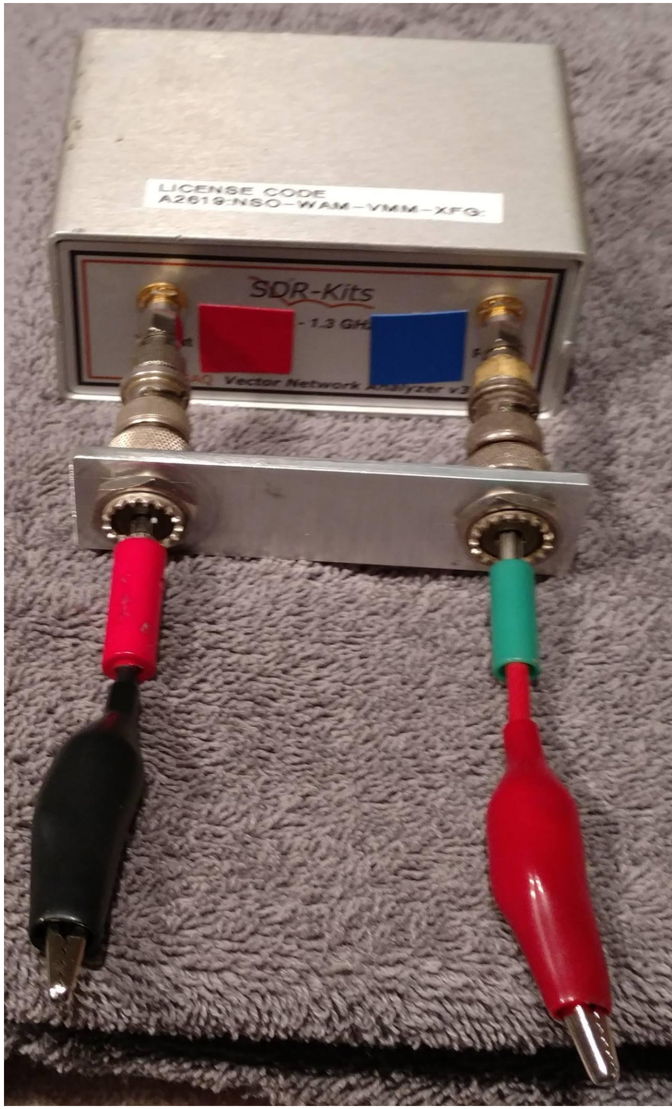
- Very difficult to measure
- Traditional "reflection" measurements give wrong results
  - Poor accuracy if 5 ohms > Zx > 500 ohms
- Stray capacitance of fixture causes additional errors
  - Some VNA's and other analyzers that claim to subtract it out <u>don't</u>
- A lot of smart people have missed all this!

Finding the Equivalent Circuit

- It's a parallel resonant circuit
  - R_P is the peak value of measured Z_{MAG}
  - L_P is the value that causes the computed curve to match the measured data below resonance
  - C_P is the value that resonates with L_P at the measured F_{RES}
  - Plot R_P, L_P, and C_P on same axes as measured data
  - Tweak L_P and C_P for best curve fit

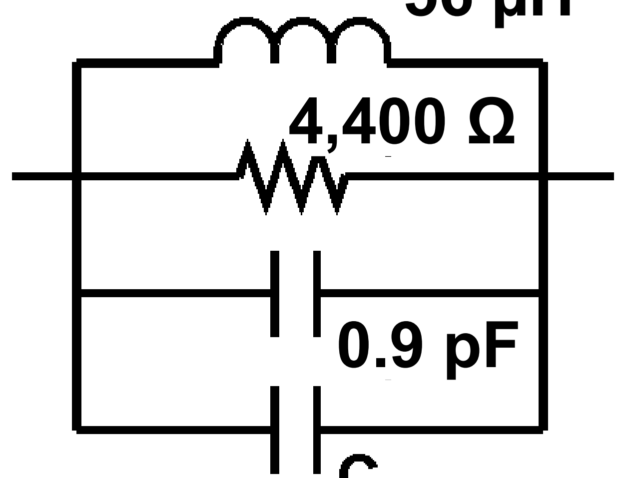
My Current Test Setup

- **VNA replaces HP gear**
- **Same measurement circuit**
- **Measures S21 (complex)**
- **DG8SAQ software computes and plots Z_{MAG}, R_S, X_S**
- **It takes ~3 minutes to make a measurement and save it**
- **VNWA 3EC**
  https://www.sdr-kits.net



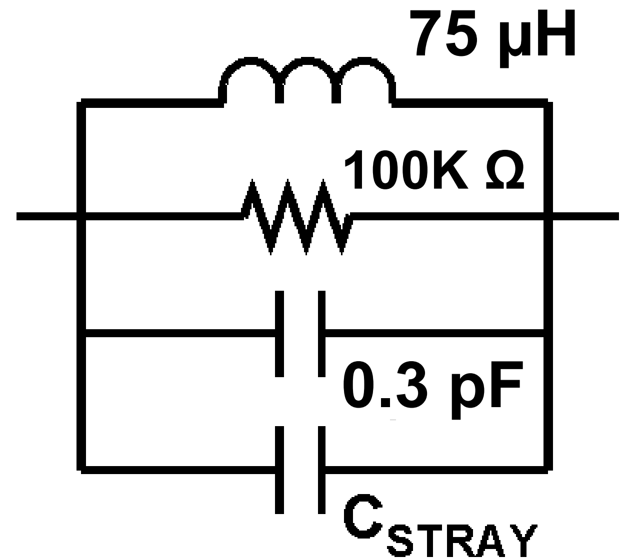
What are we Trying to Measure?

#31



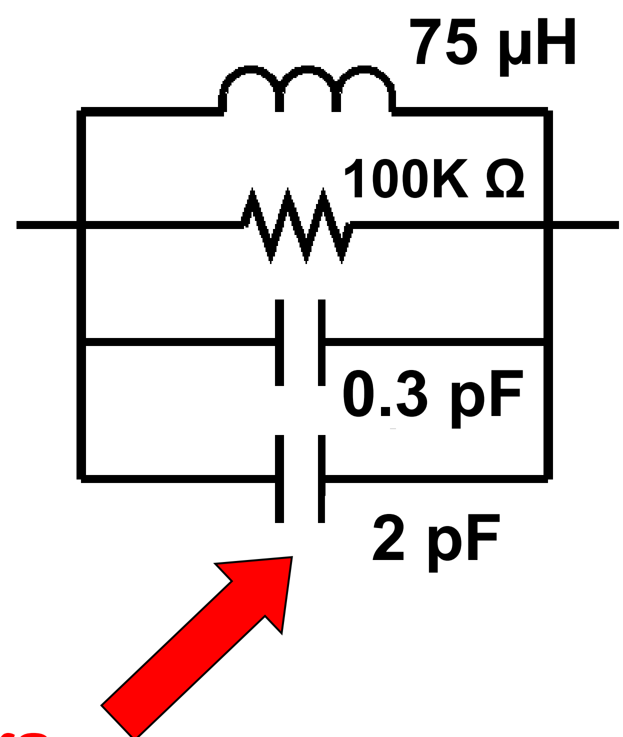
What are we Trying to Measure?

#61



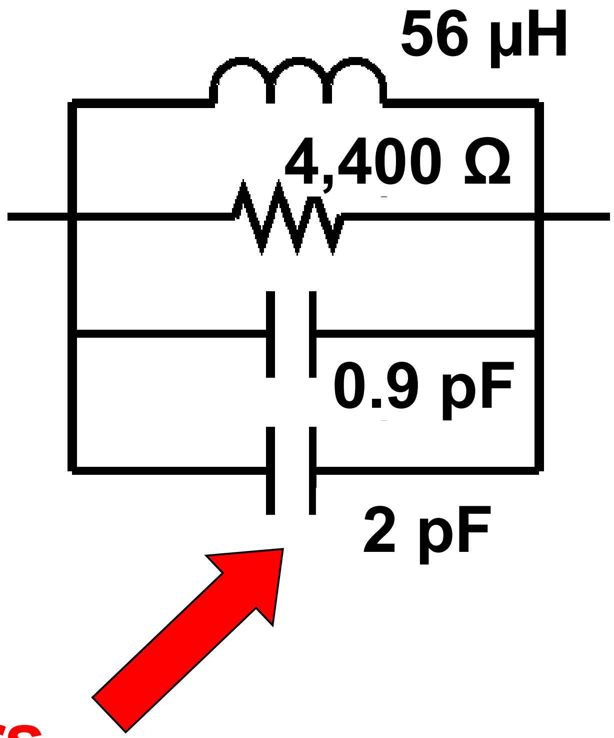
What are we Trying to Measure?

#61



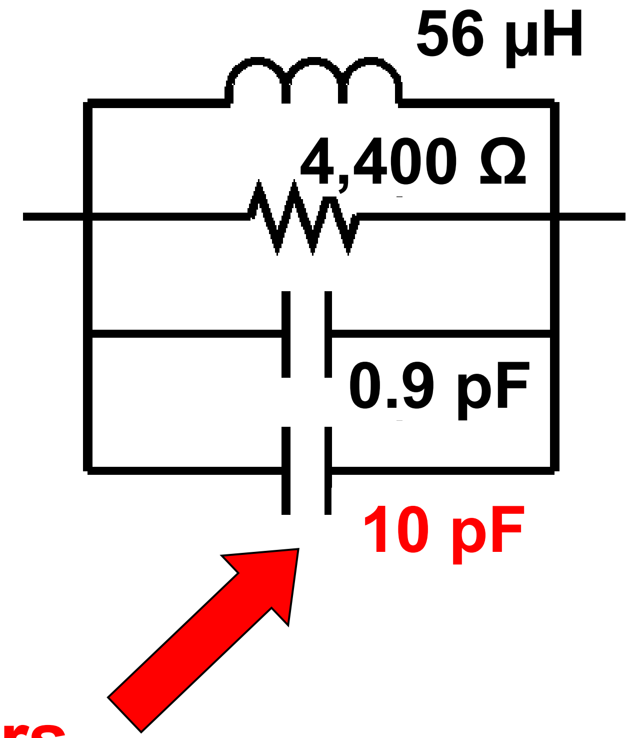
Typical "good" analyzers

What are we Trying to Measure?



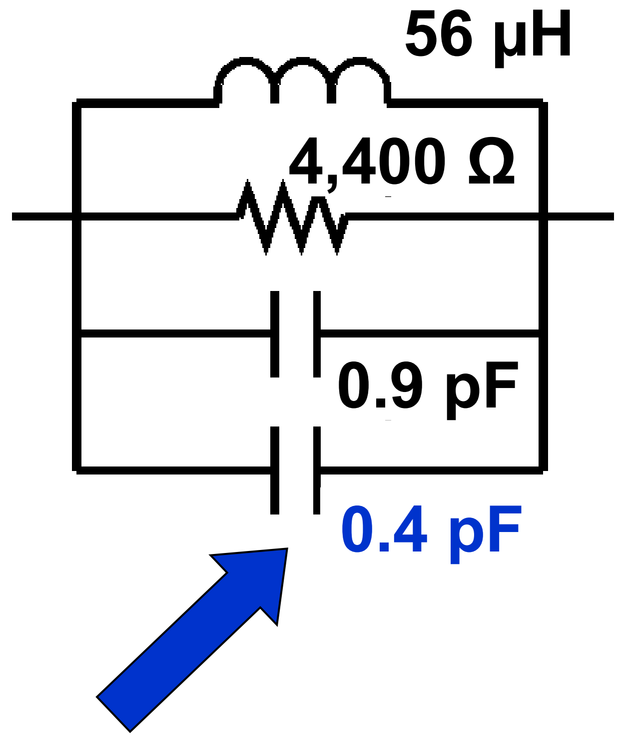
Typical "good" analyzers

What are we Trying to Measure?



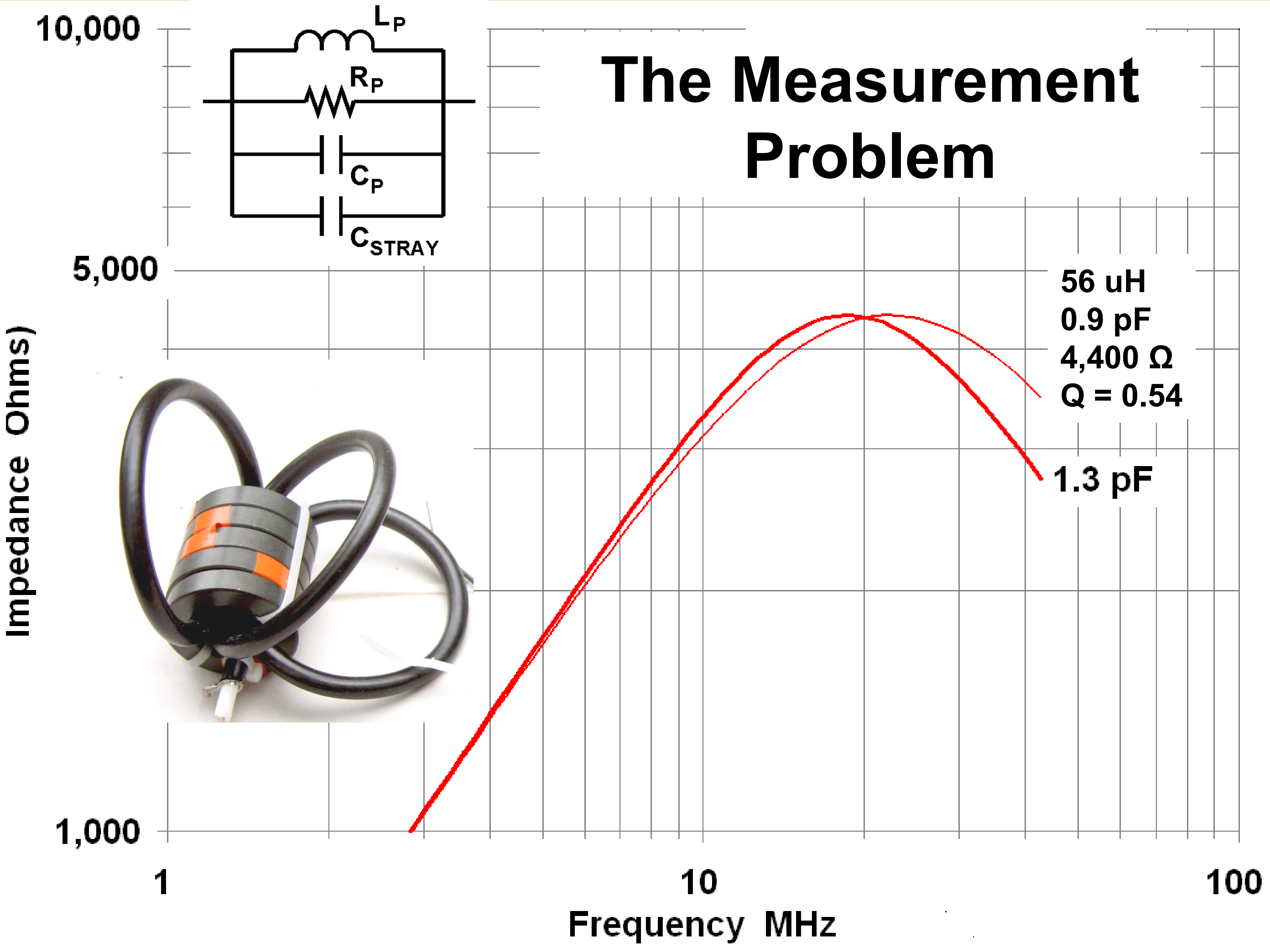
Typical "antenna" analyzers

What are we Trying to Measure?

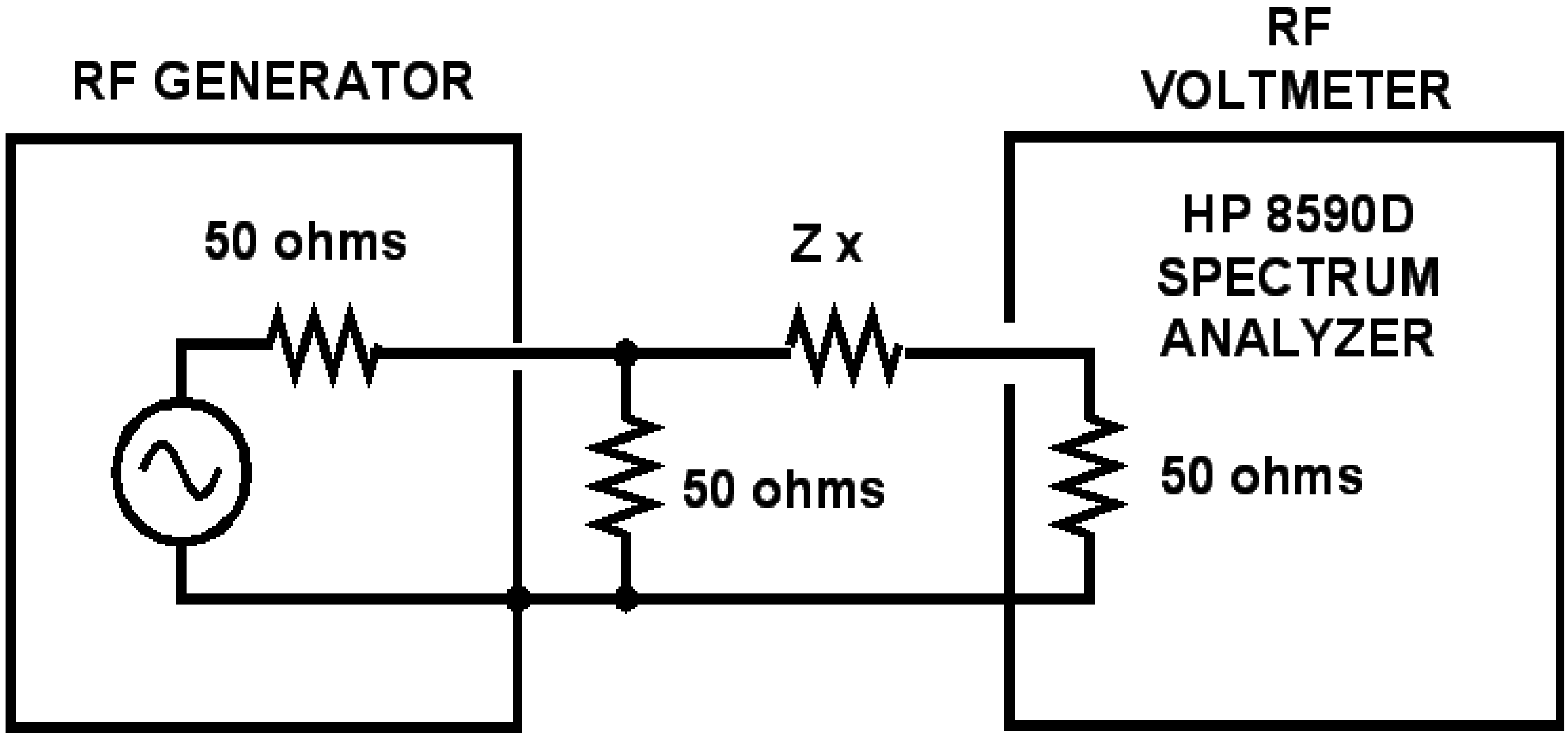


My 2008 measurement setup

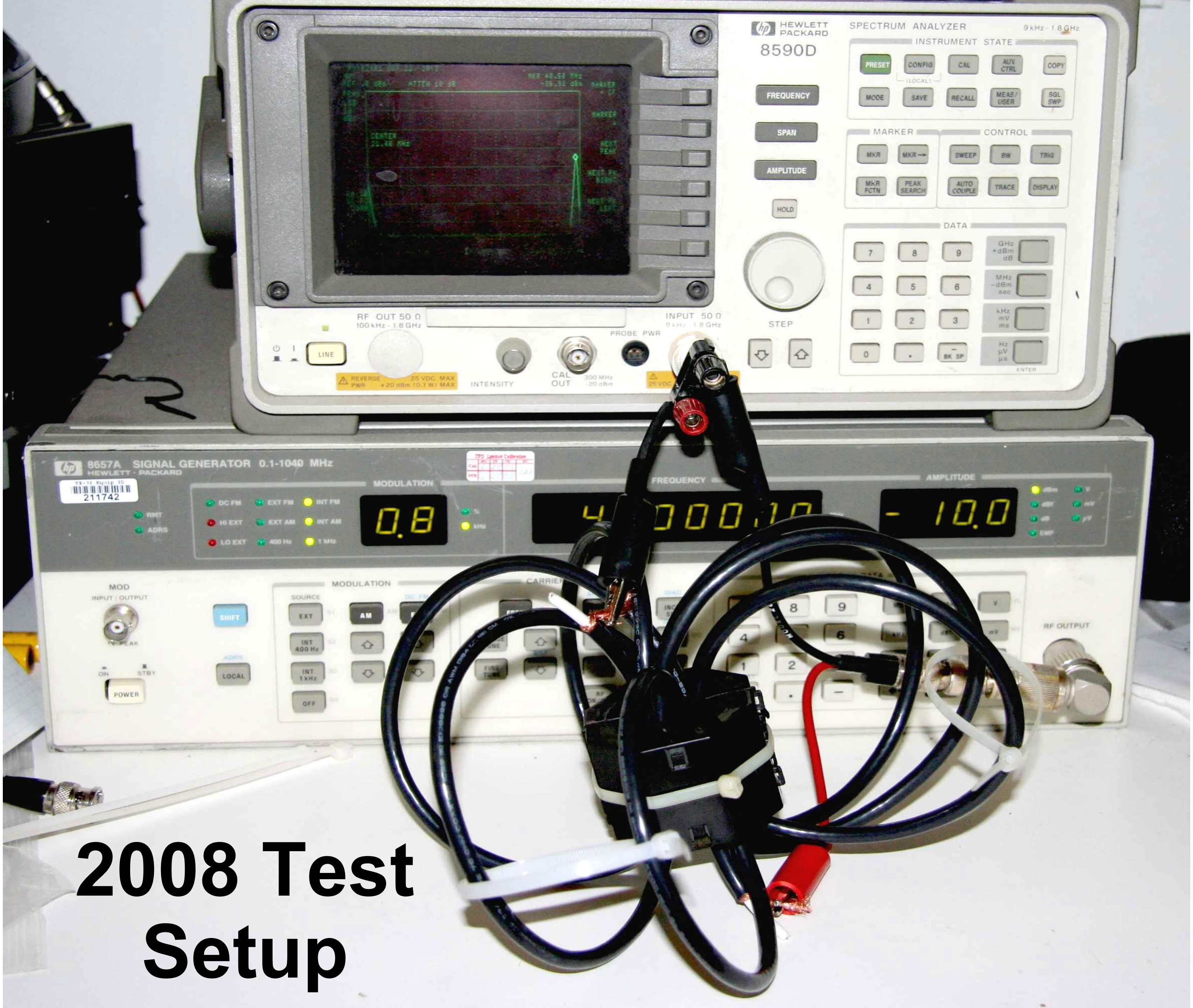
The Measurement Problem



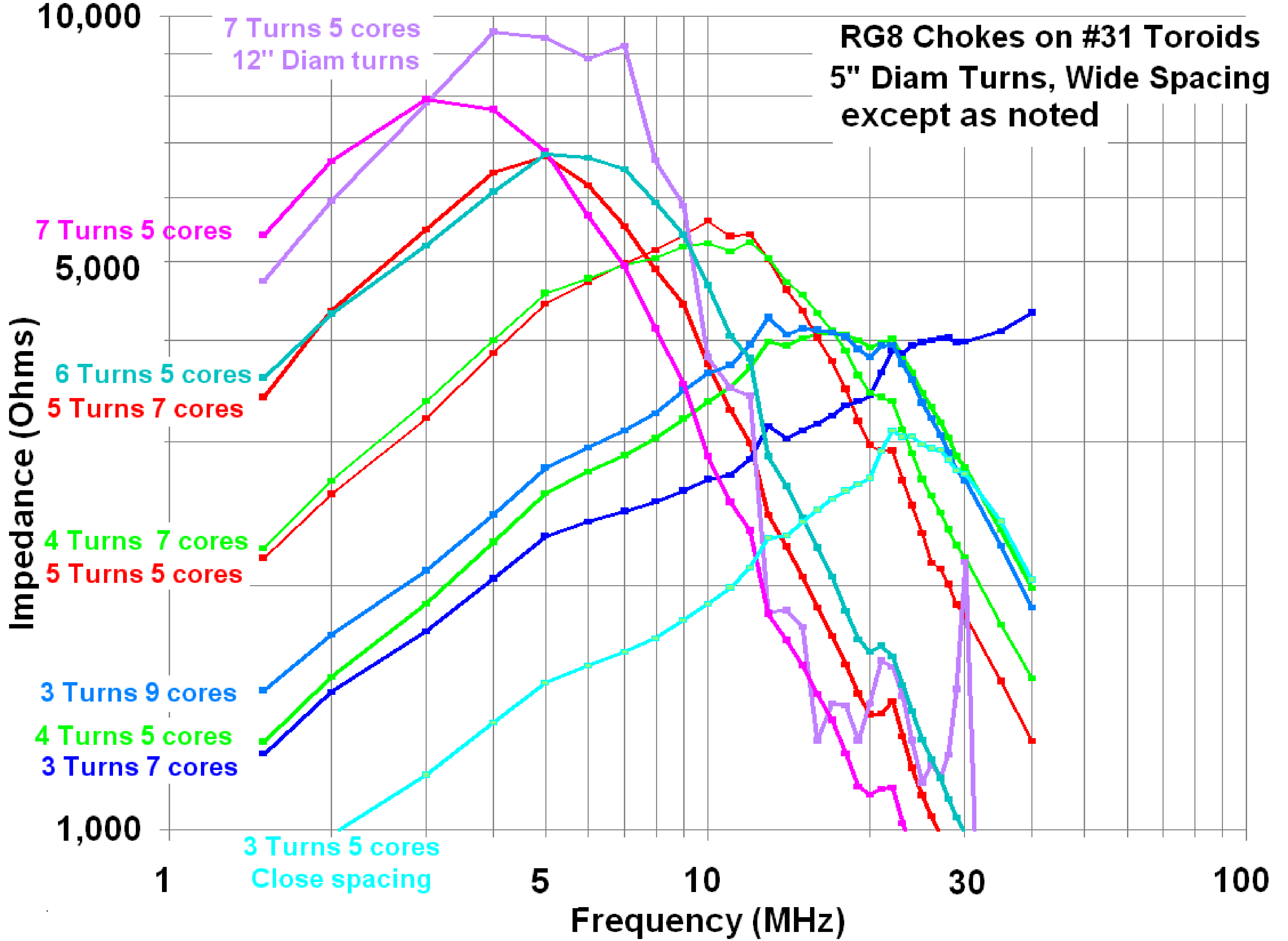
My 2008 Test Setup



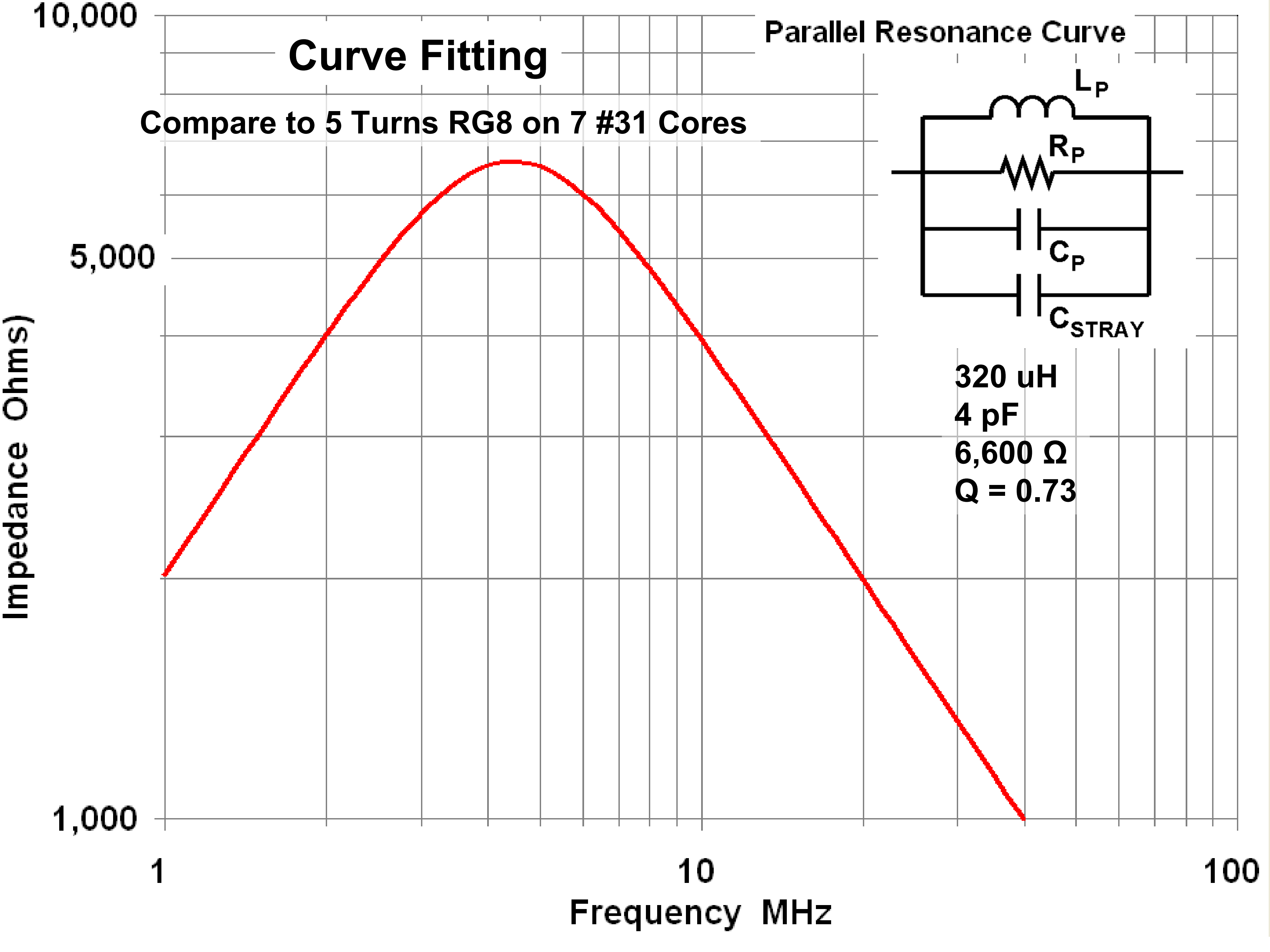
2008 Test Setup



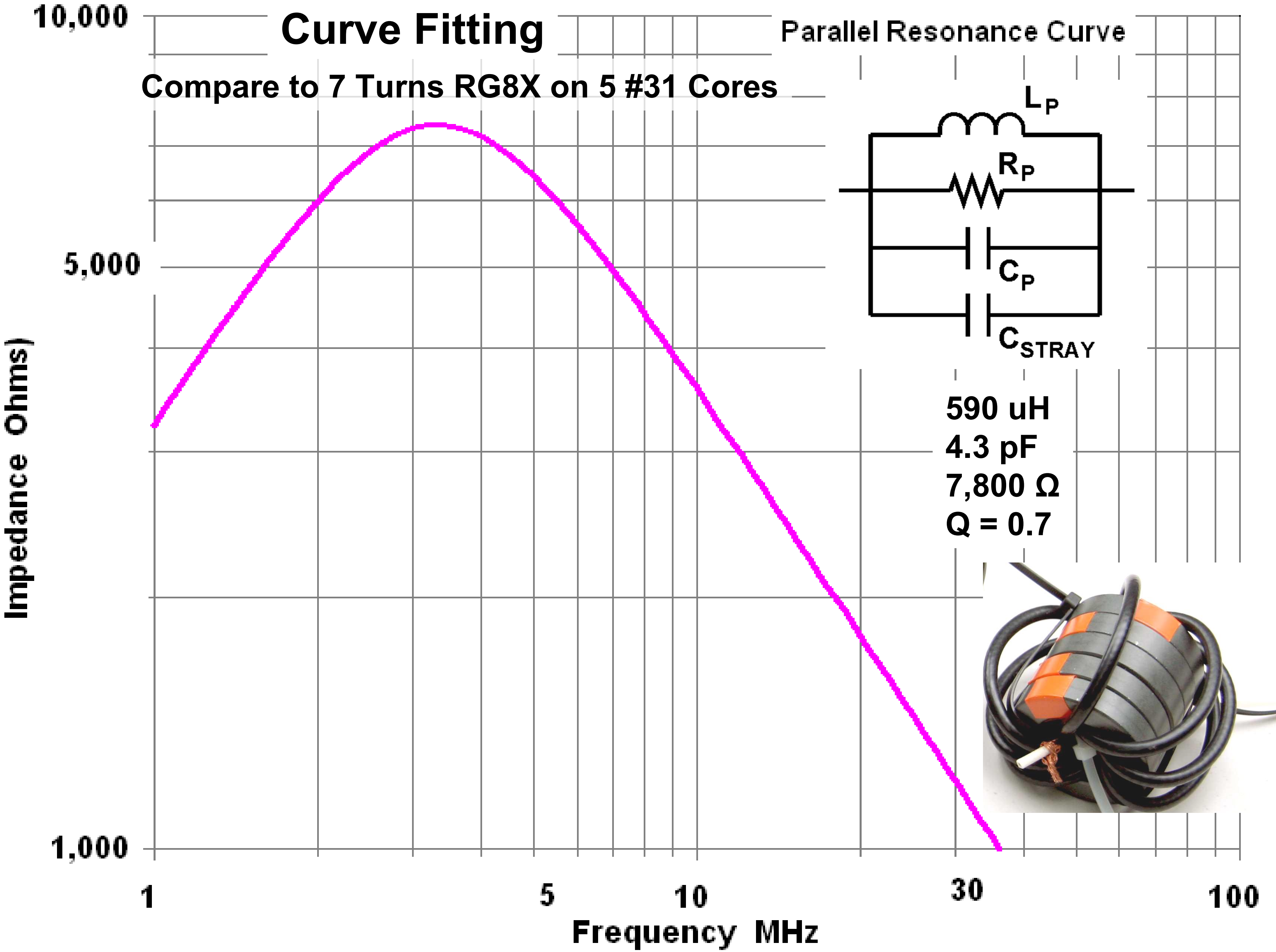
2008 Test Setup

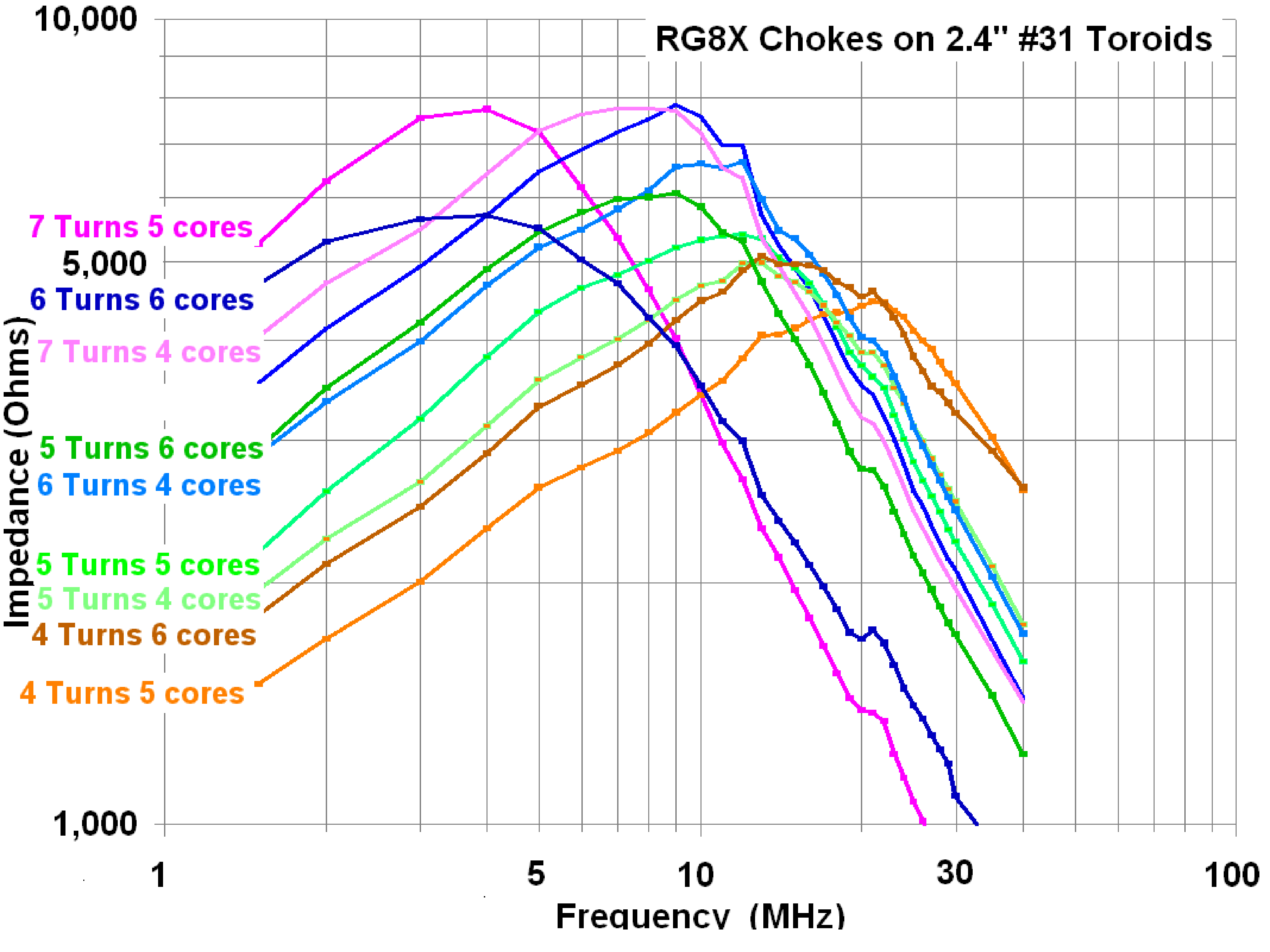

RG8 Chokes on #31 Toroids
5" Diam Turns, Wide Spacing
except as noted
7 Turns 5 cores
12" Diam turns
7 Turns 5 cores
6 Turns 5 cores
5 Turns 7 cores
4 Turns 7 cores
5 Turns 5 cores
3 Turns 9 cores
4 Turns 5 cores
3 Turns 7 cores
3 Turns 5 cores
Close spacing
10,000
5,000
1,000
Impedance (Ohms)
1
5
10
30
100
Frequency (MHz)

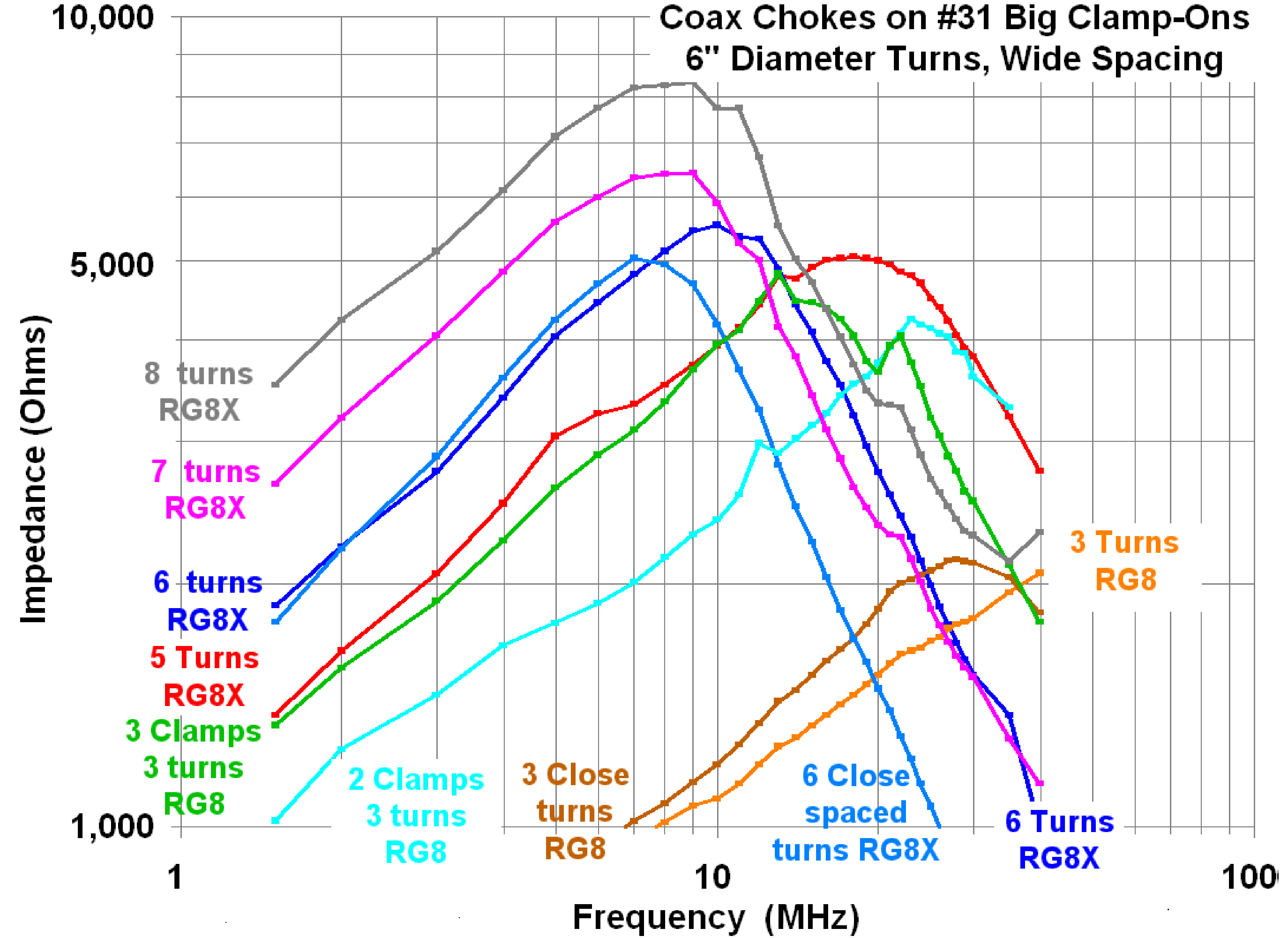
Finding The Equivalent Circuit of a Choke



Curve Fitting
Compare to 5 Turns RG8 on 7 #31 Cores
Parallel Resonance Curve
L P
R P
C P
C STRAY
320 uH
4 pF
6,600 Ω
Q = 0.73
10,000
5,000
1,000
Impedance Ohms)
1
10
100
Frequency MHz

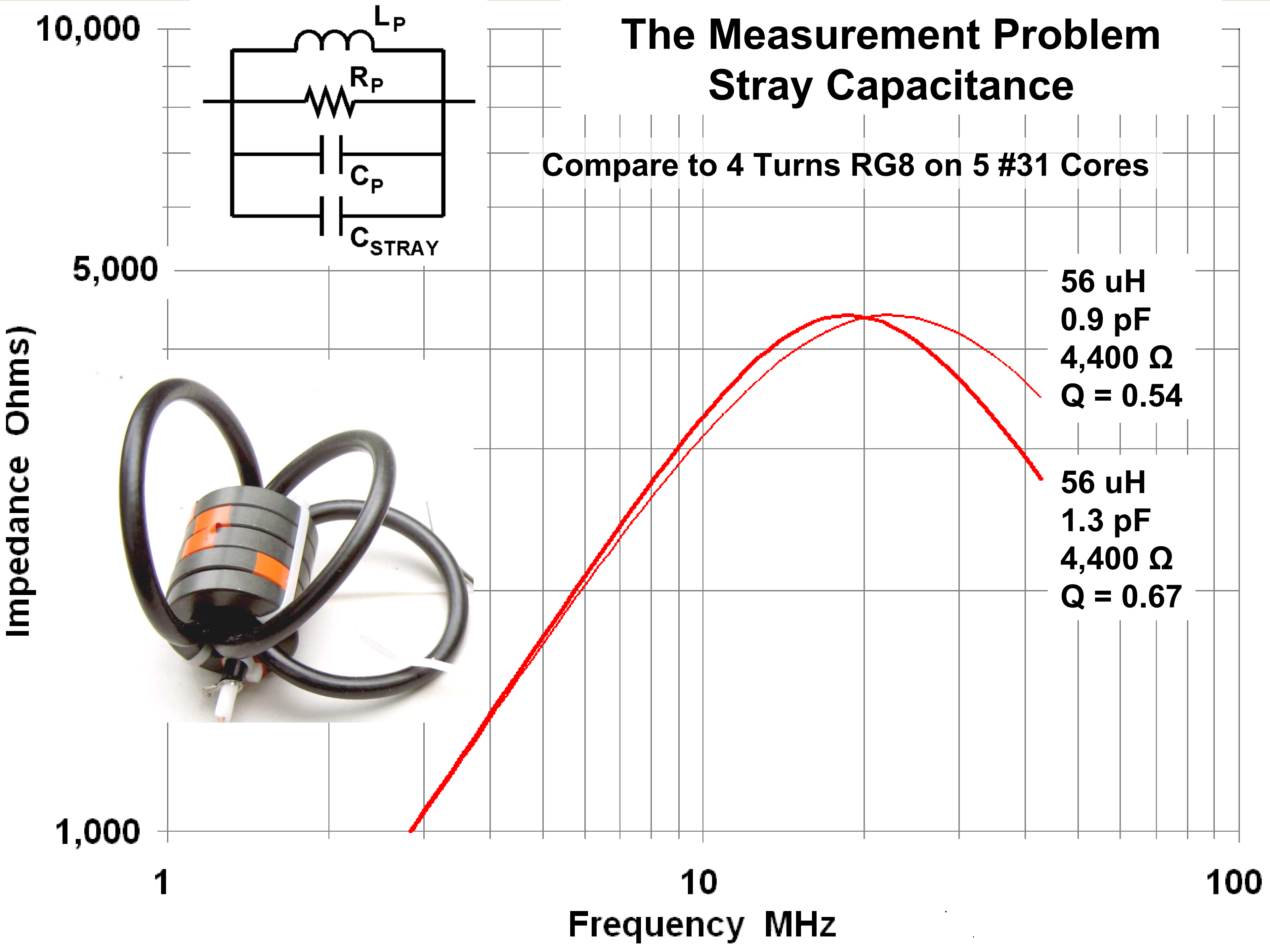

Curve Fitting
Compare to 7 Turns RG8X on 5 #31 Cores
Parallel Resonance Curve
L_P
R_P
C_P
C_{STRAY}
590 uH
4.3 pF
7,800 Ω
Q = 0.7
10,000
5,000
1,000
Impedance Ohms)
1
5
10
30
100
Frequency MHz

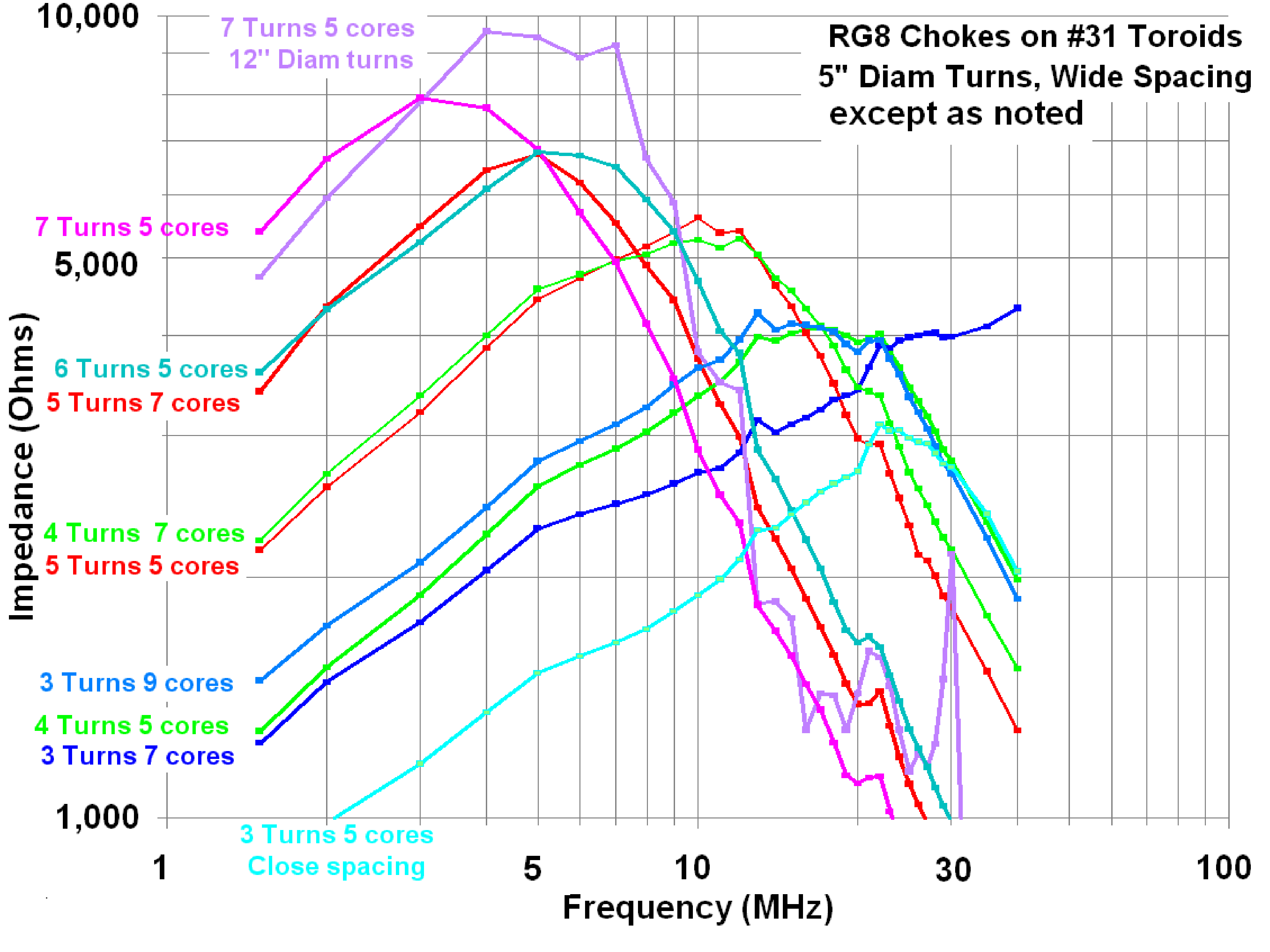

RG8X Chokes on 2.4" #31 Toroids
10,000
5,000
1,000
Impedance (Ohms)
7 Turns 5 cores
6 Turns 6 cores
7 Turns 4 cores
5 Turns 6 cores
6 Turns 4 cores
5 Turns 5 cores
5 Turns 4 cores
4 Turns 6 cores
4 Turns 5 cores
1
5
10
30
100
Frequency (MHz)



Coax Chokes on #31 Big Clamp-Ons
6" Diameter Turns, Wide Spacing
10,000
5,000
1,000
Impedance (Ohms)
1
10
100
Frequency (MHz)
8 turns RG8X
7 turns RG8X
6 turns RG8X
5 Turns RG8X
3 Clamps 3 turns RG8
2 Clamps 3 turns RG8
3 Close turns RG8
6 Close spaced turns RG8X
6 Turns RG8X
3 Turns RG8

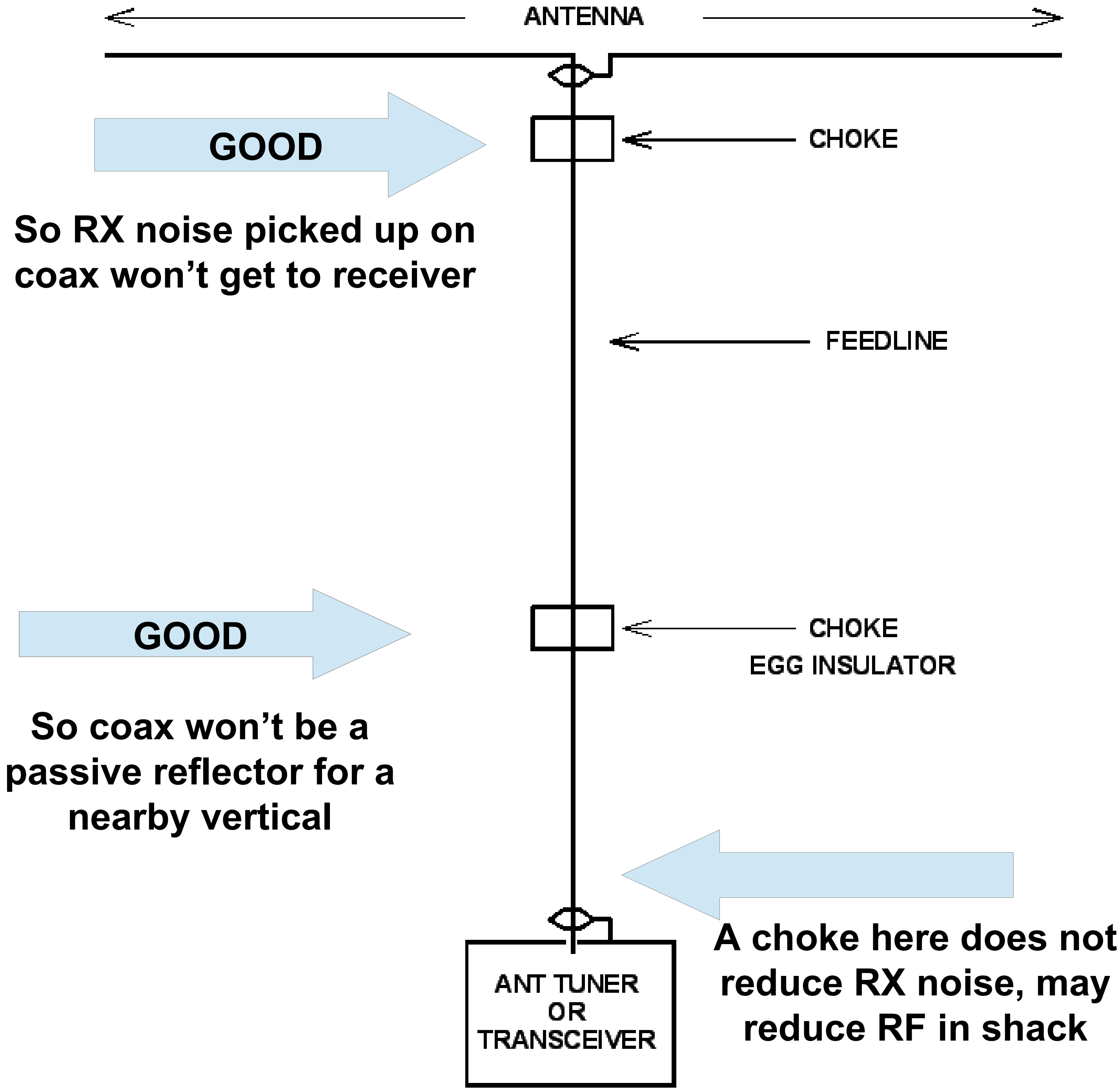
The Measurement Problem
Stray Capacitance



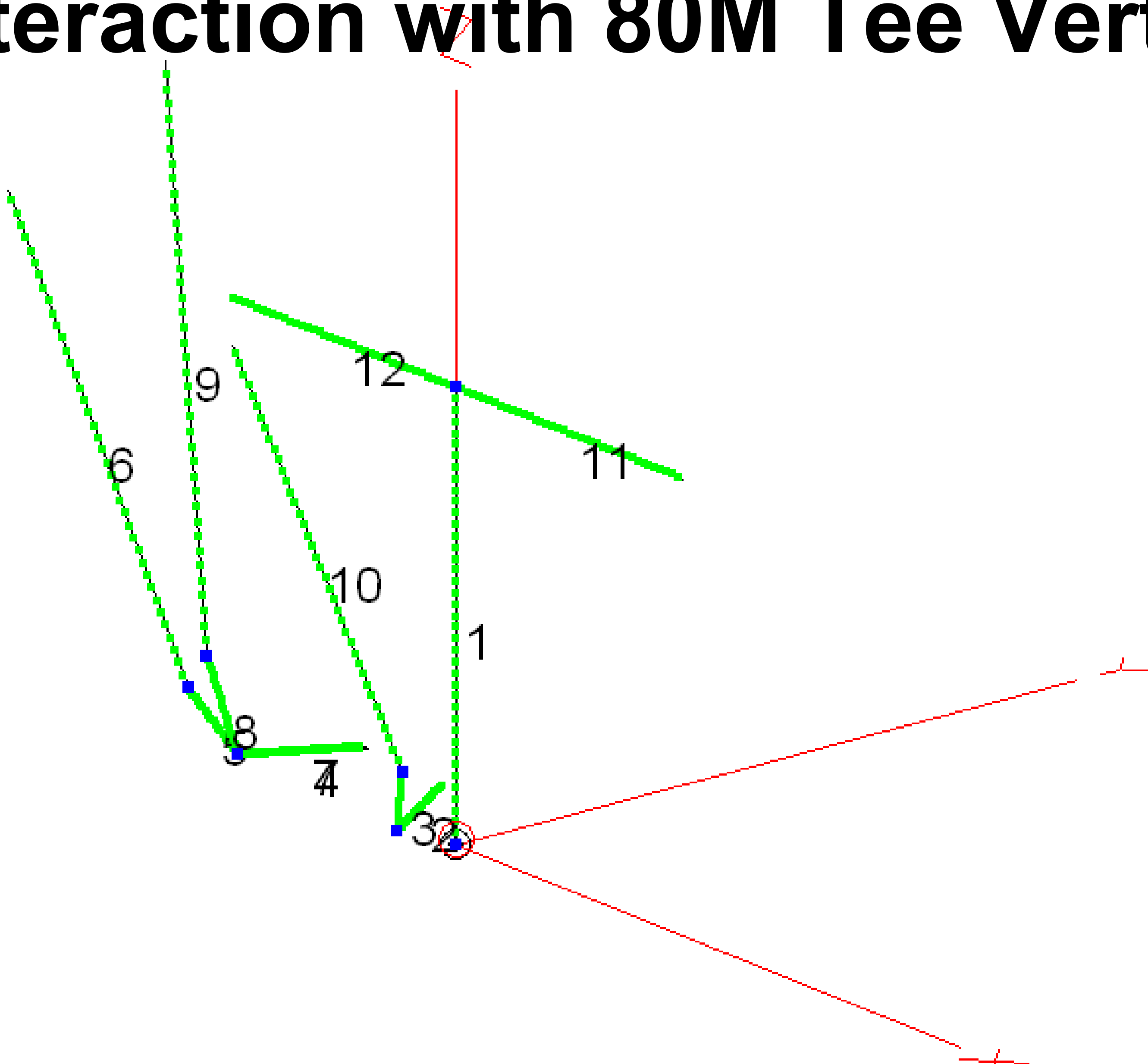


RG8 Chokes on #31 Toroids
5" Diam Turns, Wide Spacing
except as noted
7 Turns 5 cores
12" Diam turns
7 Turns 5 cores
6 Turns 5 cores
5 Turns 7 cores
4 Turns 7 cores
5 Turns 5 cores
3 Turns 9 cores
4 Turns 5 cores
3 Turns 7 cores
3 Turns 5 cores
Close spacing
Impedance (Ohms)
10,000
5,000
1,000
1
5
10
30
100
Frequency (MHz)

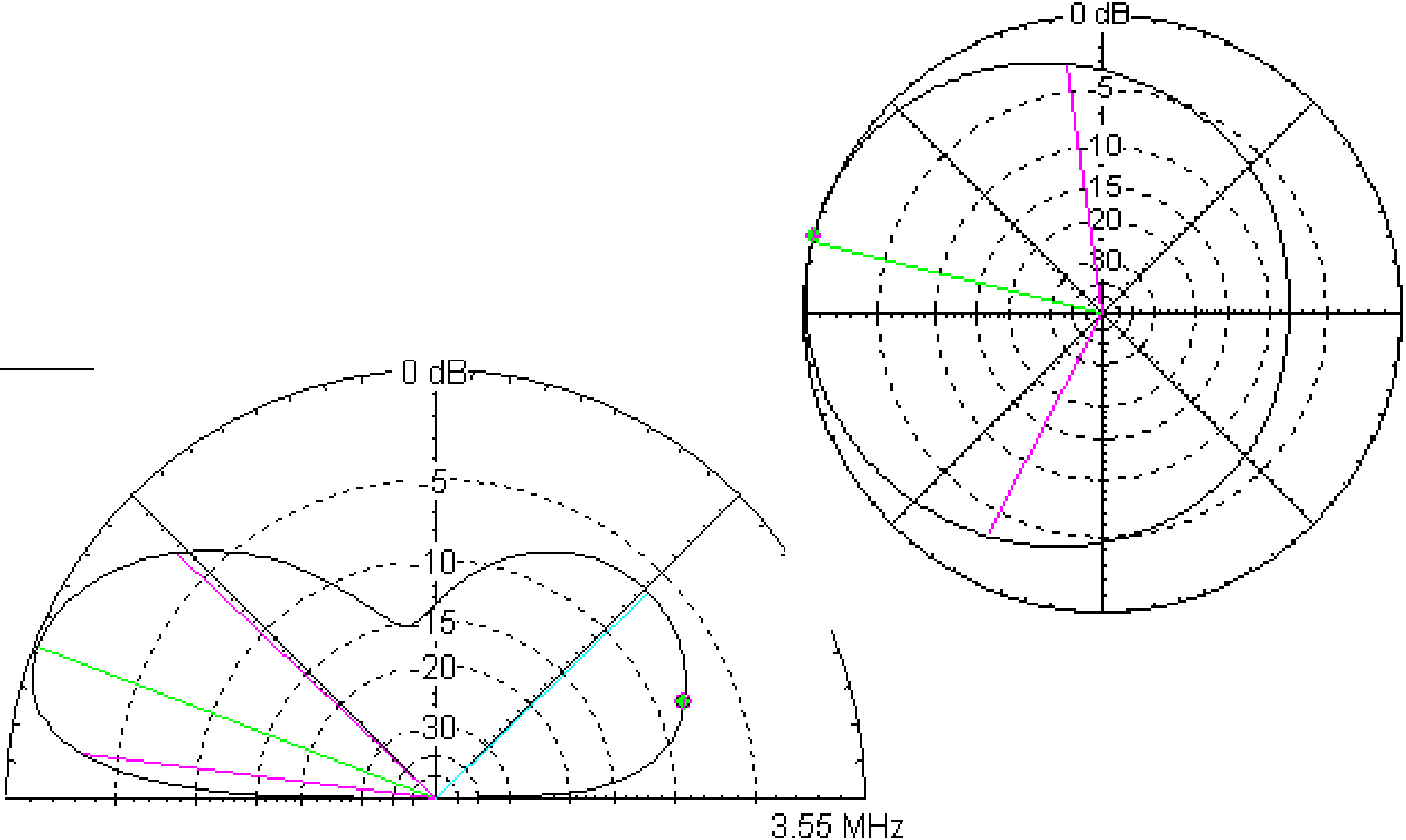
Chokes as “Egg Insulators to Break Up the Feedline


ANTENNA
GOOD
CHOKE
So RX noise picked up on coax won’t get to receiver
FEEDLINE
GOOD
CHOKE
EGG INSULATOR
So coax won’t be a passive reflector for a nearby vertical
A choke here does not reduce RX noise, may reduce RF in shack
ANT TUNER OR TRANSCEIVER

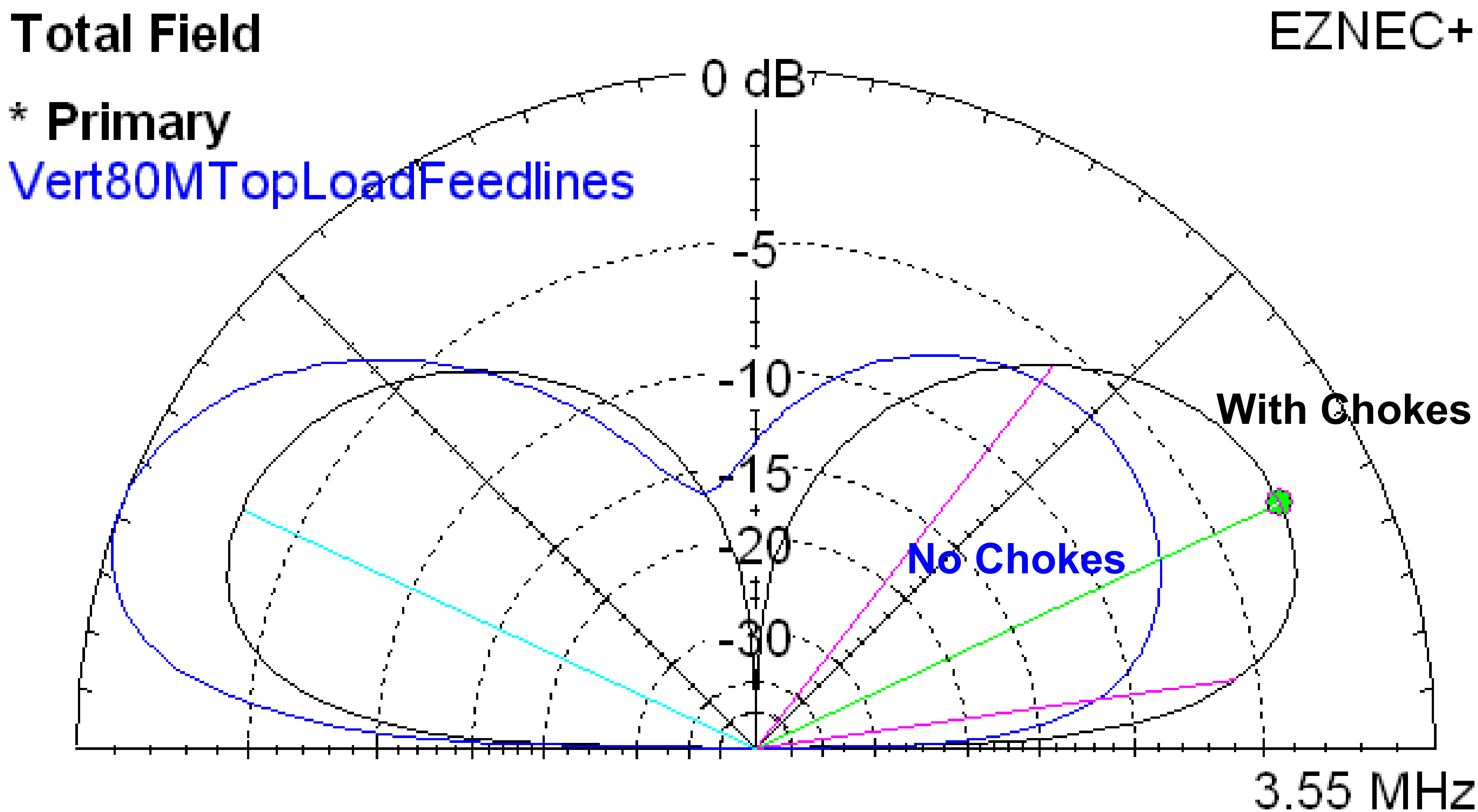
NEC Model of Feedline Interaction with 80M Tee Vertical



NEC Model of Feedline Interaction with Tee Vertical

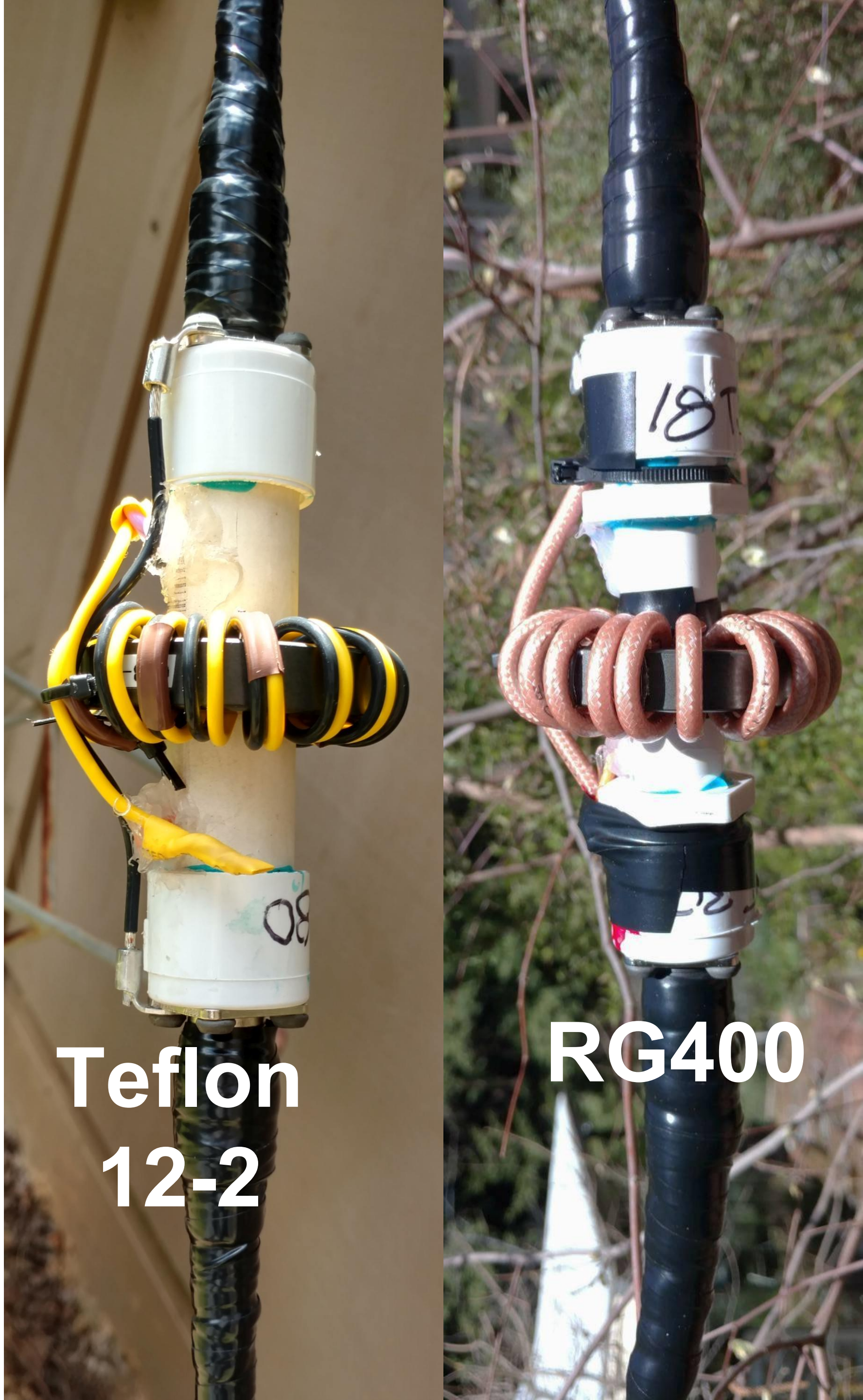


Add Choke in Each Feedline

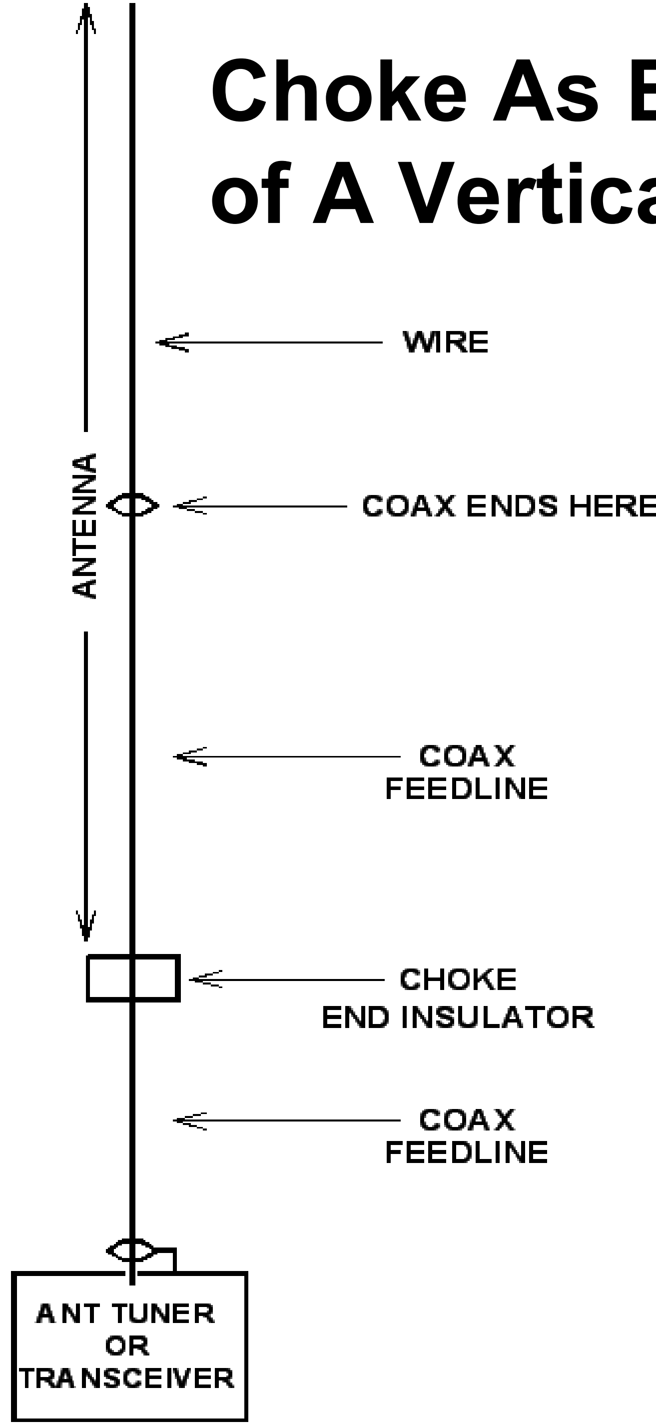


Chokes Used As "Egg Insulators"

#12-2 THHN also works well, slightly more loss, slightly less power handling



Choke As End Insulator of A Vertical Dipole



Choke As End Insulator

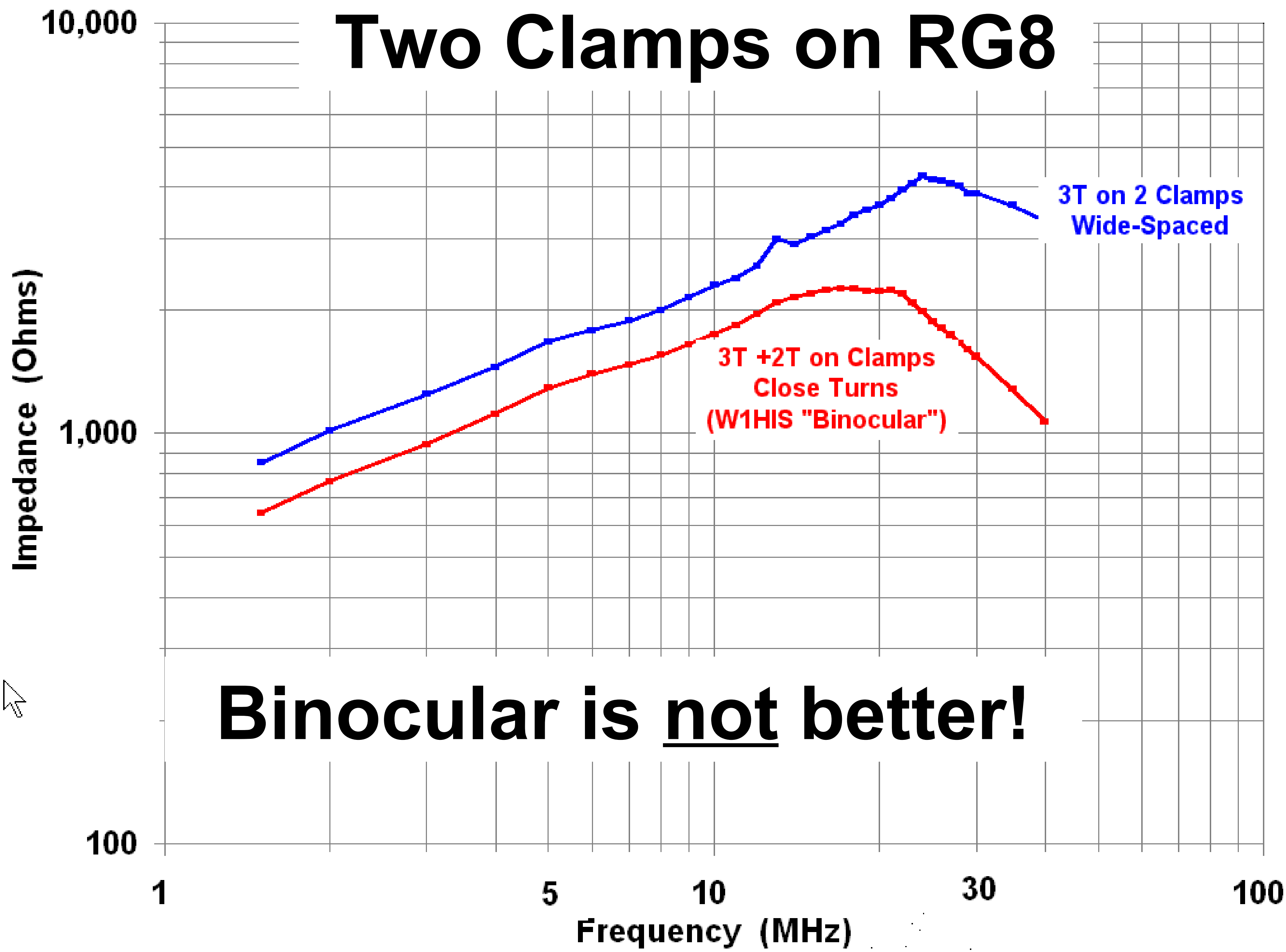
- A very demanding application, because the end of a wire is a high voltage point
  - Very high choking impedance is required
  - May need multiple chokes in series to achieve, depending on power level
- Feedpoint Z of a vertical dipole is close to 75Ω
  - 75Ω coax best for feedline
- Choke impedance not critical
  - RG400, Teflon 12-2, THHN 12-2 all work

Choke As End Insulator

- **Detailed advice in k9yc.com/VerticalDipole.pdf**

W1HIS Coaxial Choke

#43 cores


Two Clamps on RG8
10,000
1,000
100
Impedance (Ohms)
3T on 2 Clamps
Wide-Spaced
3T +2T on Clamps
Close Turns
(W1HIS "Binocular")
Binocular is not better!
1
5
10
30
100
Frequency (MHz)

Thanks to Kevin, K6TD

- **Helped me verify my suspicions about reflection-based measurements, and get good S21 data using his HP Network Analyzer**

  (Unfortunately, we didn’t have the extra hardware needed to get complex data out of the analyzer into a spreadsheet.)

Thanks to Chuck, W1HIS

- Chuck was <u>right</u> about using 5,000Ω chokes to minimize receive noise
- Chuck was <u>wrong</u> about how to build 5,000Ω chokes, because he (and his friends) didn't know how to measure them correctly!

We Were Both Wrong About #43

- #43, #52, #61 are a very poor choice for HF chokes because
  - All ferrite products have wide production tolerances (> 20%)
  - #43, #52, #61 are high Q mixes, so resonance is narrow
  - Wide tolerances can move high-Q resonance out of range of where we want them
  - In other words, designs are not repeatable

Why #31 Is The Only Choice For HF

- In a #31 choke, dimensional resonance combines with its circuit resonance to give it a much lower-Q (broader) resonance
- I measured hundreds of #31 cores, picked cores at tolerance limits, wound and measured chokes
- Recommendations are based on "worst case" of those measured data
  - That is, any #31 core (of the specified size) will be at least as good as the performance spec

More Thanks

- **Walt Maxwell, W2DU, for his great writing, and for his kind words.**
- **Danny, K6MHE, for prodding me to participate in a measurement roundtable that confirmed my work**
- **Henry Ott, WA2IRQ, for his insights, criticism, advice, and great teaching.**
- **Ron Steinberg, K9IKZ, for lots of help at critical times.**
- **The NCCC crew, for lots of antenna help.**

Thanks to Richard Heyser

Dick's "day job" was at JPL, where he worked on underwater communications and communications for the space program, but audio was his hobby.

Dick invented Time Delay Spectrometry (TDS), which revolutionized audio by revolutionizing acoustic measurements. He was an articulate writer and teacher, teaching us how to always <u>think</u> about <u>what</u> we were measuring, to always question both the <u>accuracy</u> and the <u>meaning</u> of the data on the screen, and to use new ways of <u>looking</u> at the data to learn more from it.

References

- Henry Ott, *Electromagnetic Compatibility Engineering,* Wiley Interscience, 2009
- Henry Ott, *Noise Reduction Techniques in Electronic Systems,* Wiley Interscience, 1988
- E. C. Snelling, *Soft Ferrites, Properties and Applications,* CRC Press, 1969
- E. C. Snelling and A. D. Giles, *Ferrites for Inductors and Transformers,* Research Study Press, 1983
- *Fair-Rite Products Catalog* This 200-page catalog is a wealth of product data and applications guidance on practical ferrites. http://www.fair-rite.com
- *Ferroxcube Catalog and Applications Notes* More online from another great manufacturer of ferrites. http://www.ferroxcube.com

References

- **These tutorials and applications notes are on my website for free download   k9yc.com/publish.htm**
- ***New Understandings of the Use of Ferrites in the Prevention and Suppression of RF Interference to Audio Systems*** *,* **J. Brown** (AES Preprint 6564)
- ***Understanding How Ferrites Can Prevent and Eliminate RF Interference to Audio Systems***
- ***A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing***
- ***A New Choke Cookbook for the 160–10M Bands***
- ***Build Contesting Scores by Killing Receive Noise***

Coaxial Transmitting Chokes

Jim Brown K9YC
Santa Cruz, CA

http://k9yc.com