Baluns & Common Mode Chokes

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Topics – Part 1

- A Radio Frequency Interference (RFI) Problem
- Some Basic Terms & Theory
- Baluns & Chokes
  - What is a Balun
  - Types of Baluns
  - Balun Applications
  - Design & Performance Issues
  - Voltage Balun
  - Current Balun
  - What is a Common Mode Choke
  - How a Balun/Choke works

Topics – Part 2

- Tripole
- Risk of Installing a Balun
- How to Reduce Common Mode currents
- How to Build Current Baluns & Chokes
  - Transmission Line Transformers (TLT)
  - Examples of Current Chokes
  - Ferrite & Powdered Iron (Iron Powder) Suppliers

Part 1

RFI Problem

- Problem:
  - Audio started coming thru speakers of audio amp:
    - When transmitting > 50W SSB
    - 20M & 40m (I didn’t check any other bands)
  - No other electronics affected
  - Never had this problem before
  - Problem would come and go for no apparent reason

RFI Problem – cont'd

- Observations
  - Intermittent: problem was freq dependent
  - RF Power level dependent
  - Rotating the 20 M beam appeared to have no effect
  - No RFI with dummy load
  - AC line filter had no effect
  - Common Mode Choke on transmission line to house had no effect
  - Caps (180 pF) on speaker terminals on audio amp made problem worse
    - **Caution:** don't use large caps (ie., 0.01 uF) with solid state amps => damage
  - Disconnecting 4 of 5 speakers from the audio amp eliminated problem
    - The two speakers with the longest cables were picking up RF
      - Both of these speakers needed to be connected to the amp to have the problem
      - Length of cable to each speaker ~30 ft (~1/4 wavelength on 40M)
    - None of the other three speakers contributed to the problem

RFI Problem – cont'd

- Conclusions:
  - RF is getting into the audio amp via two speaker cables
    - The SSB modulation is being rectified and amplified in the audio amp
      - This is well documented as a common cause of RFI
  - Problem does not appear to be RF on AC power line
- Solution:
  - Two snap on ferrites on each of the two speakers leads solved problem
    - Properties of the ferrite unknown

RFI Problem – cont'd

- Remaining Questions:
  - What has changed (20+ years with no RFI problems)
  - What caused the frequency dependence
  - Why were two speakers needed to cause the problem
  - Is Common Mode Current still a possible problem
    - Transmission line
    - AC power line
  - Is my solution a true fix or only a band-aid

Questions to be Addressed

- When should a balun/choke be used
- What type of balun/choke should be used
  - How to build a balun/choke
- Where should they be installed
- What should be observed after one is installed

Questions to be Addressed

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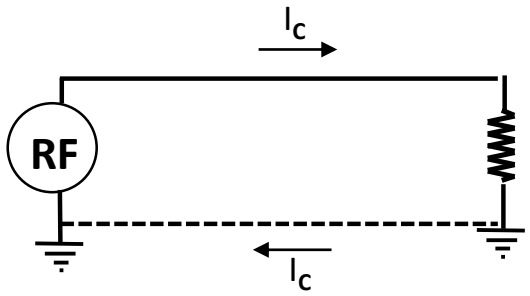
- What should be observed after one is installed

The answers to all of these questions are <u>application dependent</u>!

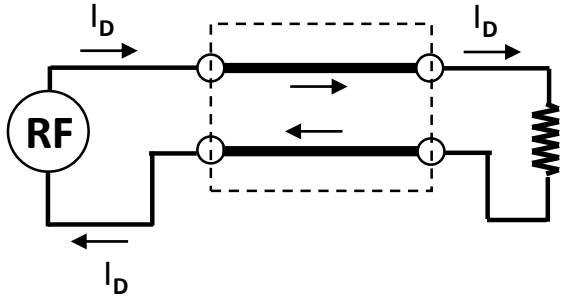
Some Basic Terms & Theory

Signal Line Types

- Unbalanced Line:
  - Single wire working against ground or a shield
  - Wire may, or may not, be shielded
    - Coax is a shielded unbalanced line
  - If unshielded, the wire **will radiate**



- Balanced Line:
  - Two collocated lines working against each other
  - Signal wires usually not shielded
    - Twin lead & ladder line are balanced lines
  - Ground is not part of the signal path
  - **No radiation** if signals on the line are also balanced

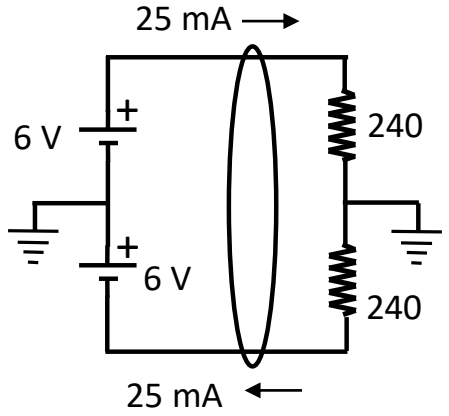


- Most antennas are neither perfectly balanced, nor perfectly unbalanced

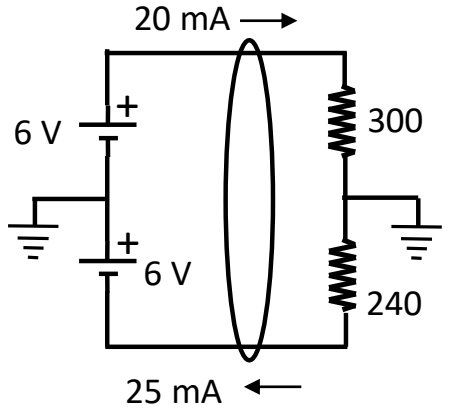
Balanced Signal

- Balanced signals have ***both***:
  - Equal amplitude currents that are 180º out of phase
  - Equal amplitude voltages that are 180º out of phase
- Balanced RF signals on a balanced line => **~no radiation**
  - No radiation is unachievable
    - Requires perfect cancellation (theoretically impossible to achieve)
  - Wire line spacing < 1/10 wavelength is usually adequate for ham applications

Example: two wire transmission line



Balanced Line
Balanced sources
Balanced loads
Balanced currents
No Common Mode Current

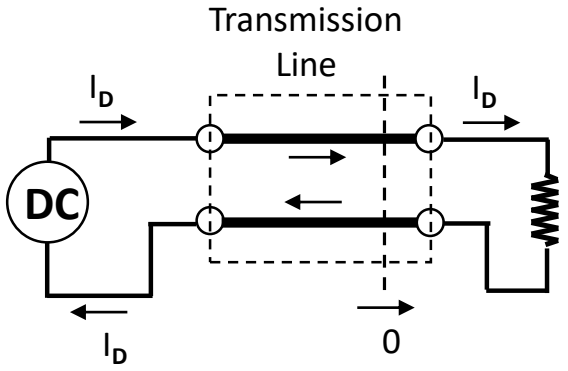


Balanced Line
Balanced sources
UNbalanced loads
UNbalanced currents
5 mA Common Mode Current

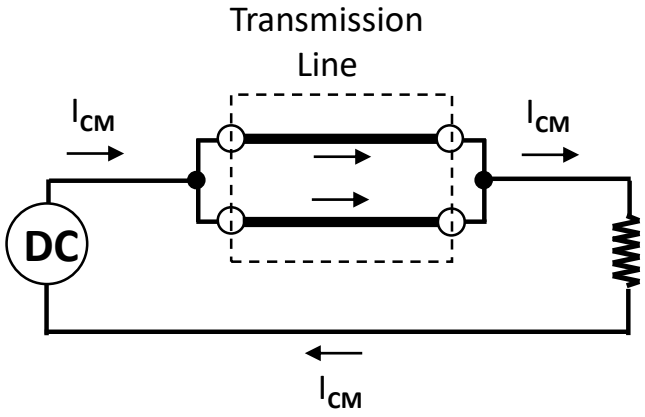
Signal Transmission Modes

- Two types of signal transmission modes

  - **Differential (Transmission Line) Mode:**
    - Signals are balanced
    - Net line current = **Common Mode Current = 0**
    - Radiation <u>won't</u> occur



  - **Common Mode**:
    - Signals are **<u>un</u>**balanced
    - Net line current = **Common Mode Current = I_{CM}**
    - Radiation <u>will</u> occur

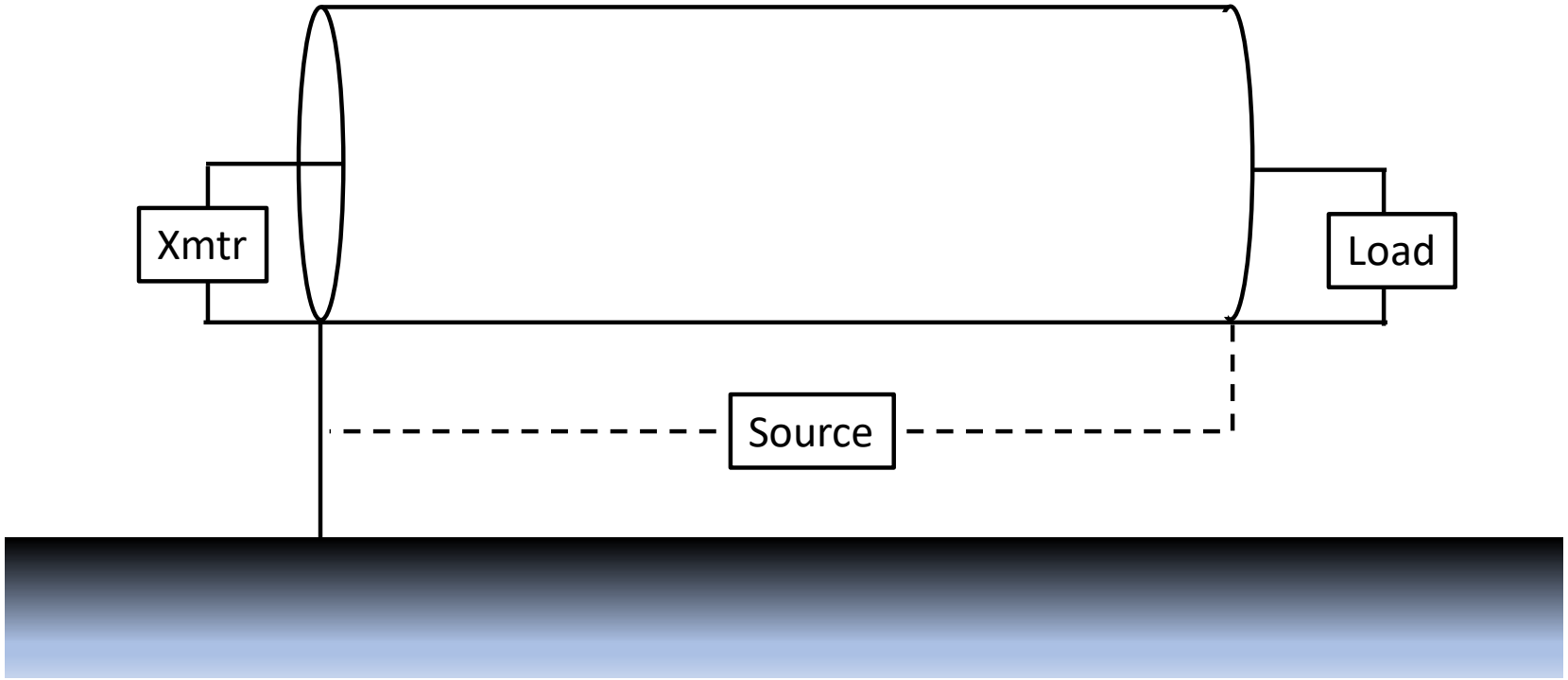


Common Mode Current

- Can cause *significant* operational problems
- Not always an issue that requires mitigation
  - If no Common Mode Current, installing a Balun/Choke will have no effect
- What can cause Common Mode Currents:
  1. Imbalanced line currents
     - Asymmetry in the antenna
       - Off center fed dipole
       - Sloping dipole
       - Dipole with elements going in different directions
       - Feedline not perpendicular to the antenna
       - Objects in the near field of the antenna
     - ***A Balun/Choke won't help with some of these problems***
  2. Ground loops
  3. Balanced to Unbalanced mismatch (Tripole)

Common Mode Current Example

- Coaxial transmission line:



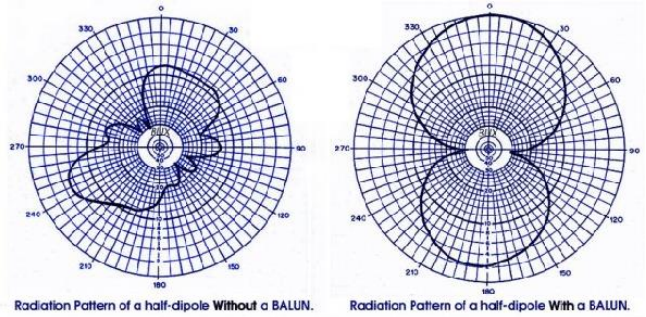
Source can be either noise or an RF signal

Problems Common Mode Currents Can Cause

- Distortion in antenna pattern and polarization
  - Reduce peak gain
  - Interference from unwanted signals
  - Increase noise
- Antenna SWR problems
  - Increase SWR
  - Shift the frequency of minimum SWR (resonance)
  - False readings on wattmeters and SWR bridges
  - Make SWR dependent on the length of coax
- RFI
  - Burning fingers/lips
  - Interference with consumer electronics (spouse + neighbors)
  - Trip transceiver and/or amplifier protection circuits
  - Distortion on audio (mics, speakers,etc)

Measured Performance

Without Balun With Balun



Half wave dipole

QST April 1980

Some ARRL Antenna Books are misleading

Baluns & Chokes

(Overview)

What is a Balun

- Bidirectional signal conversion device
  - Converts a **BAL**anced signal to an **UN**balanced signal, and vice versa
  - Outputs either equal **CURRENT** or equal **VOLTAGE** from each balanced port
    - Even with varying load impedances
  - A Balun may, or may not, reduce Common Mode Currents
- A Balun can be designed to do impedance transformations
  - The descriptor **n:1** defines **impedance** ratio
  - Common ratios: 1:1, 2:1, 4:1, 6:1, 9:1, 12:1
  - Note: 1:n is *not* the same as an n:1 (ie, 50:200 vs 50:12.5)
- 3 port power divider defined by:
  - S12 = S21 = -S13 = -S31
  - S11 = Infinity
  - S23 & S32 (port to port balance): no constraint

Types of Baluns

- **Voltage Balun**
  - *Not the best choice* for most ham applications
- **Current Balun**
- **Current Choke**
  - A Current Balun that is designed to reduce Common Mode currents
  - AKA: Choke Balun, Common Mode Choke, Line Isolator, Feedline Current Isolator
  - Good Current Balun ⇔ Good Common Mode Choke
- **Unun**
  - "**UN**balanced to **UN**balanced" signal conversion device
  - Used with ground mounted verticals and to break up ground loops
- **Babal** (my name)
  - "**Ba**lanced to **Bal**anced" signal conversion device => ???
  - ARRL Antenna book gives an example of this type of device

Balun Applications

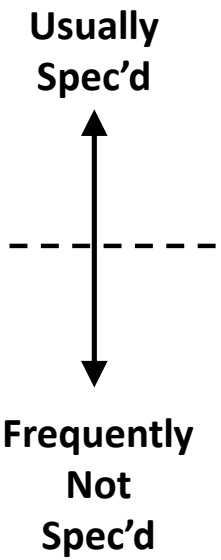
- Signal conversion
- Impedance transformation (up or down)
- **Isolation of circuits (ie, reduce Common Mode Currents)**
  - **Reduce/eliminate RFI**
  - **Improve antenna patterns and match**
  - **Eliminate ground loops**
    - **Both audio and RF**
- Delay line with Common Mode Current rejection
- Phase inverter with Common Mode Current rejection

Unless stated otherwise, comments apply to Current Baluns/Chokes

Typical Balun Performance Specs

- **Frequency Coverage***
- **System Impedance***
- **Impedance Transformation Ratio***
- **Maximum Power***[1]

- **Return Loss (SWR)***
- **Insertion Loss***
- **Common Mode Rejection Ratio (CMRR)**
  - **Choke "Impedance" is better spec for ham applications***
  - **Both R & X are important**
- Phase Balance
- Amplitude Balance
- Balanced Port Isolation
- DC/Ground Isolation
- Group Delay Flatness



***Can be important in ham applications**

1) Two problems with max power specs

- **Duty cycle is not spec'd**
- **The <u>important</u> power limit:**
  - **Not spec'd**
  - **<u>Can be much lower</u> than spec'd limit**

Design And Performance Issues

- Too many “Experts” who either don’t discuss, or don’t agree on:
  - Important performance requirements
  - Which Balun/Choke designs should be used?
  - Important “System” issues
    - Will adding a Balun/Choke help or hurt?
    - Will the Balun/Choke overheat?
- Most manufacturers:
  - Don’t provide specs for some critical parameters
    - Example: one popular manufacture’s specs:
      - Balun: 1:1 ratio, 1.8-30 MHz, 50 ohms, 2 KW/5 KW
    - Common Mode power limit is the most important, but is never spec’d
      - Not sure how it could be spec’d, or how meaningful it would be if it was published
      - **It is possible for a 100 watt transmitter to destroy a 2 KW Balun!**
  - Don’t offer much/any info on “System” issues

Design And Performance Issues

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How a Balun/Choke performs, and whether it will survive, is *application dependent*!

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Important System Issues

- “System” includes:
  - Load (antenna, etc)
  - Baluns & Chokes
  - Transmission line
  - Antenna tuners
  - ***Station RF ground (both impedance and location are important)***
- What is the risk of a Balun/Choke failing due to overheating
- Balun/Choke performance vs. load impedance
  - Manufacturer’s specs assume a 50 ohm resistive load
  - Some baluns/chokes are very sensitive to reactance

Voltage Balun

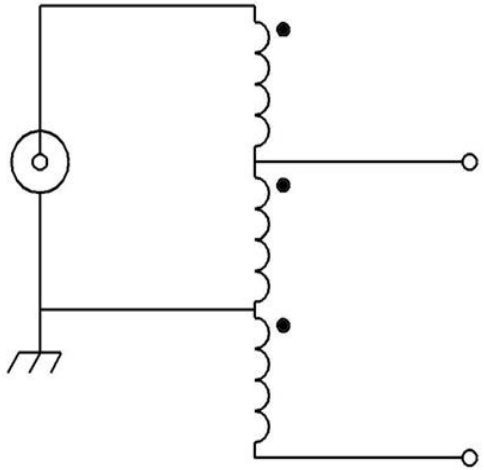
Voltage Balun

- Produces equal & opposite voltages at output ports
  - Used with voltage fed antennas (end fed half wave, long wire, etc)
- Currents are whatever is needed to generate equal output voltages
- ***Requires magnetic coupling for Differential Mode signals***
  - Ferrite and powder iron materials commonly used
  - Core can be toroid, rod, binocular style
- Hams started using the voltage Balun in the mid ‘60s
  - ***Not the best choice for most Ham applications***
    - Equal currents (not voltages) are usually required in Ham applications
    - More likely to fail due to heating of magnetics
    - Affected more by load impedance variations
  - Most commercial antenna tuners use a 4:1 voltage balun

Examples: Voltage Baluns & Ununs

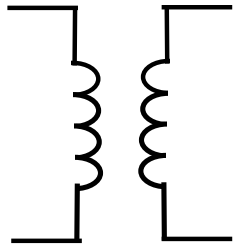
1:1 Balun

50 ohm
UNBALANCED



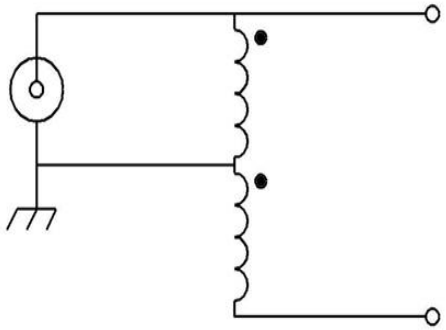
50 ohm
BALANCED

Balun/Unun

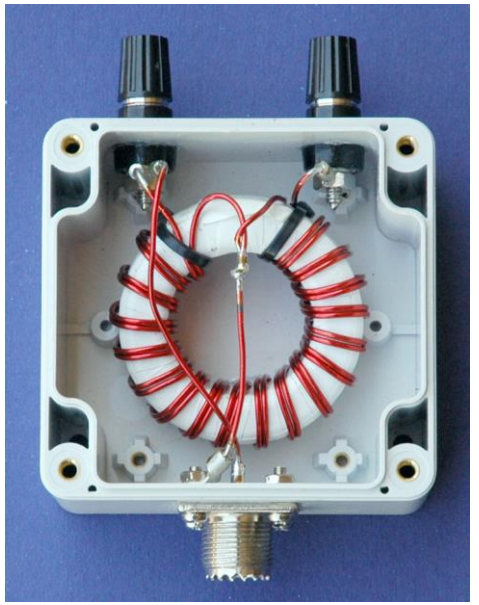


4:1 Balun

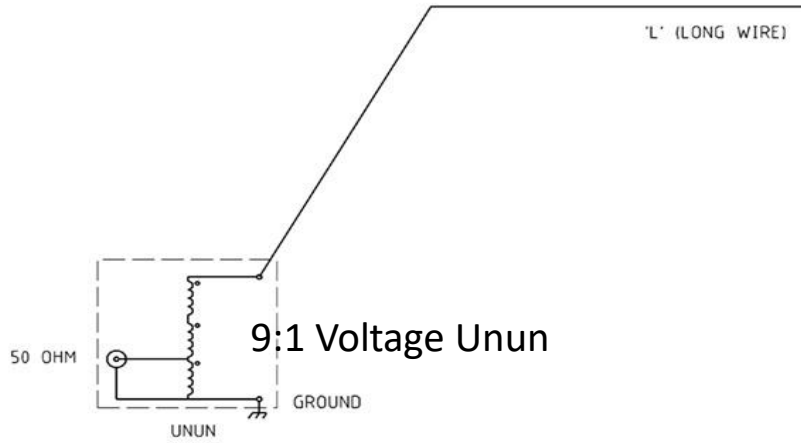
50 ohm
UNBALANCED



200 ohm
BALANCED



End Fed Halfwave Antenna



9:1 Voltage Unun

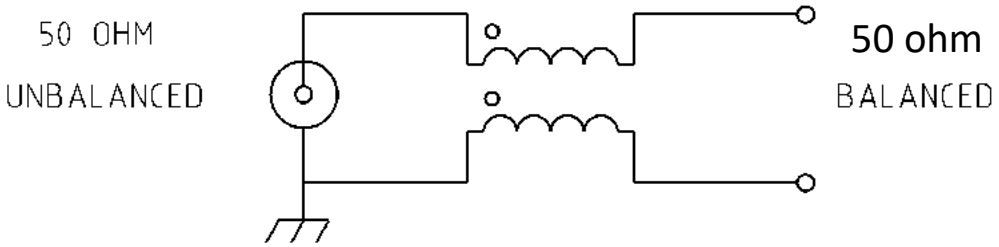
Current Balun

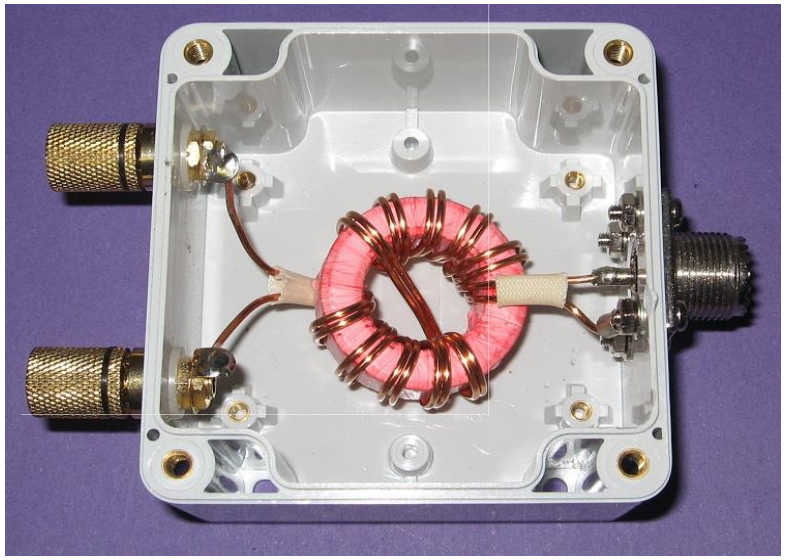
Current Balun

- Produces equal & opposite currents at output ports
- Voltages are whatever is needed to generate equal output currents
- A 1:1 Current Balun is also a Common Mode Choke
  - Exhibits high impedance to common mode signals
  - Little/no degradation of differential signals
- Magnetic coupling not required for Differential Mode signals => less loss/heating
- Best choice for most ham applications
  - Equal currents are required in most ham applications
  - Provides:
    - Better input to output isolation
    - Better power handling capability
    - Better output balance
    - Better tolerance to load variations
    - Lower loss

Examples: Current Baluns

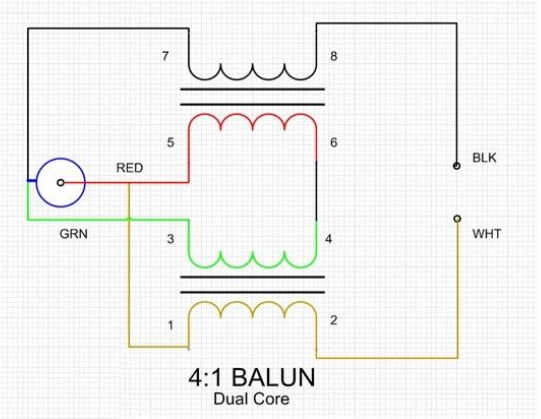
1:1 Balun/Common Mode Choke





4:1 Balun

50 ohm
UNBALANCED



200 ohm
BALANCED

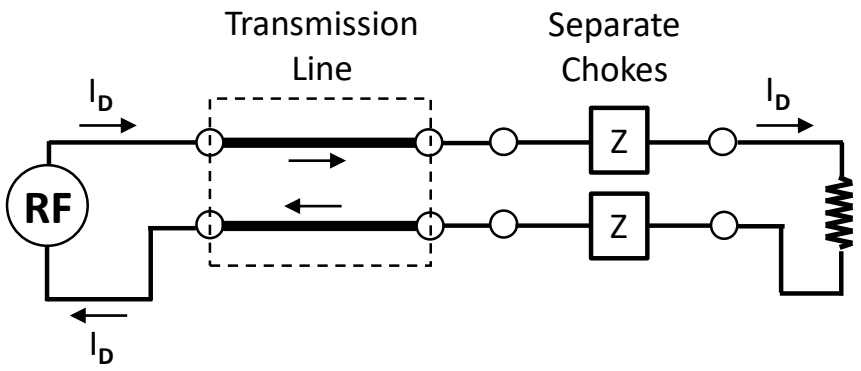
Common Mode Choke

What Is A Common Mode Choke

- Signal conversion/isolation device designed to provide:
  - Maximum Common Mode Current rejection
  - Minimum Differential (Transmission Line) Mode loss
- Can be built using:
  - Powder iron core coupling :
    - Low permeability: low loss, low inductance/turn, high Q, narrow bandwidth
  - Ferrite core coupling:
    - High permeability: high loss, high inductance/turn, low Q, wide bandwidth
  - Air coupling
    - Permeability = 1: low loss, low inductance/turn, very high Q, very narrow bandwidth
  - No coupling (coaxial half wave balun)
    - Low loss, very high Q, very narrow bandwidth

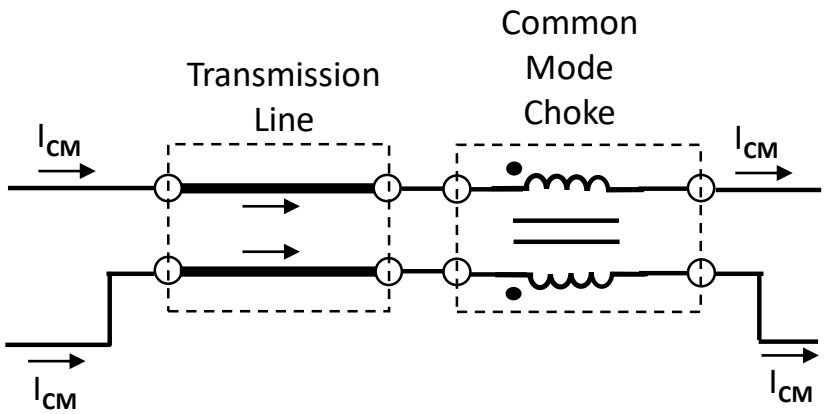
How A Common Mode Choke Works

Differential Mode Chokes



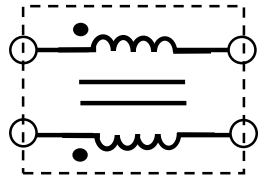
Individual Chokes yield High Z_{CM} **and** High Z_D

Common Mode Choke

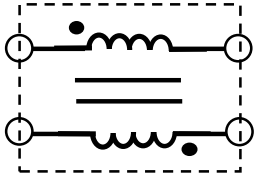


Toroidal Chokes to reduce:

Common Mode



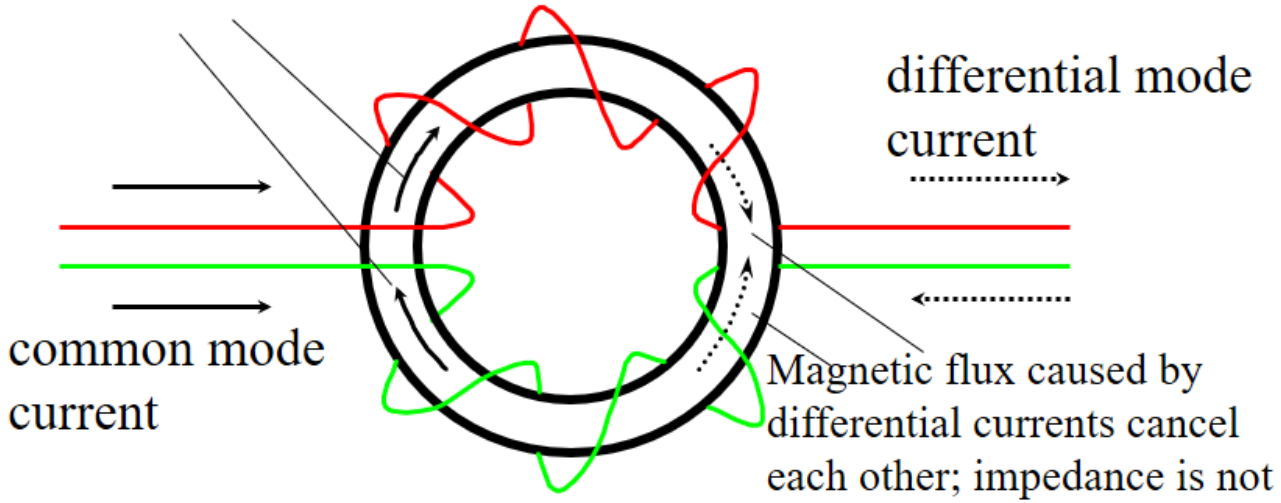
Differential Mode



How A Balun/Common Mode Choke Works – cont'd

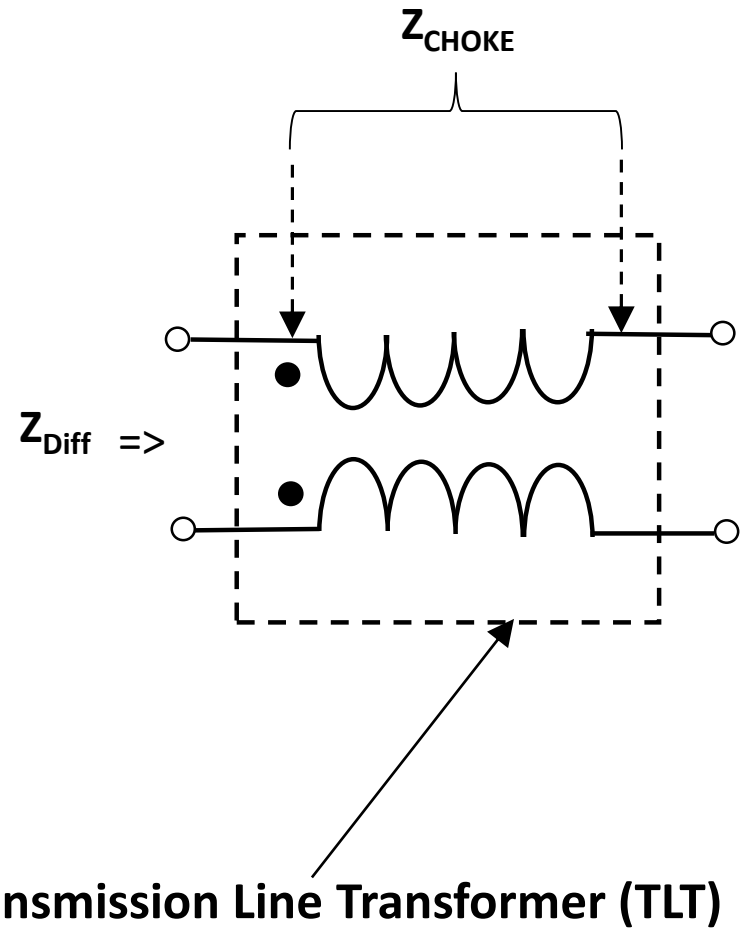
Common-Mode Chokes

Magnetic flux caused by common mode current adds up, producing an opposing impedance.



MINNTRONIX
Wind Up the Best

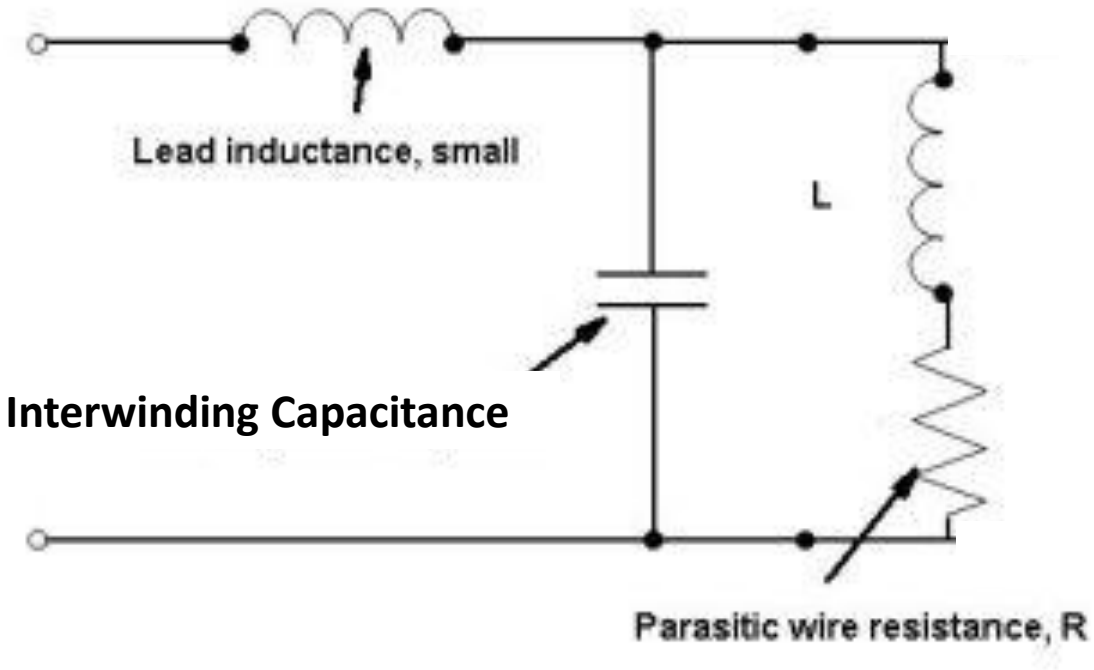
Impedance of a Balun/Choke



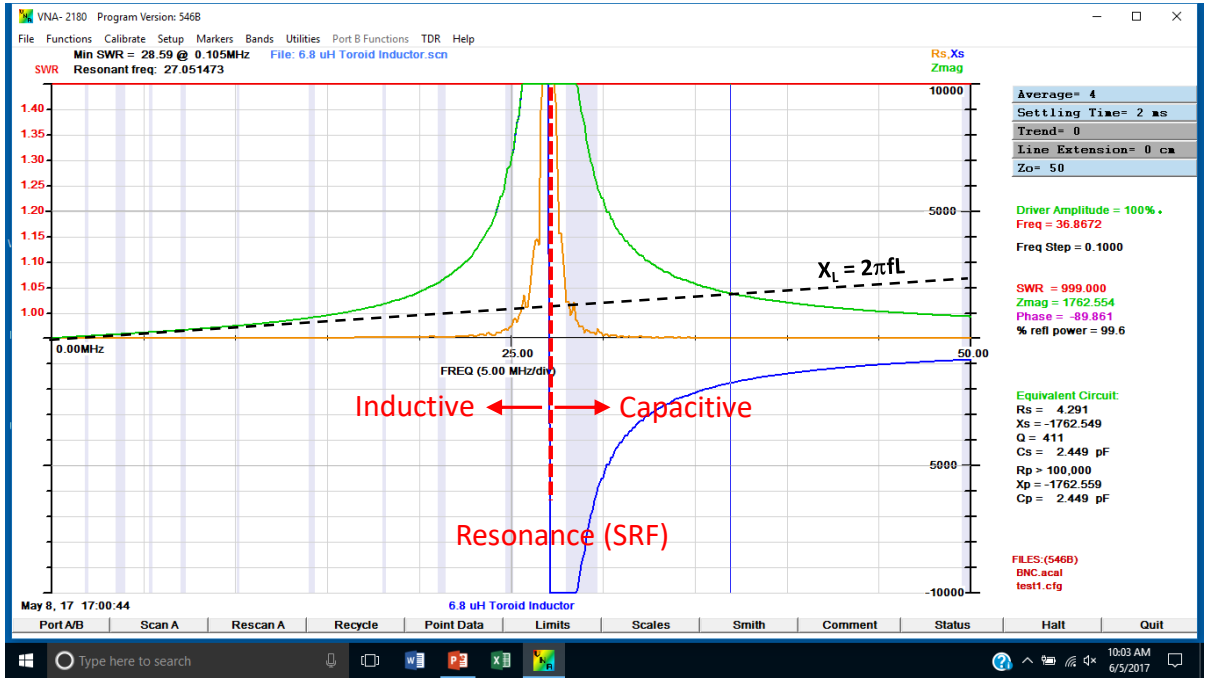
- Common Mode signal sees a choke
  - Z_{CHOKE} varies with
    - Frequency
    - Type of balun & design
- Differential signal only sees a transmission line
  - $Z_{Diff} \sim 0$
- Impedance can be:
  - Resistive and reactive
  - Mostly resistive
  - Mostly reactive
    - Inductive below **self resonant frequency (SRF)**
    - Capacitive above SRF

Self Resonance In Inductors

Equivalent circuit of a wire-wound inductor



6.8 uH **High Q** Toroid Inductor

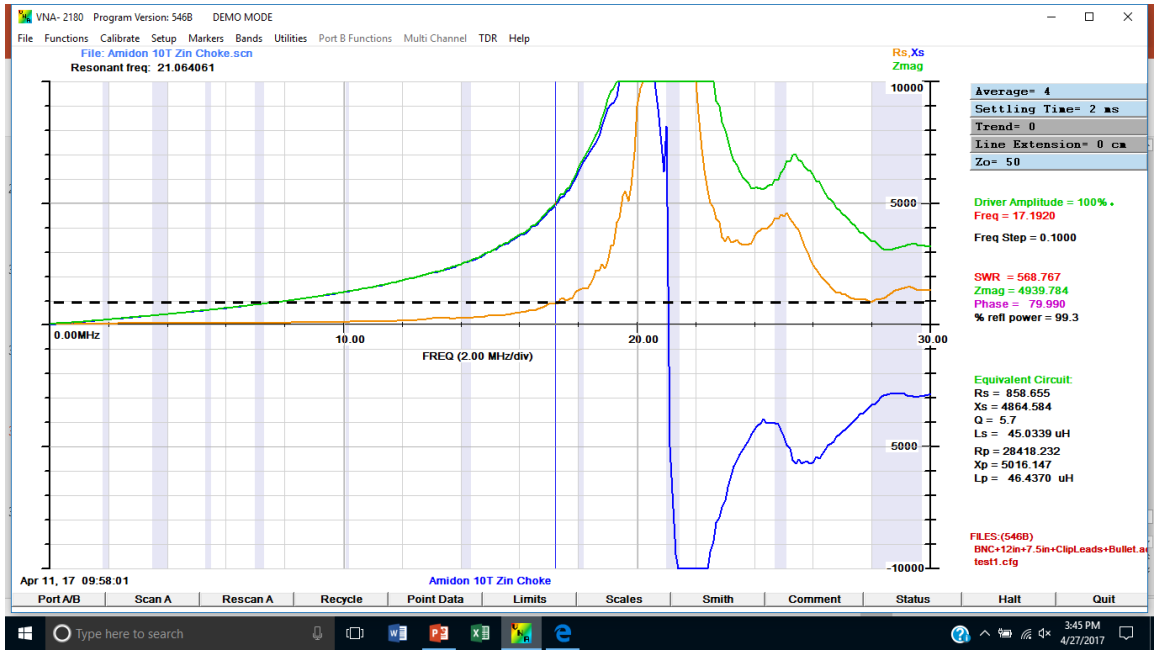


Examples: Current Chokes

Homebrew Sleeve Choke

Mostly resistive & Low Q

Homebrew Toroidal Choke



Mostly reactive & High Q

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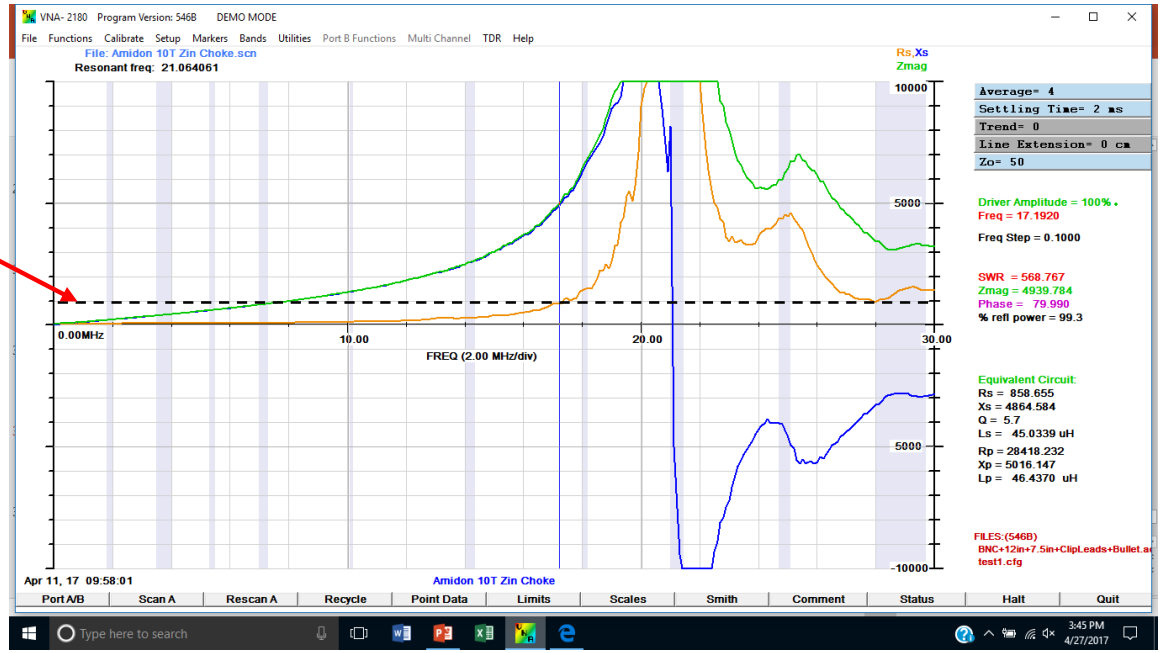


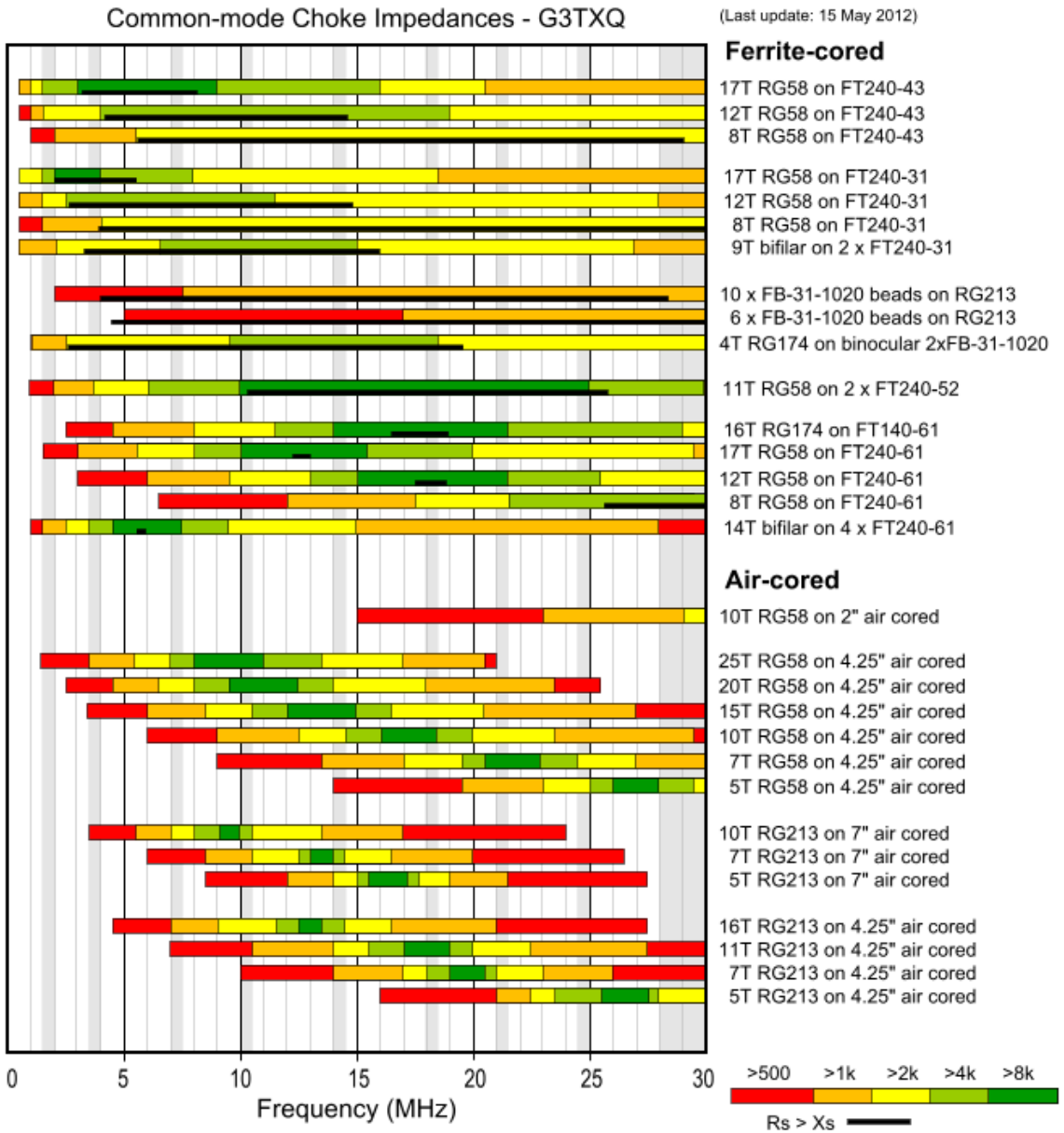
Mostly resistive & Low Q

Mostly reactive & High Q

Common Mode Choke Impedance

- Should a Common Mode Choke be mostly resistive, or mostly reactive?
  - Resistive chokes ***dissipate*** the Common Mode energy
    - Example: $Z_{Choke} = 100 + j0$
    - ***Will always decrease*** Common Mode Current
    - Difficult to achieve high resistances
      - Choke's core can overheat, **even if it is not saturated!**
      - Saturated core with low duty cycle may not overheat, but => nonlinear => distortion
  - Reactive chokes ***reflect*** the Common Mode energy (***if no System resonance***)
    - Example: $Z_{Choke} = 0 + j100$
    - **System** resonance can ***increase*** Common Mode Current
    - This choke's core is not as likely to overheat
    - Is reflected Common Mode energy radiated by the antenna?
- Which is better?
  - Must look at "System" issues to answer

Common Mode Choke Impedances (G3TXQ)



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