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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The answers to all of these questions are application dependent!
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 signals have both:
- Equal amplitude currents that are 180° out of phase
- Equal amplitude voltages that are 180° 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

![Diagram of balanced and unbalanced signals](attachment://diagram.png)
Signal Transmission Modes

• Two types of signal transmission modes

• **Differential (Transmission Line) Mode:**
  • Signals are balanced
  • Net line current = \( \text{Common Mode Current} = 0 \)
  • Radiation won’t occur

• **Common Mode:**
  • Signals are **un**balanced
  • Net line current = \( \text{Common Mode Current} = I_{CM} \)
  • Radiation **will** 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)

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**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 BALanced signal to an UNbalanced 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**
  • "UNbalanced to UNbalanced" signal conversion device
  • Used with ground mounted verticals and to break up ground loops

• **Babal** (my name)
  • “Balanced to Balanced" 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 important power limit:
    • Not spec’d
    • Can be much lower 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

• 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

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

Balun/Unun

4:1 Balun

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
50 ohm BALANCED

50 ohm UNBALANCED

200 ohm BALANCED

4:1 BALUN
Dual Core
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 Chokes

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

- Differential mode current
- Common mode current

Magnetic flux caused by differential currents cancel each other; impedance is not produced.
Impedance of a Balun/Choke

- Common Mode signal sees a choke
  - $Z_{\text{CHOKE}}$ varies with
    - Frequency
    - Type of balun & design

- Differential signal only sees a transmission line
  - $Z_{\text{Diff}} \approx 0$

- Impedance can be:
  - Resistive and reactive
  - Mostly resistive
  - Mostly reactive
    - Inductive below self resonant frequency (SRF)
    - Capacitive above SRF
Self Resonance In Inductors

6.8 uH High Q Toroid Inductor

Equivalent circuit of a wire-wound inductor

Lead inductance, small

Interwinding Capacitance

Parasitic wire resistance, R

Inductive

Capacitive

Resonance (SRF)
Examples: Current Chokes

Homebrew Sleeve Choke
- Mostly resistive & Low Q
- Resonance (SRF)

Homebrew Toroidal Choke
- Mostly reactive & High Q
Examples: Current Chokes

Homebrew Sleeve Choke

- Mostly resistive & Low Q

Homebrew Toroidal Choke

- Mostly reactive & High Q

Resonance (SRF)
Common Mode Choke Impedance

• Should a Common Mode Choke be mostly resistive, or mostly reactive?
  • Resistive chokes **dissipate** the Common Mode energy
    • Example: \( Z_{\text{Choke}} = 100 + j0 \)
    • **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 \( \Rightarrow \) nonlinear \( \Rightarrow \) distortion
  • Reactive chokes **reflect** the Common Mode energy **(if no System resonance)**
    • Example: \( Z_{\text{Choke}} = 0 + j100 \)
    • **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)

- **Ferrite-cored**
  - 1T RG58 on FT240-43
  - 12T RG58 on FT240-43
  - 6T RG58 on FT240-43
  - 17T RG58 on FT240-31
  - 12T RG58 on FT240-31
  - 8T RG58 on FT240-31
  - 9T bifilar on 2 x FT240-31
  - 10 x FB-31-1020 beads on RG213
  - 6 x FB-31-1020 beads on RG213
  - 4T RG174 on bicoil 2xFB-31-1020
  - 11T RG58 on 2 x FT240-52
  - 16T RG174 on FT140-61
  - 17T RG58 on FT240-61
  - 12T RG58 on FT240-61
  - 6T RG58 on FT240-61
  - 14T bifilar on 4 x FT240-61

- **Air-cored**
  - 10T RG58 on 2" air cored
  - 25T RG58 on 4.25" air cored
  - 20T RG58 on 4.25" air cored
  - 15T RG58 on 4.25" air cored
  - 10T RG58 on 4.25" air cored
  - 7T RG58 on 4.25" air cored
  - 6T RG58 on 4.25" air cored
  - 10T RG213 on 7" air cored
  - 7T RG213 on 7" air cored
  - 5T RG213 on 7" air cored
  - 16T RG213 on 4.25" air cored
  - 11T RG213 on 4.25" air cored
  - 7T RG213 on 4.25" air cored
  - 5T RG213 on 4.25" air cored

**Frequency (MHz)**

- >500
- >1k
- >2k
- >4k
- >8k
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