Impedance Matching 101

Ward Silver - NØAX

Why Impedance Match?

- Impedance = ratio of voltage to current
- Mechanical analogies
  - Mechanical impedance = ratio of torque to rate of rotation
  - Vehicle transmission is an impedance converter
    - Transfers power from the engine to the wheels
    - Change combination of torque and rate of rotation
- Maximize power transfer
- Reduce feed line loss (if match is at the antenna)
- Make transmitters happy!

Consequences of Not Matching

- Elevated SWR in a feed line increases loss
  - More trips through the line for reflected waves
  - Raises peak voltage – dielectric loss
  - Raises peak current – resistance loss (I^2R)
- Unhappy transmitters reduce power
- Can reduce receive sensitivity
- Reduced SWR bandwidth

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- **DOES NOT**
  - Increase RFI or noise pickup
  - Change antenna pattern
  - Cause bad breath or embarrass your mother

Why 50 or 75 ohms?

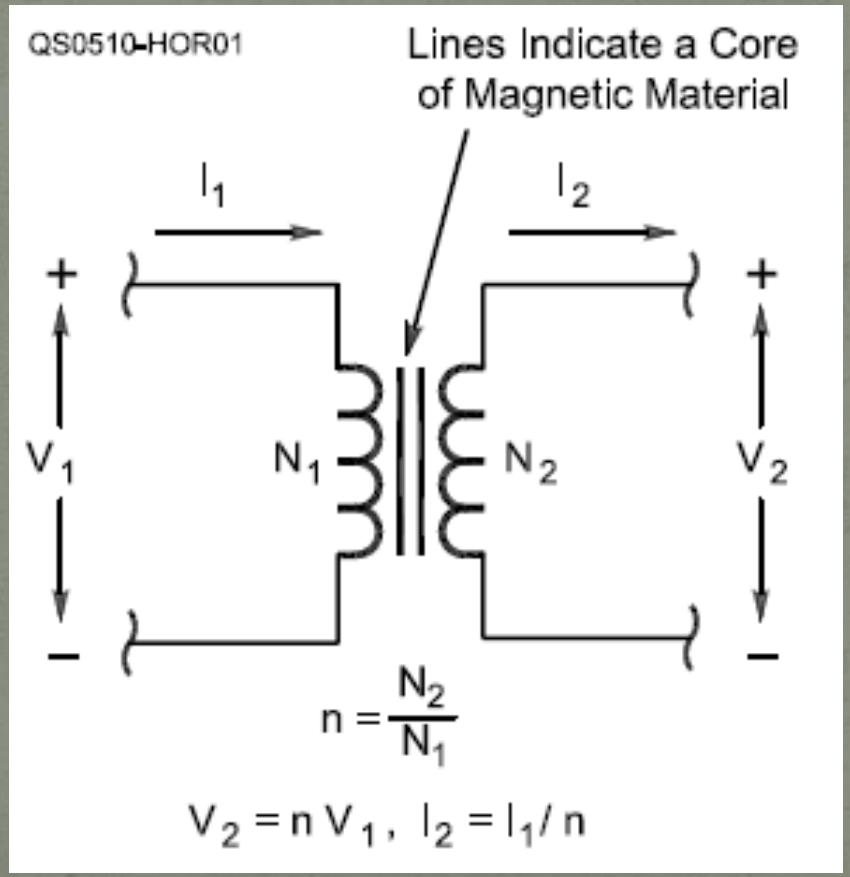
- Different optimum impedances in air-insulated lines for…
  - Loss, power-handling, peak voltage, etc
  - 30 ohms optimizes power handling
  - 70 ohms optimizes loss
- 50 ohms became common in the 1930s
  - Availability of standard tubing sizes
  - 50 ohms split the difference of 30 and 70 ohms
  - Good compromise performance
- WWII and polyethylene made 50 ohms the de-facto standard with good power handling and loss

How to Match?

- Resistive or reactive matching?
  - Resistive is cheap but dissipates power
  - Reactive is efficient but frequency sensitive
- Resistive examples
  - 50-ohm attenuator
  - Tee and Pi-network "pads"
  - Parallel and series resistors
    - TFTD folded dipole with resistive center-loading
  - Really long runs of old coax

How to Match?

- Transformers



How to Match?

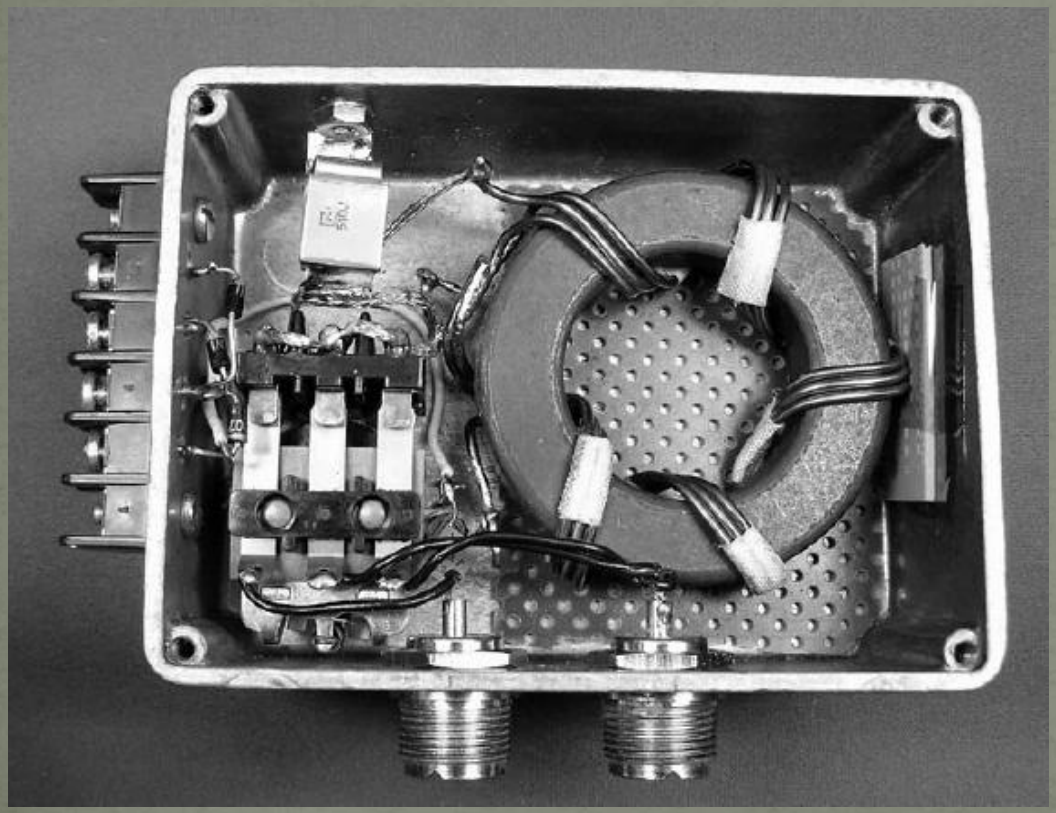
- Broadband transformers
  - Audio and modulation transformers
  - Ferrite and powdered-iron cores
- Transform voltage/current ratio

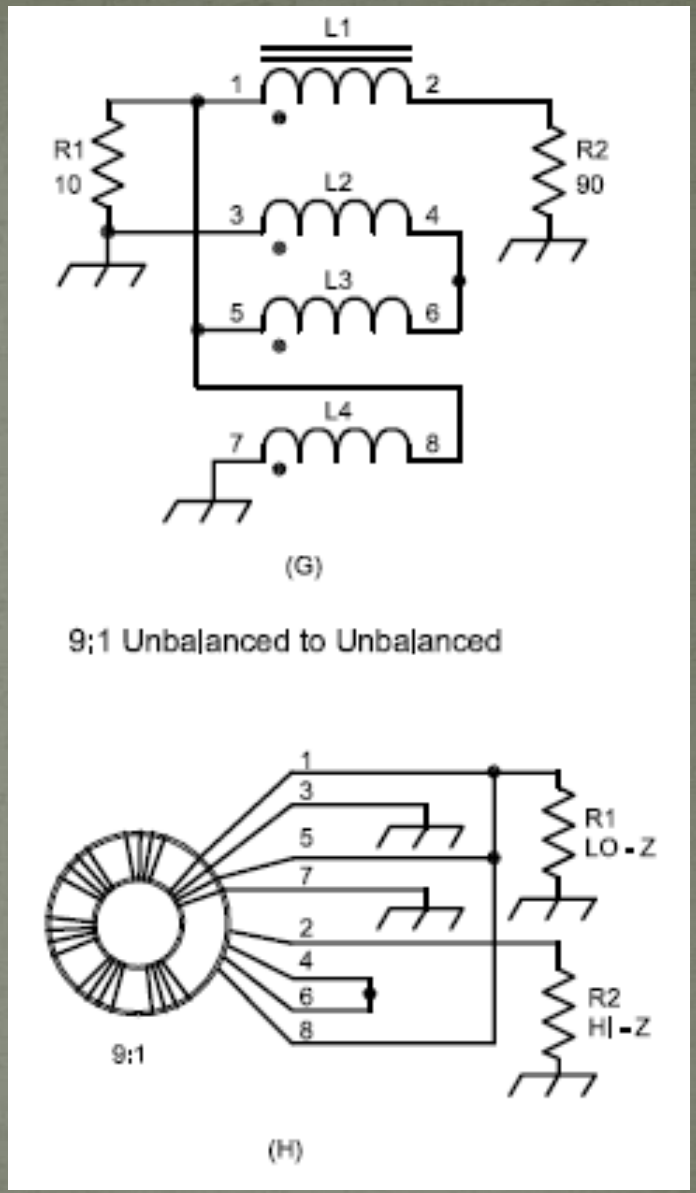
  $V_{sec} / \mathbf{I_{sec}} = \mathbf{Z_{sec}}$ and $V_{pri} / \mathbf{I_{pri}} = \mathbf{Z_{pri}}$

  $\mathbf{Z_{sec}} / \mathbf{Z_{pri}} = \mathbf{n^2}$
- If n = 2, Z ratio = 4; n = 3, Z ratio = 9, etc

How to Match?

- Broadband transformers





Time out for baluns!

The Balun is a FUNCTION

- Abbreviation of "balanced to unbalanced"
- Balanced – both conductors symmetric with respect to ground (open-wire line, free-space dipole, etc)
- Unbalanced – conductors asymmetric with respect to ground (coaxial cable, single-wire lines or systems with enclosure return, ground plane verticals)
- **ANY** device that isolates balanced and unbalanced systems while transferring power between them performs the balun function!
- Unun – operates between two unbalanced systems

Balun Types

- Current balun – forces equal currents in load terminals
- Voltage balun – forces equal voltages in load terminals
- Guanella and Ruthroff transmission line baluns
- Resonant transmission line "sleeve" baluns (λ/4, λ/2)
- Ferrite bead and coiled-coax "choke baluns"
- An impedance transformer is ***not*** necessarily a balun and vice versa!

OK – I feel better now…

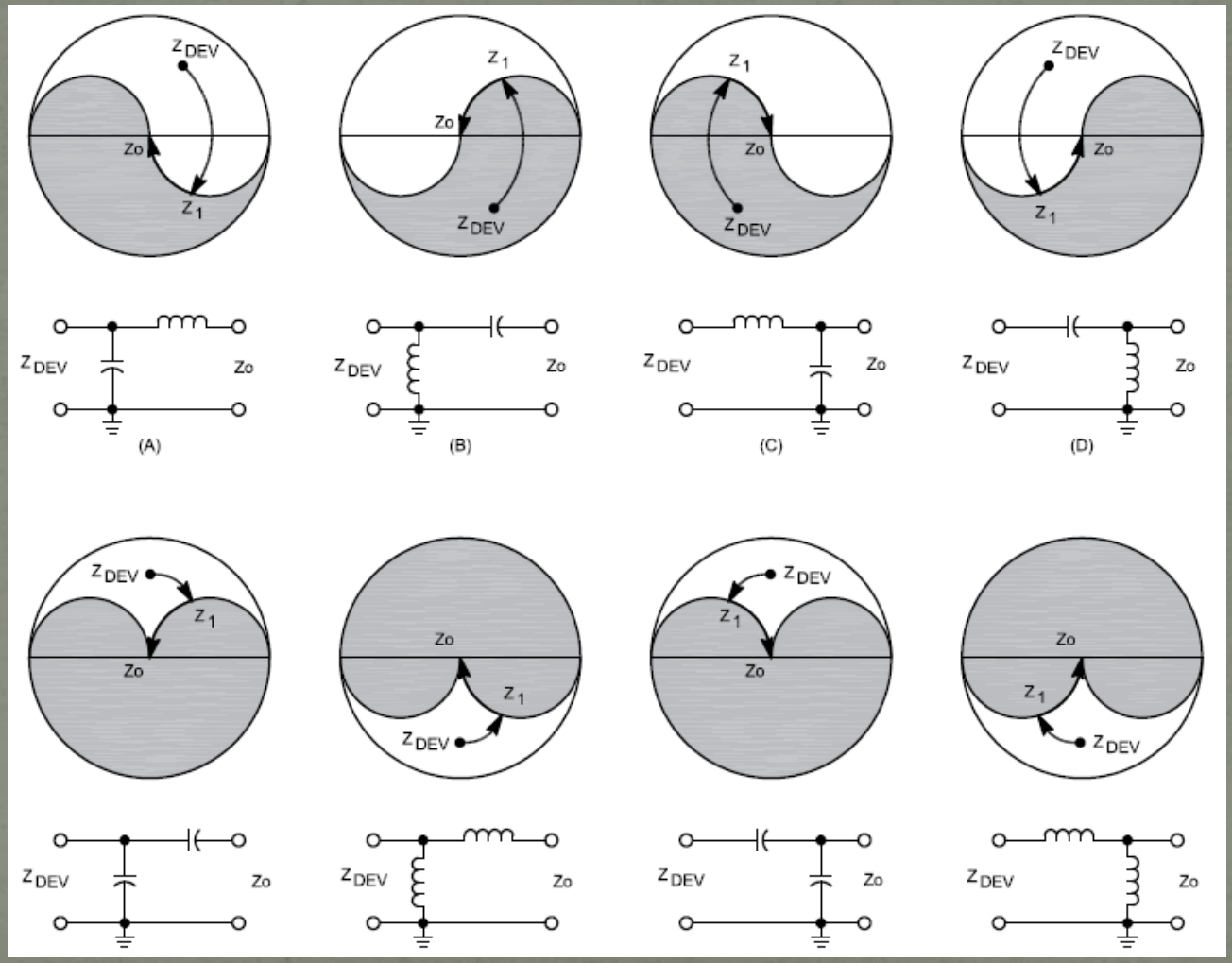
Reactive Matching

- "Reactive" meaning using L's and C's
- "Network" is just a fancy name for "circuit"
- L network
- Pi (and Pi-L) network and T-network
- Tapped-coil LC tank circuit and shunt-L
- Networks can be high-pass (series-C) or low-pass (series-L)
- Usually work at *just one frequency*

L Network

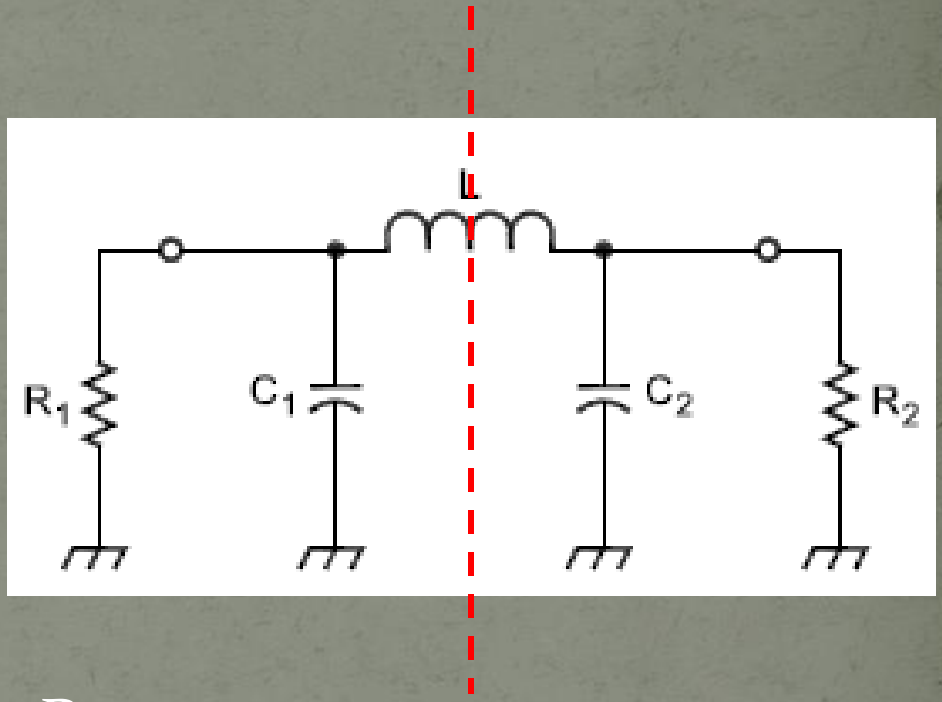
- Two components: L-C, L-L, or C-C
- Transforms high-to-low depending on the orientation of the components
- If it doesn't work, turn it around!
- Series-C is a high-pass network
- Series-L is a low-pass network

L Network



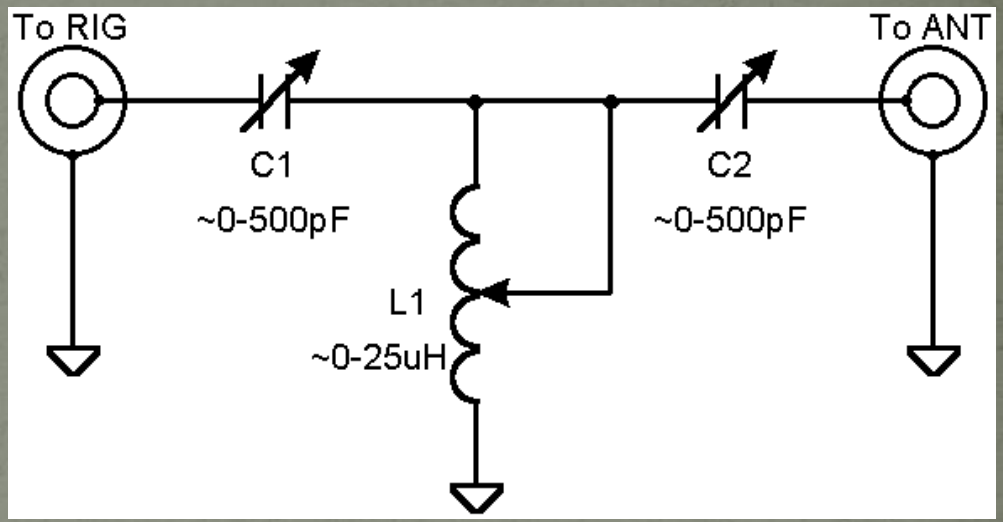
Pi Network

- Two L-networks "back to back"
- Allows more gradual impedance change
- Wider bandwidth and a larger impedance ratio
- Used in tube amplifiers
- Pi-L network adds one additional L in series with R_2



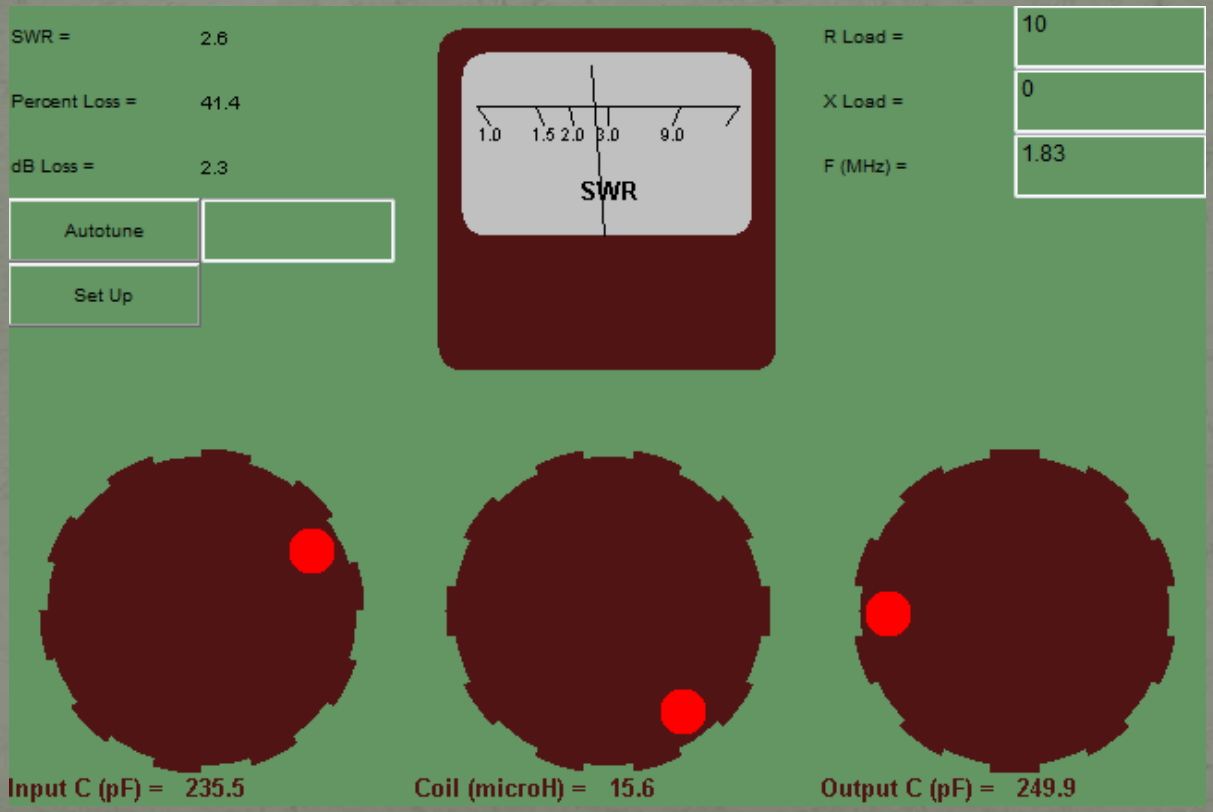
T network

- Typical of most antenna tuners sold today
- Also can be thought of as a pair of L networks
- Usually in high-pass configuration because variable capacitors are cheaper than variable inductors



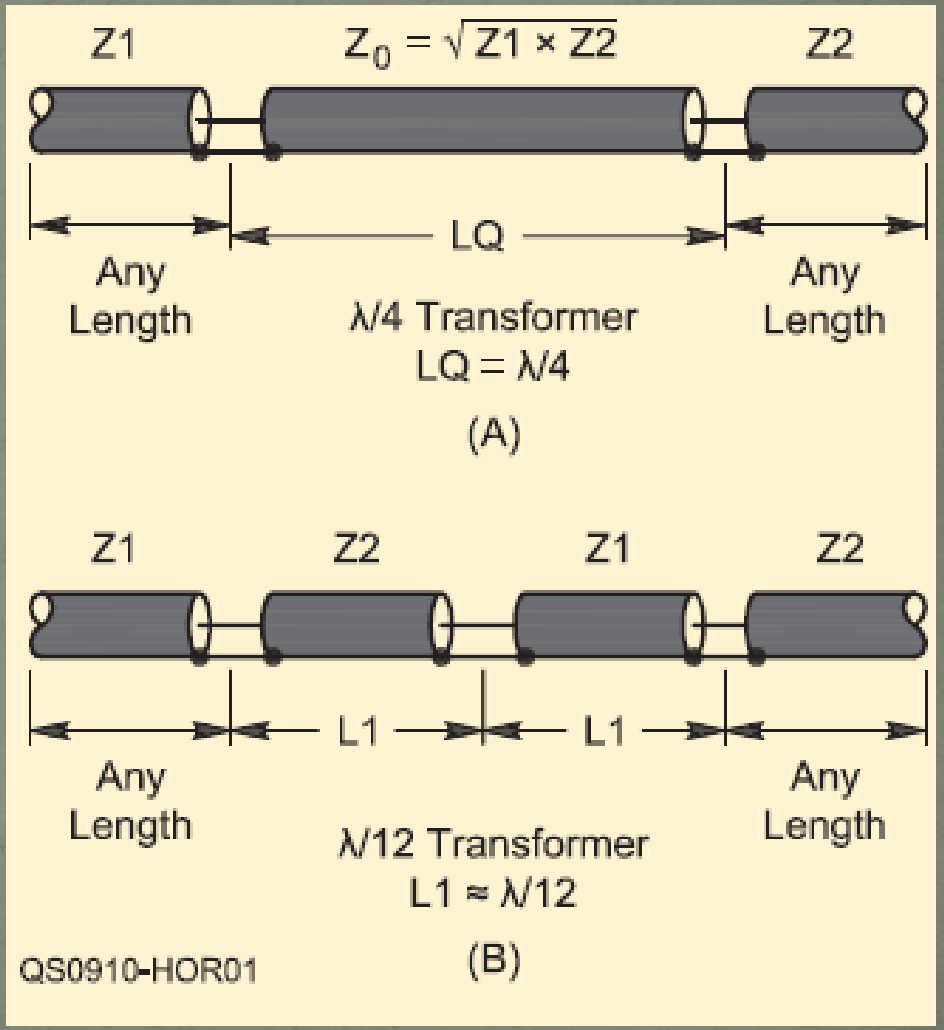
T network

- Fun tuner simulator by W9CF - fermi.la.asu.edu/w9cf/tuner/tuner.html



Transmission Line Transformers

- Synchronous transformers
- Quarter-wave or Q-section
- 1/12th-wave sections
  - Useful for 50-to-75 ohm matching
- Single-frequency match

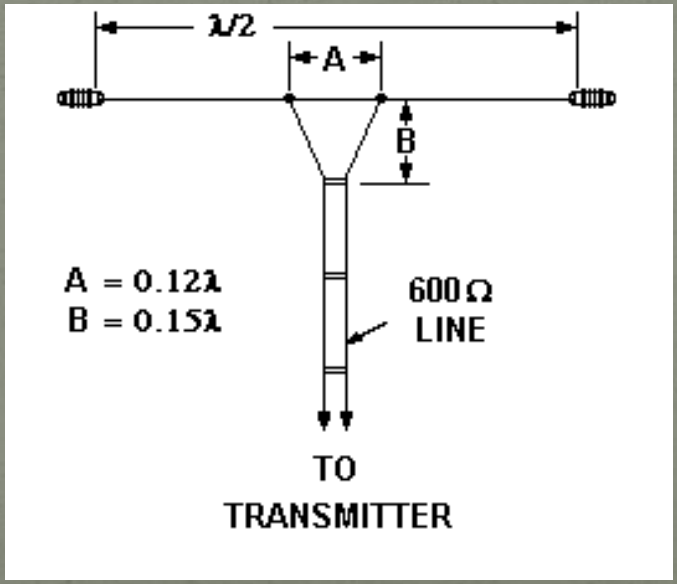


Antenna Feed Point Matching

- Structures and transmission line techniques
- Mount on the antenna or are part of the antenna feed point assembly
- Require adjustment at the antenna
- One-band matching

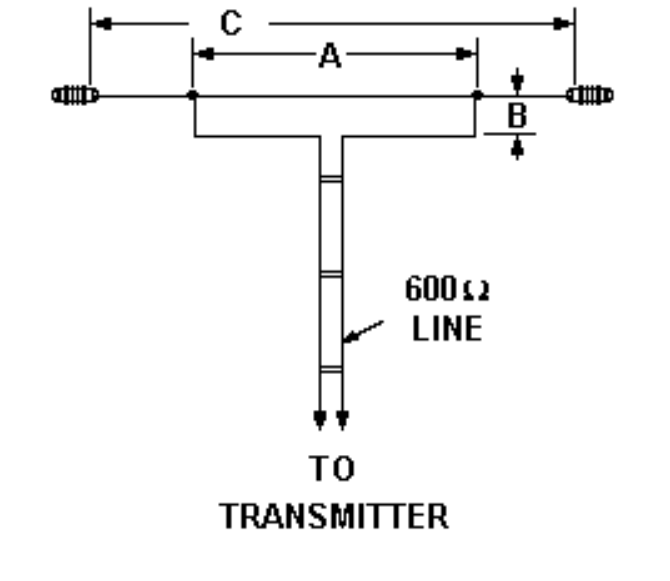
Delta Match

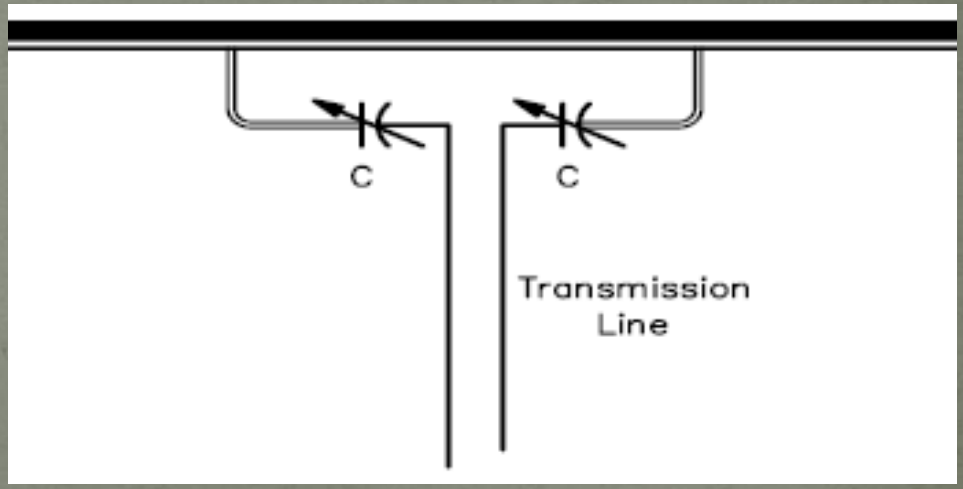
- Originally for open-wire to dipole
- Center feed point impedance 50-90 ohms
- End impedance several kohms
- Find point with open-wire impedance



T Match

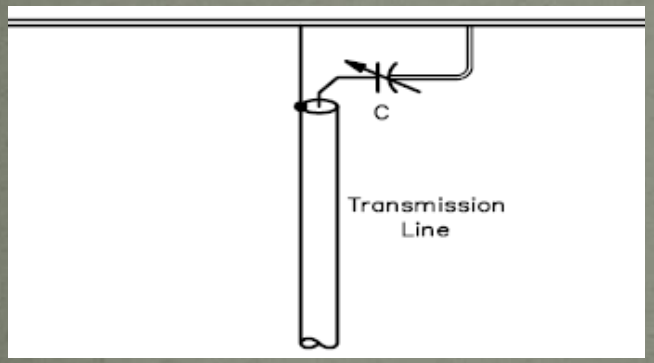
- Builds on delta match
- Made for balanced transmission line
- Constructs a transmission line on each side
- Has also been modeled as a folded dipole

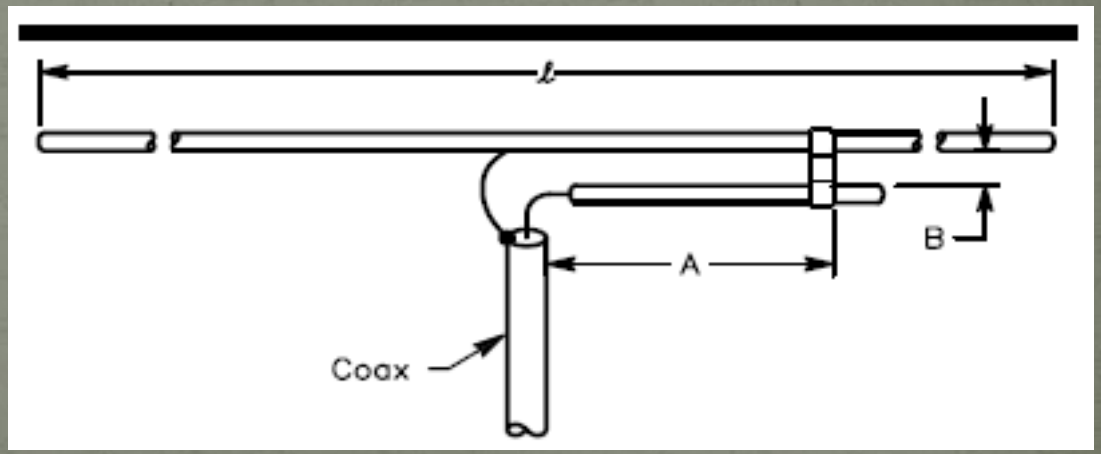




Gamma Match

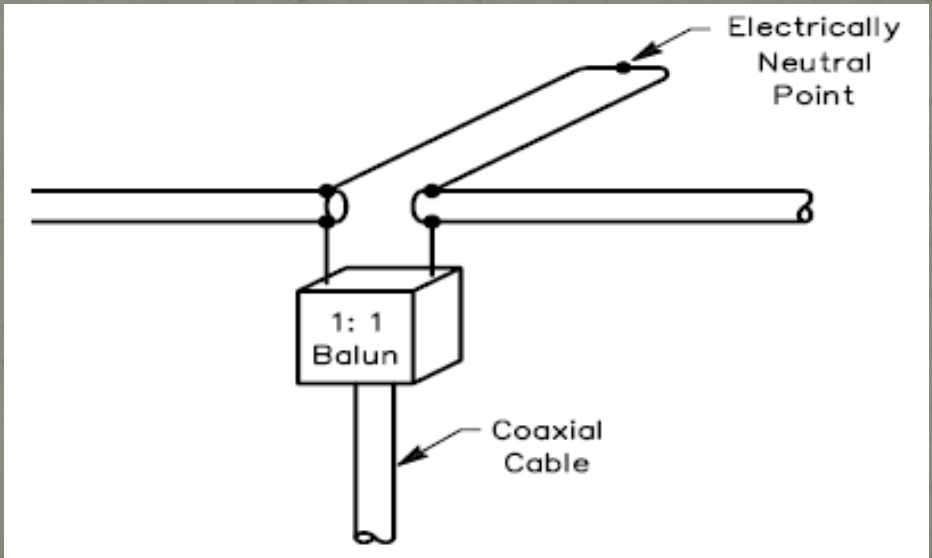
- One-half of a T match
- Allows driven element to be grounded at low-impedance point (the center)
- Capacitor usually constructed of insulated wire inside tube





Beta Match

- Also called “hairpin” match
- Requires insulated driven element
  - Center of symmetrical hairpin can be grounded
- Transforms impedance up like an L network



References and Tools

- *ARRL Handbook* and *ARRL Antenna Book*
  - Antenna Book software TLW, MATCH, etc
- *ARRL Guide to Antenna Tuners* by W1ZR
- ARRL Online Archives of *QST, QEX, NCJ*
  - *Ham Radio* also searchable, not archived
- *Antenna Compendiums*, Vol 1-8
- "Hands-On Radio" by NØAX in *QST*

References and Tools

- *Transmission Line Transformers* – J. Sevick, W2FMI (SK)
- *Reflections I, II, or III* – W. Maxwell, W2DU (SK)
- LB Cebik W4RNL (SK) - www.cebik.com now available through antennex.com online or on CD-ROM
- Online calculators (RF Café, Microwaves 101)
- HAMCALC package by VE3ERP (CQ website)
- Textbooks that are available on-line
  - Radio Engineering – Terman
  - Radio Antenna Engineering – Laport
  - See also "Antenna Fundamentals" chapter of *ARRL Antenna Book*

THANK YOU!!!