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
Consequences of Not Matching

- For a great video explaining SWR...
  - AT&T Archives on YouTube
  - “Similarities in Wave Behavior”
  - Very visual, simple math
  - Excellent introduction to Transmission Line concepts
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 and plastic
  - 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

![Diagram of a transformer with equations:]

\[ n = \frac{N_2}{N_1} \]

\[ V_2 = n V_1, \quad I_2 = I_1 / n \]
How to Match?

- Broadband transformers
  - Audio and modulation transformers
  - Ferrite and powdered-iron cores
- Transform voltage/current ratio
  \[
  \frac{V_{\text{sec}}}{I_{\text{sec}}} = Z_{\text{sec}} \quad \text{and} \quad \frac{V_{\text{pri}}}{I_{\text{pri}}} = Z_{\text{pri}}
  \]
  \[
  \frac{Z_{\text{sec}}}{Z_{\text{pri}}} = n^2
  \]
- 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 designed to 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
- 1/12\textsuperscript{th}-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*