Antenna Tuners
(Antenna Couplers)
What is an Antenna Tuner?

• An antenna tuner (coupler is a more correct term) is an impedance matching device which minimizes “mismatch” loss (maximizes power transfer).

• NOT different from any other impedance matching circuit. It does NOT tune the antenna!

• Old R.L. Drake devices were named MN-4, MN-2000, MN-2700. Guess what the MN stands for.

• Also referred to as coupler, antenna coupler, transmatch, Matchbox, etc.
Basics: Correct or Incorrect?

• An antenna operated at its resonant frequency doesn’t need a coupler.
  – *No, resonance only means the feed point is resistive and does not mean a low SWR.*

• Resonant antennas radiate better than non-resonant antennas.
  – *No, pattern may change from that at resonance and will need to match.*

• Most antennas are resonant at only one frequency.
  – *No, all antenna have multiple resonances.*
Basics: Correct or Incorrect?, Page 2

• The ability to match is more important than efficiency when choosing a coupler.
  – Yes, if the coupler doesn’t match not much else matters.

• Coupler affects magnitude of current to antenna.
  – Yes, this is how matching works.

• Coupler does not affect the pattern of the antenna.
  – Should be Yes, but only if the ratio of any common mode current on the feed line to the antenna currents remains the same.
Basics: Correct or Incorrect?, Page 3

- The SWR presented by an antenna is minimum at the fundamental resonant frequency.
  - *No, often SWR is minimum but not a requirement.*

- A coupler placed at the antenna will always result in a more efficient system than one placed at the transmitter.
  - *Generally Yes, but impedance at antenna is different and coupler might not be able to match or be as efficient for this impedance.*
Basics: Correct or Incorrect?, Page 4

• Does 50Ω coax need to be used between coupler and transmitter?
  – No, but do not use SWR meter in coupler if not 50Ω.

• True open wire #12ga. 600Ω transmission line has lower loss than 1/2” 50Ω coax.
  – Generally Yes, however if load is 5+j0, SWR on 50Ω line is 10:1 & 120:1 on open wire line. Loss for 100’ at 7MHz is 2.12dB (open wire) & 1.02dB (LMR-500).

• Couplers should not be cascaded.
  – Yes, if both auto-couplers but no otherwise.
Basics: Correct or Incorrect?, Page 5

• A multiband coupler will have reduced matching at both the top and bottom of the frequency range.
  – Yes!

• A coupler in a radio that is specified to match 3:1 SWRs matches all 3:1 SWRs and not much else.
  – No!

• Couplers do not exist at VHF and above.
  – No, but construction is done with transmission line sections and not lumped components.
Does Coupler Use = Incompetency?

• Chest pounding by some would imply so.
  – I don’t need a tuner since my antennas are designed properly. Tuners have too much loss. Idiots abound!
• A coupler is one of many tools that can be used.
• Couplers are more popular today than ever.
  – Covenants, small lot sizes, 11 HF bands (inc. 6m), etc.
  – The issue of stealth and camouflaged antennas could easily be another talk.
Choices?

• You don’t have antennas to cover all desired frequencies with an acceptable SWR for your equipment.
  – Do nothing and just don’t operate on some frequencies.
  – Lack of knowledge point of view. Most common and probably best if there are frequent antenna changes!
  – Estimating the impedance(s) needed to match by analysis or tables.
  – Knowing very closely the impedance(s) needed to match by measurement.
What do you really want/need?

- Matches nearly everything?, Match = 1.0:1 SWR?
- Improve SWR bandwidth?, Hardly ever adjusted?
- Peak/average power (mfg. ratings not reliable)?
- Adjust at low power?, Adjust at full power?
- Adjusts or can be adjusted very quickly?
- 160-10m, 80-10m, 6m, single band?
- Harmonic or band pass filtering?, Static bleed?
- Remotable?, Some combination of the above?
Matching Network Components

• Generally constructed from reactive components.
  – Exceptions: transmission lines, delta match, resistances such as the 800-900\(\Omega\) resistor in the B&W terminated folded dipole, etc.

• Why reactive components?
  – Reactive components with high unloaded Qs do not dissipate much power.
  – However physically large components have reduced ranges and more stray inductance and capacitance.
  – Transmission line components \(\sim Q=100\).
DIY Coupler

• In approximate order of ascending cost
  1) Fixed inductor
  2) Small value fixed capacitor
  3) Air variable capacitor
  4) Air differential capacitor
  5) Large voltage fixed capacitor
  6) High voltage/current switch
  7) Vacuum variable capacitor
  8) Roller inductor
Types of Tuners

- Auto, semi-auto, manual adjust, or fixed.
- Variable, switched, and/or fixed components.
- Is coupler part of transmitter or antenna?
  - If part of the antenna then changing transmitters easy.
- Included balun, antenna switch, dummy load etc.
- Power rating and matching range. Total BS!
- Coupler/antenna as a system (military & aircraft).
- No mention yet of coupler topology.
Tying it all together

- **Reflection Coefficient:**
  \[ \Gamma = \frac{Z_L - Z_O}{Z_L + Z_O} \]
  \[ \rho = |\Gamma| \quad 0 \leq \rho \leq 1 \]

- **SWR:**
  \[ \text{SWR} = \frac{1 + \rho}{1 - \rho} \]
  \[ \rho = \frac{\text{SWR} - 1}{\text{SWR} + 1} \]

- **Return Loss:**
  \[ \text{RL}_{\text{dB}} = -20 \times \log_{10}(\rho) \]

- **Mismatch Loss:**
  \[ \text{ML}_{\text{dB}} = -10 \times \log_{10} \left( \frac{P_{\text{Fwd}} - P_{\text{Ref}}}{P_{\text{Fwd}}} \right) = -10 \times \log_{10} \left( 1 - \rho^2 \right) \]
<table>
<thead>
<tr>
<th>SWR</th>
<th>$\rho$</th>
<th>Return Loss (dB)</th>
<th>Mismatch Loss (dB)</th>
<th>Power To Load$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>0.05</td>
<td>26.44</td>
<td>0.01</td>
<td>100%</td>
</tr>
<tr>
<td>1.2</td>
<td>0.09</td>
<td>20.83</td>
<td>0.04</td>
<td>99%</td>
</tr>
<tr>
<td>1.5</td>
<td>0.20</td>
<td>13.98</td>
<td>0.18</td>
<td>96%</td>
</tr>
<tr>
<td>2</td>
<td>0.33</td>
<td>9.54</td>
<td>0.51</td>
<td>89%</td>
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<tr>
<td>2.5</td>
<td>0.43</td>
<td>7.36</td>
<td>0.88</td>
<td>82%</td>
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<tr>
<td>3</td>
<td>0.50</td>
<td>6.02</td>
<td>1.25</td>
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<tr>
<td>5</td>
<td>0.67</td>
<td>3.52</td>
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<td>50</td>
<td>0.96</td>
<td>0.35</td>
<td>11.14</td>
<td>8%</td>
</tr>
</tbody>
</table>

Note 1: Does not include additional loss in transmission line due to SWR or any fold back in transmitter.
Voltages and Currents

\[ V_{pk} = \sqrt{2 \times P \times R_o} \]

\[ I_{rms} = \sqrt{\frac{P}{R_o}} \]

\[ V_{pk} \leq \sqrt{2 \times P \times R_o \times SWR} \]

\[ I_{rms} \leq \sqrt{\frac{P \times SWR}{R_o}} \]
<table>
<thead>
<tr>
<th>SWR</th>
<th>Power</th>
<th>Vpk(max)</th>
<th>Irms(max)</th>
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<tr>
<td>1:1</td>
<td>100W</td>
<td>100V</td>
<td>1.41A</td>
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<tr>
<td></td>
<td>1500W</td>
<td>387V</td>
<td>5.48A</td>
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<tr>
<td>3:1</td>
<td>100W</td>
<td>173V</td>
<td>2.45A</td>
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<td>1500W</td>
<td>671V</td>
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<td>24.5A</td>
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<td>100W</td>
<td>797V</td>
<td>10.0A</td>
</tr>
<tr>
<td></td>
<td>1500W</td>
<td>2739V</td>
<td>38.7A</td>
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</table>
Stresses Within the Tuner @ 1500W

- All are 20:1 SWRs. Stresses & losses are different.
“Small” Antenna Examples

- **Example #1**
  - 1.8MHz using 40m (67.2’) dipole, 50’ high, #12 Cu wire
  - $Z = 1.60 - j2420$ (SWR ~73000:1)
  - $I_{rms} = 30.6A$ (1500W), $V_{pk} = 104.7kV$

- **Example #2**
  - 1.8MHz using 80m (135’) dipole, 50’ high, #12 Cu wire
  - $Z = 5.9 - j1080$ (SWR ~3950:1)
  - $I_{rms} = 15.94A$ (1500W), $V_{pk} = 24.3kV$

- No tuners match these impedances well!
- A little loss is desperately needed.
What is the Smith Chart

• A polar plot of the reflection coefficient including phase.
• This results in:
  – Plots of constant SWRs are circles.
  – Inductive impedances are above the center line.
  – Capacitive impedances are below the center line.
  – The horizontal axis goes from $0\Omega$ at the far left to $R_0$ at the center to infinity at the far right.
Smith Chart Regions

Region 1
B, D

Region 2
A, C

Region 3
A, D, E, F

Region 4
B, C, G, H

L type circuits

A

B

C

D

E

F

G

H

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Example Smith Chart showing SWR circles

5:1 = Green
10:1 = Red
20:1 = Orange

50 + j0 (SWR = 1:1)
Sample Design Goals

• Match all SWRs of at least 20:1 from 160m thru 20m with reduced SWRs up thru 6m.
• Do the basic design on 40m realizing that 4X more C & L will be needed on 160m etc.
• Ignore stray C & L for now.
• Explain old Johnson Matchbox with open wire line and large antennas vs today’s use of a coupler.
Low Pass “L” Network
Type “A”

- Shunt “C” on ANT Side
- Series “L”
- Need $> C_{\text{max}}$ & $< C_{\text{min}}$

Transmitter 0.2-5uH  Antenna

Low Pass "L" Network
"L_{series-\text{Cshunt}}"  7 MHz
Low Pass “L” Network
Type “B”

- Shunt “C” on TX Side
- Series “L”

- Need $<L_{\text{min}}$ & $>C_{\text{max}}$

Transmitter 0.1-5\mu H Antenna

100 - 1500pF

Low Pass "L" Network
"Cshunt-Lseries"

7 MHz
Low Pass “L” Network Results

- C_{\text{max}} \approx 8000\text{pF} & L_{\text{max}} \approx 20\text{uH} on 160m
- C_{\text{min}} \approx 5\text{pF} & L_{\text{min}} \approx 0.02\text{uH} on 6m
- Pretty ugly component values.
- This happens when only 2 adjustable components, wide frequency, & wide matching range are wanted.
- Need some switchable offset components or variable offset components to help match especially on the higher frequencies.
High Pass “L” Network
Type “C”

- Shunt “L” on ANT Side
- Series “C”
- Need >Lmax (not good)

Transmitter 100 - 2000pF Antenna
0.3-20uH

High Pass "L" Network
"Cseries-Lshunt"
High Pass “L” Network
Type “D”

- Shunt “L” on TX Side
- Series “C”
- Need $>C_{\text{max}}$ (not good)

Transmitter 100 - 3000pF Antenna

0.3-5uH
High Pass “L” Network Results

- Worse component values than Low Pass “L”.
- Variable component “L” networks are not commonly used for wide range matching on the lower frequencies for good reason.
- Low Pass “L” networks are used in most switched component tuners with reduced 160m & 80m matching range.
- Often good choice if match impedance is known.
Adding a 3rd Component

- Does adding a 3rd adjustable component help the matching range?
- Could the Low Pass “Pi” could be this network?
- A “Pi” network is still a 2 terminal network.
Low Pass “Pi” Network

- Great matching range
- Similar component values to the Low Pass “L” network
Low Pass “Pi” Network

- Great matching range
- Notice new scaled component values!
Low Pass “Pi” Network

– Still good matching range

Transmitter 0.2-20uH Antenna

100 - 8000pF

Low Pass "Pi" Network
"Cshunt-Lseries-Cshunt"

14 MHz

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Low Pass “Pi” Network

- Not good matching range
- Needs $<C_{\text{min}}$ and $<L_{\text{min}}$

Transmitter 0.2-20uH Antenna

100 - 8000pF
Low Pass “Pi” Network

- Very good matching range
- Modified for Cmin which includes stray C to Gnd
- Includes stray L on input and output

Transmitter - 0.05-1uH - Antenna
0.05uH 20 - 400pF 0.05uH

Low Pass "Pi" Network
"Cshunt-Lseries-Cshunt"

28 MHz
Low Pass “Pi” Network

- Very good matching range
- Modified for $<C_{\text{min}}$ which includes stray C to Gnd
- Includes stray L on input and output
- 6m range better than 10m due to 0.05uH
High Pass “Tee” Network

• Neither the “L” or Low Pass “Pi” networks seems like a good candidate for use as an all band general matching network.
• The “Tee” network has an effective 3rd node which increases flexibility at the expense of possible additional loss.
• 80-90% of any coupler loss is in the inductor(s) so improving inductor Q can offset loss concerns.
High Pass “Tee” Network

- Pretty easy to see why the high pass “Tee” network is popular
- Nice component values
High Pass “Tee” Network

- Great matching range
High Pass “Tee” Network

- Still great matching range
High Pass “Tee” Network

- Very good matching range

Transmitter 30-500pF 30-500pF 5uH Antenna

High Pass "Tee" Network "C-L-C" 21 MHz

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High Pass “Tee” Network

- Obvious why the High Pass “Tee” is popular

Transmitter

Antenna

30-500pF

30-500pF

0.2-20uH

28 MHz

High Pass "Tee" Network
"C-L-C"
High Pass “Tee” Network

- What if we include the stray Cs & Ls
- Still great matching range

Transmitter

\[ 0.05\mu\text{H} \]
\[ 20\text{pF} \]
\[ \downarrow \]
\[ 0.2-20\mu\text{H} \]

Both

\[ 30-500\text{pF} \]

Antenna

\[ 0.05\mu\text{H} \]
\[ 20\text{pF} \]

High Pass "Tee" Network
"C-L-C"

28 MHz
High Pass “Tee” Network

- Matching range is poor
- $L_{\text{min}}$ is too large
  (reactance = $+j63$ @50MHz)
Fixed “L” High Pass “Tee” Network
– Fixed “L” can cover 2 bands pretty well.
– Inductor easy to make very high Q.
– Coupler best @ ~5MHz
– Matches all 10:1 SWRs & 95% of 20:1 SWRs
Fixed “L” High Pass “Tee” Network

– Matches all 5:1 SWRs & 75% of 20:1 SWRs
Fixed “L” High Pass
“Tee” Network

- Matches all 7:1 SWRs,
  60% of 10:1 SWRs, &
  40% of 20:1 SWRs
Other Network Topologies

- Lew McCoy W1ICP, Ultimate Transmatch (1970)

- Doug DeMaw W1FB, SPC Transmatch (1980)

Both had minimal to moderate harmonic suppression with a reduction in matching range vs the basic High Pass “Tee”.

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Other Network Topologies

- **Link Coupled (Johnson Matchbox)**
  - Very good for higher R matches
  - Link coupling very efficient

- **High Pass Differential Tee (MFJ & later Palstar)**
  - Only 2 controls to adjust

Slightly to significantly more loss than standard High Pass Tee & reduced matching range on higher frequencies but easier to adjust.
High Pass Differential “Tee” Network

- Based on measurements and component values of the Palstar AT-Auto with last version of inductor

![Diagram of High Pass Differential “Tee” Network](image)

- Transmitter
- 440-25-440pF
- 0.10uH
- 20pF
- 0.15uH
- 20pF
- 0.2-24.2uH
- Antenna

High Pass Differential "Tee" C-L-C 1.8 MHz

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High Pass Differential
“Tee” Network

- Palstar AT-Auto

Diagram showing a High Pass Differential "Tee" network with components labeled as follows:

- Transmitter
- Antenna
- 440-25-440pF
- 0.10uH
- 0.15uH
- 0.2-24.2uH
- 20pF

Caption: High Pass Differential "Tee" C-L-C 3.5 MHz
High Pass Differential
“Tee” Network

- Palstar AT-Auto

Diagram:
Transmitter 440-25-440pF Antenna
0.10uH 0.15uH
20pF 20pF
0.2-24.2uH

High Pass Differential "Tee" C-L-C 7 MHz
High Pass Differential “Tee” Network

- Palstar AT-Auto
- No longer matches all 5:1 SWRs
- Add 4’ of 50Ω .66VF coax for 90 deg. CW rotation if needed.

Diagram:
- Transmitter
- 440-25-440pF
- 0.10uH
- 20pF
- 0.15uH
- 20pF
- 0.2-24.2uH
- Antenna

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High Pass Differential "Tee" Network

- Palstar AT-Auto
- Matching range severely reduced

Transmitter

0.10uH
20pF

440-25-440pF

Antenna

0.15uH
20pF

0.2-24.2uH

High Pass Differential "Tee" C-L-C 28 MHz
High Pass Differential “Tee” Network

- Palstar AT-Auto
- Matching range very limited

![Diagram of High Pass Differential "Tee" Network](image)

- Transmitter
- 440-25-440pF
- 0.10uH
- 20pF
- 0.15uH
- 20pF
- 0.2-24.2uH
- Antenna

High Pass Differential "Tee" C-L-C 54 MHz
The End!
Other Topics

• Why might a full sized dipole need matching?
• Coupler topologies and stresses.
• Converting series to parallel impedances.
• Johnson Matchbox or other link couplers.
• Quarter wave section for variable impedances.
• Transmission line only tuner.
• Complex conjugate impedances.
• Graphical look at reflections.
Does a Full Sized Dipole Need Matching?

Fig 1—Variation in radiation resistance of vertical and horizontal half-wave antennas at various heights above flat ground. Solid lines are for perfectly conducting ground; the broken line is the radiation resistance of horizontal half-wave antennas at low height over real ground. Chapter 3, ARRL Antenna Book 21st edition
Dipole Matching

- $7.0\text{MHz} = 88.9 - j13.8$  $7.1\text{MHz} = 93.2 + j8.1$
  $7.2\text{MHz} = 97.7 + j29.9$  $7.3\text{MHz} = 102.2 + j51.5$
- Match with 99 deg. of 75$\Omega$ transmission line at antenna. SWR $< 1.4:1$ across entire band.
- Match with 2.55$\mu$H across antenna and 408pF in series toward TX. SWR $< 1.4:1$ across entire band.
- All matches with Q significantly less than the Q of the dipole will have 1.4:1 band edge SWRs.
\[ Z = 20 - j0 \text{ (SWR 2.5:1), 28MHz, 1500W} \]

<table>
<thead>
<tr>
<th>Type</th>
<th>Transmitter Side</th>
<th>Antenna Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP-&quot;L&quot; Cp-Ls</td>
<td>( Cp = 139.2\text{pF} ) 387Vpk, 6.7A</td>
<td>( Ls = 0.14\text{uH} ) 300Vpk, 8.7A</td>
</tr>
<tr>
<td>HP-&quot;L&quot; Lp-Cs</td>
<td>( Lp = 0.23\text{uH} ) 387Vpk, 6.7A</td>
<td>( Cs = 232\text{pF} ) 300Vpk, 8.7A</td>
</tr>
<tr>
<td>HP-&quot;Tee&quot; 250pF Cs1-Lp-Cs2</td>
<td>( Cs1 = 250\text{pF} ) 176Vpk, 5.5A</td>
<td>( Lp = 0.18\text{uH} ) 426Vpk, 9.4A</td>
</tr>
<tr>
<td>HP-&quot;Tee&quot; 500pF Cs1-Lp-Cs2</td>
<td>( Cs1 = 500\text{pF} ) 88Vpk, 5.5A</td>
<td>( Lp = 0.20\text{uH} ) 397Vpk, 8.0A</td>
</tr>
<tr>
<td>LP-&quot;Pi&quot; 200pF Cp1-Ls-Cp2</td>
<td>( Cp1 = 188.1\text{pF} ) 387Vpk, 9.1A</td>
<td>( Ls = 0.18\text{uH} ) 472Vpk, 10.6A</td>
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</table>
Z = \(5 - j200\) (SWR 157:1), 1.8MHz, 1500W

<table>
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<th>Type</th>
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<th>Antenna Side</th>
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<tbody>
<tr>
<td>LP-&quot;L&quot; Cp-Ls</td>
<td>Cp = 5302pF 387Vpk, 16.4A</td>
<td>Ls = 19.01uH 5265Vpk, 17.3A</td>
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<tr>
<td>HP-&quot;L&quot; Cs-Lp</td>
<td>Cs = 140.3pF 4882Vpk, 5.5A</td>
<td>Lp = 13.45uH 4897Vpk, 22.8A</td>
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<tr>
<td>HP-&quot;Tee&quot; 250pF Cs1-Lp-Cs2</td>
<td>Cs1 = 50.7pF 13511Vpk, 5.5A</td>
<td>Lp = 37.17uH 13517Vpk, 22.7A Cs2 = 250pF 8634Vpk, 17.3A</td>
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<tr>
<td>HP-&quot;Tee&quot; 500pF Cs1-Lp-Cs2</td>
<td>Cs1 = 74.4pF 9205Vpk, 5.5A</td>
<td>Lp = 25.31uH 9213Vpk, 22.8A Cs2 = 500pF 4323Vpk, 17.3A</td>
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<tr>
<td>HP-&quot;Tee&quot; 1000pF Cs1-Lp-Cs2</td>
<td>Cs1 = 97.2pF 7046Vpk, 5.5A</td>
<td>Lp = 19.38uH 7056Vpk, 22.8A Cs2 = 1000pF 2163Vpk, 17.3A</td>
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<td>Cp1 = 6621pF 387Vpk, 20.5A</td>
<td>Ls = 15.53uH 5270Vpk, 21.2A Cp = 100pF 4897Vpk, 3.9A</td>
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<td>LP-&quot;Pi&quot; 1000pF Cp1-Ls-Cp2</td>
<td>Cp1 = 18103pF 387Vpk, 56.1A</td>
<td>Ls = 5.85uH 5270Vpk, 56.3A Cp = 1000pF 4884Vpk, 39.1A</td>
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**Z = 2000 – j0 (SWR 40:1), 7.0MHz, 1500W**

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<td>LP-&quot;L&quot;</td>
<td>Ls = 7.10uH 2148Vpk, 5.5A</td>
<td>Cp = 71.0pF 2449Vpk, 5.4A</td>
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<td>Ls-Cp</td>
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<tr>
<td>HP-&quot;L&quot;</td>
<td>Cs = 72.8pF 2418Vpk, 5.5A</td>
<td>Lp = 7.28uH 2449Vpk, 5.4A</td>
</tr>
<tr>
<td>Cs-Lp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP-&quot;Tee&quot; 250pF</td>
<td>Cs1 = 72.7pF 2421Vpk, 5.5A</td>
<td>Lp = 7.23uH 2452Vpk, 5.4A</td>
</tr>
<tr>
<td>Cs1-Lp-Cs2</td>
<td></td>
<td>Cs2 = 250pF 111Vpk, 0.9A</td>
</tr>
<tr>
<td>HP-&quot;Tee&quot; 500pF</td>
<td>Cs1 = 72.8pF 2419Vpk, 5.5A</td>
<td>Lp = 7.25uH 2450Vpk, 5.4A</td>
</tr>
<tr>
<td>Cs1-Lp-Cs2</td>
<td></td>
<td>Cs2 = 500pF 56Vpk, 0.9A</td>
</tr>
<tr>
<td>LP-&quot;Pi&quot; 250pF</td>
<td>Cp1 = 250pF 387Vpk, 3.0A</td>
<td>Ls = 6.74uH 2610Vpk, 6.2A</td>
</tr>
<tr>
<td>Cp1-Ls-Cp2</td>
<td></td>
<td>Cp = 81pF 2449Vpk, 6.2A</td>
</tr>
<tr>
<td>LP-&quot;L&quot;</td>
<td>Ls = 7.10uH 2148Vpk, 5.5A</td>
<td>Cp = 71.0pF 2449Vpk, 5.4A</td>
</tr>
<tr>
<td>Ls-Cp</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Series/Parallel Conversion

\[ \begin{align*}
Rp &= \frac{R_s^2 + X_s^2}{R_s} \\
Rs &= \frac{R_p \times X_p^2}{R_p^2 + X_p^2} \\
X_p &= \frac{R_s^2 + X_s^2}{X_s} \\
X_s &= \frac{R_p^2 \times X_p}{R_p^2 + X_p^2}
\end{align*} \]

Note: If impedance was capacitive in series form then it is still capacitive in parallel form. Same is true for inductive impedances. Sign of \(X_p\) and \(X_s\) is the same.
80m full size dipole
- #12 wire up 40’
- No feedline
- Pink dot = 1.8MHz

What can be expected when used at all HF frequencies?
80m full size dipole
- 50’ of .66VF 50Ω lossless coax

Very wide range of impedances!

Even if loss in real coax is ignored this is a tough matching problem.
80m full size dipole
– 50’ of 600Ω lossless open wire line

Notice how impedances are high at all freq. above 3.5MHz.

The Johnson Matchbox efficiently matches higher impedances!
Lossless Transmission Line Reflections

1 electrical wavelength @ 14MHz

V(Vin1) under I(R1)
V(Vout2) under I(R2)

R1
Vin1
T1
Vout1

R2

Td=71.4n Z0=50

Perfect Match
SWR = 1.0:1
Reflection Coefficient = 0

File LosslessReflections-50.asc
Lossless Transmission Line Reflections

1 electrical wavelength @ 14MHz

V(Vin1) under I(R1)

No further reflections due to R1

SWR = 2.0:1
Reflection Coefficient = +.333
Lossless Transmission Line Reflections

1 electrical wavelength @ 14MHz

V(Vin1) under I(R1)

No further reflections due to R1

File LosslessReflections-25.asc

No further reflections due to R1

Larry Benko, W0QE
Smith Chart

• Smith Chart basics
  – Zo at center, constant SWR = circles
  – X axis is reflection coefficient (-1 to +1)
  – Top half is inductive, bottom half is capacitive
  – Need to think in terms of $Z = R \pm jX$ & $Y = G \pm jB$

• The Smith Chart allows the user to see graphical solutions to matching problems which enhances the understanding of impedance matching

• Smith Chart could easily be an entire presentation
Series Capacitor

10MHz = Green
20MHz = Red
30MHz = Blue
Series Inductor

10MHz = Green
20MHz = Red
30MHz = Blue
Shunt Capacitor

10MHz = Green
20MHz = Red
30MHz = Blue
Shunt Inductor

10MHz = Green
20MHz = Red
30MHz = Blue
Series Transmission Line (50Ω)

10MHz = Green
20MHz = Red
30MHz = Blue
Series Transmission Line (200Ω)

10MHz = Green
20MHz = Red
30MHz = Blue
2:1 Turns Transformer Step Up

10MHz = Green
20MHz = Red
30MHz = Blue
Open Stub

10MHz = Green
20MHz = Red
30MHz = Blue
Shorted Stub

10MHz = Green
20MHz = Red
30MHz = Blue
Smith Chart Regions

Region 3
A, D, E, F

Region 1
B, D

Region 2
A, C

Region 4
B, C, G, H

L type circuits

A

B

C

D

E

F

G

H

3/12/2009
Larry Benko, W0QE
Surge Impedance Again

• \( Z_0 = \sqrt{\frac{L}{C}} \) per unit length, equivalent circuit no loss

• \( Z_0 = \left( \frac{138}{\sqrt{\varepsilon}} \right) \times \log_{10} \left( \frac{OD}{ID} \right) \) for round coax

• Why a particular impedance?
  – Maximum power 30Ω, minimum loss 77Ω, max. voltage breakdown 60Ω (1929 Bell Laboratories Study)
  – Maximum power per pound of copper 52Ω (F. Terman?)
  – Today 75Ω, 50Ω, 52Ω, 53.5Ω, 25Ω, 80Ω, 93Ω, etc.