

# How to Blow Up Your Balun

(and other things too...)



Fig 36 – Coaxial Chokes Wound to Minimize L and C



Fig 37 – A Bifilar Choke

By Dean Straw, N6BV  
Sea-Pac June 7, 2014

*Photos courtesy Jim Brown, K9YC*

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- I will examine stresses placed on common-mode chokes (aka, “baluns”) as hams use/abuse them.
- I will examine the efficiency of simple dipole multi-band antennas and their feed systems.

# Stressing a Balun

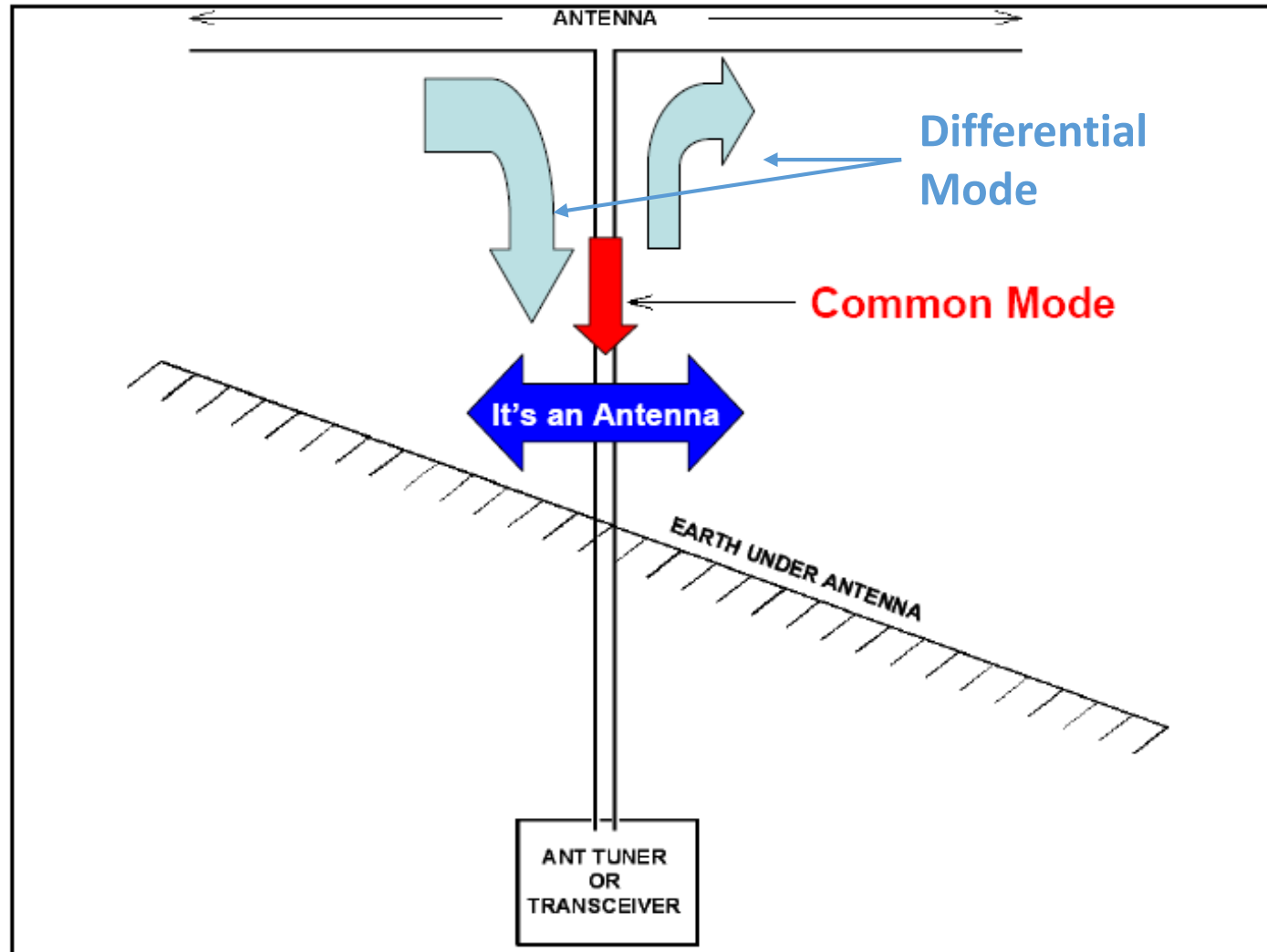


Figure courtesy  
K9YC

# What's a Common Mode Choke?

- A circuit element that reduces common mode current by adding a high impedance in series with the common mode circuit
  - Reduces radiation from the cable
  - Reduces reception by the cable

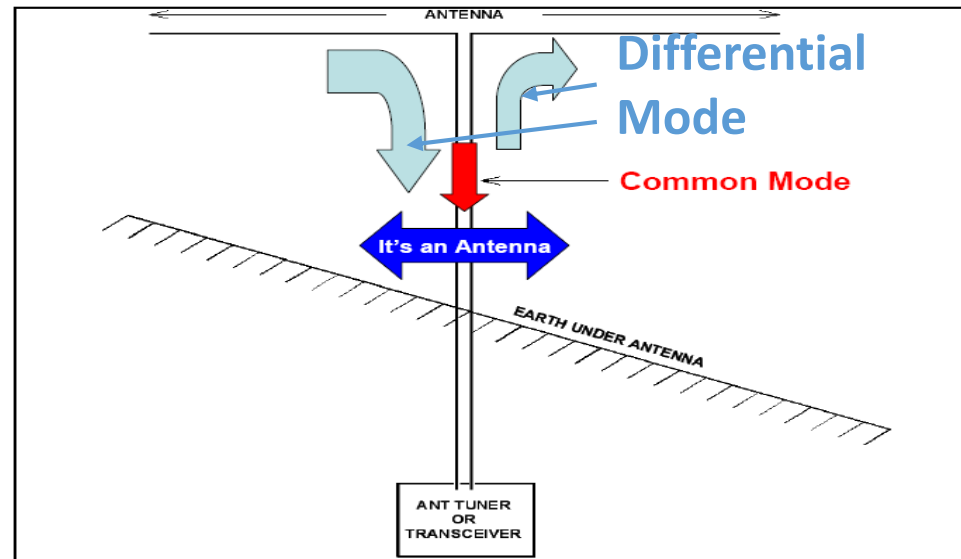
*Slide courtesy K9YC*

# Current-Mode Chokes

- Impedance is assumed high enough to “choke off” undesired common-mode currents, preventing radiation from the transmission line. This is the best case, with the least power lost in the choke balun due to common-mode current. (More on this later in discussing OCF dipoles.)

# Current-Mode Chokes

- Impedance is assumed high enough to “choke off” undesired common-mode currents, preventing radiation from the transmission line. This is the best case.
- The desired differential-mode current flows in opposite directions on the inside of a **coax cable**. The field around the transmission line is cancelled.



# Current-Mode Chokes

- Impedance is assumed high enough to “choke off” undesired common-mode currents, preventing radiation from the transmission line. This is the best case.
- The desired differential-mode current flows in opposite directions on the inside of a coax cable. The field around the transmission line is cancelled.
- The desired differential-mode currents also flows in opposite directions on **balanced transmission line**. The far field around the transmission line is cancelled.





Fig 36 – Coaxial Chokes Wound to Minimize L and C



Fig 37 – A Bifilar Choke

Example of current-mode transmission-line chokes, also known commonly as “choke baluns.” *Photos courtesy Jim Brown, K9YC.*

# Stresses on Common-Mode Chokes

- The common-mode chokes shown in the previous slide are designed by K9YC for 50- $\Omega$  antennas, and can handle SWRs up to about 10:1 without self-destructing at a 1.5 kW power level.

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- The common-mode chokes shown in the previous slide are designed by K9YC for 50- $\Omega$  antennas, and can handle SWRs up to about 10:1 without self-destructing at a 1.5 kW power level.
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# Stresses on Common-Mode Chokes

- The common-mode chokes shown in the previous slide are designed by K9YC for 50- $\Omega$  antennas, and can handle SWRs up to about 10:1 without self-destructing at a 1.5 kW power level.
- They show wideband common-mode impedances of more than 5000  $\Omega$ , effectively choking off almost any kind of common-mode currents over more than three octaves of frequency.
- The length of the RG-303 type Teflon-insulated coax used is about 1 foot per turn through the ferrite donuts, for a total of about 6 feet of RG-303 for 5 turns.

# The Quest for Multiband Operation with a Single-Wire Dipole Antenna

- Operating a dipole at even harmonic frequencies can be rough: e.g., 40 meter dipole operated on 20 meters, or on 10 meters.

Feed-point impedances for a 66-foot long, center-fed inverted-V dipole, apex at 50 feet high over ground with dielectric constant of 13, conductivity of 5 mS/m.

Freq. Feed-Point

MHz Impedance

1.83 MHz:  $1.6 - j 2257 \Omega$

3.8 MHz:  $10.3 - j 879 \Omega$  ← **Even worse!**

7.1 MHz:  $64.8 - j 40.6 \Omega$

10.1 MHz:  $21.6 + j 648 \Omega$

**Bad** → **14.1 MHz:  $5287 - j 1310 \Omega$**

18.1 MHz:  $198 - j 820 \Omega$

21.1 MHz:  $103 - j 181 \Omega$

24.9 MHz:  $269 + j 570 \Omega$

28.4 MHz:  $3089 + j 774 \Omega$  ← **Pretty bad**

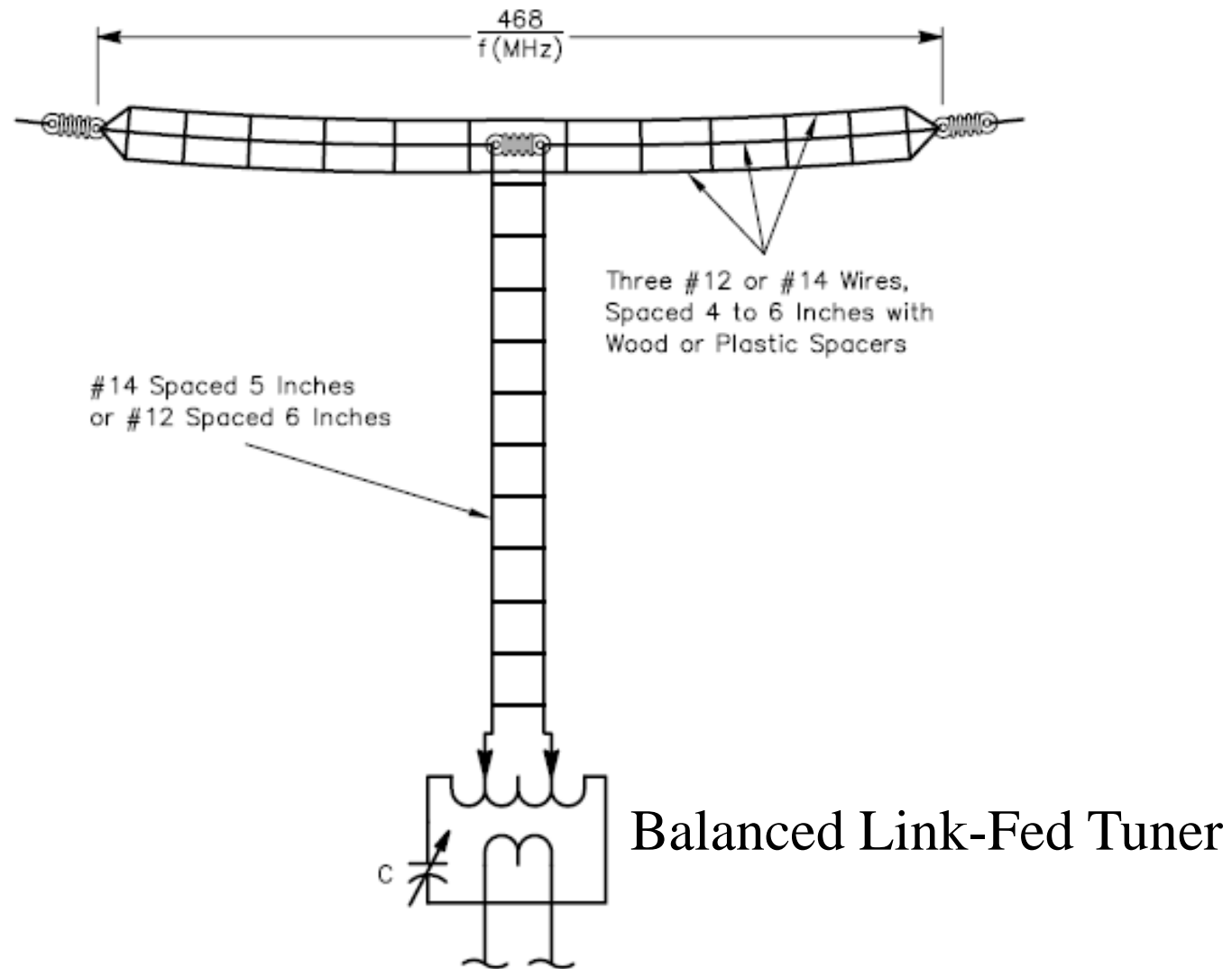
# The Quest for Multiband Operation with a Single-Wire Dipole Antenna

- Operating a dipole at even harmonic frequencies can be rough: e.g., 40 meter dipole operated on 20 meters.
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# The Quest for Multiband Operation with a Single-Wire Dipole Antenna

- Operating a dipole at even harmonic frequencies can be rough: e.g., 40 meter dipole operated on 20 meters.
- Single feed line—coax or open-wire line?
- Where should the common-mode choke balun go? I'll go through several worst-case scenarios. But first...

# Back in the Good Ole Days...

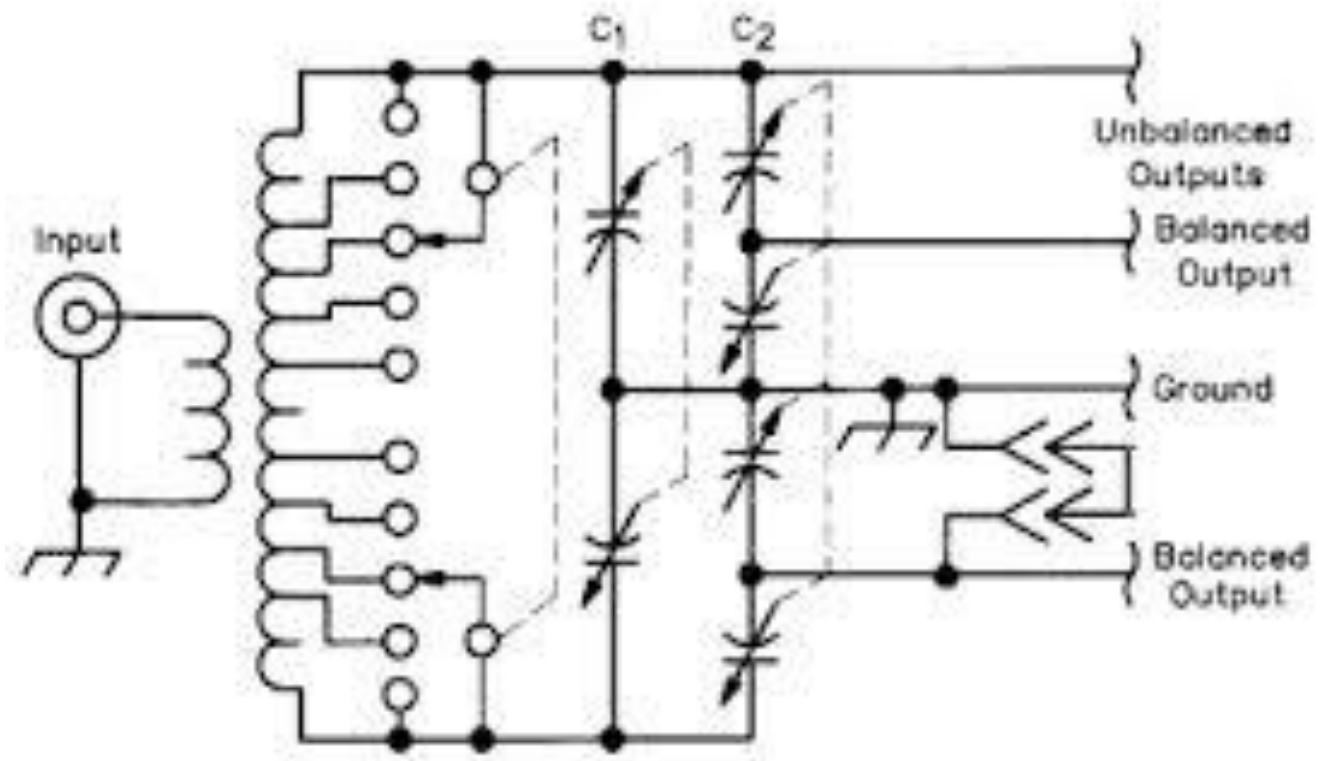




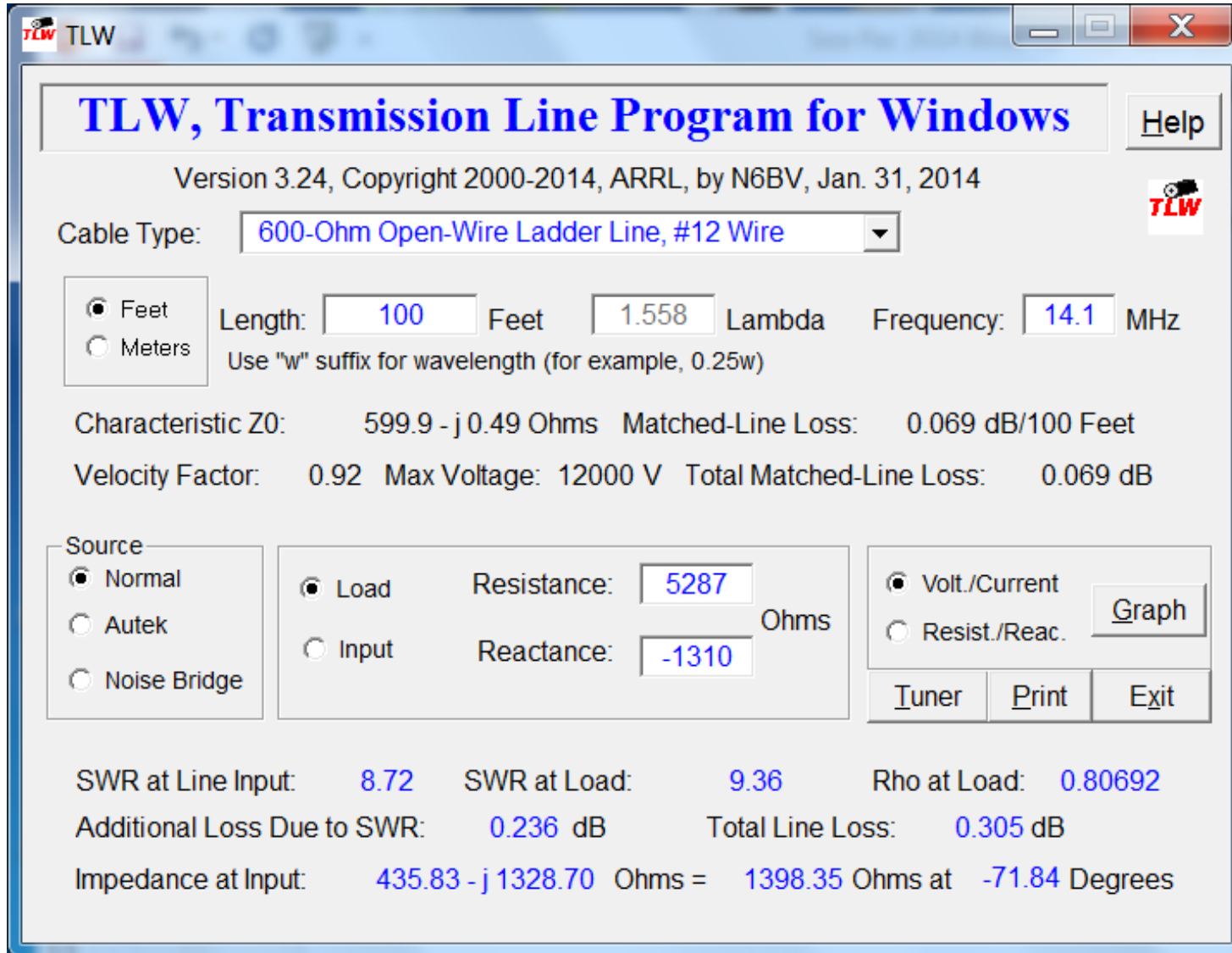
# Balanced Antenna Tuner

- An intrinsically **balanced** antenna tuner, such as a Johnson Matchbox, uses no lossy coax inside as a balun. It is link fed.





# TLW, the “Swiss Army Knife” of Transmission Lines



The latest version of *TLW* updates the matched-line losses of “Window” lines with new measurements made by the ARRL Laboratory.

# Losses in a Simple L-Network Tuner

Low-Pass L-Network

600-Ohm Open-Wire Ladder Line, #12 V Length: 100 feet Frequency: 14.1 MHz  
At load: 5287 -j 1310 ohms = 5446.9 ohms, at -13.9 degrees Load SWR = 9.36  
Eff. Q = 9.6 1.5:1 SWR BW = 598.8 kHz (4.2%) and 2:1 SWR BW = 1037.1 kHz (7.4%)  
Estimated power lost in tuner for 1500 W input: 78 W (0.23 dB = 5.2% lost)  
Transmission-line loss = 0.31 dB. Total loss = 0.54 dB. Power into load = 1325.4 W

At 1500 W:	L1	C2
Unloaded Q	200	1000
Reactance	458.648	-676.83
Peak Voltage	3553 V	3572 V
RMS Current	5.5 A	3.7 A
Est. Pwr Diss.	69 W	9 W

RMS Vin: 273.86 V at 84.06 deg. RMS Vout: 2525.67 V at 0.00 deg.

50.0 Ohms

5.18 uH

L1

C2

16.7 pF

435.83 - j 1328.70 Ohm

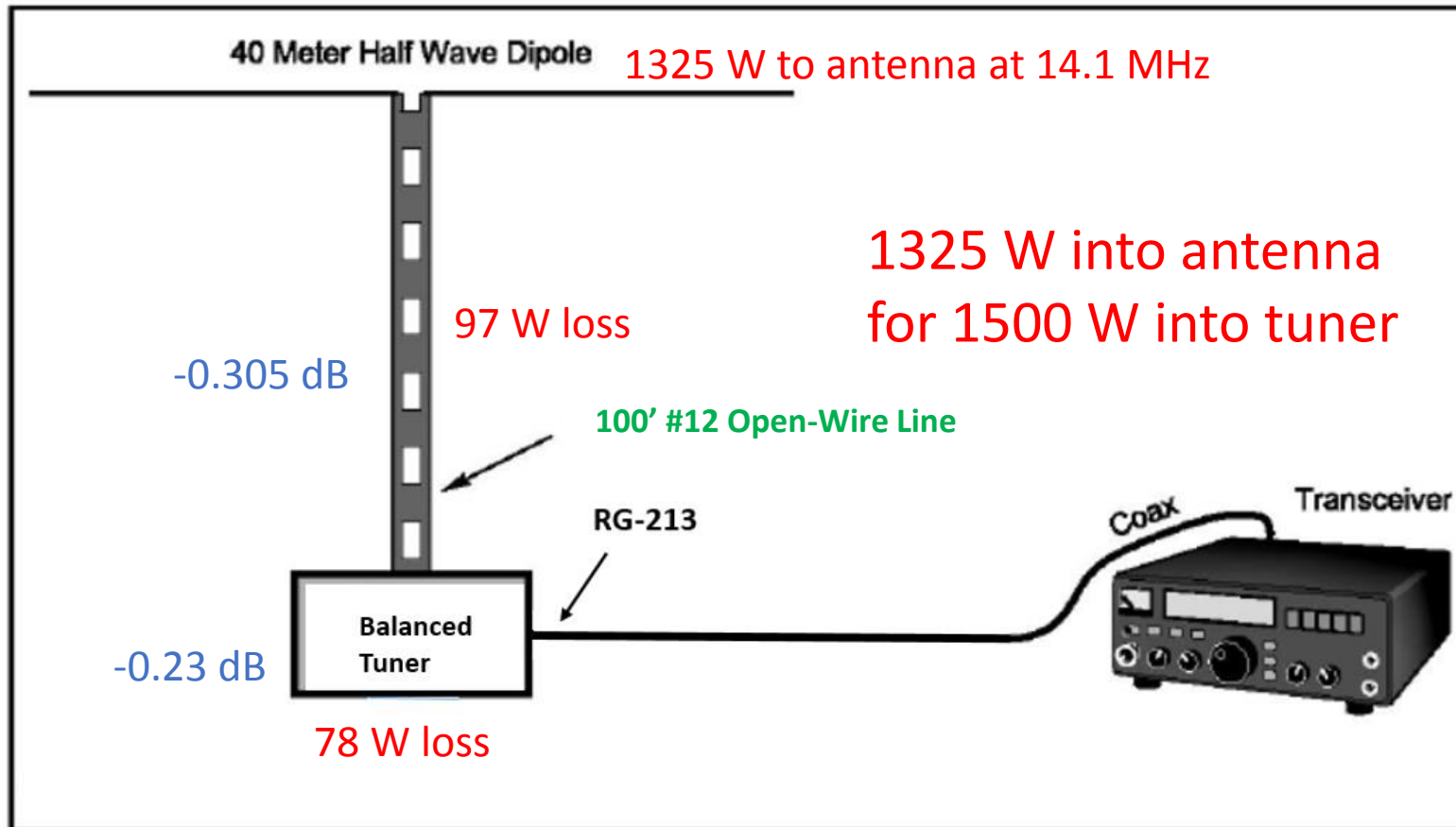
Print

Main Screen

Cancel

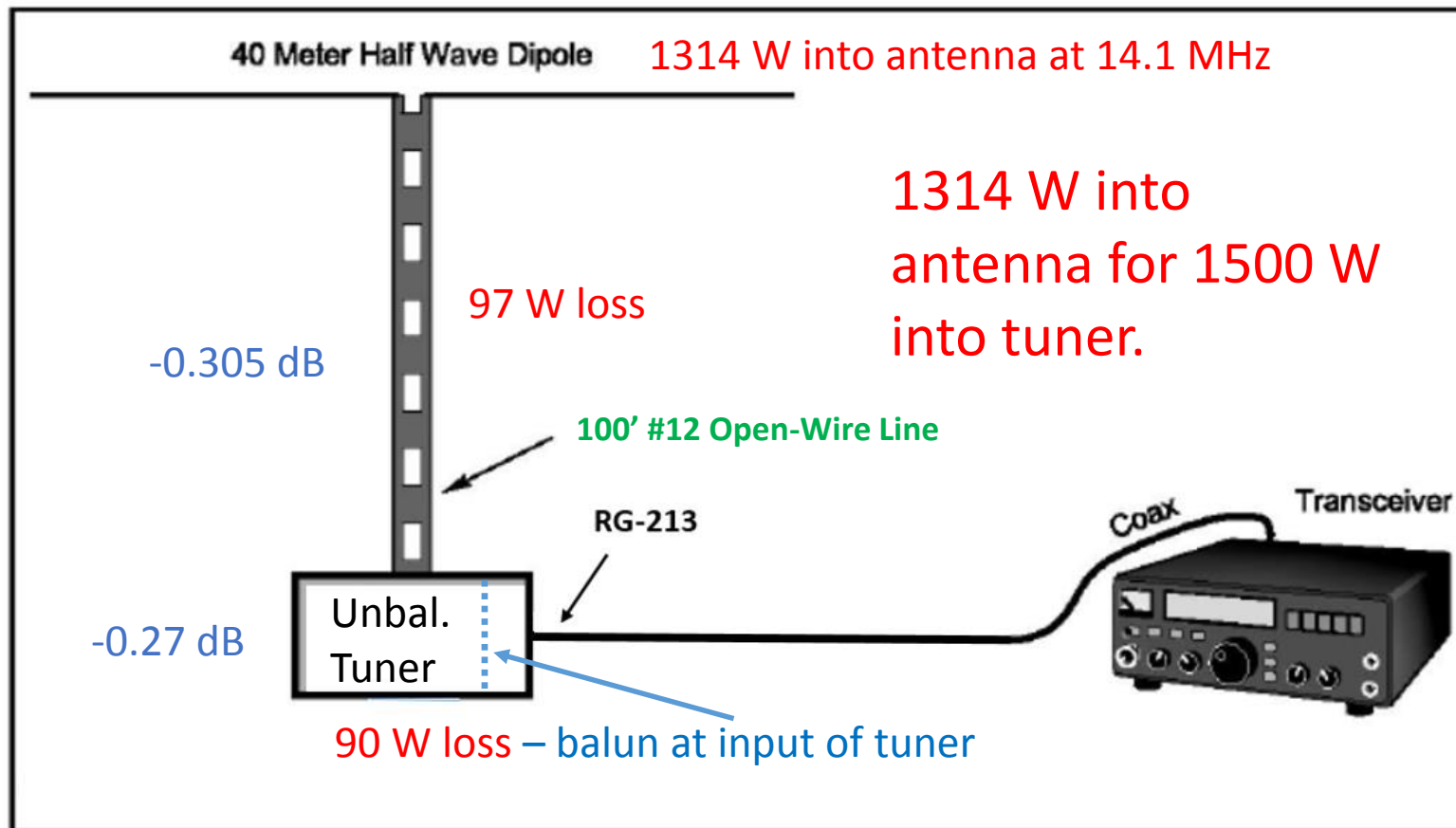
## Ex. 1: Balanced Antenna Tuner with Open-Wire Line

- An intrinsically **balanced** antenna tuner, such as a Johnson Matchbox, uses no lossy coax inside as a balun. It is link fed.



## Ex. 2: Unbalanced Tuner With Choke Balun at Input

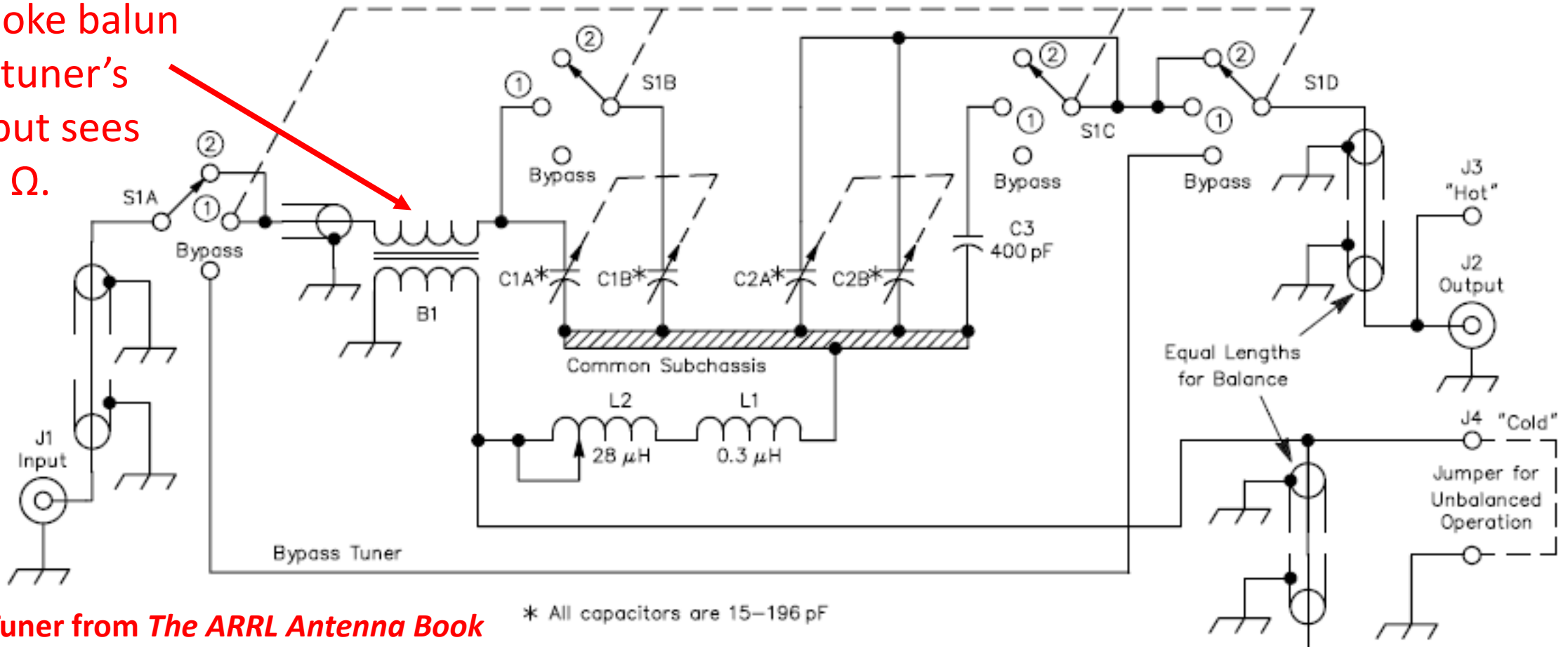
- If the choke balun is put at the 50-Ω input of an **unbalanced** tuner, the differential-mode loss due to SWR can also be low.



## Ex. 2: Unbalanced Tuner With Choke Balun at Input

- If the choke balun is at the 50-Ω input of an unbalanced tuner, the differential-mode loss due to SWR will be low.

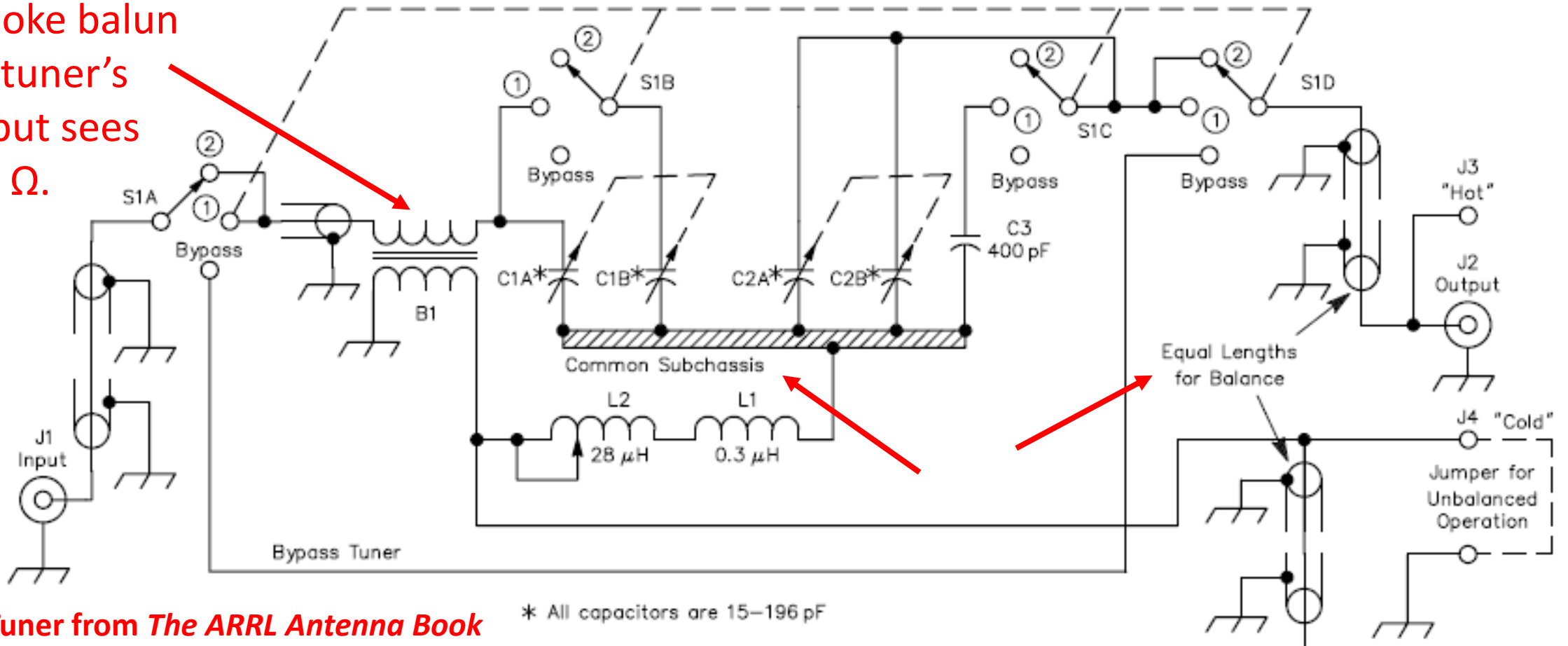
Choke balun  
at tuner's  
input sees  
50 Ω.



## Ex. 2: Unbalanced Tuner With Choke Balun at Input

- However, the mechanical configuration is more complex for a choke balun at the tuner's input.

Choke balun  
at tuner's  
input sees  
50  $\Omega$ .





# Ex. 3: Using “Window Line”

**TLW, Transmission Line Program for Windows** Help

Version 3.24, Copyright 2000-2014, ARRL, by N6BV, Jan. 31, 2014

Cable Type: 450-Ohm Window Line, Wireman #551

Feet Length: 100 Feet 1.567 Lambda Frequency: 14.1 MHz  
 Meters Use "w" suffix for wavelength (for example, 0.25w)

Characteristic Z0: 402.7 - j 1.20 Ohms Matched-Line Loss: 0.255 dB/100 Feet  
Velocity Factor: 0.915 Max Voltage: 10000 V Total Matched-Line Loss: 0.255 dB

Source  
 Normal  
 Autek  
 Noise Bridge

Load Resistance: 5287 Ohms  
 Input Reactance: -1310

Volt./Current  
 Resist./Reac. Graph

Tuner Print Exit

SWR at Line Input: 9.91 SWR at Load: 13.93 Rho at Load: 0.86603  
Additional Loss Due to SWR: 1.201 dB Total Line Loss: 1.456 dB  
Impedance at Input: 214.47 - j 816.13 Ohms = 843.84 Ohms at -75.28 Degrees

# Ex. 3: Using “Window Line”

Low-Pass L-Network

450-Ohm Window Line, Wireman #551    Length: 100 feet    Frequency: 14.1 MHz  
At load: 5287 -j 1310 ohms = 5446.9 ohms, at -13.9 degrees    Load SWR = 13.93  
Eff. Q = 8.2    1.5:1 SWR BW = 698.8 kHz (5.0%) and 2:1 SWR BW = 1210.4 kHz (8.6%)  
Estimated power lost in tuner for 1500 W input: 66 W (0.19 dB = 4.4% lost)  
Transmission-line loss = 1.46 dB. Total loss = 1.65 dB. Power into load = 1025.7 W

At 1500 W:	L1	C2
Unloaded Q	200	1000
Reactance	395.56	-743.395
Peak Voltage	3064 V	3086 V
RMS Current	5.5 A	2.9 A
Est. Pwr Diss.	59 W	6 W

RMS Vin: 273.86 V at 83.08 deg.    RMS Vout: 2182.48 V at 0.00 deg.

4.46 uH

50.0 Ohms

L1

C2

15.2 pF

214.47 - j 816.13 Ohms

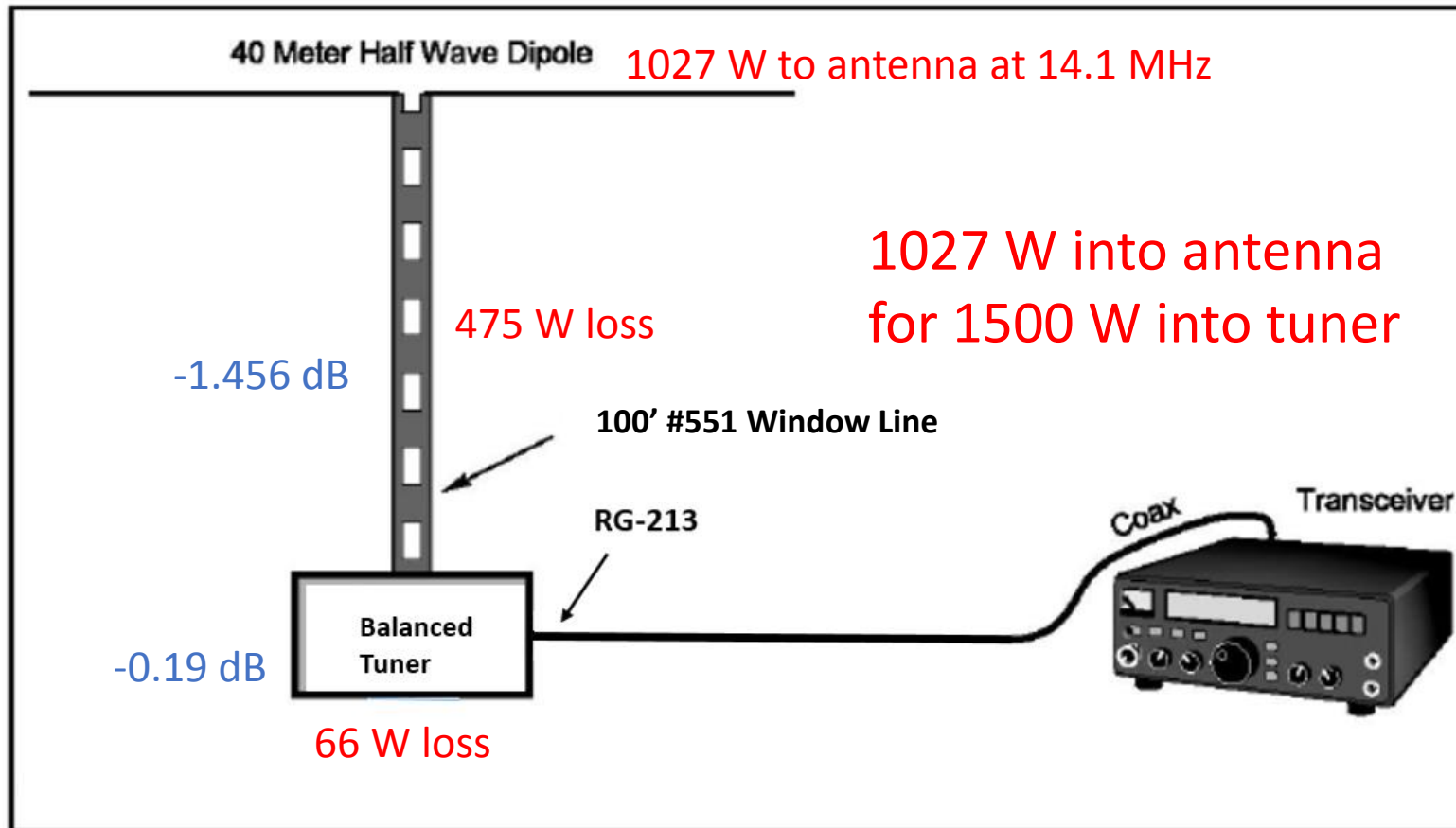
Print

Main Screen

Cancel

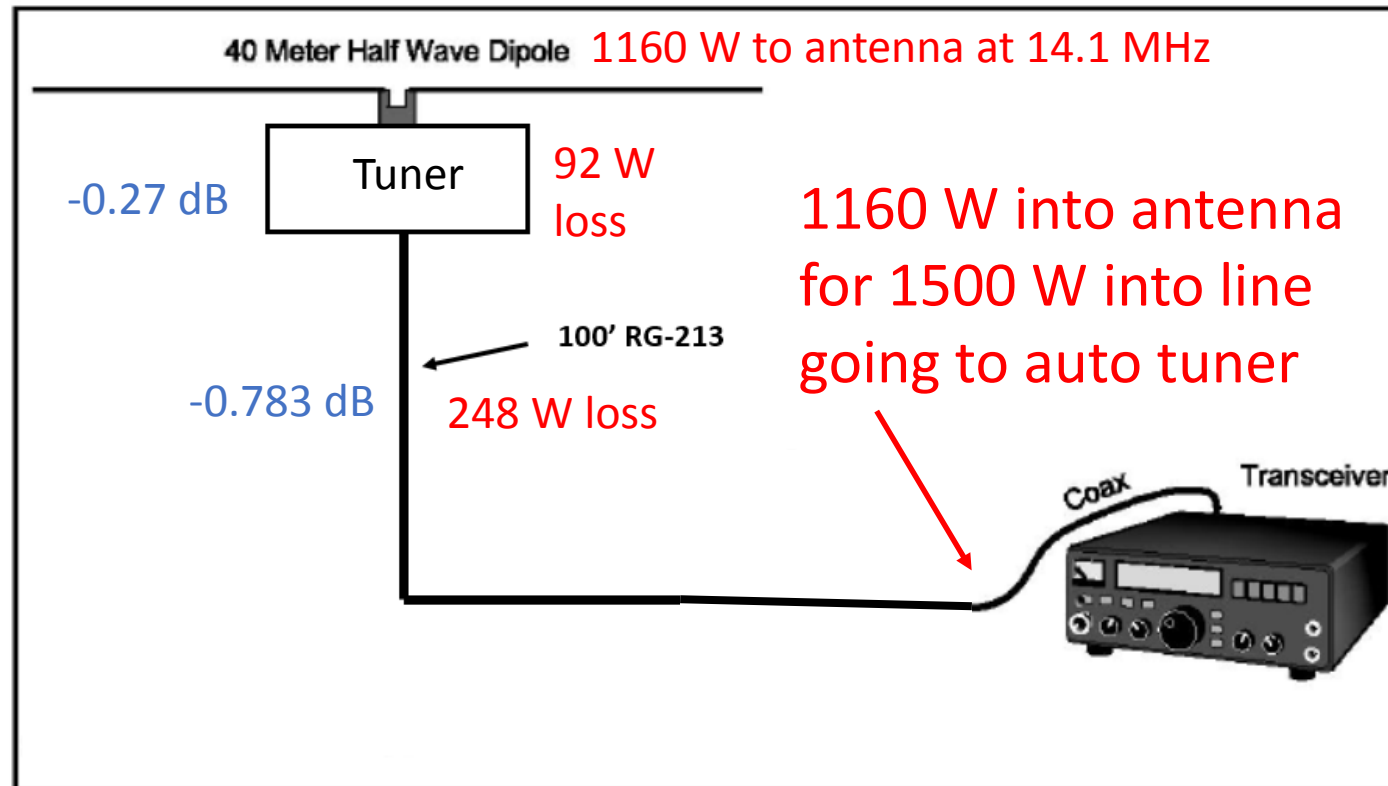
## Ex. 3: Johnson Matchbox With “Window Line”

- An intrinsically **balanced** antenna tuner, such as a Johnson Matchbox, uses no lossy coax inside as a balun. It is link fed.



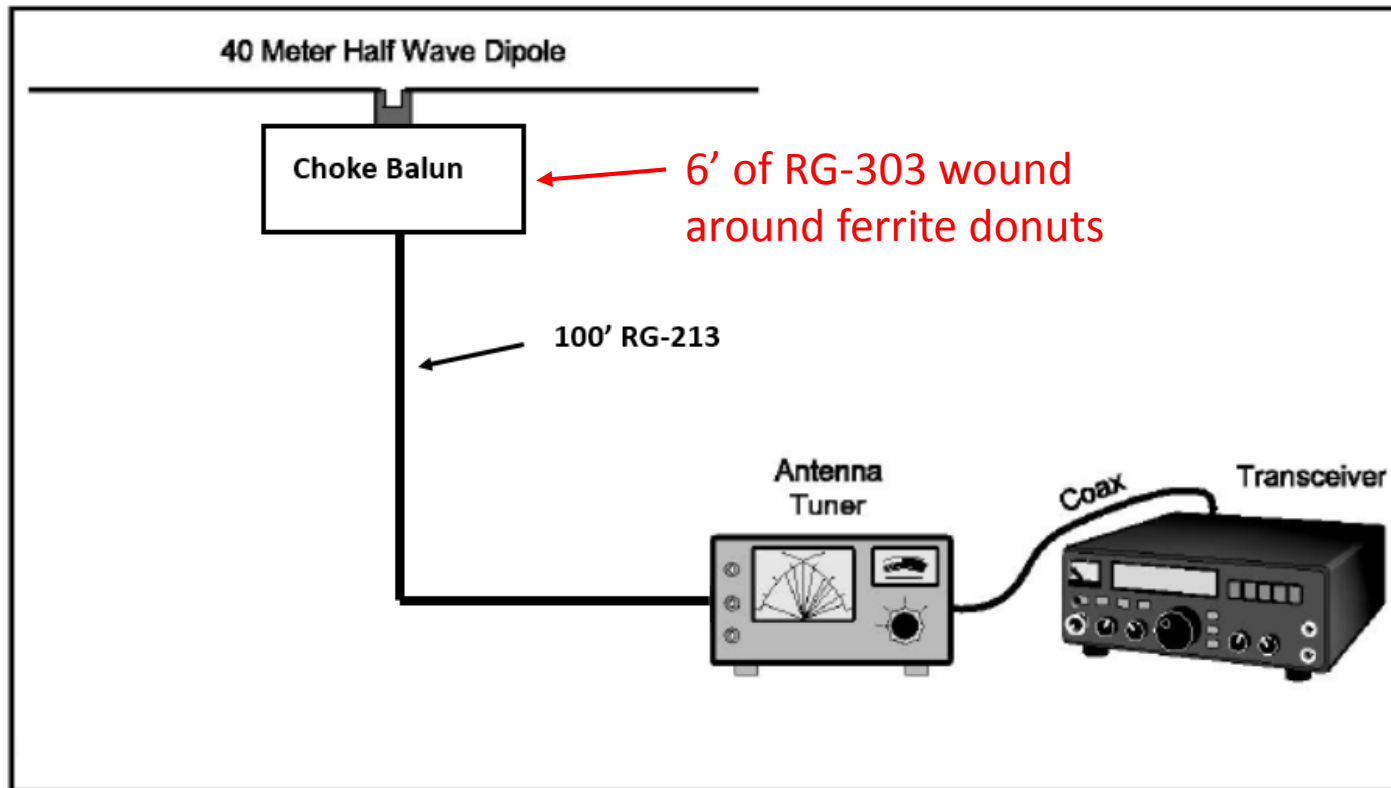
## Ex. 4: Balanced Antenna Tuner

- The loss is also low if an auto tuner is located up at the antenna feed point.



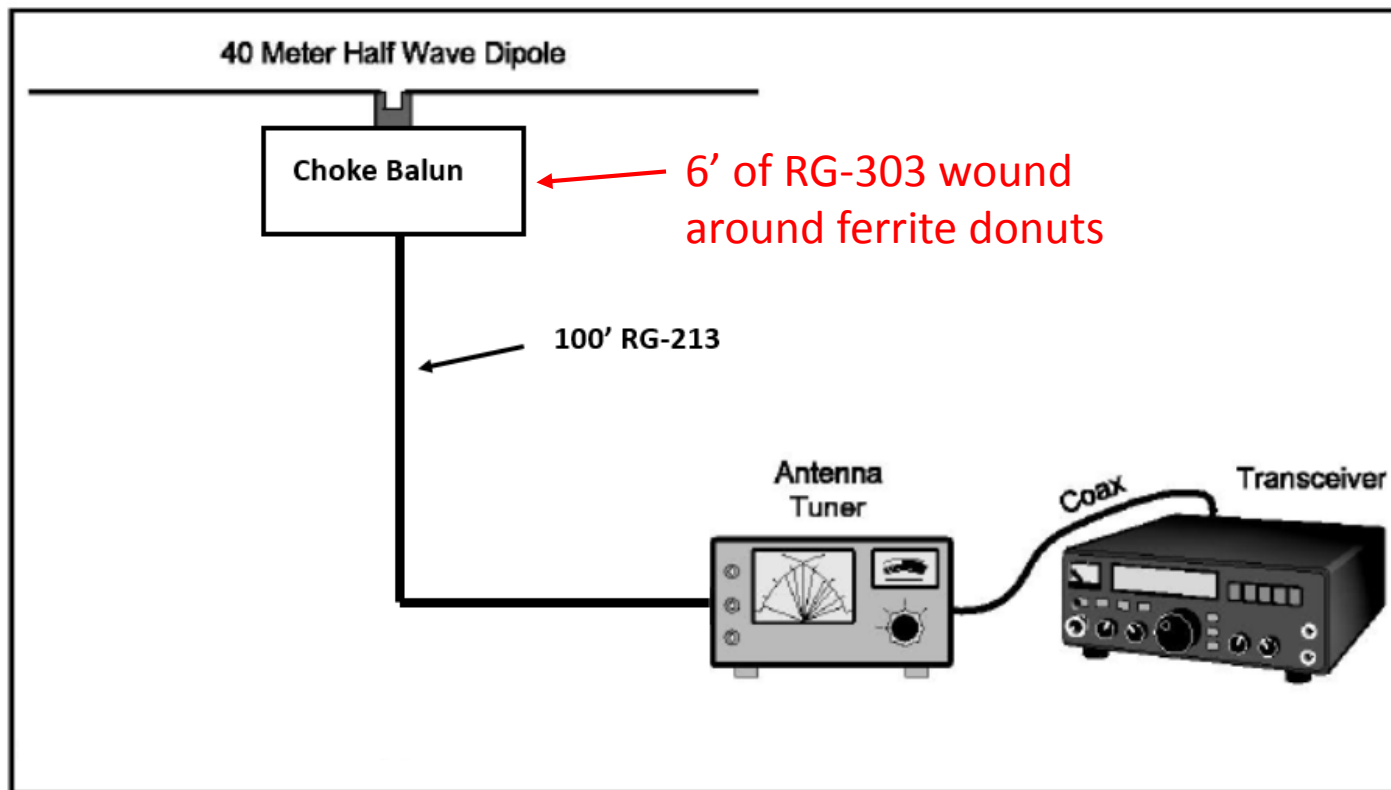
## Ex. 5: Common-Mode Choke at Feed Point

- Assume antenna is a 40-meter dipole set up as an Inverted-Vee and operated at a worst-case frequency of 14.1 MHz.



## Ex. 5: Common-Mode Choke at Feed Point

- Assume antenna is a 40-meter dipole set up as an Inverted-Vee and operated at a worst-case frequency of 14.1 MHz.
- Jim, K9YC, calls this my “train wreck” scenario!



## Ex. 5: Common-Mode Choke at Feed Point

- *EZNEC* says the feed-point  $Z$  at 14.1 MHz is  $5287 - j 1310 \Omega$ .

## Ex. 5: Common-Mode Choke at Feed Point

- EZNEC says the feed-point Z at 14.1 MHz is  $5287 - j 1310 \Omega$ .
- TLW computes the loss in 6' of RG-303 making up the choke balun as 1.436 dB. Now, we “daisy chain” coax to coax.

**TLW, Transmission Line Program for Windows**  
Version 3.00, Copyright 2000-2006, ARRL, by N6BV, Mar 14, 2006

Cable Type:

Feet Length:  Feet  Lambda Frequency:  MHz  
 Meters Use "w" suffix for wavelength (for example, 0.25w)

Characteristic Z0: 50.1 - j 0.63 Ohms Matched-Line Loss: 1.423 dB/100 Feet  
Velocity Factor: 0.695 Max Voltage: 1400 V Total Matched-Line Loss: 0.085 dB

Source  
 Normal  Autek  Noise Bridge  
 Load Resistance:  Ohms  Volt./Current  
 Input Reactance:  Ohms  Resist./Reac.

SWR at Line Input: 53.36 SWR at Load: 111.67 Rho at Load: 0.98225  
Additional Loss Due to SWR: 1.351 dB Total Line Loss: 1.436 dB  
Impedance at Input: 1.26 - j 50.66 Ohms = 50.67 Ohms at -88.58 Degrees

Z seen by 100'  
of RG-213

SWR!

Loss in choke  
balun



## Ex. 5: Common-Mode Choke at Feed Point

- *TLW* calculates that 100' of RG-213 seeing  $1.26 - j 50.66 \Omega$  plus an efficient tuner will have a loss of 9.41 dB, giving an input to the choke balun of 1500 W – 9.41 dB, or 171 W.

The screenshot displays the TLW (Transmission Line Program for Windows) interface. The main window shows the following parameters:

- Cable Type: RG-213 (Belden 8267)
- Length: 100.000 Feet
- Frequency: 14.1 MHz
- Characteristic Z0:  $50.0 - j 0.33 \text{ Ohms}$
- Matched-Line Loss: 0.783 dB/100 Feet
- Velocity Factor: 0.66
- Max Voltage: 3700 V
- Total Matched-Line Loss: 0.783 dB

The Source section is set to Load, with Resistance: 1.26 Ohms and Reactance: -50.66 Ohms. The SWR at Line Input is 9.48, and the SWR at Load is 63.55. The Total Line Loss is 9.406 dB. The Impedance at Input is  $5.83 + j 14.65 \text{ Ohms}$ .

The Low-Pass L-Network window shows the following parameters:

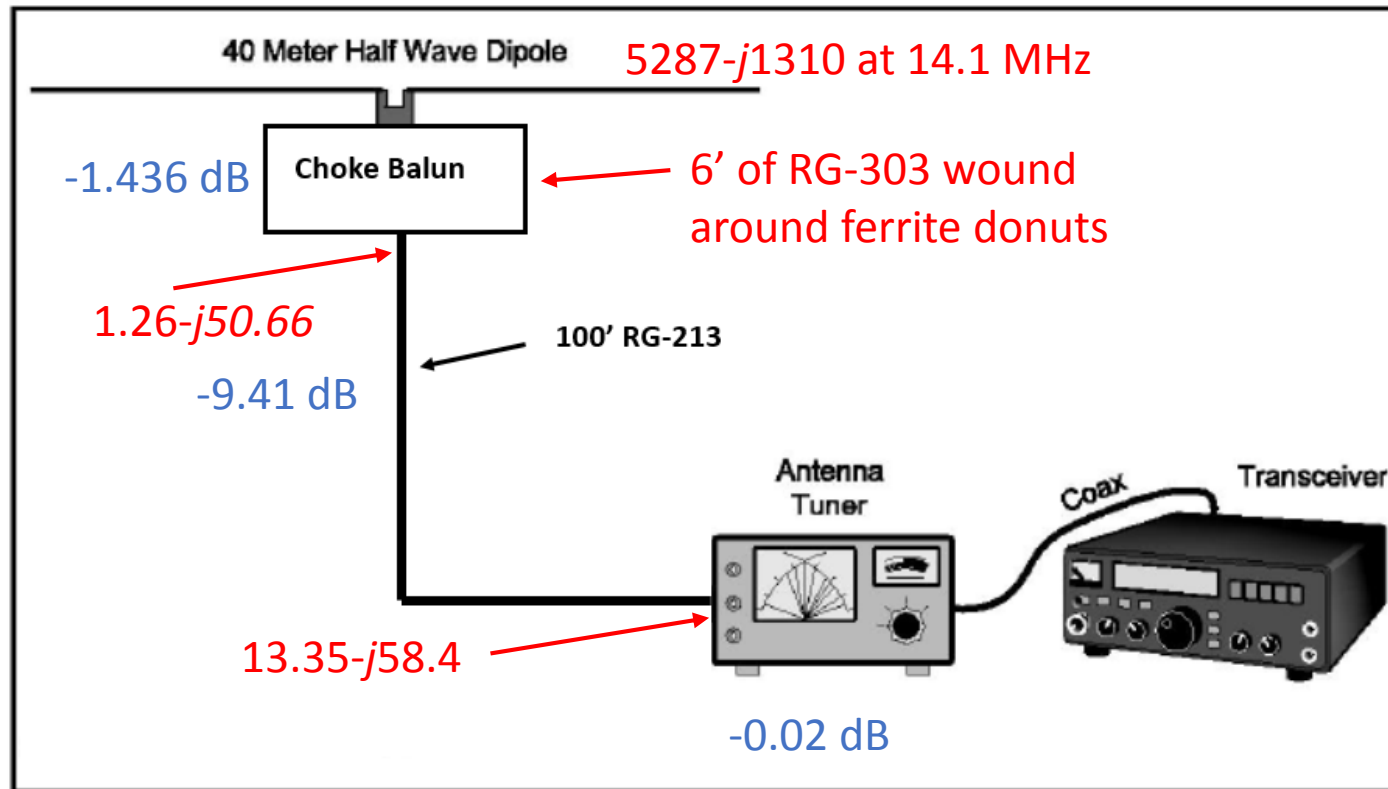
- RG-213 (Belden 8267)
- Length: 100.000 feet
- Frequency: 14.1 MHz
- At load:  $1.26 - j 50.66 \text{ ohms} = 50.7 \text{ ohms}$ , at -88.6 degrees
- Load SWR = 63.55
- Eff. Q = 2.7
- 1.5:1 SWR BW = 2121.4 kHz (15.0%) and 2:1 SWR BW = 3674.3 kHz (26.1%)
- Estimated power lost in tuner for 1500 W input: 6 W (0.02 dB = 0.4% lost)
- Transmission-line loss = 9.41 dB. Total loss = 9.42 dB. Power into load = 171.3 W

The L-network diagram shows a series inductor L2 (0.02 uH) and a shunt capacitor C1 (610.9 pF) connected to a 50.0 Ohm source. The output impedance is  $5.83 + j 14.65 \text{ Ohms}$ . The diagram also includes a stray capacitor CStray (10 pF) in shunt to ground.

Input of choke

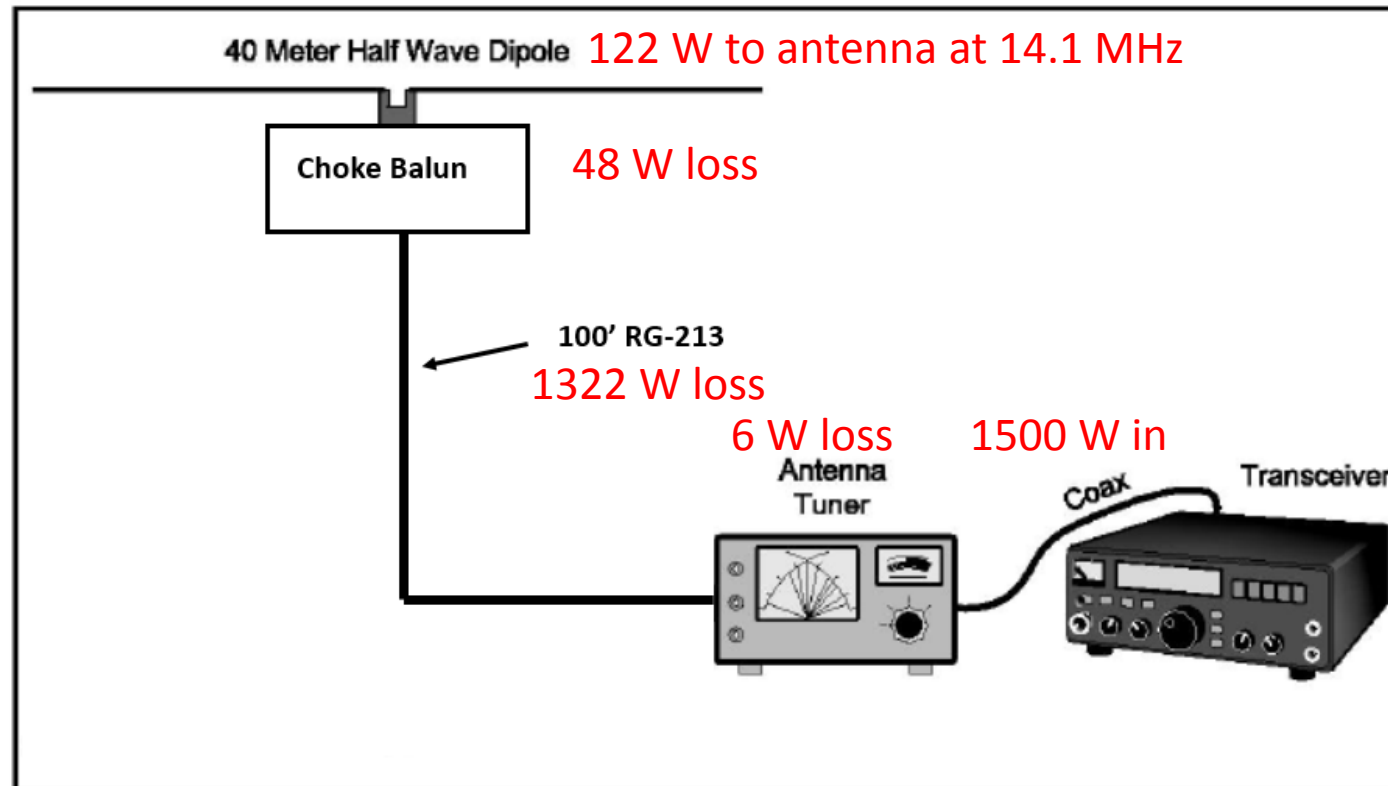
At tuner

## Ex. 5: Common-Mode Choke at Feed Point



## Ex. 5: Common-Mode Choke at Feed Point

- Loss in choke balun = **48 W**, which is **8 W/ft**; should not fry the small choke balun, even if airflow is restricted. The overall system loss is 10.87 dB. The antenna thus receives **122 W** for 1500 W power into the tuner.



Note that the high loss in the RG-213 coax is “protecting” the balun.

# Stresses on Common-Mode Chokes

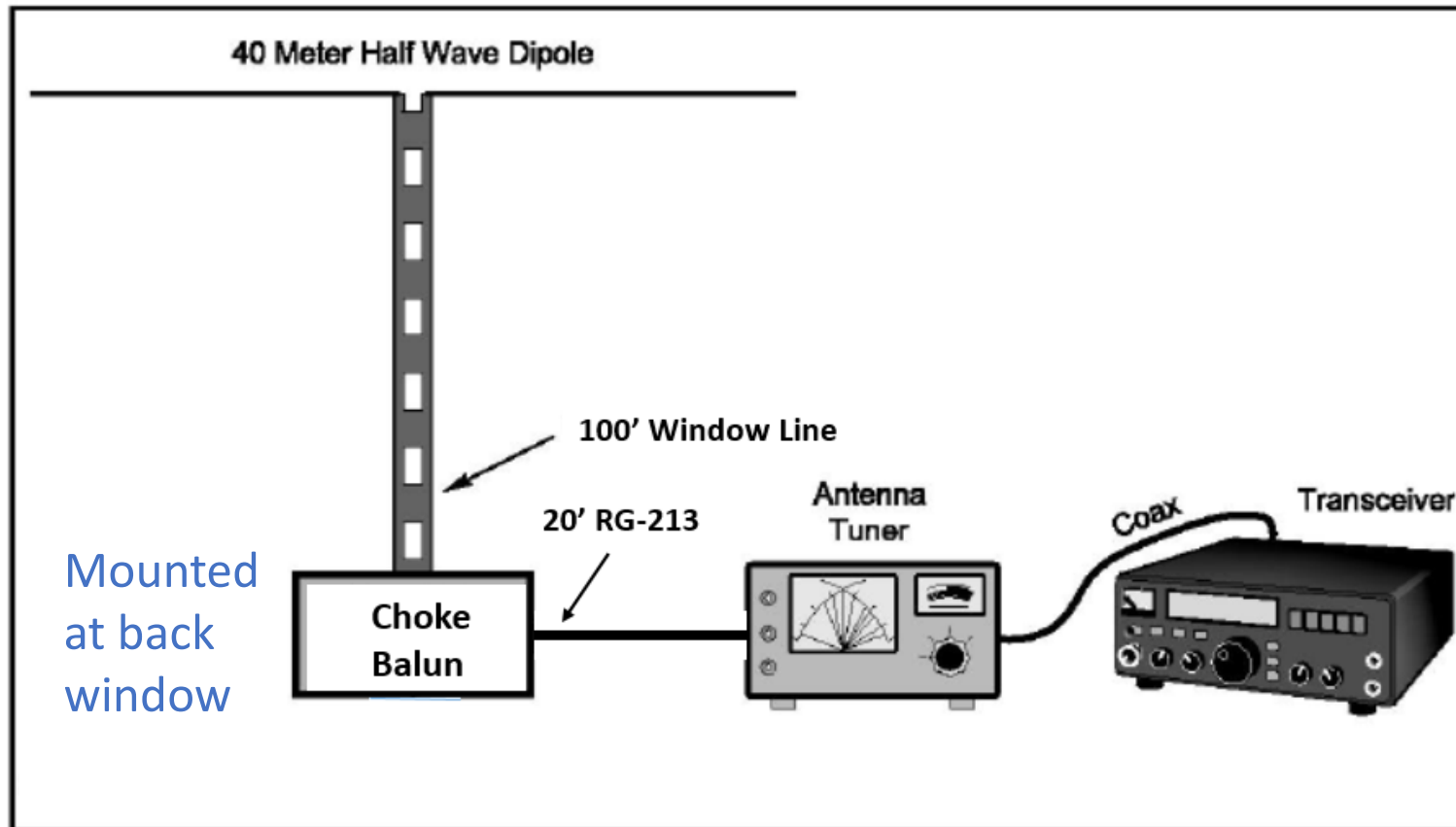
- Now what sort of dimwit would try to feed a 40-meter half-wave dipole on its full-wave resonance, through coax?

# Stresses on Common-Mode Chokes

- Now what sort of dimwit would try to feed a 40-meter half-wave dipole on its full-wave resonance, through coax? Don't ask me how I know...

## Ex. 6: Common-Mode Choke in Shack

- A common installation, where open-wire feed line goes to a choke balun placed at a rear window in the shack and then, say, a 20' coax jumper goes from the choke to the Antenna Tuner.



## Ex. 6: Common-Mode Choke in Shack

- At the full-wave frequency of 14.1 MHz for this 40-meter half-wave dipole, the total window ladder-line loss is 1.456 dB. Not too bad! Now, daisy chain Zin to the choke balun load.

TLW, Transmission Line Program for Windows  
Version 3.23, Copyright 2000-2014, ARRL, by N6BV, Jan. 25, 2014

Cable Type: 450-Ohm Window Line, Wireman #551

Length: 100.000 Feet 1.567 Lambda Frequency: 14.1 MHz

Characteristic Z0: 402.7 - j 1.20 Ohms Matched-Line Loss: 0.255 dB/100 Feet  
Velocity Factor: 0.915 Max Voltage: 10000 V Total Matched-Line Loss: 0.255 dB

Source: Normal Load Resistance: 5287 Ohms  
Autek Input Reactance: -1310 Ohms  
Noise Bridge

SWR at Line Input: 9.91 SWR at Load: 13.93 Rho at Load: 0.86603  
Additional Loss Due to SWR: 1.201 dB Total Line Loss: 1.456 dB  
Impedance at Input: 214.47 - j816.13 Ohms = 843.84 Ohms at -75.28 Degrees

## Ex. 6: Common-Mode Choke in Shack

- The loss in the 6' of RG-303 making up the choke balun at the bottom of the 100' of window line is 1.075 dB. The loss in 20' of RG-213 from the choke to the tuner is 2.967 dB; the tuner loses about 0.28 dB. Overall loss is  $1.456+1.075+2.967+0.28=5.78$  dB.

The image displays two screenshots of the TLW Transmission Line Program for Windows software. The left screenshot shows a 6-foot RG-142/303 High-Temp. Teflon cable at 14.1 MHz, with a Total Line Loss of 1.075 dB. The right screenshot shows a 20-foot RG-213 (Belden 8267) cable at 14.1 MHz, with a Total Line Loss of 2.967 dB. Red arrows point to specific values in both screenshots.

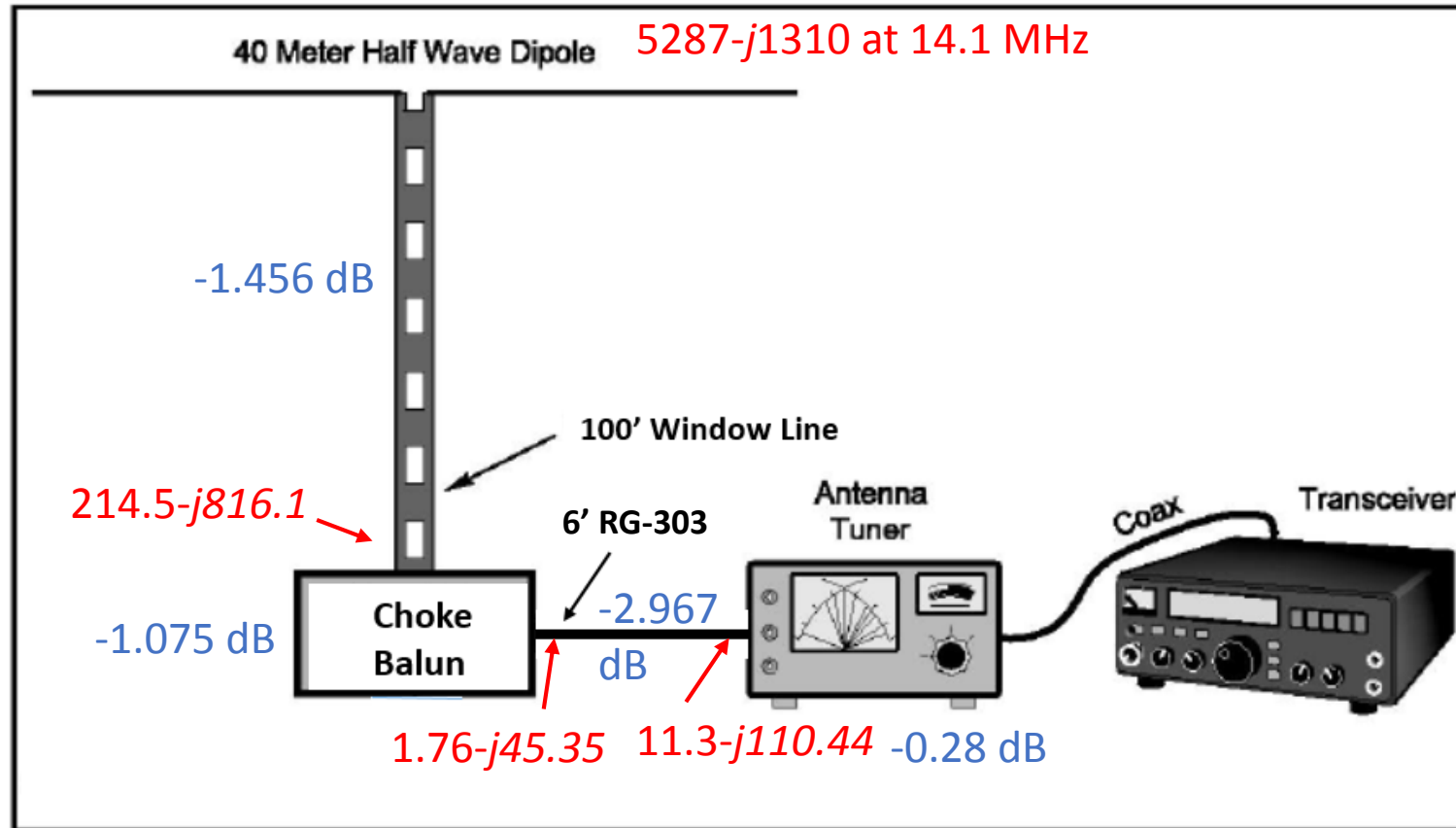
Parameter	6' RG-142/303 High-Temp. Teflon	20' RG-213 (Belden 8267)
Cable Type	RG-142/303 High-Temp. Teflon	RG-213 (Belden 8267)
Length (Feet)	6	20
Length (Lambda)	0.124	0.434
Frequency (MHz)	14.1	14.1
Characteristic Z0	50.1 - j0.63 Ohms	50.0 - j0.33 Ohms
Matched-Line Loss (dB/100 Feet)	1.423	0.783
Velocity Factor	0.695	0.66
Max Voltage	1400 V	3700 V
Total Matched-Line Loss (dB)	0.085	0.157
Source	Normal	Normal
Load Resistance (Ohms)	214.5	1.76
Load Reactance (Ohms)	-816.1	-45.35
SWR at Line Input	39.14	24.60
SWR at Load	63.43	44.26
Rho at Load	0.96896	0.95581
Additional Loss Due to SWR (dB)	0.990	2.810
Total Line Loss (dB)	1.075	2.967
Impedance at Input (Ohms)	1.76 - j45.35	11.30 - j110.44
Impedance at Input (Ohms)	45.39	111.01
Phase at Input (Degrees)	-87.78	-84.16

This is the choke balun

20' jumper from tuner to balun

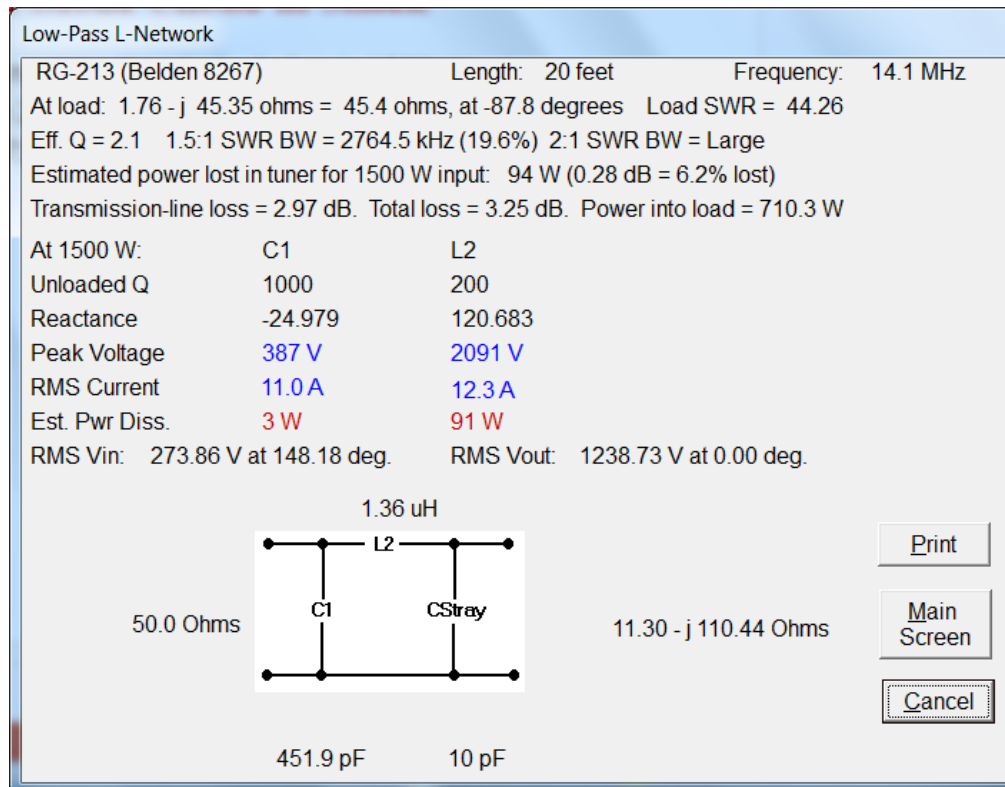


## Ex. 6: Common-Mode Choke in Shack



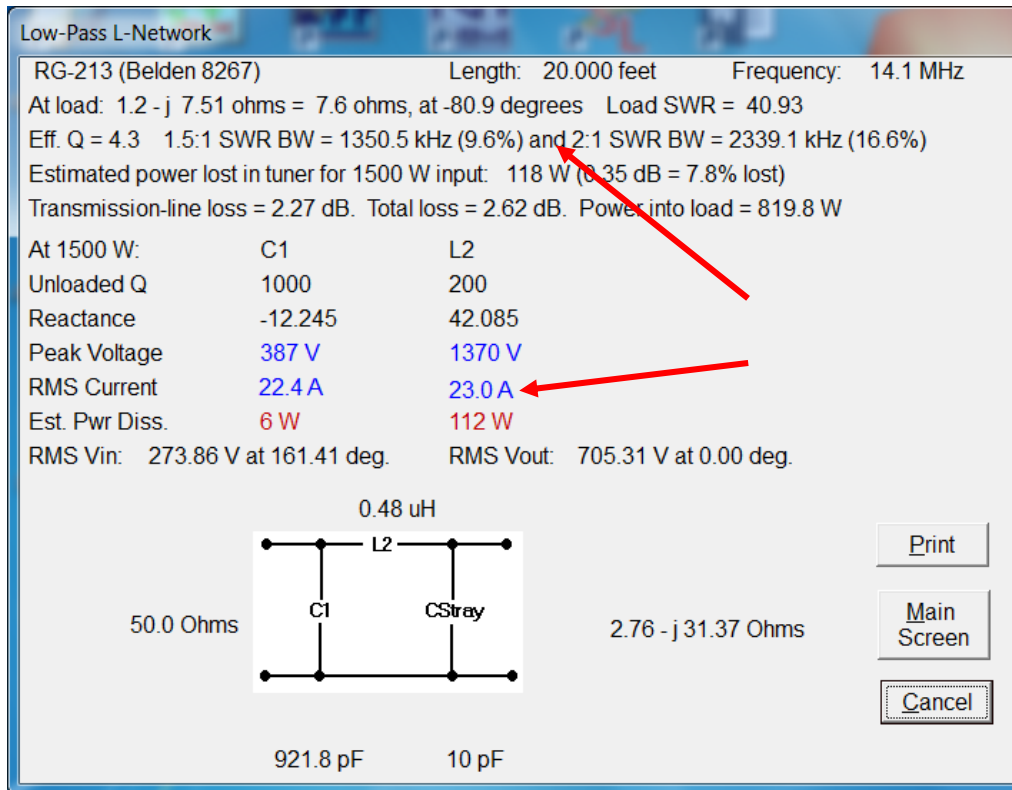
## Ex. 6: Common-Mode Choke in Shack

- The power available at the input to the choke balun is 1500 W minus loss in antenna tuner and in 20' of RG-213 jumper from antenna tuner to the choke balun = 710 W at balun. The 696 W lost in the 20' jumper is 35 W/ft. Goodbye jumper!

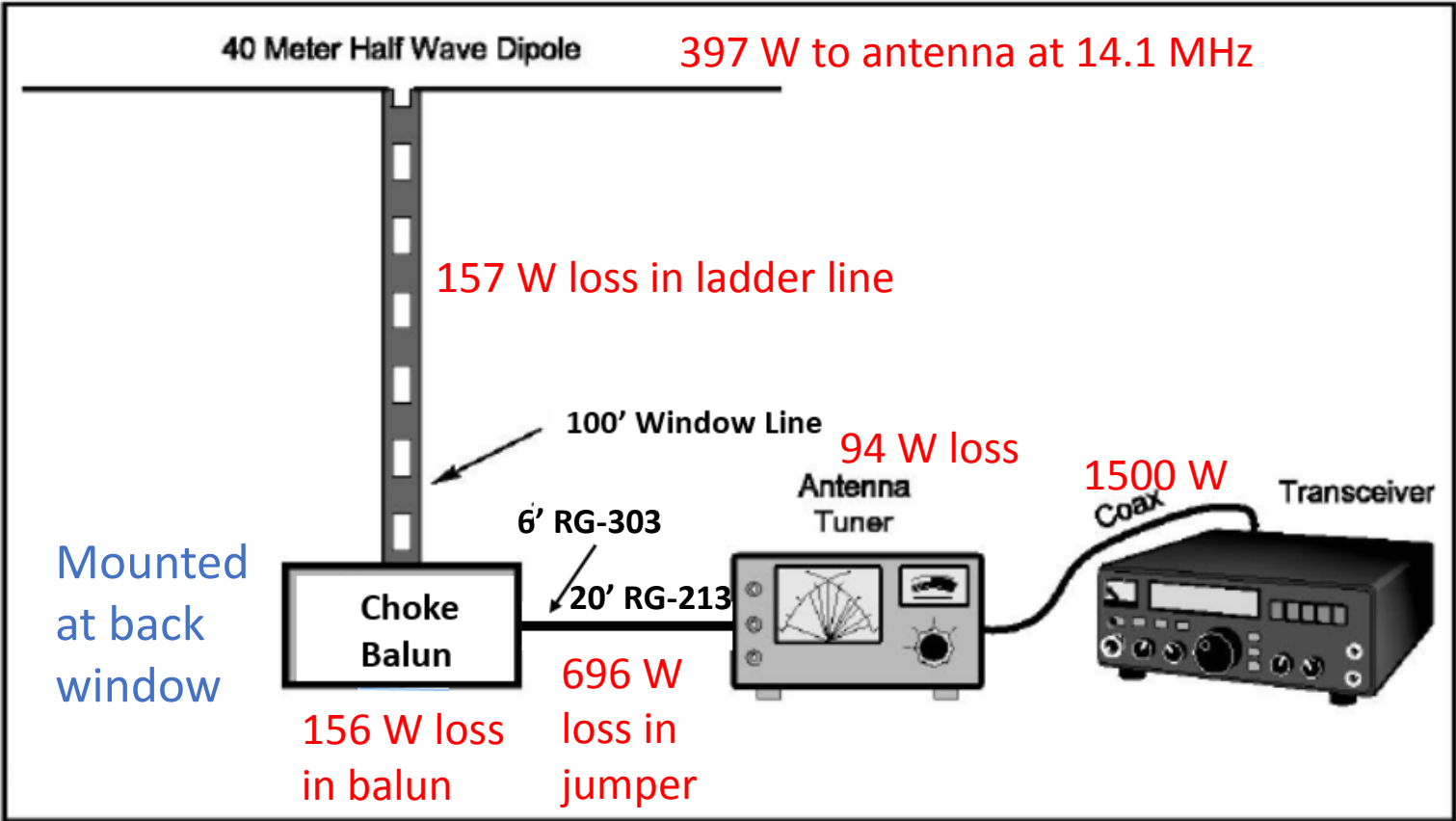


## Ex. 6: Common-Mode Choke in Shack

- The power lost in the choke balun is  $710\text{ W} - 554\text{ W} = 156\text{ W}$ , **26 W/ft.**, a dangerous level for a balun.
- Note tuner loss: **118 W**, **112 W** in the coil.

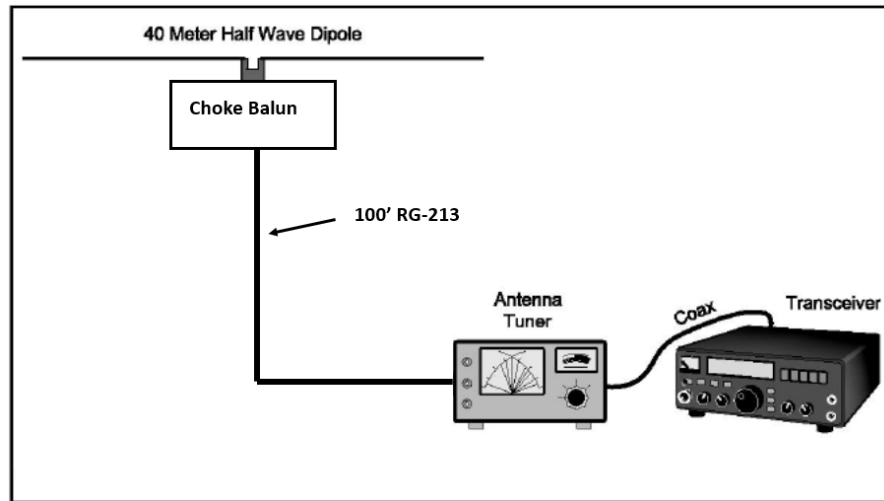


# Ex. 6: Common-Mode Choke in Shack

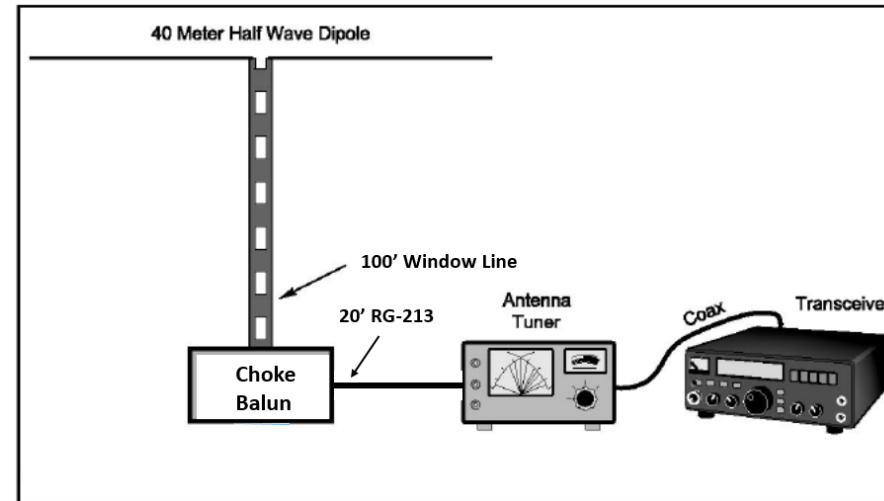


# Stresses on Common-Mode Chokes

- An overall feed-line loss of 5.68 dB is better than the previous loss of 10.87 dB, but it still isn't anything to write home about. And the choke-baluns probably won't survive QRO power.



10.87 dB total system loss:  
**122 W** gets to antenna for  
1500 W input; not very  
efficient use of RF.

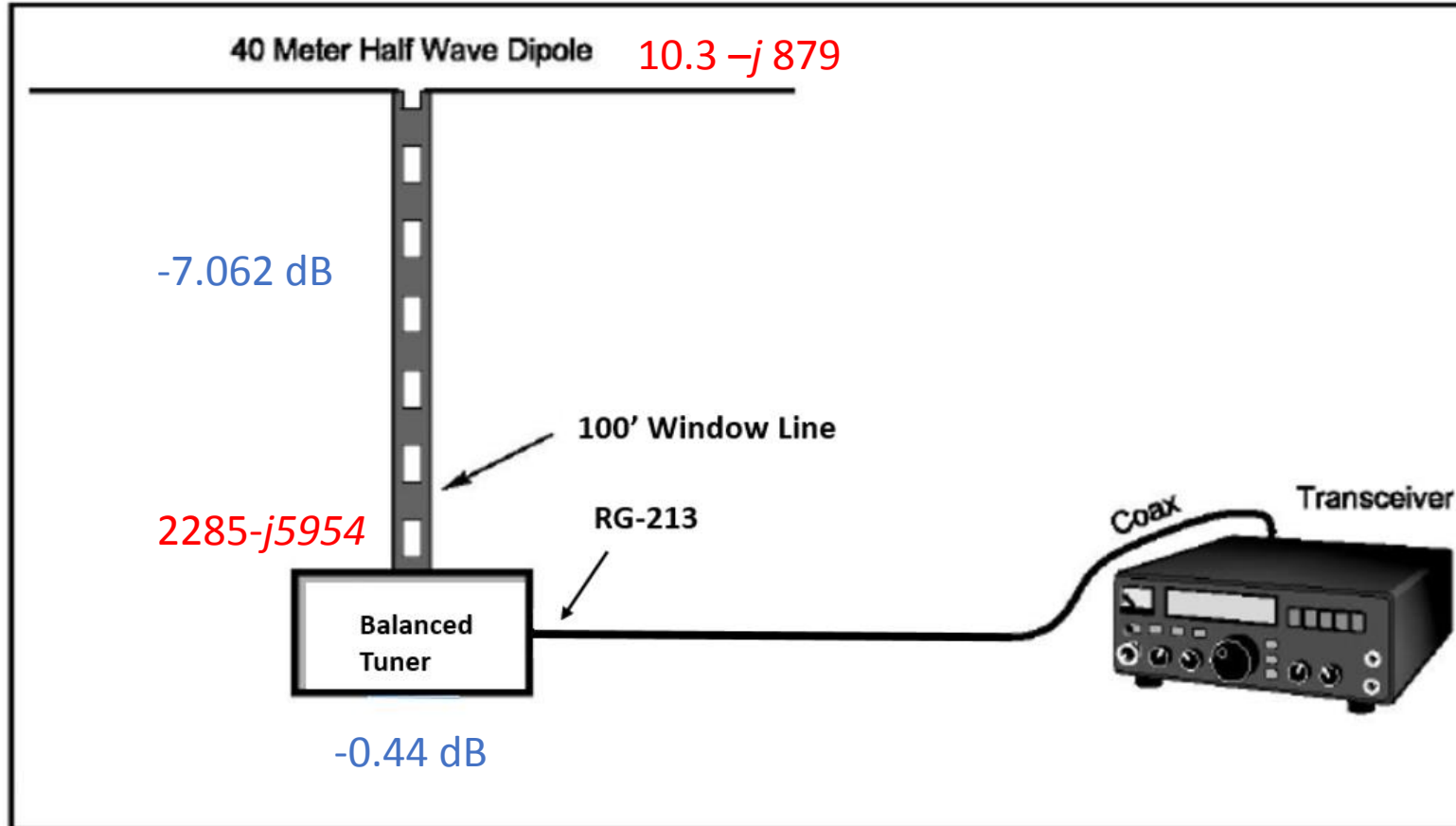


5.87 dB system loss: **397 W** at  
antenna for 1500 W input; we  
have smoke inside the tuner, the  
jumper and in the choke balun.

Setup: Inv. V 40-m Dipole used at 14.1 MHz	Power in Tuner	Power in Balun	Power in Feed Line	Power in Antenna
Classic 100' long #12 open-wire line Ex. 1	78 W, Johnson Matchbox	NA	97 W, in #12 OWL	1325 W
Classic 100' long #12 open-wire line Ex. 2	90 W, balun at unbalanced tuner's input	12 W balun in tuner	97 W, in #12 OWL	1314 W
Balanced tuner at dipole's feed point; 100' RG-213; Ex. 4	92 W, in autotuner	NA	248 W, in 100' RG-213	1160 W
#551 100' window-line; Ex. 3	66 W, Johnson Matchbox	NA	475 W, in 100' #551 window line	1027 W
Balun in shack; 100' #551; Ex. 6	94 W	156 W in balun; 696 W in 20' RG-213 jumper	157 W, in 100' #551 window line	397 W
Choke balun at dipole's feed point; 100' RG-213; Ex. 5	6 W	48 W	1322 W in 100' RG-213	122 W

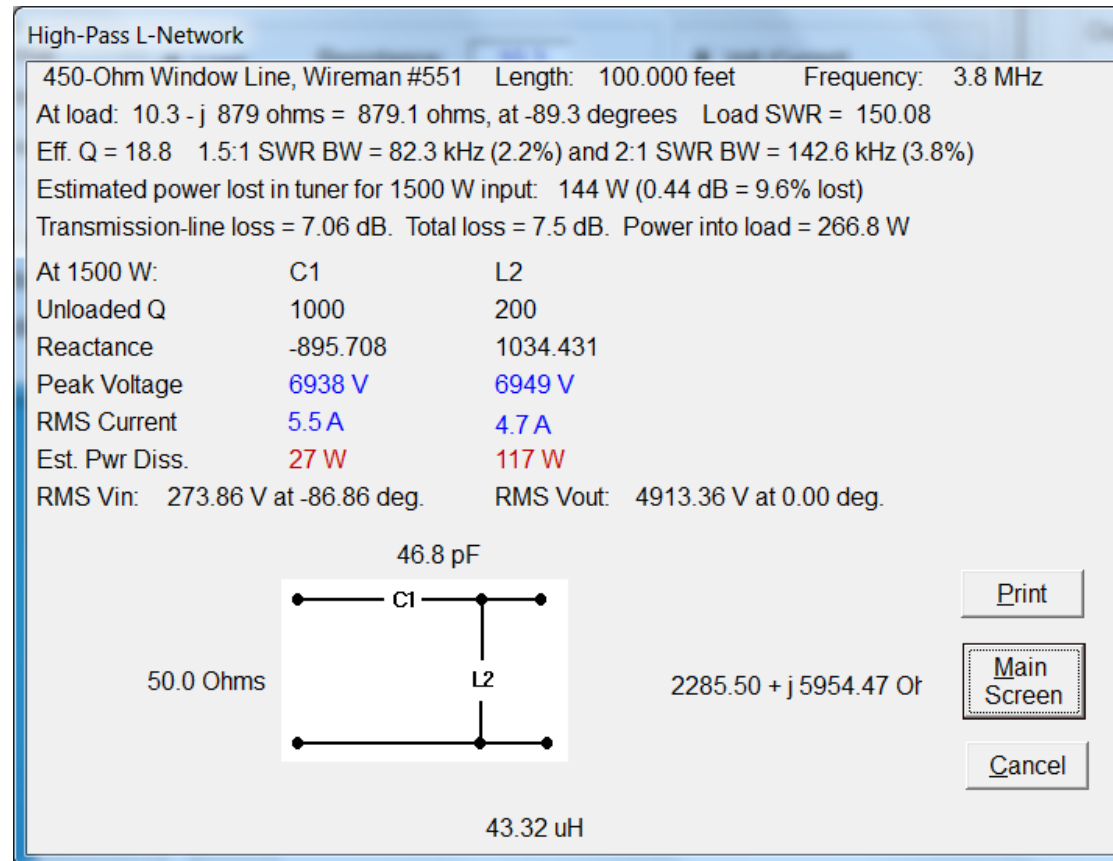
## Ex. 8: 40-Meter Dipole Used on 80 Meters

- Loss in ladder-line at 3.8 MHz (where antenna feed point is  $10.3 -j 879$ ) is 7.062 dB, surprisingly high for window line.
- Loss in balanced tuner is 0.44 dB. Overall loss is 7.50 dB.



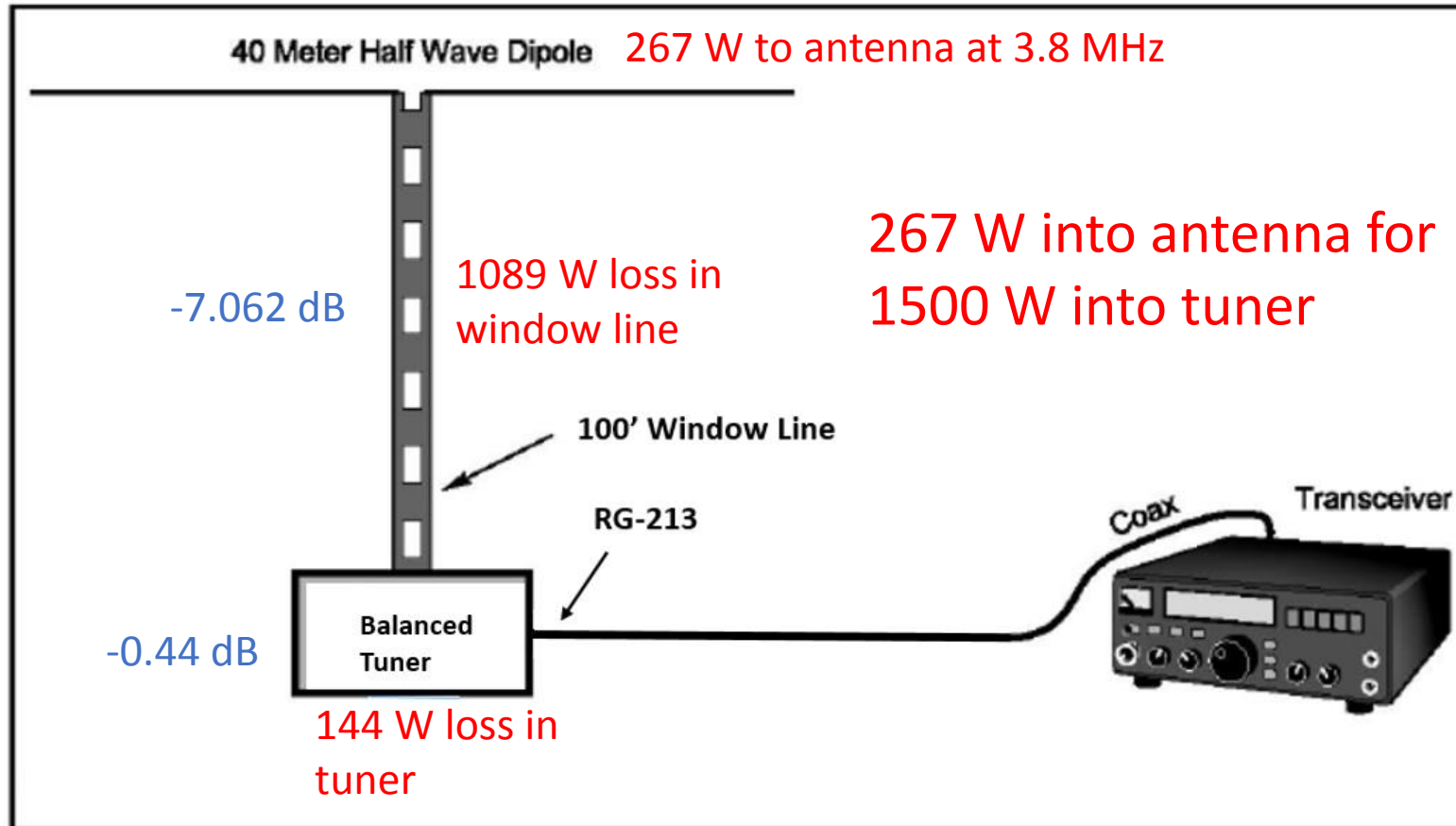
## Ex. 8: 40-Meter Dipole Used on 80 Meters

- Loss in balanced tuner is 0.44 dB. The loss is mainly in the coil (117 W) but 27 W is in the tuning capacitor.
- The peak voltages inside the tuner are close to 7000 V peak.





## Ex. 8: 40-Meter Dipole Used on 80 Meters

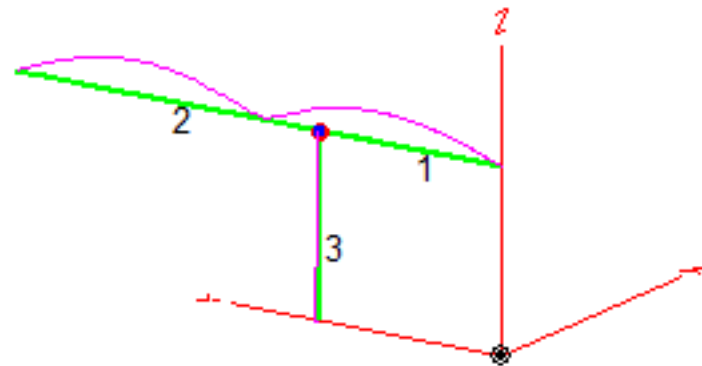


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EZNEC Pro/4

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- You should make sure there is air circulation inside a choke balun, especially on high-duty-cycle modes — like RTTY.
- Even at low transmitter power that allows a choke balun to survive, the system losses build up surprisingly high. After all, 11 dB down from 5 W QRP is 0.4 W QRPp.



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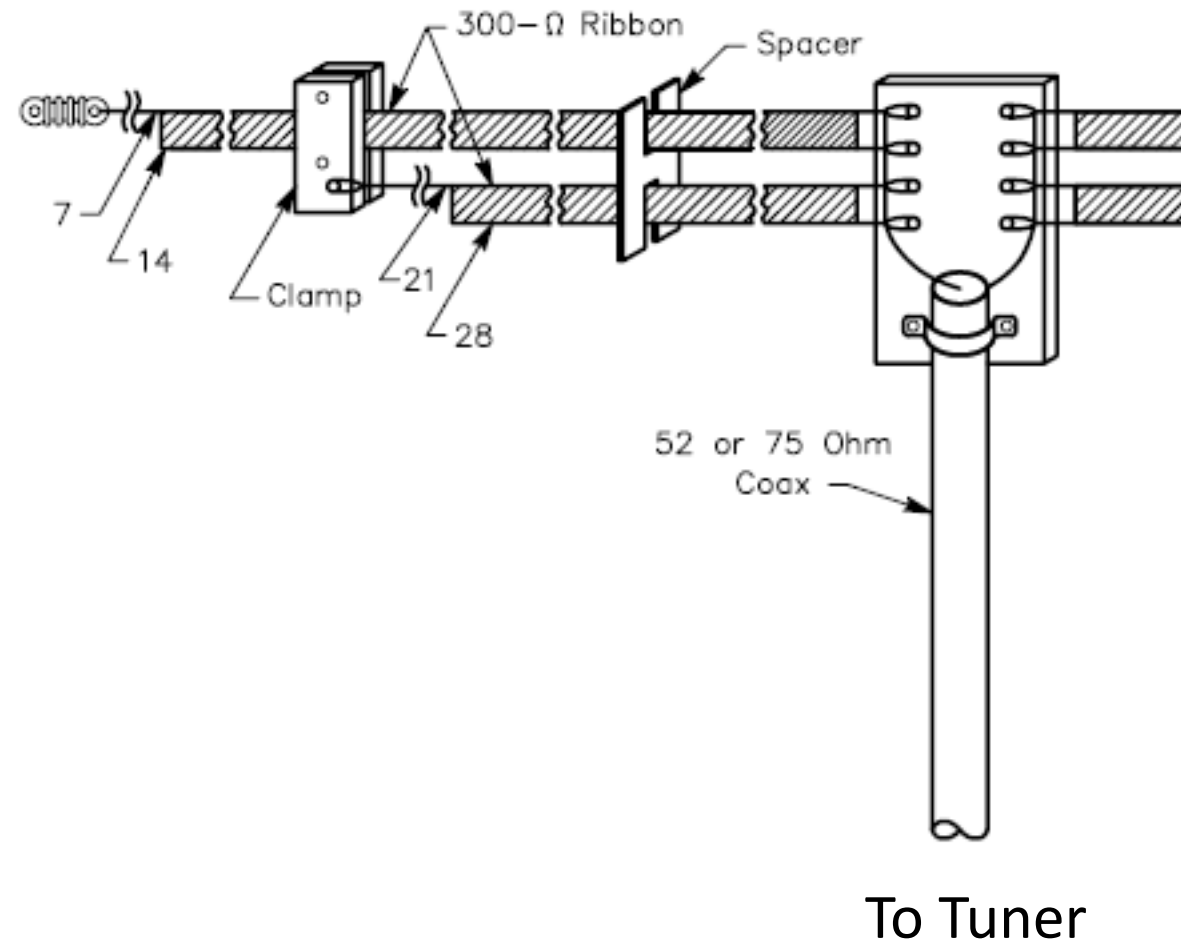
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# Multiple Parallel Dipoles at Common Feed Point



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- Do the system math – before blowing up components!
- Read K9YC's treatise "RFI, Ferrites and Common Mode Chokes for Hams." <http://audiosystemsgroup.com/publish.htm>.