TRANSMISSION LINES

By Mike Kieffer, KD8OUT

I will be using ARRL Antenna Book 22nd addition as my primary source material for this presentation.

I also uses a series of articles by M. Walter Maxwell W2DU/W8HKK in QST from 4/73 to 8/76 titled: "Another look at reflections". These articles are available for down load from ARRL site, under "Transmission Lines". A transceiver generates an AC (alternating current) signal that is delivers to a load or antenna to dissipate (transmit) the power.



"Transmission lines" in this presentation include all the connections from the transceiver to the energy emitting elements of the antenna. These elements form the "transmission system".

Because all modern transceivers are designed to work on a 50 ohm impedance, we must consider how impedance affects the design of an effective transmission system.

We need to review what is meant by "Impedance"

- Impedance is the AC analog to DC resistance.
- Remember E=IR For DC resistance?
- Impedance follows the same math, except we add a "complex" component, reactance.
- > Z = R + j X ; we want 50 ohms
 - Z= impedance, R= restive component, j= the complex operator, X= reactance
- > The math gets ugly fast, hold on.

Impedance on the Cartesian system



Where $\omega = 2^* \prod^* F$; X = reactance ohms, F=hertz, R = ohms, C = Farads, I = Henrys

Here is impedance in Polar coordinates:



Where $\omega = 2^* \prod^* F$; X = reactance ohms, F=hertz, R = ohms, C = Farads, I = Henrys

Impedance calculates by:

Series: $Z_T = Z_1 + Z_2$

Parallel: $Z_T = (Z_1Z_2)/(Z_1 + Z_2)$

- We must also understand the Decibel system of measuring power.
- The Decibel is a base 10 logarithmic system. The losses introduced in a transmission system are measured in db(Decibel) lost. By using db, we can, add each part of the transmission system's loss of power, to get the total loss and therefore how much useful power is delivered to the antenna.

db to power remaining: % Power left=10^{db/10}

db lost	Power	Watts	Watts	
	left %	OUT	OUT	
		100w	600w	
-0.1	97.72%	97.7	586.3	
-0.2	95.50%	95.5	573.0	
-0.44	90.36%	90.4	542.2	
-0.5	89.13%	89.1	534.8	
-1	79.43%	79.4	476.6	
-2	63.10%	63.1	378.6	
-3	50.12%	50.1	300.7	
-5	31.62%	31.6	189.7	
-6	25.12%	25.1	150.7	
-7	19.95%	20.0	119.7	
-8	15.85%	15.8	95.1	
-9	12.59%	12.6	75.5	
-10	10.00%	10.0	60.0	
-11	7.94%	7.9	47.7	
-12	6.31%	6.3	37.9	
-13	5.01%	5.0	30.1	

Common antenna impedances*:

- > Loop horizontal (1 λ) 100 ohms rising to 200 ohms at higher frequencies.
- $\blacktriangleright Dipole 72 to 74 ohms(1/2 \lambda)$
- > Vertical- $35-40 \text{ ohms} (1/4 \lambda)$
- Off center fed dipole 150 to 300 ohms
- Electrically short antennas are –X (Capacitive)
- Electrically long antennas are +X (Inductive)
- Electrically equal antennas are OX(Resonate)
- The antenna impedance varies with height off the ground, proximity to objects, configuration, operational frequency.

> *at resonance.

Feed lines have several important characteristics:

- Impedance
- Loss in db per 100 feet (matched line loss)
- Dielectric strength (short over voltage)
- Insulation type (Polyethylene, Teflon)
- Velocity factor
 - Each type of transmission line has a characteristic "velocity factor", which is a measure of how much slower the signal propagates through the transmission line, when compared to the ideal speed of light.
 - So the electrical wave length, in a practical transmission line, is always shorter than the wave length in free space.

Common Feed lines





Figure 23.23 — Construction of flexible parallel conductor and coaxial lines with solid dielectric. A common variation of the double shielded design at E has the braids in continuous electrical contact.

TRANSMISSION LINE MISSMATCH

- A transmission line is said to be "mismatched" if the lines characteristic impedance, the load's impedance and transceiver's impedance are different.
- The greater the mismatch, the more power is "reflected" back toward the source(your transceiver) and is re-reflected to the load.
- Most reflected power is re-reflected and eventually transmitted. More later.

> MATCHED LINE LOSS:

The power lost (attenuated) in a perfectly matched line/load is called the "matched line loss" for the feed line and is usually given by the manufacturer as db loss/100 FEET and is <u>frequency dependent</u>. The higher the frequency for a given type of transmission line the greater the attenuation/100 feet.



Figure 23.24 — Nominal matched-line attenuation in decibels per 100 feet of various common transmission lines. Total attenuation is directly proportional to length. Attenuation will vary somewhat in actual cable samples, and generally increases with age in coaxial cables having a type 1 jacket. Cables grouped together in the above chart have approximately the same attenuation. Types having foam polyethylene dielectric have slightly lower loss than equivalent solid types, when not specifi-

What is Insertion Loss of connectors:

- There are 3 main causes of Insertion Loss: Reflected losses, Dielectric losses and Copper losses. Reflected losses are those losses caused by the VSWR of the connector. Dielectric losses are those losses caused by the power dissipated in the dielectric materials (Teflon, Rexolite, Delrin, etc.). Copper losses are those losses caused by the power dissipated due to the conducting surfaces of the connector. It is a function of the material and plating used.
- A typical 2\$ Ampenol UHF connector is 0.1-0.3 db attenuation at HF/VHF frequencies. 0.2 db for BNC connectors. Ampenol will not quote insertion loss or impedance for UHF connectors because they have too much variability and are not 50 Ω. An Ampenol Type N connector is specified at 50 Ω and insertion loss of 0.15 db up to 10 GHZ.

> Typical connectors used by Hams:









Insertion losses from devices:

- Every device you insert into the transmission line has an associated loss. These will be specified by the manufacturer in db, within a frequency range.
 - Meters
 - Lightning arrestors
 - Matching units
 - Baluns
 - Matching transformers
 - Connectors

Total losses in a transmission line is the sum of:

- Matched line attenuation
- Connector attenuation
- Device attenuation
- > Additional loss due to SWR.
 - Additional loss overlaid as a result of the other losses
- You can add up all these losses, in db and calculate how many watts are lost in the transmission of power from source to load.

SWR (standing wave ratio) and reflected power:

- It is a measure of the mismatch of a transmission system.
- Reflected power is the amount of power sent back from the load toward the source, re-reflected until eventually transmitted.
- Most reflected power is eventually transmitted, only the transmission line losses (attenuation of all kinds present) absorbs power and is wasted.
- > The SWR (standing wave ratio) is:

$$SWR = \frac{1 + \sqrt{P_r/P_f}}{1 - \sqrt{P_r/P_f}}$$

Pr = Power reverse, Pf = Power forward



It is a common misconception that minimum SWR occurs when the antenna is at resonance.

- By definition resonance is where the "reactive" component of impedance is 0, or purely resistive.
- > Impedance = r + j0
- This can be seen on a "Smith Chart", because as the frequency changes, the impedance of the antenna changes.
- When the load is purely resistive, the antenna is said to be perfectly matched.

> Additional loss of power due to SWR

- This is the loss beyond the "matched line attenuation", and insertion attenuations.
- You take the line system attenuations in db and calculate the additional loss due to SWR and add them together for total transmission system loss.
- There are various calculators for determining the additional loss from SWR.
- At lower frequencies, even moderately high SWRs 10:1 or more, can generate small losses if the transmission system attenuations that are use to determine the "additional SWR loss", are small.

ADDITIONAL LOSS DUE TO SWR:



db lost	Power	Watts	Watts	
	left %	OUT	OUT	
		100w	600w	
-0.1	97.72%	97.7	586.3	
-0.2	95.50%	95.5	573.0	
-0.44	90.36%	90.4	542.2	
-0.5	89.13%	89.1	534.8	
-1	79.43%	79.4	476.6	
-2	63.10%	63.1	378.6	
-3	50.12%	50.1	300.7	
-5	31.62%	31.6	189.7	
-6	25.12%	25.1	150.7	
-7	19.95%	20.0	119.7	
-8	15.85%	15.8	95.1	
-9	12.59%	12.6	75.5	
-10	10.00%	10.0	60.0	
-11	7.94%	7.9	47.7	
-12	6.31%	6.3	37.9	
-13	5.01%	5.0	30.1	

- b db to power remaining":
- ▶ % Power left= $10^{db/10}$

- Voltages in transmission line due to SWR:
 - \triangleright E(max) = $\sqrt{P * Z * SWR}$ P=Power watts, Z= Imp Ω
 - ► Example:
 - P=100w, Z0=50Ω, SWR=10: Emax = 223volts
 - P=1000w, Z0=50, SWR=10: Emax = 707volts
 - I(max) = E(max) / Z0
 - With a highly reactive load Z0 can get large and so does E(max)
 E(max) can easily reach 10,000volts and arc over coax.

The moral of the story is:

- SWR is not an indication of transmission line efficiency. If you have low transmission system losses, high SWRs can be tolerated, with a transmatch or utilizing a low matched loss transmission line. If you have high attenuation from line, connectors or devices, you need to tightly control SWR.
- Forward power minus reflected power IS NOT the net power radiated. Line system attenuation losses (matched, insertion, device and additional due to SWR) determine net power radiated or lost due to attenuation. Of course there are losses within the antenna itself, beyond transmission line losses, that affect real radiated power.

> Antenna tuners(better named transmatch):

- A device between the source (rig) and the transmission line (typically) to present a 50 ohm load to the source match by conjugate matching.
- A tuner is typically coil(s) and capacitor(s) combination that cancels out the reactive component of the load(conjugate matching) and leaves a 50Ω resistive result.
- > The tuner can be at the beginning or end of the feed line.



A commonly held misconception is that if "I tune an antenna to a good SWR, I have low losses."

No, a tuner cannot change the physics of the load system. All it is doing is matching the load impedance to the 50 ohm transceiver, keeping your rig happy and reflecting the SWR reflections back to the load. All the attenuation losses in transmission line system and antenna remain(such as ground losses) remain and dissipate power. **INCIDENT POWER:** power after the matching unit, equals the source power plus the reflected power.

Incident power is greater that source power whenever the SWR is greater than zero because of conservation of energy and wave mechanics.

All power delivered to the load is absorbed or reflected back to the source and rereflected to the load. Only attenuation losses and additional loss due to SWR dissipate(waste) power in the transmission system.



WHERE IS THE BEST PLACE TO PUT YOUR TRANSMATCH(TUNER)?

Tuner Settings and Performance

<i>Example</i> (<i>Fig 24.18</i>) 1	Frequency (MHz) 3.8 28.4	<i>Tuner Type</i> Rev L Rev L	L (μΗ) 1.46 0.13	C (pF) 2308 180.9	<i>Total Loss (dB)</i> 8.53 12.3	
2	3.8 28.4	L L	14.7 0.36	46 15.6	2.74 3.52	
3	3.8 28.4	L L	11.37 0.54	332 94.0	1.81 2.95	



EXAMPLE:

- In this example, the antenna is a 100' flat top, 50' over average ground. The dipole and is NOT resonate at either of the test frequencies. The antenna feed point impedance is:
 - > 3.8 mhz 39-j362
 - > 28.4 mhz 2493-j1375
- As you can see, direct feeding the antenna with a 1:1 balun and 200' of RG-213 coax has losses 8.53 to 12.3 db.
- Using 300 ohm twin lead is better. Losses from 2.74 to 3.52 db
- Remote placement of the tuner is the best solution. Losses from 1.81 to 2.95 db.
- The ideal would be a tuner at the "Y" point of the antenna. This is possible on verticals, not so much of dipoles.

> An example at 3.8 mhz (200' RG-213)

τέ <mark>ν</mark> TLW		
TLW, Tr	ransmission Line Program for Windows	
_	A 3.1, Copyright 2000-2008, ARRL, by N6BV, Dec 01, 2008	
C Motoro 🗋	e "w" suffix for wavelength (for example, 0.25w)	
-	Z0: 50.0 - j 0.60 Ohms Matched-Line Loss: 0.381 dB/100 Feet r: 0.66 Max Voltage 3700 V Total Matched-Line Loss: 0.762 dB	
Source Normal Autek	Imput Resistance: 39 Ohms Ohms Ohms Ohms	
© Noise Bridge SWR at Line In	put: 9.67 SWR at Load: 62.34 Rho at Load: 0.96842	
Additional Loss Impedance at Ir	s Due to SWR: 7.664 dB Total Line Loss: 8.426 dB nput: 5.68 - j 18.80 Ohms = 19.64 Ohms at -73.18 Degrees	

> An example at 28.4 mhz (200' RG-213):

TLW					
TLW, Tı	ansmiss	ion Line Pr	ogram fo	r Windows	<u>H</u> elp
Version	3.1, Copyrigh	t 2000-2008, ARRL	, by N6BV, De	ec 01, 2008	TLW
Cable Type:	RG-213 (Belde	en 8267)		•	1100
C Matera	gth: 200 "w" suffix for v	Feet 8.75 vavelength (for examp		Frequency: 28	4 MHz
Characteristic Z	.0: 50.0	-j0.24 Ohms Mat	ched-Line Loss	s: 1.151 dB/100	Feet
Velocity Factor	: 0.66 Max	Voltage 3700 V	Total Matche	d-Line Loss: 2.3	302 dB
Source					
Normal Autok	Coad	Resistance:	2493 Ohms	Volt./Current	Graph
C Autek	C Input	Reactance:	1375	C Resist./Reac.	
O Noise Bridge				<u>T</u> uner <u>P</u> rint	E <u>x</u> it
SWR at Line In	put: 3.66	SWR at Load:	64.84	Rho at Load: 0	.96963
Additional Loss	Due to SWR	: 10.532 dB		oss: 12.834 dB	

db lost	Power	Watts	Watts	
	left %	OUT	OUT	
		100w	600w	
-0.1	97.72%	97.7	586.3	
-0.2	95.50%	95.5	573.0	
-0.44	90.36%	90.4	542.2	
-0.5	89.13%	89.1	534.8	
-1	79.43%	79.4	476.6	
-2	63.10%	63.1	378.6	
-3	50.12%	50.1	300.7	
-5	31.62%	31.6	189.7	
-6	25.12%	25.1	150.7	
-7	19.95%	20.0	119.7	
-8	15.85%	15.8	95.1	
-9	12.59%	12.6	75.5	
-10	10.00%	10.0	60.0	
-11	7.94%	7.9	47.7	
-12	6.31%	6.3	37.9	
-13	5.01%	5.0	30.1	

- b db to power remaining":
- ▶ % Power left= $10^{db/10}$

COMMON MODE CURRENTS IN COAX CABLE



How to get rid of common mode current:

Purchase a "current balun". It forces equal current in each antenna leg.





 Wind a coax choke balun – winding depend of frequency, any where from 6 to 40 feet of coax, longer for low bands, shorter for the high bands.



Figure 24.53 — Winding a coaxial choke balun as a singlelayer solenoid may increase impedance and self-resonant frequency compared to a flat-coil choke.

> Add ferrite bead choke. Use 500-1000 Ω of impedance.





What is a balun:

- Balanced to unbalanced
- A dipole is a balanced load, coax is unbalanced, ladder line is balanced.
- A current balun forces equal current on both balanced legs and is used for impedance matching and stopping common mode currents.
- A voltage balun forces equal voltage on each balanced leg and is used for impedance matching.

What is an unun

- > Unbalanced to unbalanced
- > A vertical is an unbalanced load.
- > Feeding a vertical with coax can use an unun.

> You can combine a transformer with a balun or unun:

- Say you want to feed your 50 ohm dipole with 450 ohm ladder line, you could use a 9:1 current balun. On the load side, many manual tuners have a built in balun to convert the balanced line back to coax.
- Remember antenna impedance varies with height, configuration and very much with frequency. With multiband antennas, the impedance matching ratio might be completely different.

Conclusions:

- Except in single band, resonant systems, your feed line is part of the "bulk" impedance your source sees. Changing the feed line in any way will change the impedance of the load system. If you are in doubt:
- Down load the ARRL "TLW program" . it is great to calculate complex feed line/antenna impedances.
- Use the best transmission line and connectors you can afford. Keep an eye on the losses from inserted devices.

Conclusions:

- If you use coax, deal with common mode currents.
 Ladder lines do not have this problem.
- You can use two coax lines in parallel as a balanced feed line (tie shields together) and this setup does not suffer from interference from near by objects, but the line impedance is twice of each coax's characteristic impedance.



Figure 23.25 — Shielded balanced transmission lines utilizing standard small-size coaxial cable, such as RG-58 or RG-59. These balanced lines may be routed inside metal conduit or near large metal objects without adverse effects.

If you use ladder type lines, they cannot come near metal objects. They are best when there is a direct route from load to transmitter.

Transmatches are helpful, but they do not eliminate inherent system attenuation(s) and should be placed as close to the load, if possible. This eliminates the overlay of SWR losses for the section of transmission line from source to the transmatch.

> LAST:

 Don't worry about SWR to the exclusion of all other factors. SWR only affects transmission line loses as a multiplier of the underlying attenuations (matched, insertion and device).
 If those attenuations are low for your operating frequency, and you have a transmatch (that has enough range) to protect your source, SWR can be discounted.