Newcomers Notebook. Transmission lines – not all coax is the same.

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All hams use transmission lines at some time in their life. But have you ever thought about the line you are using? What is the characteristic impedance, transit time, return loss and how does the SWR impact my transmission line?

Transmission Lines

Transmission lines (feeders or feedlines) are specially designed lines to connect radio transmitters and receivers with their antennas. The lines have a uniform cross section over the length with a consistent characteristic impedance.

Transmission lines in the Ham world are usually balanced parallel line, such as ladder line or ribbon line or coaxial cable which is unbalanced.

Around 1837, operational morse code telegraph was established and in 1858 the first coax cable was laid across the transatlantic. So, these cables have been in use for a long time now.

Looking inside the cable

Coaxial cable (coax) has an inner conductor surrounded by a concentric dielectric then a plastic-coated metallic shield. The common impedance of coax for ham use is 50 ohms. The coax with 75 Ohms characteristic impedance is common in video and TV applications.

Ladder line consists of two parallel conductors separated by an insulator and has a characteristic impedance of 300 Ω, 450 Ω and 600 Ω.

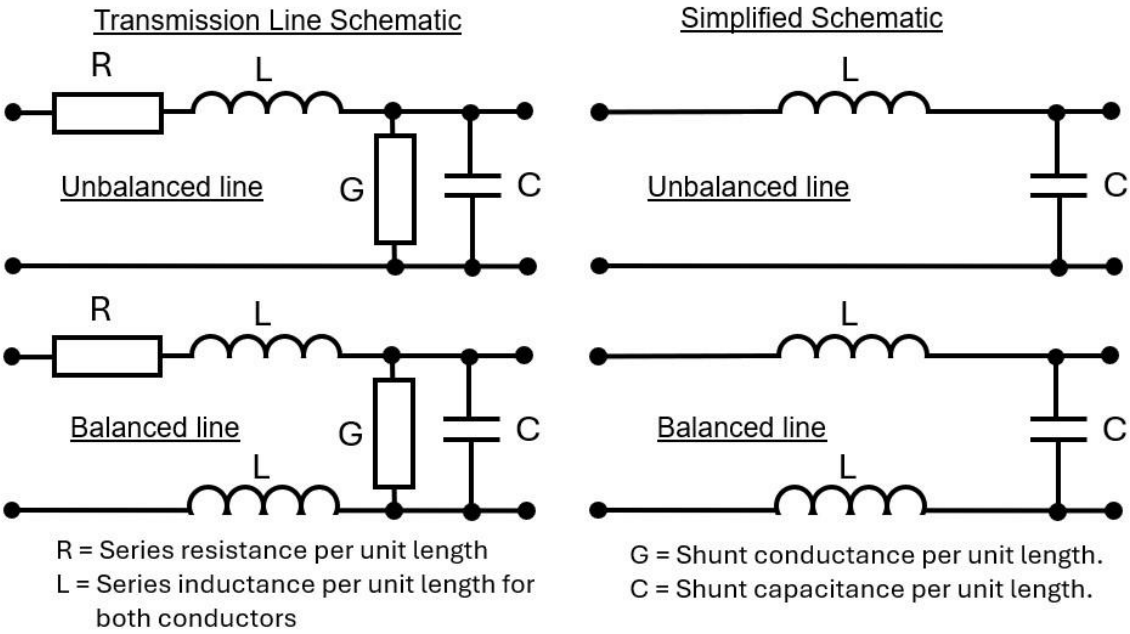


Figure 1 Transmission line model.

Figure 1 is a representation of transmission lines. The resistance (R) and conductance (G) are necessarily small otherwise the cable has too much loss. A simplified diagram of transmission lines negating the resistance and conductance, as used in most handbooks, is also shown in Figure 1. This diagram shows the series inductor (L) and the parallel capacitor (C).

Looking at the data sheet for RG58 we can see the real values for the series capacitance is 85.3 pF/M and the inductance is 0.254 uH/m.

Why 50 Ohms?

In the 1930s, engineers developed transmission cables for very high power (kilowatts) radio stations. They found that 50 Ohms provided the best compromise between minimum losses, maximum power transfer and maximum voltage handling.

Characteristic impedance (Zo)

Characteristic impedance is the main feature of the cable that most hams are concerned about so let’s explore what is impedance. Impedance is a complex number showing resistance and reactance. In Figure 2, resistance is the line to the right as we can only have positive resistance. Inductive reactance is the ascending line, and capacitive reactance is the descending line. The impedance number has two parts. The first number is the resistance value and the number starting with j is the reactance part. Positive for inductive reactance and negative for capacitive reactance. We will not be doing complex maths but remember the makeup of this number for later articles.

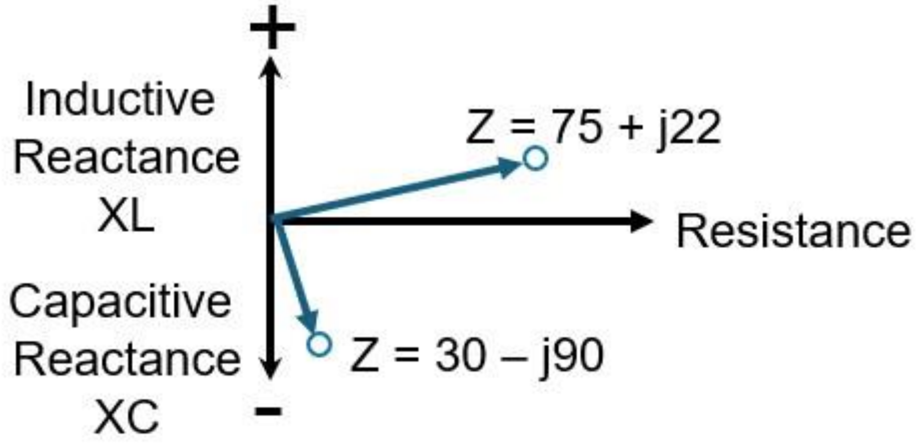


Figure 2 Impedance.

We can see from the transmission line components in Figure 1 that transmission lines have both inductance and capacitance. The cable is designed and manufactured to have these characteristics. The capacitance and inductance are crucial for calculating the characteristic impedance. Figure 3 shows the calculation of characteristic impedance from the cable data sheet.

$$Zo = \sqrt{\frac{L}{C}}$$

Example using RG58U (50 Ohm coax)
L = 0.254 uH per metre = 0.000000254
C = 101 pF per metre = 0.000000000101

$$Zo = \sqrt{\frac{0.000000254}{0.000000000101}}$$

$$Zo = \sqrt{2514}$$ Rounded figures

$$Zo = 50 \text{ Ohms}$$

Figure 3 Characteristic impedance calculation.

Transit Time

Radio waves in free space (vacuum) travel at the speed of light which is 299,792,458 metres per second (m / s). So even at this speed radio waves take time to travel along a line. In the case of a hundred (100) meters of coax transmission line, the time to cover this length, in a perfect line, would be 333 nS. In the case of the RG58U coax, the signal delay is 5.03 nS/m. For the hundred metres of coax, the delay is 503nS or an increase of 170nS. Now the total transit time for a real signal to travel the hundred metres is 836nS. This matches the RG58U data sheet for velocity of signal propagation is 66% slower than the free space signal.

Most transmission lines would be shorter than 100 metres so transit times for HF signals is not a concern.

These transit times are important when we later look at the Time Domain Reflectometer.

How does the transmission line work?

Looking at Figure 1, this represents the whole line. If we break the transmission line into smaller segments, as in Figure 4, and analyse how each segment works.

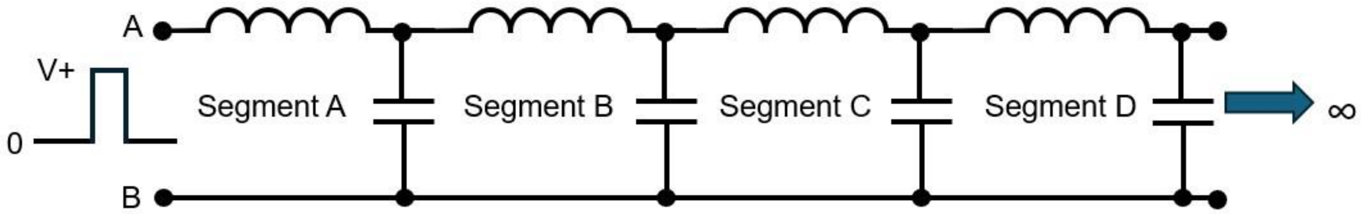
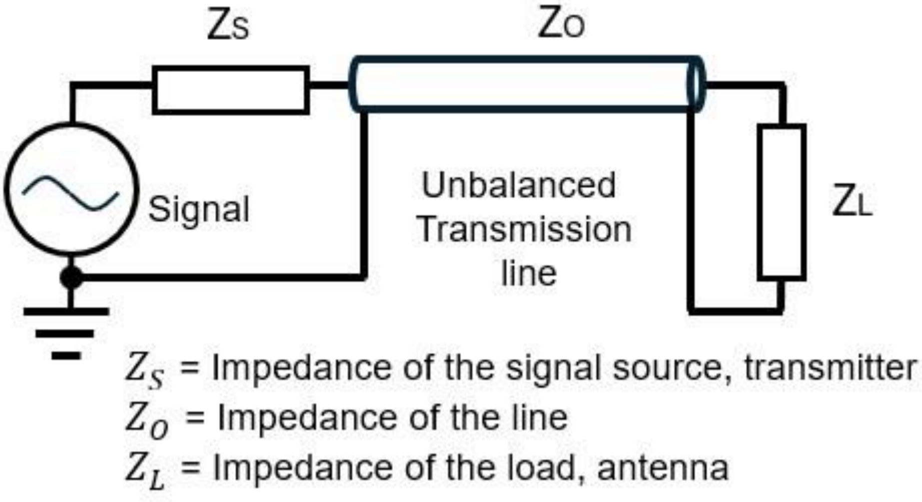


Figure 4 Line segments.

A pulse enters at point A and B on a transmission line of infinite length. Once the capacitor in segment A is charged the pulse moves down the line to charge the next capacitor and so on. The pulse is propagated along the line in this method. This charging of capacitors has a finite time and this is where the delay of 5 nS per metre, for the RG58U, originates.



Z_S = Impedance of the signal source, transmitter
Z_O = Impedance of the line
Z_L = Impedance of the load, antenna

Figure 5 Load resistances.

Terminations

In Figure 5, the same transmission line is shown with source and load resistances.

- If Zs = Zo = ZL then all the power from the source will be radiated through the load.
- If Zs = Zo and ZL is open circuit (infinite resistance) then all the signal will be reflected back to the source as a positive signal.
- If Zs = Zo and ZL is short circuit (0 resistance) then all the signal will be reflected back to the source as a negative signal.

The symbol gamma (Γ) in Figure 5, represents the return coefficient of the cable.

Examples: Zs = Zo = 50 Ohms and ZL is between 50 Ohms and infinity, the reflected signal will be positive.

Zs = Zo = 50 Ohms and ZL is between 50 Ohms and 0, the reflected signal will be negative.

Reflection coefficient and SWR

The reflection coefficient describes how much of a signal wave is reflected by a mismatch in the transmission line. Hang on, isn’t that the SWR? Yes, they are related. Now I need to show a bit more maths in Figure 6, but it’s necessary to show the relationships.

$$\Gamma = \frac{Zl - Zo}{Zl + Zo} \qquad \text{Formula A}$$

$$SWR = \frac{1 + \Gamma}{1 - \Gamma} \qquad \text{Formula B}$$

$$SWR = \frac{1 + \frac{(Zl - Zo)}{(Zl + Zo)}}{1 - \frac{(Zl - Zo)}{(ZL + Zo)}} \qquad \text{Formula C}$$

$$SWR = \frac{V\,max}{V\,min} \qquad \text{Formula D}$$

Figure 6 Formula.

Formula A shows that the reflection coefficient is derived from the transmission line and load (antenna) impedances. Formula B shows the SWR is derived from the reflection coefficient which all makes sense to see how they are related. Now substitute gamma (Γ) from formula A to Formula B and we get Formula C.

Formula D is the operational way of determining the VSWR.

Losses

Loss is the reduction in magnitude as a wave propagates through a medium. In our case a transmission line. This is where the cable resistance (R) and conductance (G) come in. Conductance is the undesirable current loss induced between conductors through the dielectric material.

So, every transmission line will have some losses and keeping these losses to a minimum is important. Line losses vary with frequency, SWR and the design of the cable. In the case of RG58U, the operating range of the cable can vary largely from megahertz to gigahertz.

Other factors causing losses are the attenuation constant defined as Alpha (α) and the phase constant defined as Beta (β).

The table below is a comparison between the Belden low loss RG58 50 Ohm and a standard Pro-Power RG58.

Frequency	Belden RG58 Low loss 9913	Pro-Power RG58
MHz	Decibels loss per metre	
5	0.012	0.04
10	0.016	NA
50	0.032	0.123
100	0.045	NA
200	0.058	0.225
400	0.084	0.325
900	0.133	0.45

Example: A perfectly matched transmission line carrying a 50 MHz signal of 100 W from the transmitter to the antenna through 10 metres of Pro-Power RG58U with a rated loss of 0.123 db/m. The radiated power will be 75.3 W. So, buy the best coax you can afford.

High SWR and Line loss

A high SWR also increases transmission line loss because the power initially reflected at the load makes more trips along the line. The signal travels back to the antenna tuner or radio, and then back to the load. The signal traveling up has losses, and the return trip also has losses. The higher the SWR and the longer the line, the greater the loss.

The table below provides a comparison of cables losses with varying frequencies and SWR. The transmitter power is 100 W and the cable length is 10 metres.

Cable	Power Radiated	3.5 MHz		28 MHz		144 MHz	
		1:1 SWR	6:1 SWR	1:1 SWR	6:1 SWR	1:1 SWR	6:1 SWR
Belden 9913		98.29 W	94.94 W	95.16 W	86.64 W	89.01 W	73.17 W
Belden 8240		95.18 W	86.7 W	86.53 W	68.58 W	70.4 W	46.15 W
Ladder line 600 ohm		99.73 W	99.17 W	99.22 W	97.65 W	98.18 W	94.64 W

Lessons Learnt

1. Every transmission line has losses so investigate the line losses of the cables you want to buy.
2. Buy the best coax you can afford.
3. Explore parallel transmission lines.

4. Tune your antenna as close as you can to 50 ohms for maximum power transfer.

References

- “Let’s Talk Transmission Lines Don’t neglect one of the most important parts of your station!” By Edward J. Farmer, AA6ZM – June 2006 QST magazine.
- The ARRL Antenna Book 2000
- Coax loss calculator by KV5R at kv5r.com
- Belden 50 Ohm RG-58 Product:9913 datasheet
- Pro-Power RG58 datasheet.

Have fun and stay safe.