Electromagnetic Propagation, Antennas and Transmission Lines

Transmission Lines

Questions to get you thinking…

A certain vertical antenna and ground radial system has a perfect 50 ohm resonant feed point impedance at 10 MHz. The only coax on hand is 15m (approx. 50 ft) of high-quality, undamaged, negligible-loss RG11 cable with characteristic impedance of 75 ohms and VF of 66.7%. If this coax is used:

1. The VSWR on the line (at 10 MHz) will be:
   a) 1:1
   b) 1.5:1
   c) 2.25:1
   d) Not enough info
2. The impedance seen at the transceiver (at 10 MHz) will be:
   a) 50 ohms
   b) 75 ohms
   c) 112.5 ohms
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3. Would the above answers change if you shortened the line to 10m (33 ft)?

Just think about it for now and we'll answer them at the end of the presentation.

Transmission Lines

- Role of transmission line:
  - Bring RF power from Transmitter to Antenna or vice-versa
- Transmission Line Types
  - Spaced twin-wire
  - Twisted Pair
  - Coaxial
  - Waveguide

Perfect (Ideal) Feedline

- ***A perfect feedline will have:***

  - No radiation from the feedline itself
  - No loss of signal while passing along the line
  - Constant electrical characteristics throughout
  - Such a feedline will pass 100% of the RF energy through it.

Feedline (transmission line)

- USUALLY 2 CONDUCTORS

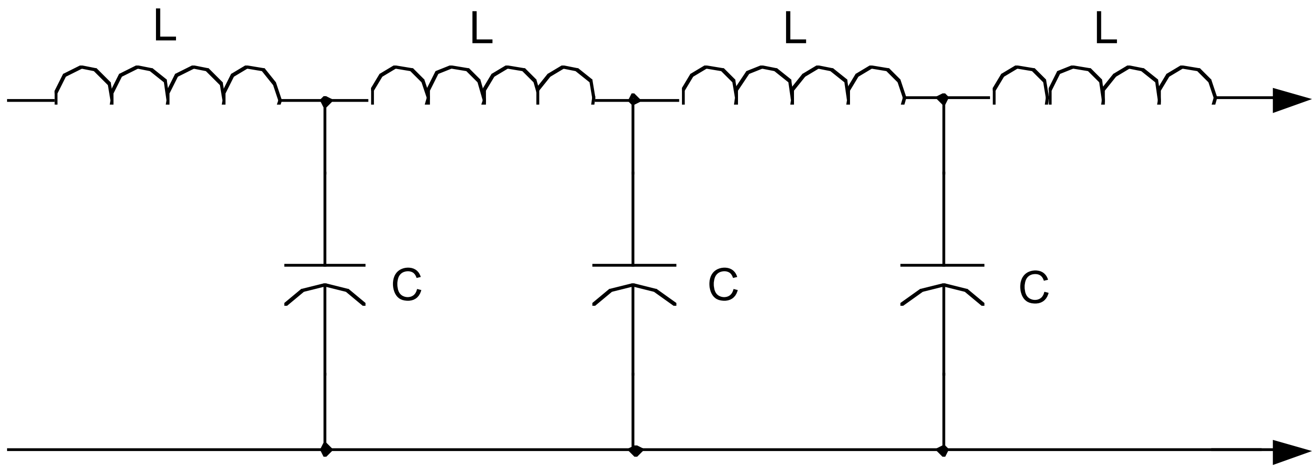
–Certain capacitance per meter because of 2 parallel conductors and a certain inductance because of the length of the conductors.

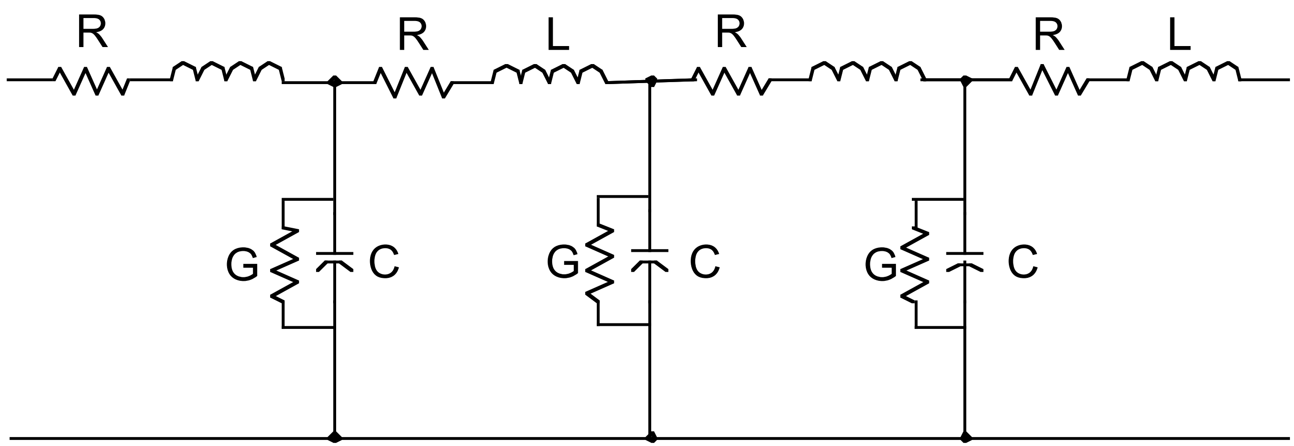
–The series inductance and parallel capacitance of a feedline is a circuit that produces an inherent impedance to the passage of AC current and the value stays approximately the same over a wide range frequency and length. This value is called the characteristic impedance of the circuit. (Z_o)

–Resistance in the metal itself restricting the flow, responsible for the attenuation (loss) but usually does not significantly affect the impedance.

–At lower frequencies, the signal passes through the whole conductor while at higher frequencies, the signal tends to pass along the surface, or skin of the wire. This is known as 'skin effect' causing the effective resistance and hence the losses increase with the frequency

Transmission Line Model





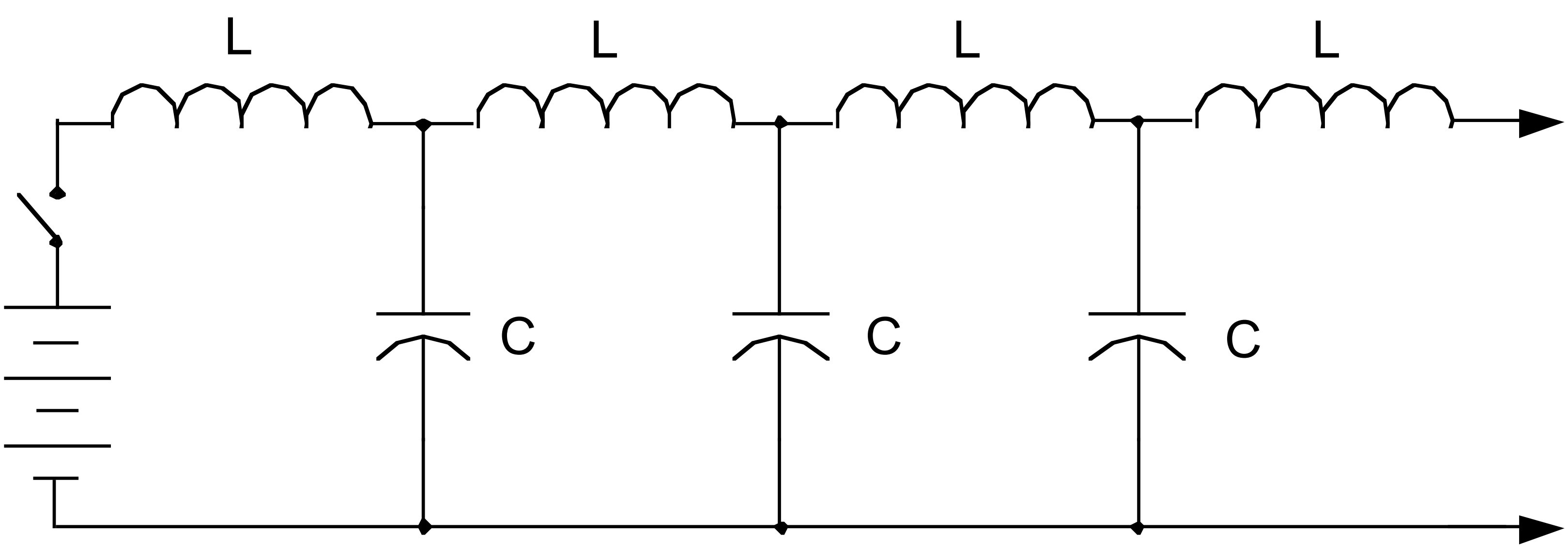
Operating vs. Characteristic Impedance

"Operating Impedance" is defined as the ratio of Voltage/Current Z = V/I.

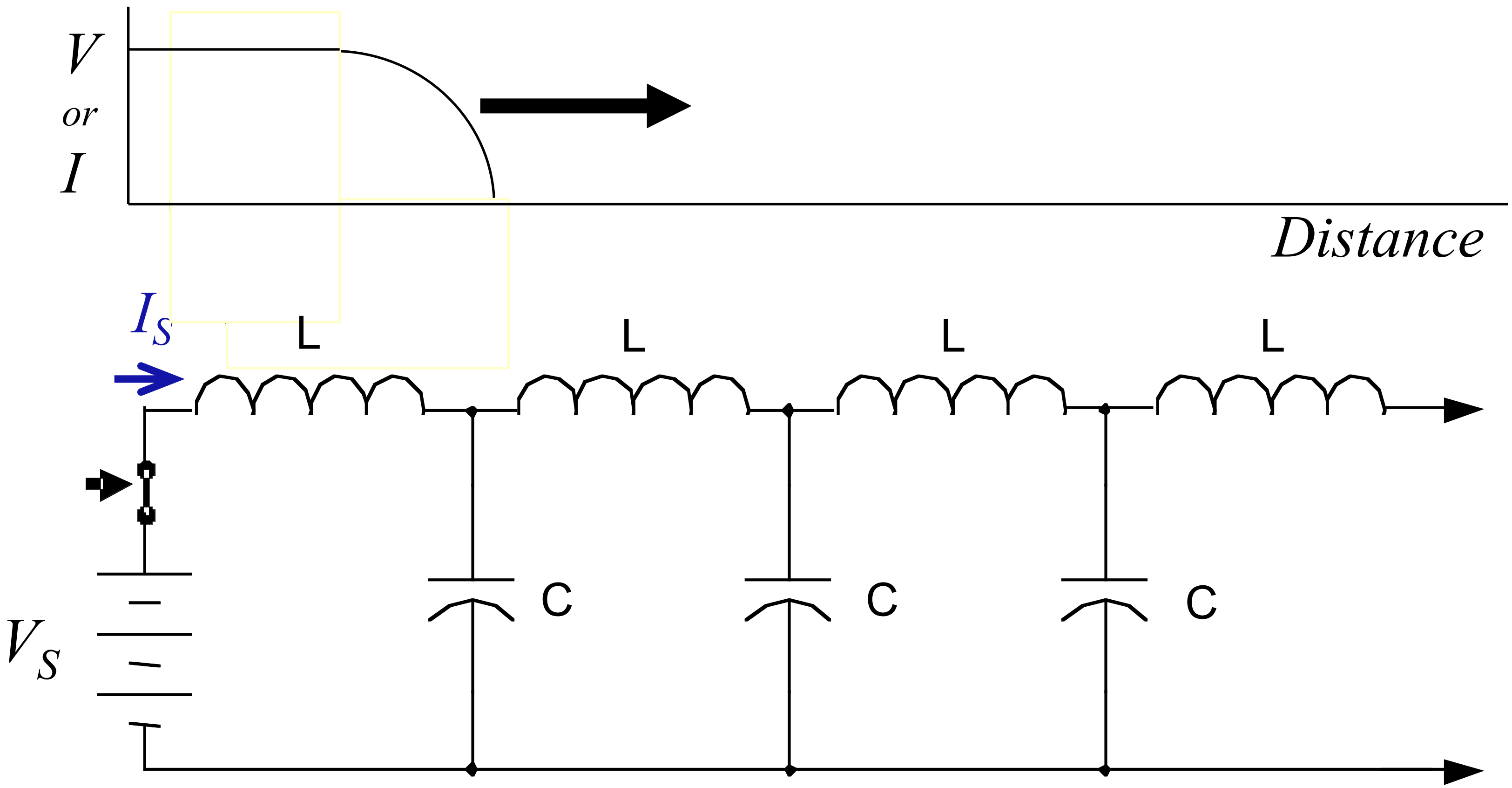
- If the voltage and current are in-phase, the impedance is purely resistive (e.g. 50 + j0 ohms).
- If the voltage leads the current, the impedance has an inductive component (e.g. 50 +j31 ohms)
- If the current leads the voltage, the impedance has a capacitive component (e.g 50 – j12 ohms)

But when we talk about a "50 ohm cable", we're referring to it's "Characteristic Impedance" Z_0, which is not necessarily the same as the operating impedance V/I. The characteristic impedance is a property of the cable, determined by its dimensions and materials.

$Z_0 = \sqrt{\frac{L}{C}}$ where L is the inductance per meter and C is the capacitance per meter of the cable.

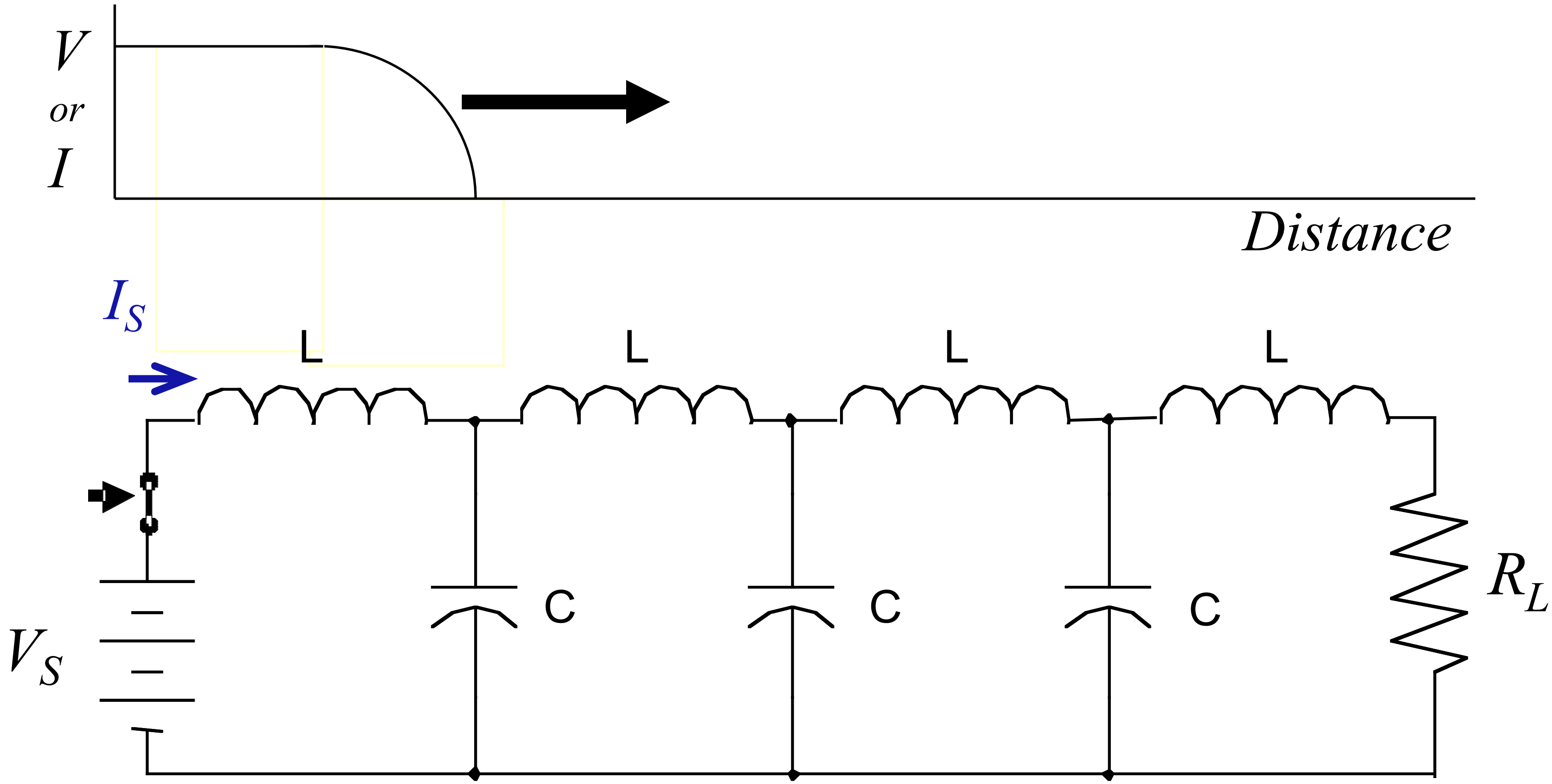


Characteristic Impedance Z_0



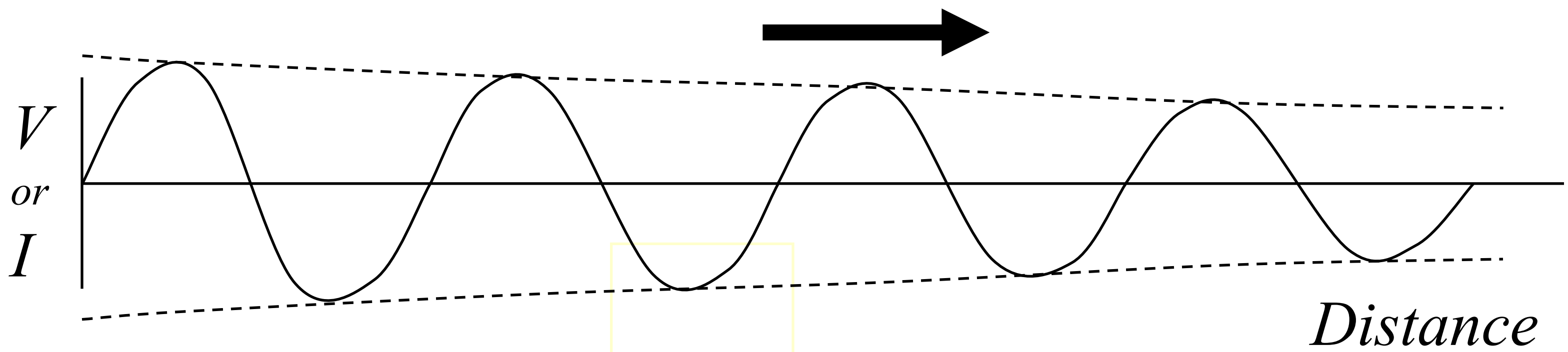
If the transmission line is **infinitely long**: $Z_0 = \frac{V_s}{I_S} = \sqrt{\frac{L}{C}}$

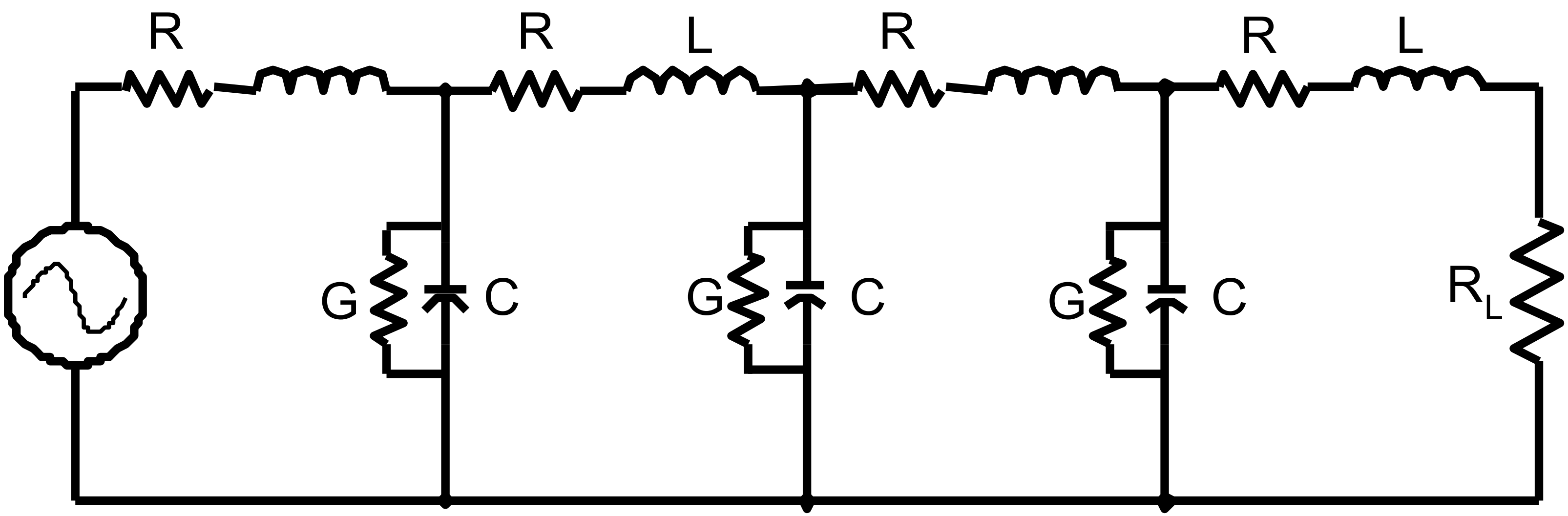
Characteristic Impedance Z_0 of a Finite Line



For a finite length transmission line, there may be a reflection when the wave hits the end. But if we terminate the line with a load resistor R_L, such that $R_L = Z_0$, there will be no reflection (all power goes into load) and the transmission line *appears* infinitely long to an observer at the source end.

Attenuation





The internal resistance and conductance of the transmission line causes power loss with distance

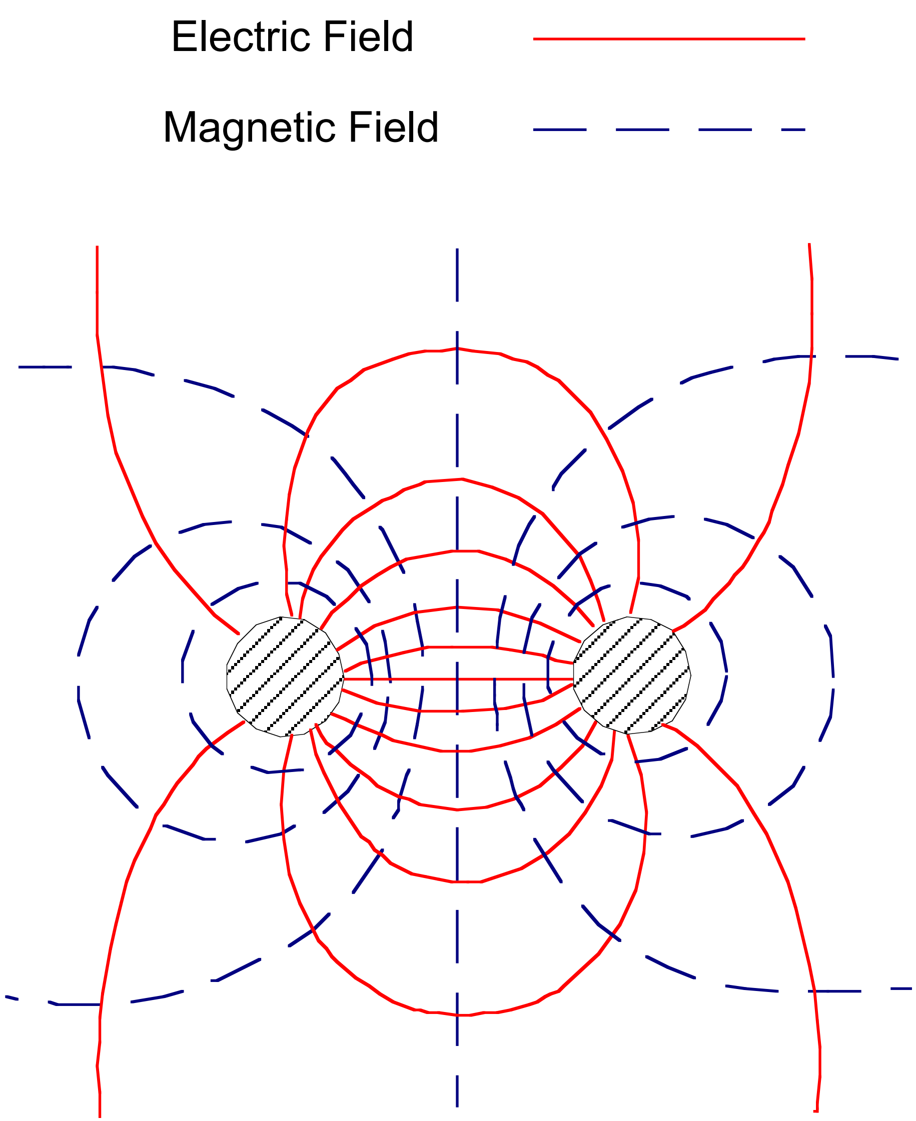
Feed Lines

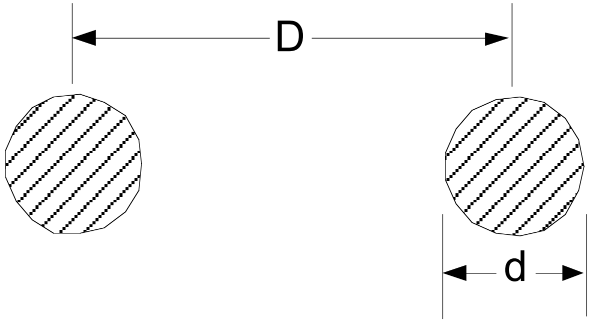
The two favourite for amateur radio are the coaxial cable and twin lead (open wire feedlines, ladder, window)

Balanced feedlines

- Open wire feedlines must be kept away from metal objects.
- Characteristic impedance typically 200 – 600 Ω depending on the diameter of the wire and the distance between them.
- Both conductors have a similar impedance to ground (neither one is directly connected to ground).

Twin-Wire (Balanced) Transmission Lines



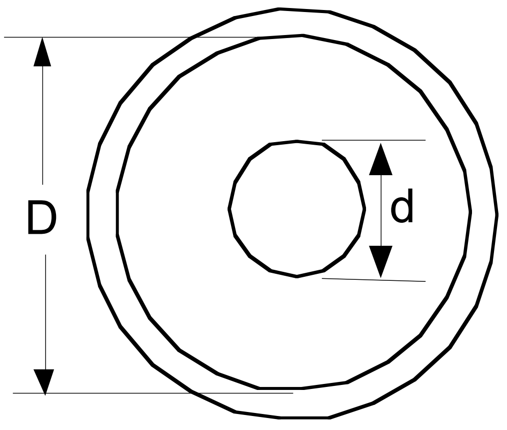


$$Z_0 = \frac{120}{\sqrt{\varepsilon_r}} \ln\left(\frac{2D}{d}\right)$$

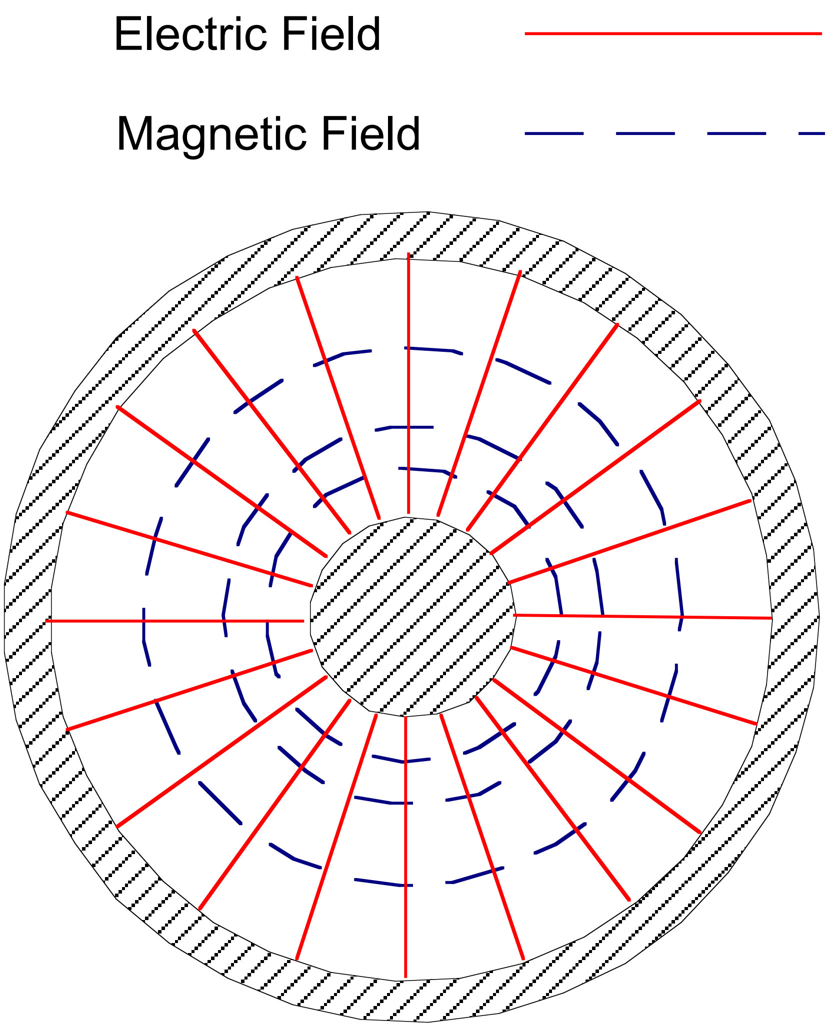
Unbalanced feedlines

- One conductor is grounded at some point in the system
- Coaxial cable can be waterproof, some can be directly buried.
- RG-213 and LMR-400 are common choices
- Common characteristic impedance is 50 ohms (most common in radio communications) or 75 ohms

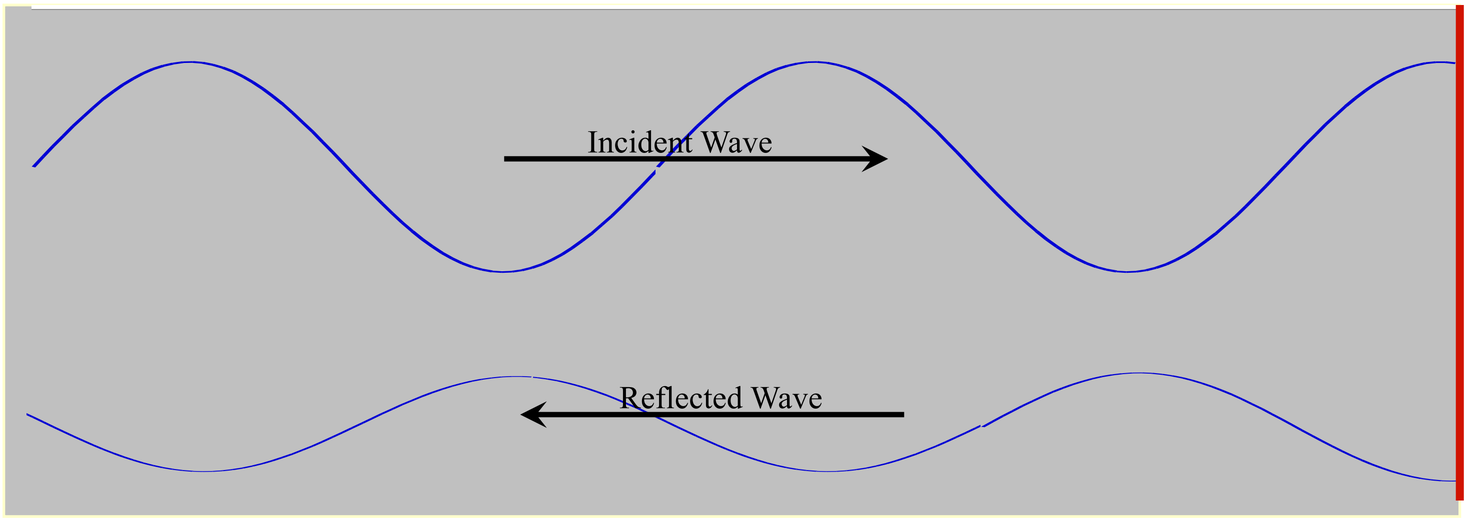
Coaxial Transmission Lines



$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln\left(\frac{D}{d}\right)$$



Reflections, Standing Waves and Return Loss



Here $Z_L < Z_0$ so the reflected wave is inverted (negative) with respect to the forward wave arriving at the load.

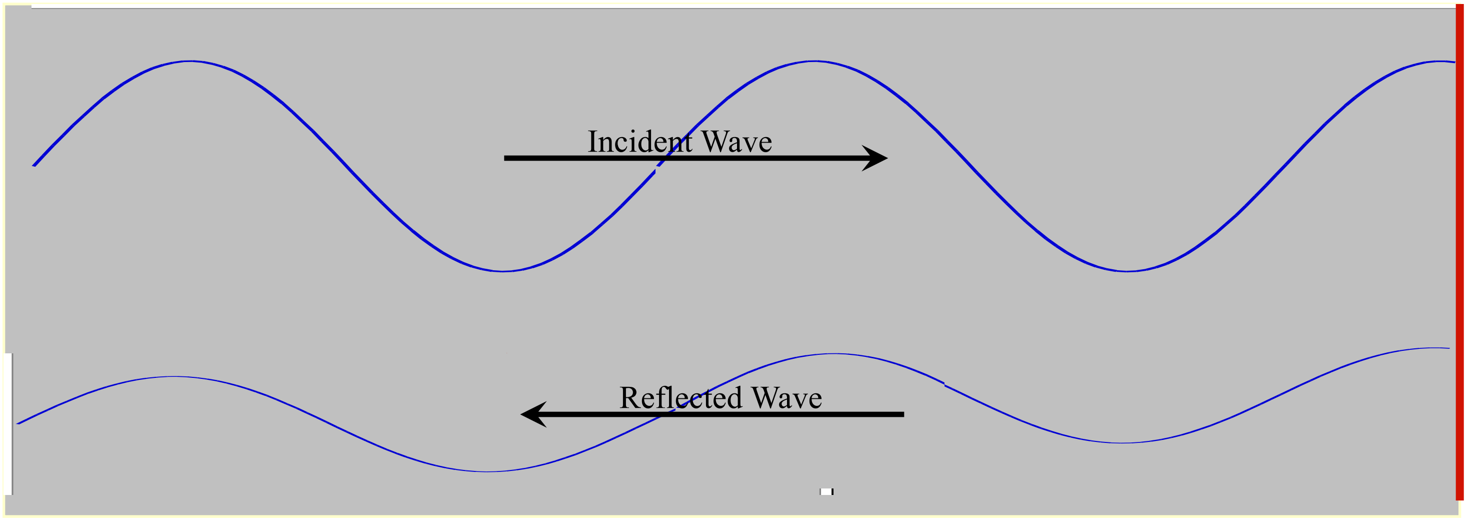
VF and Wavelength

Wavelength = distance a wave travels in the time it takes to complete one cycle (wave period T= 1/f).

In free space, electromagnetic waves propagate at the speed of light c = 300,000,000 m/s. If a wave is travelling at the speed of light, the wavelength in meters λ_0 **= 300/f(in MHz)**

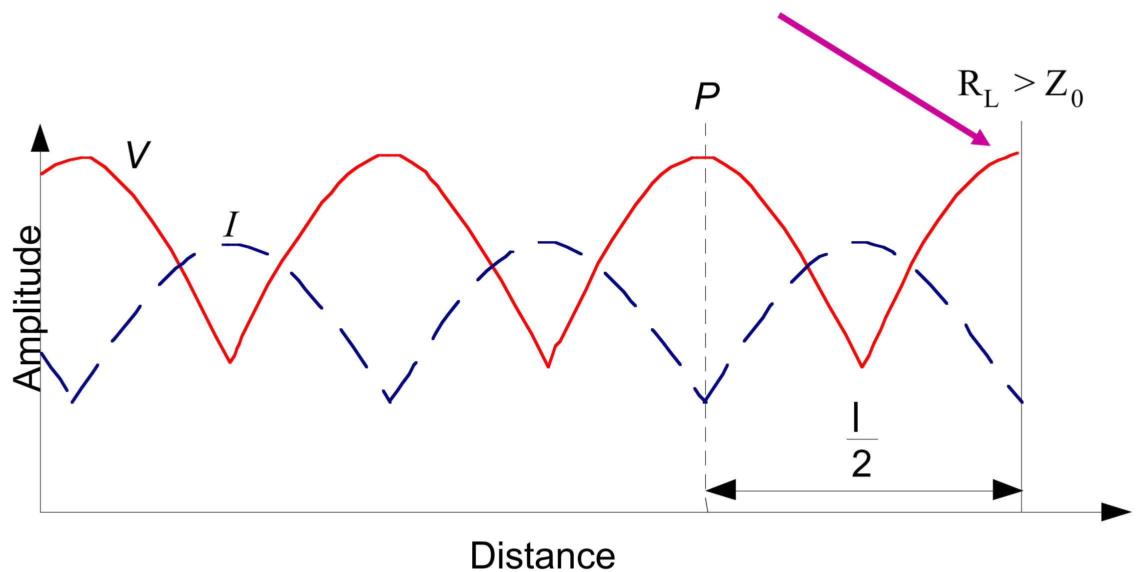
In a transmission line, due to the inductance and capacitance, waves travel somewhat slower. The propagation velocity in a cable is given by the velocity factor VF which is the percentage of the speed of light. A wave of the same frequency that is travelling in a cable slower propagates slower so it doesn't get as far in one wave period as a wave traveling in free space. λ_G **= 300* VF/f(in MHz)**

Reflections, Standing Waves and Return Loss



If the load impedance R_L is higher than the characteristic impedance Z_0, there is a positive (in-phase reflection at the end of the cable. In that case the forward and reflected waves add, boosting the total voltage.

On the other hand if the load impedance R_L is less than the characteristic impedance $Z_{0,}$ the reflection would be inverted and subtract from the forward wave, reducing the total voltage at the end of the cable.



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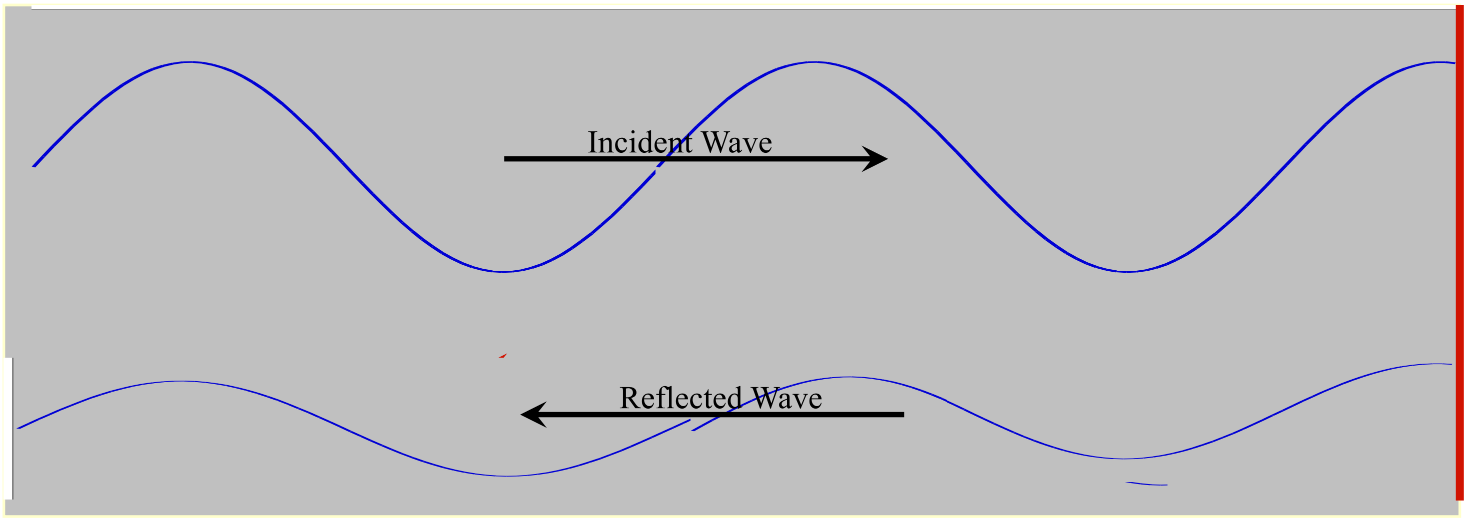
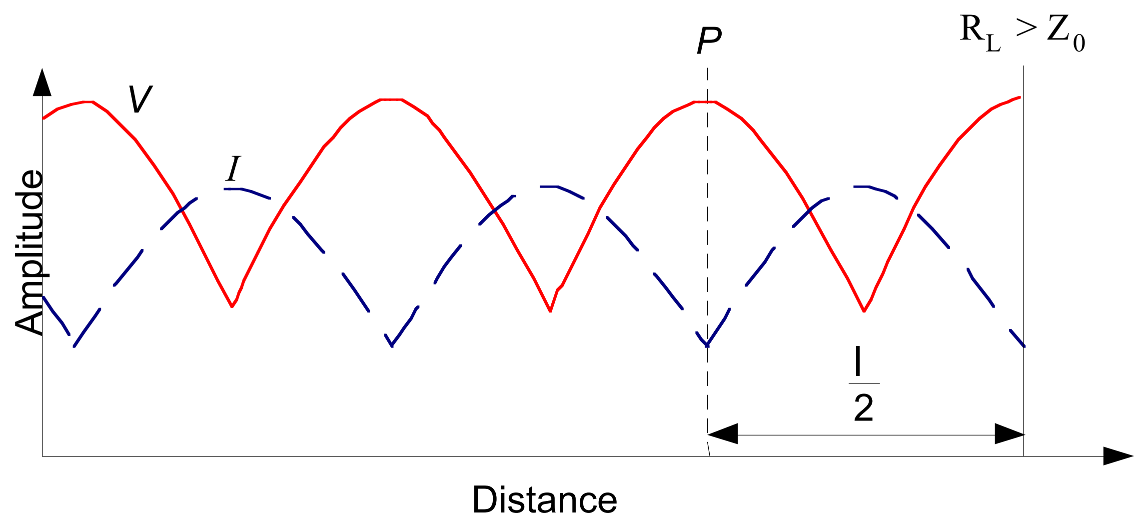


VSWR = Vmax/Vmin
where Vmax is the highest voltage amplitude where the incident and reflected waves add in-phase and Vmin is the voltage amplitude where the incident and reflected waves are out-of-phase and subtract.

VSWR is caused by an impedance mismatch. VSWR = ZH/ZL where ZH is the higher impedance and ZL is the lower impedance. VSWR is always greater than one and is usually expressed as a ratio :1

Example: a mismatch between a 200 ohm antenna and a 50 ohm transmission line would be 200/50 = 4, so you would say VSWR = 4:1. In the reverse situation of 200 ohm line and 50 ohm antenna, the VSWR would also be 4:1 but the reflection coefficient would now be negative.

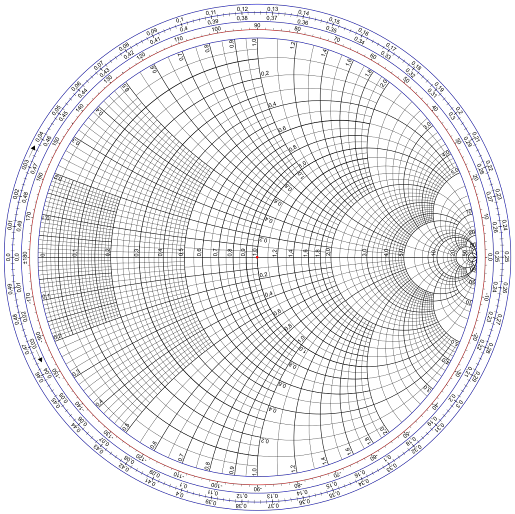


The VA2MM Excel TL Model

It is possible to calculate the complex operating impedance Z(d) at any point **d** along a lossless transmission line given:

- The characteristic impedance Z_0 of the cable
- The complex termination (load) impedance Z_L
- The length of cable **d** in wavelengths to the load

This calculation can be done graphically using a ruler, a compass and a Smith chart, or mathematically using the following equation:



$$\mathbf{Z(d)} = \mathbf{Z_0} \frac{\mathbf{Z_L + jZ_0 \tan\beta d}}{\mathbf{Z_0 + jZ_L \tan\beta d}}$$

which I have written in Excel as:

```
=COMPLEX(ROUND(IMREAL(IMPRODUCT(COMPLEX(L$9,0,"j"),IMDIV(IMSUM(L$12,COMPLEX(0,L$9*TAN(6.28*
D6),"j")),IMSUM(COMPLEX(L$9,0,"j"),IMPRODUCT(COMPLEX(0,1,"j"),L$12,COMPLEX(TAN(6.28*D6),0,"j")))))),
2),ROUND(IMAGINARY(IMPRODUCT(COMPLEX(L$9,0,"j"),IMDIV(IMSUM(L$12,COMPLEX(0,L$9*TAN(6.28*D6),"
j")),IMSUM(COMPLEX(L$9,0,"j"),IMPRODUCT(COMPLEX(0,1,"j"),L$12,COMPLEX(TAN(6.28*D6),0,"j")))))),2),"j")
```

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Let's use the VA2MM TL Model Excel sheet to get the answer.

User Input Parameters		
Frequency (MHz)=	10	MHz
Line Length (m) =	10.00	m
Line Rel. Velocity =	67%	of c
Line Char. Impedance Z0 =	75	Ohms
Load Resistive component=	50	Ohms
Load Reactive component=	0	j Ohms
d Impedance in Complex notation=	50	Ohms

Calculated Parameters		
Wavelength in cable =	20.01	m
Line Length (wavelengths) =	0.50	λ
Refl Coeff. =	-0.2	
Line VSWR=	1.50	:1
Return Loss=	14.0	dB
Mismatch Loss=	0.18	dB
Zin =	50-0.13j	Ohms

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Yes! Now the line is exactly ½ wavelength long, so $Z_{IN} = Z_L$. The VSWR on the line is still 1.5:1 because the antenna impedance doesn't match Z_0, but due to the ½ wavelength long line, the transceiver "sees" an impedance of 50 ohms.